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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-3 : Analog and Digital Communication Systems [All topics]
Signals and Systems-1 + Microprocessors and Microcontroller [Part Syllabus]
Network Theory-2 + Control Systems-2 [Part Syllabus]

Name : ....

Roll No :

Test Centres				Student's Signature
Delhi ☐	Bhopal ☑	Jaipur ☐		
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	92

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IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
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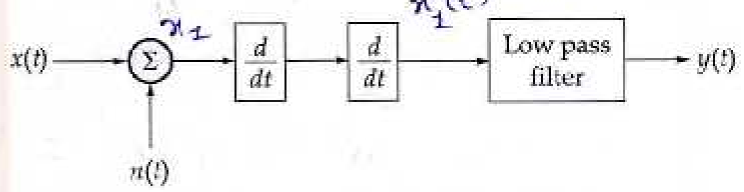
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Analog and Digital Communication Systems

Q.1 (a) Consider the system shown in figure. The signal $x(t)$ is defined by:

$x(t) = A\cos 2\pi f_c t$

$x_1'(t) = x_1''(t) + n''(t)$



The low pass filter has unity gain in the passband and bandwidth W, where $f_c < W$. The noise $n(t)$ is white with two sided power spectral density $\frac{1}{2}N_0$. Determine the signal to noise ratio at the output $y(t)$.

[12 marks]

$x(t) + n(t) = A\cos 2\pi f_c t + n(t)$

$x_1'(t) = \frac{d^2}{dt^2}\left[A\cos 2\pi f_c t + n(t)\right]$

$x_1'(t) = -A(2\pi f_c)^2 \cos 2\pi f_c t + \frac{d^2}{dt^2} n(t)$

- $n(t) \longrightarrow S_n(f)$

$\frac{d}{dt} n(t) \longrightarrow (j2\pi f)^2 S_n(f)$

$\frac{d^2}{dt^2} n(t) \longrightarrow (j2\pi f)^4 S_n(f)$

$y(t) = s_o(t) + n_o(t)$

$\frac{d^2}{dt^2} n(t) \longrightarrow \boxed{LPF} \longrightarrow$

power of $n_o(t) = \int_{-\infty}^{\infty} S_{n_o} \cdot df$

$S_{n_o}(f) = (j2\pi f)^4 \times \frac{N_0}{2} \times |H(f)|^2$

$S_{n_o}(f) = \frac{N_0}{2}(2\pi f)^4$

$\text{Power} = \int_{-W}^{W} \frac{N_0}{2}(2\pi f)^4 df = 8\pi^4 N_0 \int_{-W}^{W} f^4 df$

$= \frac{8\pi^4 N_0}{5} 2f^5$

power $= \frac{16\pi^4 N_0}{5} w^5$

power of message signal $=$ power of $A\cos(2\pi f_c)^2 \{\cos 2\pi f_c t\}$

$= A^2 (2\pi f_c)^4 \times \frac{1}{2}$

$= \frac{\cancel{A^2}}{\cancel{2}} 8\pi^4 A^2 f_c^4$

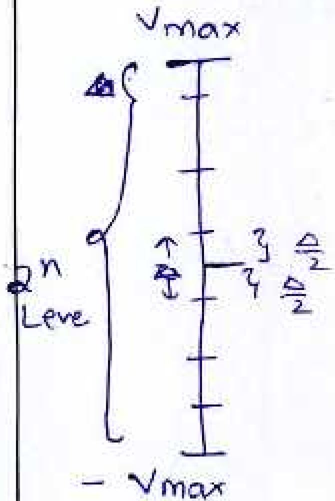
Signal to Noise ratio $= \frac{S_0}{N_0} = \frac{8\pi^4 A^2 f_c^4}{2\, \frac{16\pi^4 N_0 w^5}{5}}$

$SNR = \frac{5 A^2 f_c^4}{2 N_0 w^5}$

Q.1 (b) Consider a continuous input signal whose amplitude V lies in the range $[-V_{max}, +V_{max}]$. This is applied to a uniform quantizer of mid-rise type where the step size is given by Δ and L denotes the number of representation levels. Let σ_Q^2 represent the variance of the quantization error and 'n' represent the number of bits per sample. Show that $\sigma_Q^2 = \frac{1}{3} V_{max}^2 \cdot 2^{-2n}$ and that the output signal to noise ratio of a uniform quantizer is

$$(SNR_Q) = \frac{3P}{V_{max}^2} \cdot 2^{2n} \text{ where } P \text{ is signal power}$$

[12 marks]



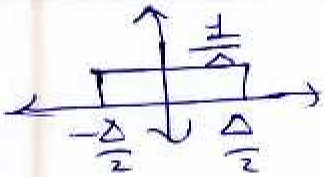
Let whole amplitude range is divided into 2^n interval

Step size $= \frac{V_{PP}}{\text{No of Level}} = \frac{2V_{max}}{2^n}$

$\Delta = \frac{2V_{max}}{2^n}$

After quantisation maximum error can be $\pm \frac{\Delta}{2}$.

Since process is random and error distributed in the interval $-\frac{\Delta}{2}$ to $\frac{\Delta}{2}$ so we can find it's power as follows



$$\text{Power}[Q_e] = \int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} Q_e^2 \times \frac{1}{\Delta}\, dQ_e$$

$$\text{power} = \frac{1}{\Delta} \times \left(\frac{Q_e^3}{3}\right]_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}}$$

$$\text{power}[Q_e] = \frac{\Delta^2}{12}$$

$$\text{Noise power} = \frac{\Delta^2}{12}$$

~~Mean~~ ~~No~~ $\sigma_n^2 = \text{Noise power} = \frac{\Delta^2}{12}$

put $\Delta = \frac{2V_{max}}{2^n}$

$$\sigma_n^2 = \frac{\left(\frac{2V_{max}}{2^n}\right)^2}{12} = \frac{V_{max}^2}{3\, 2^{2n}} = \frac{1}{3} V_{max}^2 \times 2^{-2n}$$

$$SNR = \frac{\text{Signal power}}{\text{noise power}}$$

Let Signal power is P

$$SNR = \frac{P}{\frac{1}{3} V_{max}^2 \times 2^{-2n}} = \frac{3P}{V_{max}^2}(2^{2n})$$

Q.1 (c) The random process $X(t)$ is defined by

$X(t) = X\cos 2\pi f_0 t + Y\sin 2\pi f_0 t$

where X and Y are two zero mean independent Gaussian random variable each with variance σ^2.

(i) Find $m_X(t)$.

(ii) Find $R_X(t+\tau, t)$. Is $X(t)$ stationary? Is it cyclostationary?

[12 marks]

(i) $m_X(t) = E[X(t)]$

$= E[X\cos 2\pi f_0 t + Y\sin 2\pi f_0 t]$

E(X) is a function of random variable and independent of time so

$= E[X\cos 2\pi f_c t] + E[Y\sin 2\pi f_0 t]$

$= \cos 2\pi f_c t \; E[X] + \sin 2\pi f_0 t \; E[Y]$

Given $E[X] = E[Y] = 0$

$m_X(t) = \cos 2\pi f_c t \times 0 + \sin 2\pi f_c t \times 0 = 0$

(ii) $R_X(t+\tau, t) = E[X(t)\,X(t+\tau)]$

$= E[(X\cos 2\pi f_0 t + Y\sin 2\pi f_0 t)$
$(X\cos 2\pi f_0(t+\tau) + Y\sin 2\pi f_0(t+\tau))]$

$= E[X^2\cos(2\pi f_0 t)\cos 2\pi f_0(t+\tau)]$
$+ E[Y^2 \sin 2\pi f_0 t \sin 2\pi f_0(t+\tau)]$
$+ E[XY\sin 2\pi f_0(t+\tau)\cos 2\pi f_0 t]$
$+ E[XY\cos 2\pi f_0 t \sin 2\pi f_0(t+\tau)]$

$E[XY\sin 2\pi f_0 t \cos 2\pi f_0(t+\tau)] = \sin 2\pi f_0 t \cos 2\pi f_0(t+\tau)\, E[XY]$

Since X and Y are indepent so $E[XY] = E[X]E[Y]$
$= 0\times 0 = 0$

$R_x(t+\tau, t) = \cos 2\pi f_0 t \; \cos 2\pi f_0 (t+\tau) \; E(x^2)$

$+ \sin 2\pi f_0 t \; \sin 2\pi f_0 (t+\tau) \; E(Y^2)$

Given $E[x^2] = E[Y^2] = \sigma^2$ [mean is zero so variance $= E[x^2]$]

$R_x(t, \tau) = \sigma^2 [\cos 2\pi f_0 t \; \cos 2\pi f_0 (t+\tau) + \sin 2\pi f_0 t \; \sin(2\pi f_0 (t+\tau))]$

$R_x(t, \tau) = \sigma^2 \; \cos(2\pi f_0 (t+\tau) - 2\pi f_0 t)$

$= \sigma^2 \cos(2\pi f_0 \tau)$

Since $R_x(t, \tau)$ is independent of t so given process is stationary

Q.1 (d) A PCM system uses a uniform quantizer followed by a 8-bit binary encoder. The bit rate of the system is equal to 60 Mbps.

