UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
JANUARY 2025 SEMESTER

COURSE : **EEB2043/EFB2043 - COMMUNICATION SYSTEMS**

DATE : **10 APRIL 2025 (THURSDAY)**

TIME : **9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **TEN (10)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

1. a. Suppose the noise power at the input to a receiver is 1 nW in the bandwidth of interest. What would be the required signal power for a signal-to-noise ratio of 25 dB?

[2 marks]

b. Determine the noise figure in decibels of company ABC's receiver that has a noise temperature of 100 K. A competing company, Company XYZ, has a receiver with an equivalent noise temperature of 90 K. Assuming its other specifications are equal, is the receiver of company XYZ better or worse than receiver of company ABC? Explain your answer.

[4 marks]

c. A three-stage amplifier is to have an overall noise temperature no greater than 70 K. The overall gain of the amplifier is to be at least 45 dB. The amplifier is to be built by adding a low-noise first stage to an existing two-stage amplifier that has the gain and noise figures shown below.

Stage	Power Gain	NF
2	20 dB	3 dB
3	15 dB	6 dB

i. Determine the minimum gain (in dB) for the first stage of the amplifier.

[2 marks]

ii. Using the gain you calculated in **part (c)(i)**, calculate the maximum noise figure (in dB) that the first stage can have.

[6 marks]

iii. Suppose the gain of the first stage could be increased by 3 dB without affecting its noise figure. Analyze the effect on the noise temperature of the complete amplifier.

[6 marks]

2. a. Consider an Amplitude Modulation (AM) wave signal as given below:

$$v(t) = [15 + 4\sin(44 \times 10^3 t)]\sin(46.5 \times 10^6 t)\ \text{V}$$

with a load resistance, R_L = 100 Ω.

i. Determine the type of AM signal.

[2 marks]

ii. Calculate the:

- sideband powers (in Watts)
- total power (in Watts)
- ratio of the sideband powers to the total power

[6 marks]

iii. Convert all the powers calculated in **part (a)(ii)** to dBm and draw the power spectrum in dBm. Clearly label the frequencies and amplitudes for all the frequency components.

[6 marks]

2. b. **FIGURE Q2** below shows the block diagram of a typical AM Single Sideband Suppressed Carrier (SSBSC) transmitter. The system is designed to transmit the upper-sideband (USB) of the modulated signal. The input modulating signal has a frequency range of 0 to 10 kHz.

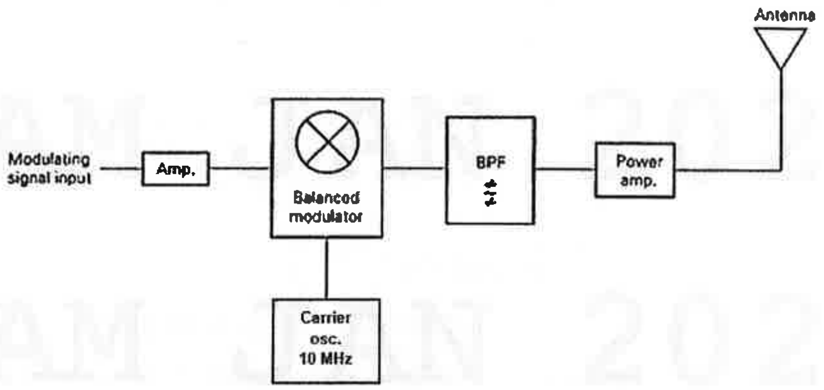

FIGURE Q2

i. Determine the bandwidth (BW) at the output of the Balanced Modulator. Next, sketch the output frequency spectrum of the modulated signal.

[4 marks]

ii. Determine the BW at the output of the Bandpass Filter (BPF) and sketch the output frequency spectrum of the filtered signal.

[3 marks]

iii. The signal input is changed to a single-modulating signal with a frequency of 5 kHz. Determine the output frequency of the BPF and sketch the corresponding output frequency spectrum.

