

Final Review

Instructions on the Final Open-Book Exam

Time: 2:00pm - 4:00pm 24-Apr-2023.

Location: NRE 2-001

Scope: All materials.

1. The exam is open-book. Students can bring textbook, lecture notes, assignments and solutions to the exam. E-versions of the above materials are allowed. Please be aware of the University of Alberta's Code for Student Behaviour and complete the final assessment independently.
 2. You may also bring a non-programmable calculator.
 3. Show your work by providing necessary details on calculations and reasoning unless mentioned otherwise.
 4. A Fourier transform table, properties of Fourier transform, and commonly used formulas will be provided.
 5. One-card (or other photo ID) is required for identification. Please put your ID on the desk before the exam begins.
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Course Material Overview

(Please focus on lecture notes posted on eClass. You may refer to the textbook for further information.)

Chapter 1 Introduction

Section 1.1 Communication System Structure

Section 1.2 Applications (Haykin & Moher 1.1, 1.3)

Section 1.3 Primary Resources and Operational Requirements (Haykin & Moher 1.3)

Section 1.4 Underpinning Theories and Related Topics (Haykin & Moher 1.4)

Chapter 2 Fourier Representation of Signals and Systems - Review

Section 2.1 Fourier Transform (Haykin & Moher 2.1)

Section 2.2 Properties of Fourier Transform (Haykin & Moher 2.2)

Section 2.3 Fourier Series and Fourier Transform of Periodic Signals (Haykin & Moher 2.4 and 2.5)

Section 2.4 Transmission of Signals through Linear Time-Invariant Systems (Haykin & Moher 2.6 partial)

Section 2.5 Filters (Haykin & Moher 2.7 partial)

Section 2.6 Energy Spectral Density and Autocorrelation Function for Energy Signals (Haykin & Moher 2.8 partial)

Section 2.7 Power Spectral Density and Autocorrelation Function for Power Signal (Haykin & Moher 2.9)

Chapter 3 Amplitude Modulation

Section 3.1 Fundamentals of AM and Conventional AM (Haykin & Moher 3.1, 3.2)

Section 3.2 Double Sideband-Suppressed Carrier Modulation (Haykin & Moher 3.3, 3.4)

Section 3.3 Quadrature-Carrier Multiplexing (Haykin & Moher 3.5)

Section 3.4 Single Sideband Modulation (Haykin & Moher 3.6)

Section 3.5 Vestige Sideband Modulation (Haykin & Moher 3.7 partial)

Chapter 4 Angle Modulation

Section 4.1 Fundamental Theories of Angle Modulation (Haykin & Moher 4.1)

Section 4.2 Properties of Angle Modulation (Haykin & Moher 4.2, 4.3)

Section 4.3 Spectral Analysis of FM (Haykin & Moher 4.4, 4.5, 4.6)

Section 4.4 Generation and Demodulation of FM (Haykin & Moher 4.7,4.8 partial)

Chapter 5 Pulse Modulation

Section 5.1 Sampling Process (Haykin & Moher 5.1)

Section 5.2 Pulse-Amplitude Modulation (Haykin & Moher 5.2 partial)

Section 5.3 Pulse-Position Modulation (Haykin & Moher 5.3)

Section 5.4 Time-Division Multiplexing (Haykin & Moher 5.10 partial)

Section 5.5 Quantization: Transition from Analog to Digital Communications (Haykin & Moher 5.5 and 5.6 partial)

Section 5.6 Pulse-Code Modulation (Haykin & Moher 5.4 and 5.6)

Section 5.7 Delta Modulation (Haykin & Moher 5.7)

Section 5.8 Differential Pulse-Code Modulation (Haykin & Moher 5.8)

Section 5.9 Linear Codes (Haykin & Moher 5.9)

Chapter 6 Digital Communications

Section 6.1 Source Coding / Decoding

Section 6.2 Channel Coding / Decoding

Section 6.3 Binary shift keying modulation

Section 6.4 M-ary shift keying modulation

Section 6.5 Constellation Design

Section 6.6 Detection Design

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ECE 380
Introduction to Communication Systems
Final Examination

Name:

ID No.:

Instructions:

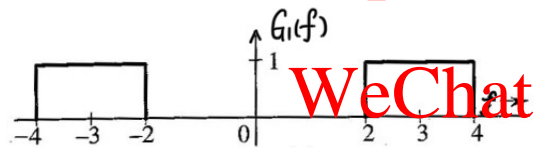
1. **Print your name and ID number** on your answer.
2. Your online submission is due at 4:10pm on Dec. 15, 2021. Please make sure to submit the copy of your answer to eClass successfully. No late submission is accepted.
3. Please follow the definitions of basic functions in the lecture notes and formula sheet posted on eClass.
4. **Show your work.**
5. **Cheating is an academic offense.** The University of Alberta is committed to the highest standards of academic integrity and honesty.