(i) What is the maximum message bandwidth for which the system operates satisfactory?

(ii) Determine signal to quantization noise ratio for uniform distributed sample of message signal having uniform quantization level.

[12 marks]

$R_b = 60$ Mbps

$n = 8$ bit

$R_b = n f_s$

Let message bandwidth is f_m (Maximum)

$f_s = 2 f_m$ (Minimum sampling to operate satisfactory

$60 \text{ Mbps} = 8 \times 2 f_m = 16 f_m$

$f_m = \frac{60 \text{ MHz}}{16} = 3.75 \text{ MHz}$

(i) Maximum message BW $= 3.75$ MHz

(ii) Sample of message are uniformly distributed so we can message signal as

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Q.1 (e) What are the capture effect and threshold effect in an FM system? List two different methods used for FM threshold improvement.

[12 marks]

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Q.2 (a) A communication channel has a bandwidth of 100 kHz. This channel is to be used for transmission of an analog source $m(t)$, where $|m(t)| < 1$, whose bandwidth is 4 kHz. The power content of the message signal is 0.1 W.

(i) Find the ratio of the output SNR of an FM system that utilizes the whole bandwidth, to the output SNR of a conventional AM system with a modulation index of $\mu = 0.85$. What is this ratio in dB?

(ii) Show that if an FM system and a PM system are employed and these systems have same output signal to noise ratio, we have

$$\frac{BW_{PM}}{BW_{FM}} = \frac{\sqrt{3}\beta_f + 1}{\beta_f + 1} \qquad (\beta_f = \text{Modulation index of FM})$$

[10 + 10 marks]

SNR conventional AM system with $\mu = 0.85 < 1$
Envelope detection possible

$$(SNR)_{AM} = \frac{k_a^2 P_m}{1 + k_a^2 P_m} = \frac{\mu^2}{2+\mu^2} \text{ (for sinusoidal signal)}$$

Given $\mu = 0.85$
No information given so take message signal as sinusoidal signal

$$(SNR)_{AM} = \frac{(0.85)^2}{2+(0.85)^2} = \frac{289}{1089} = 0.26538$$

$$(SNR)_{FM} = \frac{3}{2}\beta^2 \text{ (for sinusoidal signal)}$$

FM utilize full channel
Using Carson formula Channel $BW = 2(\beta+1) f_{max}$

Given $f_{max} = 4\,kHz$, $BW = 100\,kHz$

$100\,kHz = 4\,kHz\,(\beta+1)$

$\beta + 1 = 25$

$\boxed{\beta = 24}$

$$(SNR)_{FM} = \frac{3}{2}\beta^2 = \frac{3}{2}(25)^2 = 937.5$$

$$\frac{(SNR)_{FM}}{(SNR)_{AM}} = \frac{937.5}{0.26538} = 3532.$$

Ratio in dB = $10 \log(\text{ratio})$

$= 10 \log(3532)$

$= 35.48$ dB

(ii) $(SNR)_{FM} = \frac{3}{2}\beta_{FM}^2$

$(SNR)_{PM} = \frac{\beta_{PM}^2}{2}$

Given $(SNR)_{FM} = (SNR)_{PM}$

$\frac{3}{2}\beta_{FM}^2 = \frac{\beta^2_{PM}}{2}$

$\boxed{\beta_{FM} = \frac{\beta_{PM}}{\sqrt{3}}} = \beta_f \Rightarrow \beta_{PM} = \sqrt{3}\beta_f$

$BW_{FM} = 2(\beta_{FM}+1) f_m$

$BW_{PM} = 2(\beta_{PM}+1) f_m = 2(\sqrt{3}\beta_f+1) f_m$

$$\frac{BW_{FM}}{BW_{PM}} = \frac{2(\beta_f+1) f_m}{2(\sqrt{3}\beta_f+1) f_m} = \frac{(\beta_f+1)}{(\sqrt{3}\beta_f+1)}$$

$$\frac{BW_{PM}}{BW_{FM}} = \frac{(\sqrt{3}\beta_f+1)}{(\beta_f+1)}$$

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Q.2 (b) An analog signal having 5 kHz bandwidth is sampled at twice the Nyquist rate and each sample is quantized into one of 256 equally likely levels. Assume the samples to be statistically independent.

(i) Calculate the information rate of the source.

(ii) Can the output of the source be transmitted without error over an AWGN channel with a bandwidth of 10 kHz and $\left(\frac{S}{N}\right)$ ratio of 40 dB?

(iii) Find the $\left(\frac{S}{N}\right)$ ratio so that the output of this source is transmitted without error over an AWGN channel with a bandwidth of 10 kHz.

(iv) Find the bandwidth requirement for an AWGN channel for an error free transmission of the output of this source if $\left(\frac{S}{N}\right)$ ratio is 40 dB.

[20 marks]

$f_m = 5\text{ kHz}$, $NR = 2f_m$

$f_s = 2\times(2f_m) = 4f_m = 20\text{ kHz}$

Each sample quantised into 256 equally likely level

No. of bit required for 256 level will be $n = \log_2(256) = 8$ bit

(i) Information rate $R_b = nf_s = 8\times 20\text{k} = 160$ kbps

(ii) Channel capacity $C = B\left(1+\log_2\left(\frac{S}{N}\right)\right)$

Channel capacity $C \geq R_b$

Given $\frac{S}{N}$ in dB $= 40$dB

$\frac{S}{N} = 10^4$

Minimum channel capacity required $= 10\left(1+\log_2(10^4)\right)$ kHz

$= 132.88$ kHz

$C = 132.88\text{ kHz} \not> 160\text{ kHz}$

So output of the source can not be transmitted.

(iii) for without error transmission Channel capacity should be atleast R_b

$$160 \text{ Kbps} = B \log_2\left(1+\frac{S}{N}\right)$$

$$160 \text{ kHz} = 10 \text{ kHz} \log_2\left(1+\frac{S}{N}\right)$$

$$16 = \log_2\left(1+\frac{S}{N}\right)$$

$$1+\frac{S}{N} = 2^{16}$$

$$\frac{S}{N} = 2^{16}-1 = 65535$$

$$\left(\frac{S}{N}\right)_{dB} = 10\log(65535) = 48.16 \text{ dB}$$

(iv) $\left(\frac{S}{N}\right) = 40 \text{ dB} \Rightarrow \frac{S}{N} = 10^4$

Channel capacity $= R_b = 160$ Kbps

$$160 = B\left(1+\log_2(10^4)\right)$$

$$\boxed{B = 11.2 \text{ KHz}}$$

Minimum Bandwidth required $= 11.2$ KHz

Q.2 (c) (i) The two sided power spectral density of the channel noise is 1×10^{-11} W/Hz and the carrier used in the transmitter is 15 cos $(2\pi f_c t)$ mV. Binary data (equiprobable bits) with a rate of 0.5 Mbps is transmitted through an AWGN channel using different modulation schemes. In each case of different modulation schemes, the signal are received by their respective correlator receiver with exact phase synchronisation and with optimum threshold detection. Find the average symbol error probability for modulation schemes BASK, BFSK and BPSK.