[3 marks]

3. a. A 400 kHz sinusoidal carrier with 10 V of amplitude is frequency modulated by a 3 kHz sinusoidal information signal, with an amplitude of 3 V. The frequency deviation sensitivity of this system is 25 kHz per volt. Explain how the resulting carrier frequency, f_c changes with time. You may use **FIGURE Q3a** for illustration purposes **(re-draw in your answer booklet with proper labeling)** and provide calculations where necessary.

[6 marks]

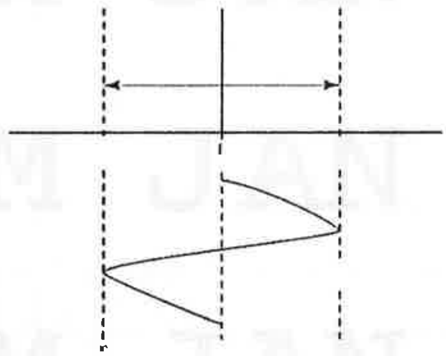

FIGURE Q3a

b. When a carrier signal, $V_c(t) = 5\sin(12 \times 10^5 \pi t)$ V is frequency modulated by a message signal $V_m(t) = 2\sin(12 \times 10^3 \pi t)$ V, the peak frequency deviation is ± 5 % from its unmodulated carrier frequency.

i. Determine the modulation index and the frequency sensitivity of this Frequency Modulation (FM) system.

[4 marks]

ii. Determine the actual minimum bandwidth from the Bessel function table, provided in **Appendix I**. Then, approximate the minimum bandwidth using Carson's rule. Compare the percentage saving in bandwidth of this FM system.

[6 marks]

3. c. **FIGURE Q3c** illustrates the frequency spectrum of a frequency modulated signal. This signal is transmitted over a 10 Ω antenna.

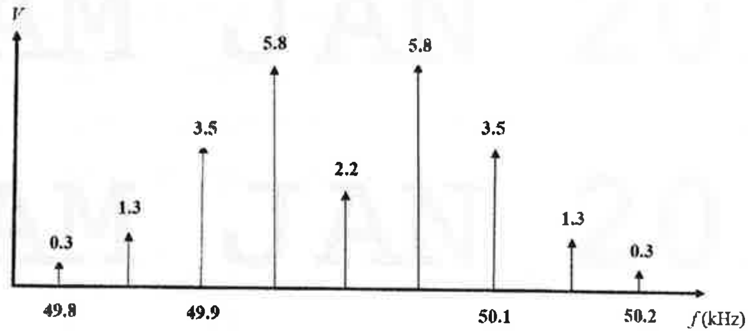

FIGURE Q3c

i. Determine the frequency of the modulating signal (f_m), the frequency of the carrier signal (f_c), and the peak frequency deviation if the modulation index, $m = 2$.

[6 marks]

ii. Write the mathematical expression of this frequency modulated signal, V_{FM}.

[2 marks]

iii. Calculate the total transmitting power of this modulator. The modulator is then followed by a band pass filter (BPF) with a centre frequency equals to carrier frequency, (f_c) from **part 4(c)(i)** and a bandwidth of 120 Hz. Determine the percentage saving in transmission power while transmitting the filtered signal compared to the entire FM signal transmission.

[6 marks]

4. a. A Pulse Code Modulation (PCM) system using 8-bit encoding operates with the maximum analog signal frequency, $f_a = 4\,\text{kHz}$ and the sampling rate, $f_s = 10\,\text{kHz}$.

i. Determine the minimum sampling rate required to satisfy the Nyquist criterion. Justify your answer.

[4 marks]

ii. Calculate the:

- total number of quantization levels available
- bit rate
- actual dynamic range (DR) in decibels (dB)

[6 marks]

b. **FIGURE Q4** shows a 16-Quadrature Amplitude Modulation (16-QAM) modulator with a carrier frequency of 100 MHz. Four bits are serially clocked and encoded, forming quad bits and producing 16 different outputs conditions.