Question	Mark Earned	Full Mark
# 1		10
# 2		15
# 3		15
# 4		15
# 5		15
# 6		15
# 7		15
Total		100

Problem 1. (10 points) (a) Use the frequency-shifting property of Fourier Transform to show that if $g(t) \rightleftharpoons G(f)$, then $2g(t) \cos(2\pi f_c t) \rightleftharpoons G(f - f_c) + G(f + f_c)$.

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(b) Use (a) to find the time-domain representation and the energy of the signal shown in the following figure.



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Problem 2. (15 points) A message $m_0(t)$ is given as follows:

$$m_0(t) = e^{-2|t|} + 100 \operatorname{sinc}(100t).$$

The signal first passes through an ideal low pass filter whose cutoff frequency is 40Hz. The output of the ideal low pass filter is called $m(t)$.

(a) The upper single-sideband amplitude modulation (USSB AM) is used for $m(t)$ to produce the modulated wave $s(t)$ where the carrier frequency is 300 Hz. Please sketch the frequency spectrum of $s(t)$. Can $m(t)$ be demodulated correctly from $s(t)$ using coherent detection? Please explain your answer.

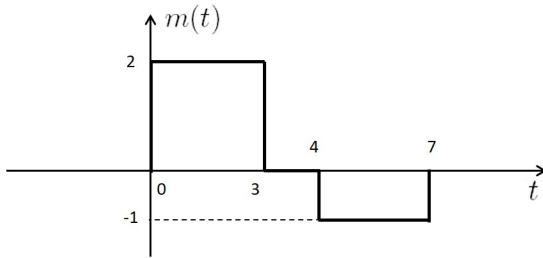
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(b) If the double sideband-suppressed carrier (DSB-SC) modulation is used for $m(t)$ to produce the modulated wave $s(t)$ where the carrier frequency is 30 Hz. Please sketch the frequency spectrum of $s(t)$. Can $m(t)$ be demodulated correctly from $s(t)$ using coherent detection? Please explain your answer.

Problem 3. (15 points)(a) Consider the message $m(t)$ shown in the following figure. If frequency modulation (FM) is used, sketch the modulated FM waveform and discuss your result.



(b) For the modulation in Part (a), if the frequency-sensitivity factor is $k_f = 0.1$, what is the maximum frequency deviation and the maximum phase deviation of the modulated wave?

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(c) Consider the FM modulation of a signal whose bandwidth is $W = 10^3$ Hz. The carrier frequency is $f_c = 10^6$ Hz and the maximum frequency deviation is $\Delta f_{\max} = 200$ Hz. Use Carson's rule to approximate the bandwidth of the modulated FM wave.

Problem 4. (15 points) The signal $g(t) = \sin(2\pi t)$ is uniformly sampled where the sampling interval is $T_s = 0.2$ second.

(a) The instantaneous sampled signal is passed through an ideal low-pass filter with cutoff frequency 5 Hz. Find the frequency spectrum of the output signal.

(b) Pulse-coded modulation (PCM) is used for this signal $g(t)$ with the following 4-level quantizer

$$v = Q(m) = \begin{cases} 0.75 & \text{if } 0.5 \leq m \leq 1 \\ 0.25 & \text{if } 0 \leq m < 0.5 \\ -0.25 & \text{if } -0.5 \leq m < 0 \\ -0.75 & \text{if } -1 \leq m < -0.5 \end{cases}.$$

Find the binary PCM coded sequence with natural coding for the first 5 samples starting from $t = 0$.

(c) If PCM is used for this signal $g(t)$ with a 16-level quantizer, what is the minimum permissible bit rate and its corresponding bit interval?

Problem 5. (15 points) A message sample has the following probability density function (PDF):

$$f_M(m) = \begin{cases} \frac{1}{10} & m \in [-1, 0) \\ \frac{9}{10} & m \in [0, 1) \\ 0 & \text{otherwise} \end{cases}.$$

(a) Design the 2-level uniform quantizer for the message sample.