(ii) For a minimum hamming distance of "5",

1. How many errors can be detected?
2. How many errors can be detected and corrected?

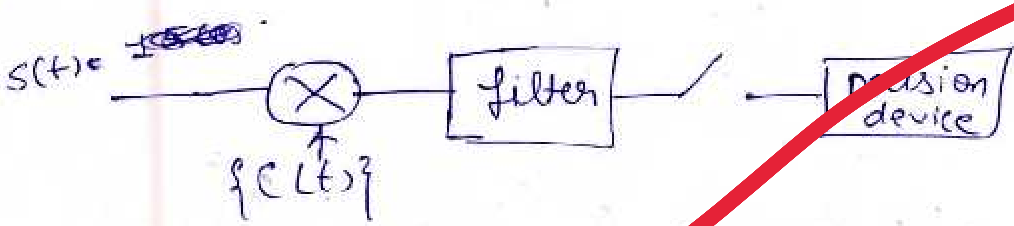
[14 + 6 marks]

Given $\frac{N_0}{2} = 1\times10^{-11}$ W/Hz $\Rightarrow N_0 = 2\times10^{-11}$ W/Hz

$c(t) = 15 \cos(2\pi f_c t) \times 10^{-3}$ V

$R_b = 0.5$ Mbps $\Rightarrow T_b = \frac{1}{0.5\text{M}b} = 2\times10^{-6}$ sec

phase and frequency synchronization present



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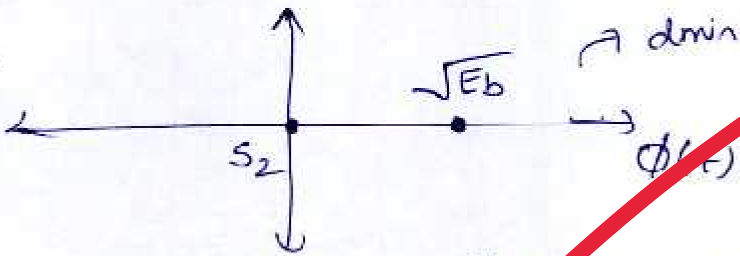
(i) BASK

$S_1 : \; 15 \cos(2\pi f_c t)\, mV \quad 0 \le t \le T_b$ (1 Txed)

$S_2 : \quad 0$ (0 Txed)

$P_e = P(0\,Tx) \times P\left(\frac{\text{output}(1)}{0\;Tx}\right) + P(1\,Tx) \times P\left(\frac{\text{output}(0)}{1\,(Tx)}\right)$



$E_b = \int s^2(t)\, dt = \int_0^{T_b} (15)^2 \cos^2 2\pi f_c t \, dt$

$E_b = \frac{225}{2} \times T_b \times 10^{-6} = 2.25 \times 10^{-10}$

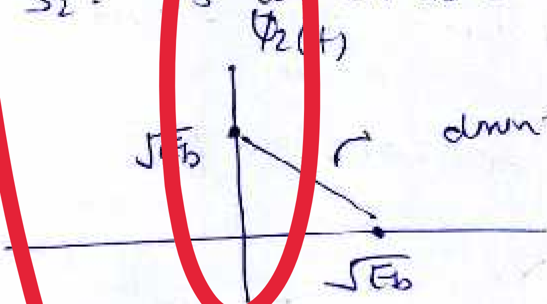
$P_e = Q\left[\sqrt{\frac{d^2_{min}}{2N_0}}\right] = Q\left[\sqrt{\frac{E_b}{2N_0}}\right]$

$P_e = Q\sqrt{\frac{2.25 \times 10^{-10}}{2 \times 10^{-11}}} = Q\sqrt{11.25}$

(ii) BFSK

$S_1 : \; 5 \cos 2\pi f_1 t \; mV \quad 0 \le t \le T_b$ (1 Txed)

$S_2 : \; 5 \cos 2\pi f_2 t \; mV \quad 0 \le t \le T_b$ (0 Txed)



$E_b = 2.25 \times 10^{-10}$

$P_e = Q\left(\sqrt{\frac{d^2_{min}}{2N_0}}\right) = Q\left(\sqrt{\frac{2E_b}{2N_0}}\right) = Q\left(\sqrt{\frac{E_b}{N_0}}\right)$

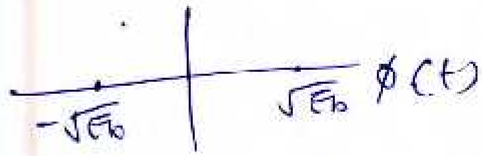
$= Q\left(\sqrt{22.5}\right)$

(iii) BPSK

$s_1(t) = A\ 15 \cos 2\pi f_c t$ mV $\quad 0 \le t \le T_b$

$s_2(t) = -15 \cos 2\pi f_c t$ mV $\quad 0 \le t \le T_b$

$d_{min} = 2\sqrt{E_b}$



$$P_e = Q\left(\sqrt{\frac{d^2_{min}}{2N_0}}\right) = Q\left(\sqrt{\frac{4E_b}{2N_0}}\right) = Q\left[\sqrt{\frac{2E_b}{N_0}}\right]$$

$$P_e = Q\left(\sqrt{2 \times 22.5}\right) = Q\left(\sqrt{45}\right)$$

BPSK $P_e = Q\ \sqrt{45}$

2 (c) (ii) (a) $d_{min} \ge t + 1$

where t is the no. of errors which can be detected

$5 \ge t + 1$

$t \le 5 - 1$

$t \le 4$

Maximum 4 bit error can be detected

(b) $d_{min} \ge 2s + 1$

where s no. of bit error can be detected and corrected

$5 \ge 2s + 1$

$2s \le 4$

$s \le 2$

Maximum 2 bit error can be detected and corrected.

Q.3 (a) A Gaussian signal pulse given by,

$$x(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(t^2/2\sigma^2)}$$

is applied to the input of matched filter and the noise on the channel is a white noise with power density spectrum of $\frac{N_0}{2} = 10^{-20}$ Watt/Hz, then calculate the maximum signal to noise ratio $\left(\frac{S}{N}\right)_{\max}$ in dB achieved by this filter with $\sigma = 1$.

[20 marks]

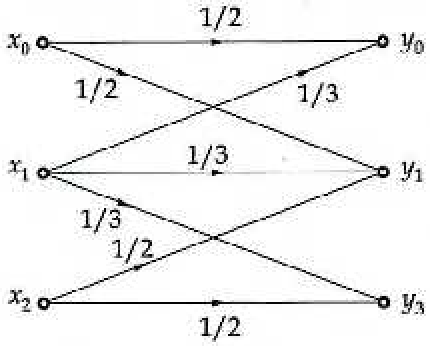
Q.3 (b) For each of the following processes, find the power spectral density.

(i) $X(t) = A\cos(2\pi f_0 t + \theta)$, where A is a constant and θ is a random variable uniformly distributed on $\left[0, \frac{\pi}{4}\right]$.

(ii) $X(t) = x + y$, where x and y are independent, x is uniformly distributed on $[-1, 1]$ and y is uniformly distributed on $[0, 1]$.

[10 + 10 marks]

Q.3 (c) Consider the discrete memoryless channel shown below:



If the input probabilities are $P(x_0) = P(x_2) = \frac{1}{4}$ and $P(x_1) = \frac{1}{2}$, then determine the mutual information $I(X ; Y)$.

[20 marks]

Q.4 (a) An AM signal has the form

$u(t) = [20 + 2\cos 3000\pi t + 10\cos 6000\,\pi t]\cos 2\pi f_c t$

where $f_c = 10^5$ Hz.

(i) Sketch the (voltage) spectrum of $u(t)$.

(ii) Determine the power in each of the frequency components.

(iii) Determine the modulation index.

(iv) Determine the power in the sidebands, the total power, and the ratio of the sidebands power to the total power.