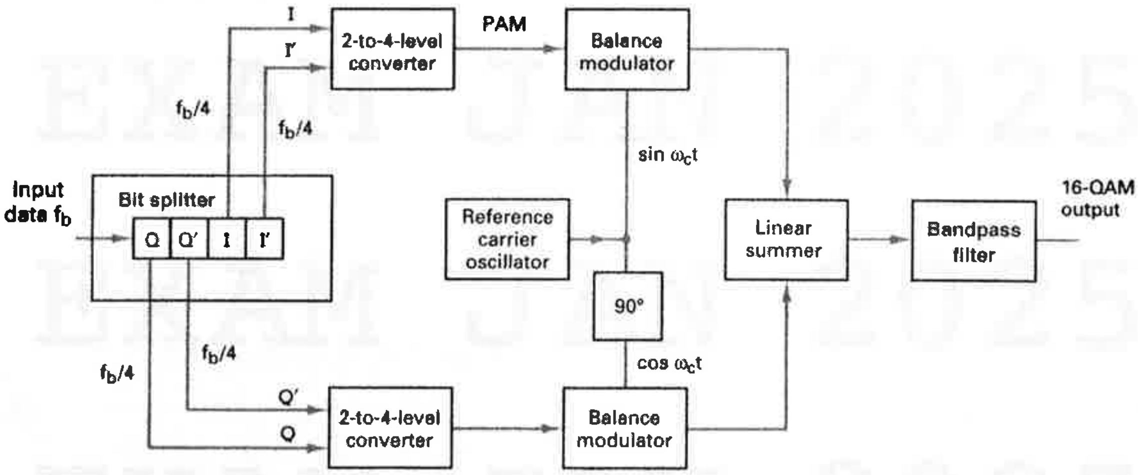

FIGURE Q4

i. **TABLE Q4** is the truth table for I-channel (left) and Q-channel (right). Construct the truth table for the 16-QAM Linear summer's output in the order of: $[Q, Q', I, I',]$.

[8 marks]

TABLE Q4

I	I'	Output
0	0	−0.22 V
0	1	−0.821 V
1	0	+0.22 V
1	1	+0.821 V

Q	Q'	Output
0	0	−0.22 V
0	1	−0.821 V
1	0	+0.22 V
1	1	+0.821 V

ii. Draw the phasor diagram and constellation diagram, showing all the details.

[8 marks]

– END OF PAPER –

APPENDIX I

Bessel Functions of the First Kind, $J_n(m)$

Modulation Index	Carrier	Side Frequency Pairs										
m	J_0	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8	J_9	J_{10}	J_{11}
0.00	1.00	—	—	—	—	—	—	—	—	—	—	—
0.25	0.98	0.12	—	—	—	—	—	—	—	—	—	—
0.5	0.94	0.24	0.03	—	—	—	—	—	—	—	—	—
1.0	0.77	0.44	0.11	0.02	—	—	—	—	—	—	—	—
1.5	0.51	0.56	0.23	0.06	0.01	—	—	—	—	—	—	—
2.0	0.22	0.58	0.35	0.13	0.03	—	—	—	—	—	—	—
2.4	0	0.52	0.43	0.20	0.06	0.02	—	—	—	—	—	—
2.5	-0.05	0.50	0.45	0.22	0.07	0.02	0.01	—	—	—	—	—
3.0	-0.26	0.34	0.49	0.31	0.13	0.04	0.01	—	—	—	—	—
4.0	-0.4	-0.07	0.36	0.43	0.28	0.13	0.05	0.02	—	—	—	—
5.0	-0.18	-0.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02	—	—	—
5.45	0	-0.34	-0.12	0.26	0.40	0.32	0.19	0.09	0.03	0.01	—	—
6.0	0.15	-0.28	-0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02	—	—
7.0	0.30	0.00	-0.30	-0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02	—
8.0	0.17	0.23	-0.11	-0.29	-0.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03