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(b) Calculate the mean squared error (MSE) of the quantizer you designed in (a).

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(c) Find another 2-level quantizer with a lower MSE and justify your answer.

Problem 6. (15 points) A random source produces X with alphabet $\mathcal{A} = \{a, b, c, d, e, f\}$ with the following probabilities:

$$\begin{aligned} P[X = a] &= 0.15, & P[X = b] &= 0.2, & P[X = c] &= 0.08, \\ P[X = d] &= 0.15, & P[X = e] &= 0.12, & P[X = f] &= 0.3. \end{aligned}$$

(a) Find the entropy of X .

(b) Consider the following source coding:

Element	a	b	c	d	e	f
Codeword	000	001	010	011	1	10

Find the average number of bits per symbol. Is the source compressed without distortions using this source coding and why?

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(c) Design a Huffman coding scheme for this source. What is the the average number of bits per symbol?

Problem 7. (15 points) Consider a 5-point constellation: $\mathcal{A} = \{0, -2, 2, -j, j\}$.

(a) Find the average transmit energy and the minimum distance of this constellation.

(b) The minimum distance rule is used for detection. If the received signal is $0.5 + 0.4j$, what is the detection result? Justify your answer.

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(c) If the minimum distance rule is used for detection, what is the detection region for the constellation element 2 in \mathcal{A} ? (Simplify your result when possible.)

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Table 1: Basic Fourier transform pairs	
Time-domain function $g(t)$	Fourier transform $G(f)$
1	$\delta(f)$
$\delta(t)$	1
$u(t)$	$\frac{1}{2}\delta(f) + \frac{1}{j2\pi f}$
$\text{rect}\left(\frac{t}{T}\right)$	$T \text{sinc}(fT)$
$2W \text{sinc}(2Wt)$	$\text{rect}\left(\frac{f}{2W}\right)$
$\Delta\left(\frac{t}{T}\right)$	$\frac{T}{2} \text{sinc}^2\left(\frac{fT}{2}\right)$
$e^{-at}u(t) \quad (a > 0)$	$\frac{1}{a + j2\pi f}$
$e^{-a t } \quad (a > 0)$	$\frac{2a}{a^2 + (2\pi f)^2}$
$\sin(2\pi f_c t)$	$\frac{1}{2j}[\delta(f - f_c) - \delta(f + f_c)]$
$\cos(2\pi f_c t)$	$\frac{1}{2}[\delta(f - f_c) + \delta(f + f_c)]$

Properties of Fourier transform

1. **Linearity:** $c_1 g_1(t) + c_2 g_2(t) \Rightarrow c_1 G_1(f) + c_2 G_2(f)$
2. **Time scaling:** $g(t) \Rightarrow G(f)$ then $g(at) \Rightarrow \frac{1}{|a|} G\left(\frac{f}{a}\right)$ (Dilation)
3. **Conjugation:** $g^*(t) \Rightarrow G^*(-f)$
4. **Duality:** $g(t) \Rightarrow G(f)$ then $G(t) \Rightarrow g(-f)$
5. **Time shifting:** $g(t - t_0) \Rightarrow e^{-j2\pi f t_0} G(f)$
6. **Frequency shifting:** $g(t) \exp(j2\pi f_c t) \Rightarrow G(f - f_c)$ for any constant f_c .

7. Areas under $g(t)$ and $G(f)$:

$$\int_{-\infty}^{+\infty} g(t) dt = G(0) \quad \text{and} \quad \int_{-\infty}^{+\infty} G(f) df = g(0)$$

8. Differentiation and integration:

$$\frac{d}{dt} g(t) \Rightarrow j2\pi f G(f) \quad \text{and} \quad \int_{-\infty}^t g(\tau) d\tau \Rightarrow \frac{1}{j2\pi f} G(f) + \frac{1}{2} G(0) \delta(f)$$

9. Convolution and Modulation:

$$g_1(t) * g_2(t) \Rightarrow G_1(f) \cdot G_2(f) \quad \text{and} \quad g_1(t) \cdot g_2(t) \Rightarrow G_1(f) * G_2(f)$$

10. Parseval's theorem:

$$E_g = \int_{-\infty}^{+\infty} |g(t)|^2 dt = \int_{-\infty}^{+\infty} |G(f)|^2 df$$