[5 × 4 marks]

(i) $u(t) = 20\left[1 + \frac{1}{10}\cos(3000\pi t) + \frac{1}{2}\cos(6000\pi t)\right]\cos 2\pi f_c t$

$u_{max} = 20\left[1 + \frac{1}{10} + \frac{1}{2}\right] = 32\,V$

$U_{min} = 20 - 2 - 10 = 8\,V$

We have two message signal present in amplitude modulated signal $u(t)$

$f_1 = 1500$ Hz, $f_2 = 3000$ Hz (Two message freq.)

At, $t = \frac{1}{1500}$ $u(t) = 2032$

At, $t =$

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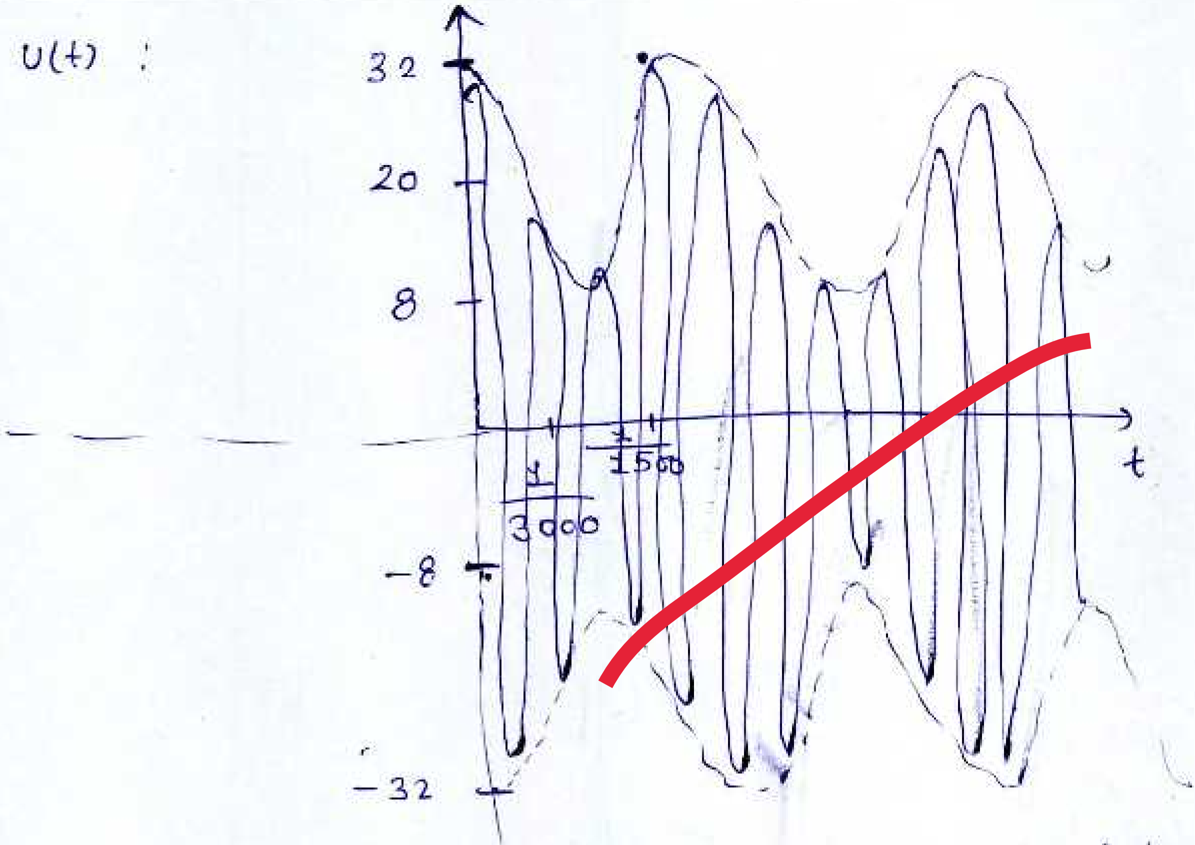
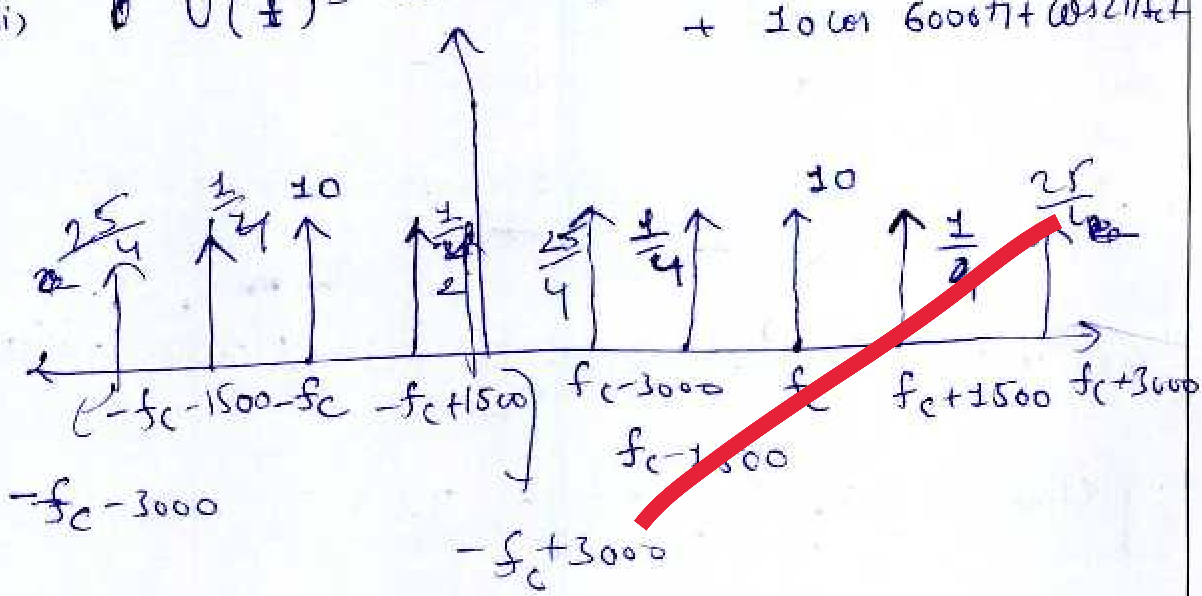
$U(t)$:



(ii) $U(f) = 20\cos 2\pi f_c t + 2\cos 3000\pi t \cos 2\pi f_c t + 10\cos 6000\pi t \cos 2\pi f_c t$



power : $f_c \to \frac{20^2}{2} = 200$ W

$f_c+1500 \to \frac{1}{2}$ W , $f_c-1500 \to \frac{1}{2}$ W

$f_c+3000 \to \frac{25}{2} = 12.5$ W

$f_c-3000 \to 12.5$ W

(iii) $\mu_t = \sqrt{\mu_1^2 + \mu_2^2}$ $\mu_1 = \frac{A_{m1}}{A_c} = \frac{2}{20} = 0.1$

$\mu_1 = \frac{2}{20} = \frac{1}{10} = 0.1$ $\mu_2 = \frac{A_{m2}}{A_c} = \frac{10}{20} = 0.5$

$\mu_2 = \frac{1}{2}$

$\mu_t = \sqrt{0.1^2 + 0.5^2} = 0.5099$

(iv) Power in the sideband

$P_{SB} = P_c \frac{\mu_t^2}{2} = 200 \times \frac{(0.5099)^2}{2} = 26W$

Total Power $= P_c + P_{SB} = 200 + 26 = 226W$

$\frac{P_{SB}}{P_T} = \frac{26}{226} = 0.115$

~~$A_R = A_c (1 + \mu_t$~~

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Q.4 (b) (i) A message source generates six message symbols $m_1, m_2, \ldots, m_6$ with probabilities 0.3, 0.2, 0.08, 0.25, 0.12, 0.05 respectively. Give Huffman code for these symbols. Determine the efficiency and redundancy of the code.

(ii) For an AM modulator with carrier frequency f_c = 200 kHz and a maximum modulating signal frequency $f_{m(max)}$ = 6 kHz, determine,

1. Frequency limits for the upper and lower sidebands.
2. Bandwidth
3. Upper and lower side frequencies produced when the modulating signal is a single frequency 2 kHz tone.