Some Useful Mathematical Relationships

Trigonometric Identities	Integrals
$\cos(x) = (e^{jx} + e^{-jx}) / 2$	$\int \cos(x)dx = \sin(x)$
$\sin(x) = (e^{jx} - e^{-jx}) / 2j$	$\int \sin(x)dx = -\cos(x)$
$\cos(x \pm y) = \cos(x)\cos(y) \mp \sin(x)\sin(y)$	$\int x\cos(x)dx = \cos(x) + x\sin(x)$
$\sin(x \pm y) = \sin(x)\cos(y) \pm \cos(x)\sin(y)$	$\int x\sin(x)dx = \sin(x) - x\cos(x)$
$\cos(2x) = \cos^2(x)\cos(y) - \sin^2(x)$	$\int x^2\cos(x)dx = 2x\cos(x) + (x^2 - 2)\sin(x)$
$\sin(2x) = 2\sin(x)\cos(x)$	$\int x^2\sin(x)dx = 2x\sin(x) - (x^2 - 2)\cos(x)$
$2\cos^2(x) = 1 + \cos(2x)$	$\int e^{\alpha x}dx = e^{\alpha x} / a$
$2\sin^2(x) = 1 - \cos(2x)$	$\int xe^{\alpha x}dx = e^{\alpha x}[(x / a) - (1/a^2)]$
$\cos^2(x) + \sin^2(x) = 1$	$\int x^2e^{\alpha x}dx = e^{\alpha x}[(x^2 / a) - (2x / a^2) - (2 / a^3)]$
$2\cos(x)\cos(y) = \cos(x - y) + \cos(x + y)$	$\int dx / (\alpha + \beta x) = (1/\beta)\ln \alpha + \beta x$
$2\sin(x)\sin(y) = \cos(x - y) - \cos(x + y)$	$\int \frac{1}{a^2 + x^2}dx = \frac{1}{a}\tan^{-1}\frac{x}{a}$
$2\sin(x)\cos(y) = \sin(x - y) + \sin(x + y)$	

APPENDIX II

Fariiss's Formula:

$$F_T = F_1 + \frac{F_2 - 1}{A_1} + \frac{F_3 - 1}{A_1 A_2} + \ldots + \frac{F_n - 1}{A_1 A_2 \ldots A_{n-1}}$$

Information Capacity:

$$C = B\log_2\left(1 + \frac{S}{N}\right) = 3.32B\log_{10}\left(1 + \frac{S}{N}\right)$$

Angle Modulation Summary

	FM	PM
Modulated wave	$m(t) = V_c \cos\left[\omega_c t + \frac{K_1 V_m}{f_m}\sin(\omega_m t)\right]$	$m(t) = V_c \cos[\omega_c t + KV_m \cos(\omega_m t)]$
or	$m(t) = V_c \cos[\omega_c t + m\sin(\omega_m t)]$	$m(t) = V_c \cos[\omega_c t + m\cos(\omega_m t)]$
or	$m(t) = V_c \cos\left[\omega_c t + \frac{\Delta f}{f_m}\sin(\omega_m t)\right]$	$m(t) = V_c \cos[\omega_c t + \Delta\theta \cos(\omega_m t)]$
Deviation sensitivity	K_1 (Hz/V)	K (rad/V)
Deviation	$\Delta f = K_1 V_m$ (Hz)	$\Delta\theta = KV_m$ (rad)
Modulation index	$m = \frac{K_1 V_m}{f_m}$ (unitless)	$m = KV_m$ (rad)
or	$m = \frac{\Delta f}{f_m}$ (unitless)	$m = \Delta\theta$ (rad)
Modulating signal	$v_m(t) = V_m \sin(\omega_m t)$	$v_m(t) = V_m \cos(\omega_m t)$
Modulating frequency	$\omega_m = 2\pi f_m$ rad/s	$\omega_m = 2\pi f_m$ rad/s
or	$\omega_m/2\pi = f_m$ (Hz)	$\omega_m/2\pi = f_m$ (Hz)
Carrier signal	$V_c \cos(\omega_c t)$	$V_c \cos(\omega_c t)$
Carrier frequency	$\omega_c = 2\pi f_c$ (rad/s)	$\omega_c = 2\pi f_c$ (rad/s)
or	$\omega_c/2\pi = f_c$ (Hz)	$\omega_c/2\pi = f_c$ (Hz)