[10 + 10 marks]

Huffman code are the code which are repeated prefix code same prefix ~~can not be~~ for other symbol.

Arrange in decreasing order of probability.

0.3	→	0	→ 1
0.25	→	00	→ 2
0.2	→	011	→ 3
0.12	→	0110	→ 4
0.08	→	01101	→ 5
0.05	→	011010	→ 6

Efficiency =

L ~~Total bits required/symbol~~ = $1\times0.3 + 2\times0.25 + 3\times0.2 + 4\times0.12 + 5\times0.08 + 6\times0.05$

$= 1.875$

~~Lmin~~ = L_{min} = $-\sum P(x_i)\log_2 P(x_i)$

$= 2.36$

Units 9 X 5

Efficiency = $\frac{I_{min}}{I_{max}}$ = $\frac{1.8/\sqrt{5}}{2.36} \times 100\%$

Efficiency = 77%

(ii) ① $f_c = 200kHz$, $f_{max} = 6kHz$

Upper sideband limit $f_c + f_{max} = 200+6 = 206kHz$

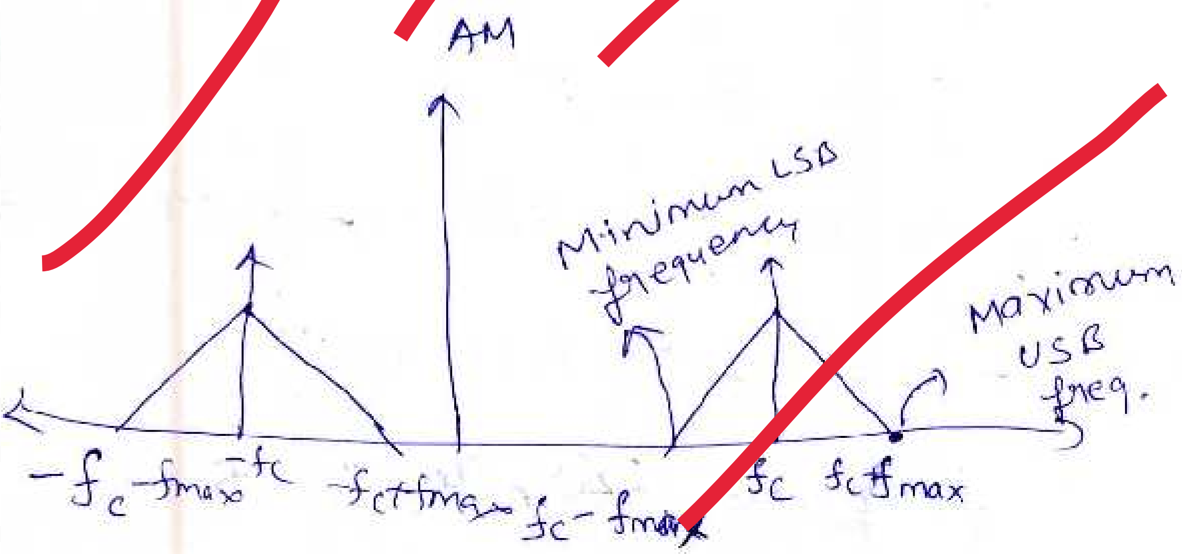
Lower sideband limit $f_c - f_{max} = 200-6 = 194kHz$

② Bandwidth = $2f_{max} = 2\times 6kHz = 12kHz$

③ Given single message with $f_m = 2kHz$

USB frequency = $f_c + f_m = 200+2 = 202kHz$

LSB frequency = $f_c - f_m = 200-2 = 198kHz$



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Q.4 (c) A single-tone modulating signal $m(t) = A_m \cos(2\pi f_m t)$ is used to generate the VSB signal

$$S(t) = \frac{1}{2} a A_m A_c \cos[2\pi(f_c + f_m)t] + \frac{1}{2} A_m A_c (1-a)\cos[2\pi(f_c - f_m)t]$$

where 'a' is a constant, less than unity, representing the attenuation of the upper side frequency.

(i) Find the quadrature component of the VSB signal $S(t)$.

(ii) The VSB signal, plus the carrier $A_c \cos(2\pi f_c t)$, is passed through an envelope detector. Determine the distortion produced in recovering the message signal.

(iii) What is the value of constant 'a' for which this distortion reaches its worst possible condition?

[20 marks]

Any Band pass can be represented as

$S(t) = S_I(t) \cos 2\pi f_c t - S_Q(t) \sin 2\pi f_c t$

↳ Quadrature component

(i) $S(t) = \frac{1}{2} a A_m A_c \cos(2\pi(f_c + f_m)t) + \frac{1}{2} A_m A_c (1-a)$

$\cos 2\pi (f_c - f_m)t \}$

$= \frac{1}{2} a A_m A_c [\cos 2\pi (f_c + f_m)t - \cos 2\pi (f_c - f_m)t]$

$+ \frac{1}{2} A_m A_c [\cos 2\pi (f_c - f_m)t]$

$= \cancel{\frac{1}{2} a A_m A_c [-2\sin(4\pi} f_c t)$ S

$\cos\left[2\pi(f_c+f_m)t\right] - \left[\cos 2\pi(f_c-f_m)t\right]$

$= -2\sin 2\pi f_c t \ \sin 2\pi f_m t$,

$s(t) = -\frac{1}{2} a A_m A_c \ \sin(2\pi f_c t)\ \sin 2\pi f_m t$

$+\frac{1}{2} A_m A_c \left[\cos 2\pi f_c t \ \cos 2\pi f_m t\right)$

$+\frac{1}{2} A_m A_c \left[\sin 2\pi f_c t \ \sin 2\pi f_m t\right)$

for the band pass signal of form

$x(t) = A\cos\omega_c t - B\sin\omega_c t$

Quadrature component is B

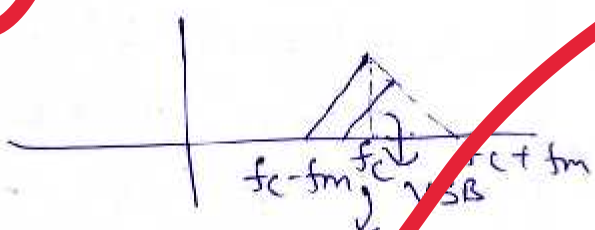
compare $\sin 2\pi f_c t$ term in $s(t)$

Quadrature component $= \left\{\frac{a A_m A_c}{2} - \frac{1}{2} A_m A_c\right\}$

$\sin 2\pi f_m t$

$Q_I(t) = A_m A_c\left[a - \frac{1}{2}\right] \ \sin 2\pi f_m t$

(ii) $y(t) = A_c(\cos 2\pi f_c t) + s(t)$



some part of other side band added.

$s(t) = \left[\frac{A_m A_c}{2} \cos 2\pi f_m t\right] \cos 2\pi f_c t)$

$-\left\{A_m A_c\left[a - \frac{1}{2}\right] \sin 2\pi f_m t\right] \sin 2\pi f_c t$

output of Envelope detector

$$S(t)_{out} = \sqrt{\left(\frac{A_m A_C}{2}\cos 2\pi f_m t\right)^2 + \left(A_m A_C\left(a-\frac{1}{2}\right)\sin 2\pi f_m t\right)^2}$$

$$S_{out} = A_m A_C\sqrt{\frac{\cos^2(2\pi f_m t)}{4} + \frac{(2a-1)^2}{4}\sin^2(2\pi f_m t)}$$

$(2a-1)$ extra term present will create distortion in recovering the original signal.

Section B : Signals and Systems-1 + Microprocessors and Microcontroller-1 + Network Theory-2 + Control Systems-2

Q.5 (a) Consider a system described by the differential equation $\ddot{y}(t)+2y(t)+3\dot{y}(t)=x(t)$ with $x(t)=3e^{-4t}$, $y(0)=3$ and $\dot{y}(0)=4$. Find its Z.I.R and Z.S.R.

[12 marks]

ZIR: Zero Input response

put $x(t)=0$ and then solve the differential eq^n

$$\ddot{y}(t)+2y(t)+3\dot{y}(t)=0$$

Apply laplace transform both side

$$\ddot{y}(t) \xrightarrow{L\text{-}T} s\left[s\left[y(s)\right]-y(0)\right]-\dot{y}(0)$$

$$\ddot{y}(t) \xrightarrow{LT} s^2Y(s)-sy(0)-\dot{y}(0) = s^2Y(s)-3s-4$$

$$\dot{y}(t) \xrightarrow{LT} sY(s)-y(0) = sY(s)-3$$

Eq^n in Laplace domain

$$s^2Y(s)-3s-4+2Y(s)+3sY(s)-9=0$$

$$(s^2+3s+2)\,Y(s) = 13+3s$$

$$Y(s) = \frac{13+3s}{s^2+3s+2} = \frac{3s+13}{s^2+3s+2}$$

$$Y(s) = \frac{10}{s+1} - \frac{7}{s+2}$$

$$y(t) = \{10e^{-t}-7e^{-2t}\}\,u(t)$$

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ZSR

Take all state as zero

$\ddot{y}(t) + 2y(t) + 3\dot{y}(t) = x(t)$

$s^2 y(s) + 2y(s) + 3s\,y(s) = \frac{3}{s+4}$

$y(s) = \frac{3}{(s+4)(s^2+3s+2)}$

$y(s) = \frac{A}{s+4} + \frac{B}{s+2} + \frac{C}{s+1}$

$y(s) = \frac{1}{2(s+4)} \cancel{+} \frac{3}{2(s+2)} + \frac{1}{s+1}$ → Apply Inverse Laplace transf

$$\boxed{y(t) = \frac{1}{2}e^{-4t} - \frac{3}{2}e^{-2t} + e^{-t}}$$

Q.5 (b) Describe the following instructions of 8086:

(i) LDS R_d, M

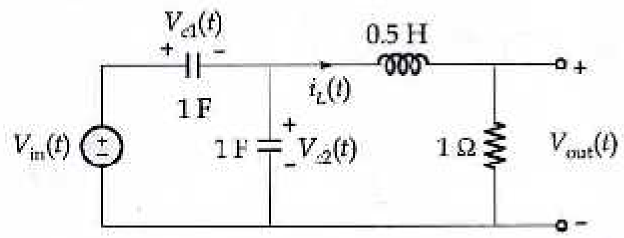
(ii) AAM

(iii) DAS

(iv) CLI

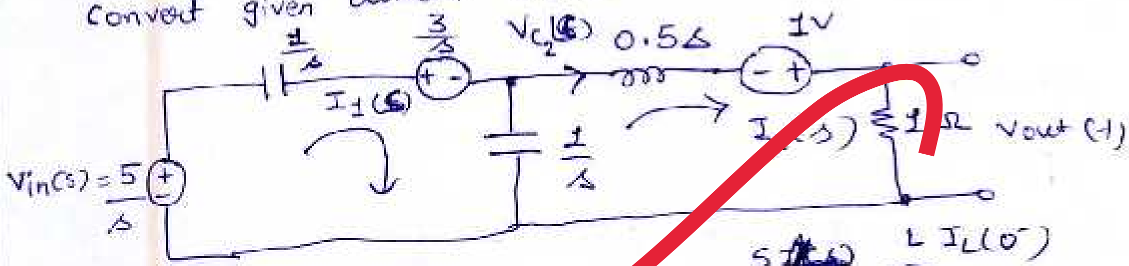
[12 marks]

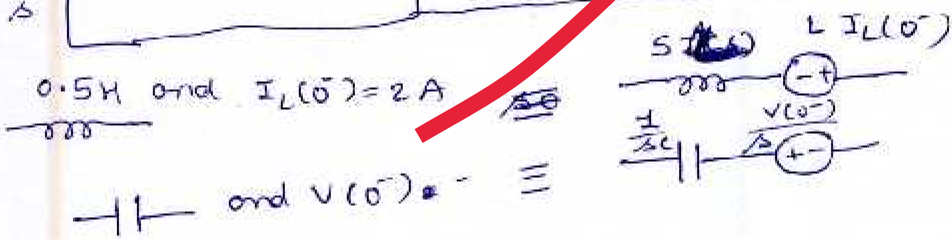
Q.5 (c) Consider the circuit below in which $V_{in}(t) = 5u(t)$ V, $V_{c1}(0^-) = 3$ V, $V_{c2}(0^-) = 0$ V and $i_L(0^-) = 2$ A. Find $V_{out}(t)$ and also obtain V_{out} at $t = 1$ sec.



[12 marks]

Convert given domain signal into Laplace domain





Apply KVL in Loop ①

$$\frac{5}{s} = \frac{I_1(s)}{s} + \frac{3}{s} + \{I_1(s) - I_2(s)\}\frac{1}{s}$$

$$\frac{2}{s} = \frac{2I_1(s)}{s} - \frac{I_2(s)}{s}$$

$$2I_1(s) - I_2(s) = 2 \quad — ①$$

Apply KVL in loop ②

$$0.5s\, I_2(s) - 1 + I_2(s) + \frac{1}{s}(I_2(s) - I_1(s)) = 0$$

$$\left(0.5s + 1 + \frac{1}{s}\right) I_2(s) - \frac{I_1(s)}{s} = 1 \quad — ②$$

put $I_1(s) = \dfrac{2 + I_2(s)}{2}$ in eqn ②

$$\left(0.5s + 1 + \cancel{\frac{1}{s}}\right) I_2(s) - \cancel{\frac{1}{s}}\;\frac{I_2(s)}{2} = 1$$

$$0.5s\, I_2(s) + \frac{I_2(s)}{2} = 1$$

$$s I_2(s) + I_2(s) = 2 \quad — ③$$

$I_2(s) = \frac{2}{s+1} \Rightarrow V_{out}(s) = 1 \times I_2(s) = \frac{2}{s+1}$

Apply Inverse Laplace transform

$V_{out}(s) = \frac{2}{s+1}$

$V_{out}(t) = ILT\left\{\frac{2}{s+1}\right\} = 2e^{-t}u(t)$

$V_{out}(t) = 2e^{-t}u(t)$

put $t = 1$

$V_{out}(1) = \frac{2}{e} \simeq 0.736$

Q.5 (d) The transfer function of a controller is given by,

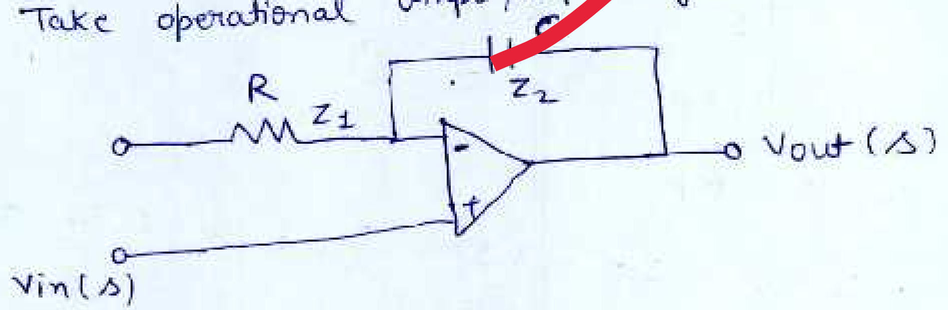
$$G_c(s) = \frac{10s+4}{s}$$

If this controller is realised using an operational amplifier, then find the other parameters of the controller assuming the capacitor value of 25 μF.

[12 marks]

$G_c(s) = 10 + \frac{4}{s} = 10\left\{1 + \frac{2}{5s}\right\} = 10\left\{1 + \frac{1}{\frac{5s}{2}}\right\}$

Take operational amplifier as follow



$V_{out}(s) = \left(1 + \frac{Z_2}{Z_1}\right) V_{in}(s)$

$G_c(s) = \frac{V_{out}(s)}{V_{in}(s)} = \left\{1 + \frac{Z_2}{Z_1}\right\}$

$\dashv\vdash \equiv \dashv\vdash \frac{1}{sC}$

25 μF

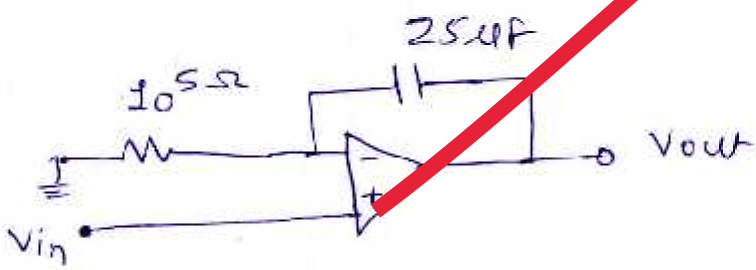
$\dashv\vdash \equiv \frac{1}{s \times 25 \times 10^{-6}}$

$$1+\frac{Z_2}{Z_1} = 1+\frac{1}{\frac{5s}{2}}$$

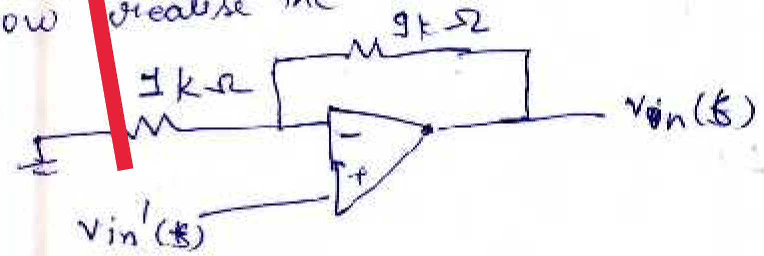
$$\frac{Z_2}{Z_1} = \frac{\frac{1}{sC}}{R} = \frac{1}{sCR} = \frac{1}{\frac{5s}{2}}$$

$$\therefore RC = \frac{5}{2}$$

$$R = \frac{5}{2C} = \frac{5}{2\times 25\times 10^{-6}} = 10^{5}\ \Omega$$

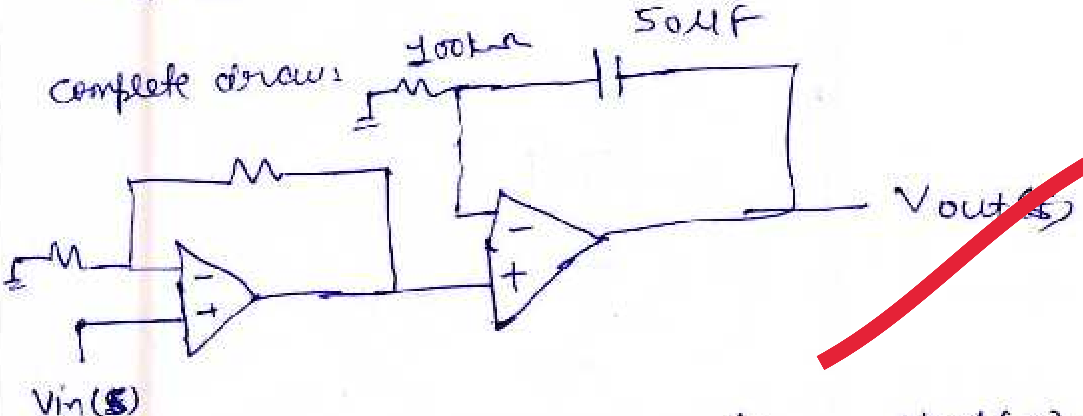


Now realise the Gain 10



$$\frac{Vin(s)}{vin'(s)} = 1+\frac{9}{1} = 10$$

Complete circuit



$$\frac{Vout(s)}{Vin(s)} = \cancel{\frac{Vout(s)}{Vin'(s)}} \times \cancel{\frac{Vin'(s)}{Vin(s)}} \quad \frac{Vout(s)}{Vin'(s)} \times \frac{Vin'(s)}{V(s)}$$

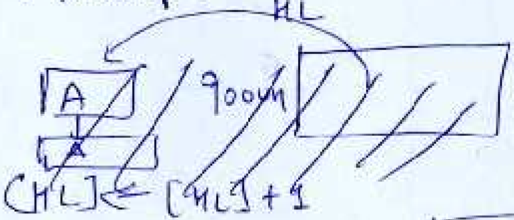
$$G_c(s) = 10\times\left(1+\frac{1}{\frac{5s}{2}}\right) = \frac{10s+4}{s}$$

Q.5 (e) Write a 8085 program to find 2's complement of the number stored in memory location 9000 H, and store the result in memory location 9001 H. Also give the flow chart of the program and calculate execution time of program if operating frequency is 5 MHz.

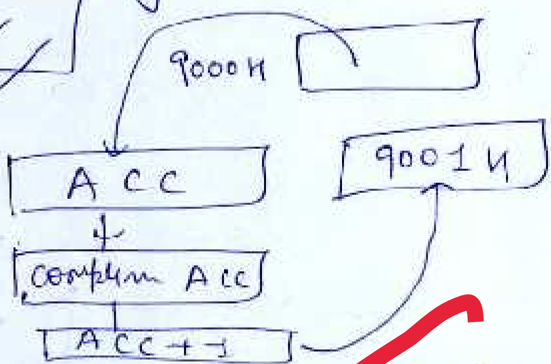
[12 marks]

2's compliment of Number = 1's complement + 1

1's complement in 8085 is same as CMA instruction



flow chart




```
LXI  H, 9000H    ; Initialize HL = 9000 H
MOV  A, M        ; move 9000H content to accumulator
CMA              ; compliment accumulator
ADI  01 H        ; Add 1 to find 2's compliment
INX  H           ; Increment HL to point to 9001 H
MOV  M, H        ; move content of accumulator
                 ; to 9001 H location.
HLT
```

LXI H, 9000H	10 T
MOV A, M	7 T
CMA	4 T
ADI 01H	7T
INX H	6 T
MOV M, H	7 T
HLT	5 T

Total T state = 46 T state

$f_{clk} = 5\,MHz$

$\text{Time } (T) = \dfrac{1}{5\,Mhz}$

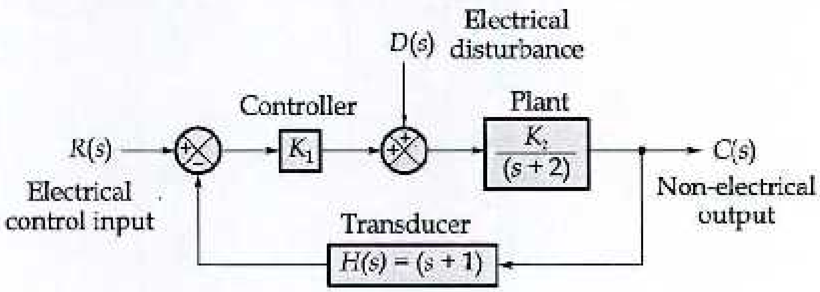
$\text{Total delay} = \dfrac{46}{5\,Mhz} = 9.2\,\mu s$

Q.6 (a) **(i)** Explain all the basic machine cycles of 8085 microprocessor and differentiate between instruction cycle (IC) and machine cycle (MC).

(ii) Draw the timing diagram of OUT instruction for 8085 microprocessor.

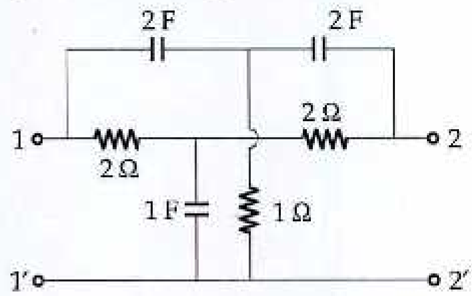
[10 + 10 marks]

Q.6 (b) For the system shown in the figure below, both the electrical control input and the disturbance are unit step signals. Find the sensitivity of the steady-state error for changes in K_1 and in K_2 individually, when $K_1 = 100$ and $K_2 = 0.10$.

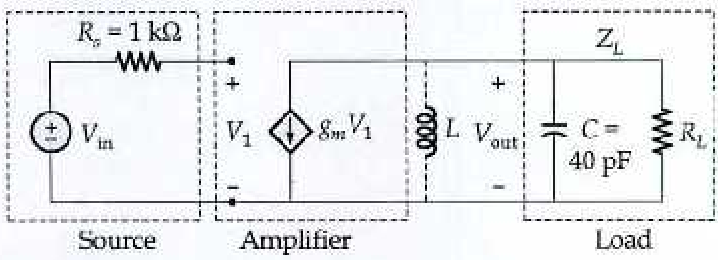


[20 marks]

Q.6 (c) **(i)** Determine the Y parameters of given network.



(ii) Below given figure displays an amplifier model containing a VCCS with $g_m = 2$ mS (milli-Siemens) and $R_L = 20$ kΩ. The applied sinusoidal voltage $V_{in}(j\omega)$ has a magnitude of 0.1 V at 10 MHz. The load is modeled by the parallel combination of R_L and the 40-pF capacitor. The capacitance accounts for such real-world phenomena as wiring capacitance, the device input capacitance, and other embedded capacitances. This capacitance cannot be removed from the circuit and often has deleterious effects on the amplifier performance.



1. With the load connected directly as shown (without L), find the magnitude of the output voltage.
2. If an inductance L is connected across the load to tune out the effect of the capacitance, find the value of L and the resulting $|V_{out}|$. What is the impact on the amplifier gain?

[8 + 12 marks]

Q.7 (a) **(i)** Explain the addressing modes of 8086 with one example each.

(ii) Obtain the physical address and effective address for different addressing modes of 8086 with the contents of register as given below:

Offset = 1000 H; [AX] = 5000 H; [BX] = 2000 H; [SI] = 3000 H; [BP] = 5000 H;

[DI] = 4000 H; [SP] = 6000 H, [DS] = 7000 H

1. Register indirect addressing mode (assuming DI).
2. Based addressing mode (assuming BX)
3. Based index addressing mode (assuming DX).
4. Based index with displacement addressing mode (assuming BX).

[14 + 6 marks]

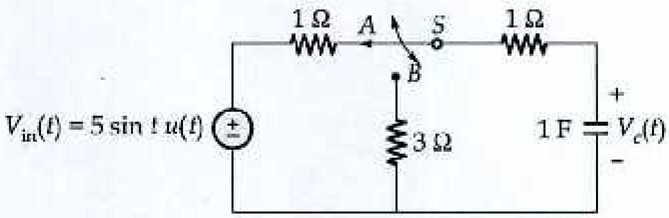
Q.7 (b) A system is described by the following state and output equations:

$$\frac{dx_1(t)}{dt} = -3x_1(t) + x_2(t) + 2u(t)\,; \quad \frac{dx_2(t)}{dt} = -2x_2(t) + u(t)\,; \quad y(t) = x_1(t)$$

If $u(t)$ is the input and $y(t)$ is the output, then find the system transfer function and state transition matrix of the above system.

[20 marks]

Q.7 (c) In the circuit given below $V_{in}(t) = 5 \sin t\, u(t)$ V and $V_c(0^-) = 0$. The switch is initially in position A. The switch 'S' moves from position 'A' to position 'B' at $t = 1s$ and from position 'B' to position 'A' at $t = 2s$, where it remains for all subsequent time. Find $V_c(t)$ for $t \geq 0$.



[20 marks]

Q.8 (a) Determine the unilateral Laplace transform of the signals given below. Specify the property used, if any, in each step.

(i) $x(t) = [u(t-1) + u(-t-4)] * e^{-2t}u(t-1)$

(ii) $x(t) = t \cdot \frac{d}{dt}\left[e^{-t} \cdot \cos t\, u(t) + e^{-(t+1)}u(-(t+1))\right]$

[10 + 10 marks]

(i)

Q.8 (b) A series circuit consists of a 300 Ω non-inductive resistor, a 7.95 μF capacitor and a 2.06 H inductor of negligible resistance.

If the supply voltage is

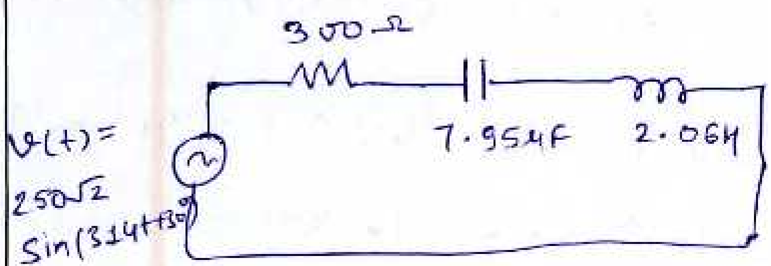
$v(t) = 250\sqrt{2}\sin(314t + 30°)$ V, calculate

(i) the circuit current,

(ii) the voltage drop across each component in the circuit,

(iii) the power consumed in the circuit.

[5 + 10 + 5 marks]



Supply $= 250\sqrt{2}\ \sin(314t+30°)$ V

$\omega = 314$ rad/sec

$$Z_c = \frac{1}{j\omega C} = \frac{1}{j\times 314\times 7.595\times 10^{-6}} = -j400.5928\ \Omega$$

$$Z_L = j\omega L = j\times 314\times 2.06 = j646.84\ \Omega$$

$$Z_{eq} = R + Z_c + Z_L = 300 + j246.2471\ \Omega$$

$$Z_{eq} = 388.12 \angle 39.4°$$

Do not write in this margin

(i) Circuit current $I = \dfrac{v(t)}{Z_{eq}} = \dfrac{v(t)}{|Z|} \sin(\theta(t) + \angle Z^\circ)$

$$I = \frac{250\sqrt{2}}{388.12} \sin(314t + 30^\circ - 39.4^\circ)$$

$$I = 0.9109 \sin(314t - 9.34^\circ) \text{ A}$$

(ii) $V_R = IR = (0.9109) \times 300 \quad \sin(314t - 9.34^\circ) \text{A}$

$= 273.281 \sin(314 - 9.34^\circ) \text{A}$

$V_C = I \times Z_C = (0.9109) \times (-j\,400.5928) \sin(314t - 9.34^\circ)$

$= 364.91 \sin(314t - 9.34^\circ - 90^\circ)$

$= 364.91 \sin(314t - 99.34^\circ) \text{ A}$

$V_L = I \times Z_L = (0.9109) \times j(646.84) \sin(314t - 9.34^\circ)$

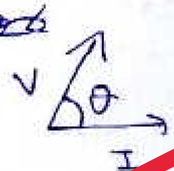
$= 589.2066 \sin(314t - 9.34^\circ + 90^\circ)$

$= 589.2066 \sin(314t + 80.66^\circ)$

(iii) Power consumed $P = \text{Re}[V I^*] = V_{RMS} I_{RMS} \cos\theta$

$P = 250\sqrt{2} \sin(314t + 30^\circ) \times$ ~~...~~

$\times 0.9109 \sin(314t + 9.34^\circ)$



$P = \dfrac{250\sqrt{2} \times 0.9109 \cos(\theta_V - \theta_I)}{2}$

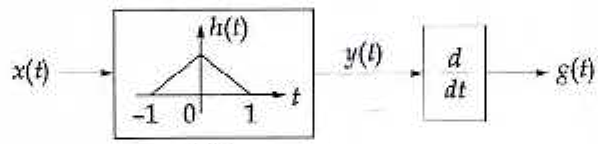
$= V_{RMS} \times I_{RMS} \times \cos(\angle\theta_V - \theta_I)$

$= \dfrac{250\sqrt{2} \times 0.9109}{2} \times \cos(30^\circ + 9.34^\circ)$

$= 124.537 \text{ W}$

18

Q.8 (c) **(i)** Consider an LTI system has the impulse response $h(t)$ shown in figure below:



If the input $x(t) = \delta(t-1) + \delta(t-2) + \delta(t-3)$, then sketch output $g(t)$.

(ii) A voltage waveform $V(t)$ has a period $T = 2$ second, its Fourier series coefficient values are:

$C_0 = 1,\ C_1 = 2j,\ C_2 = 2$

Obtain the value of $V(t)$ at $t = 0$.

[10 + 10 marks]

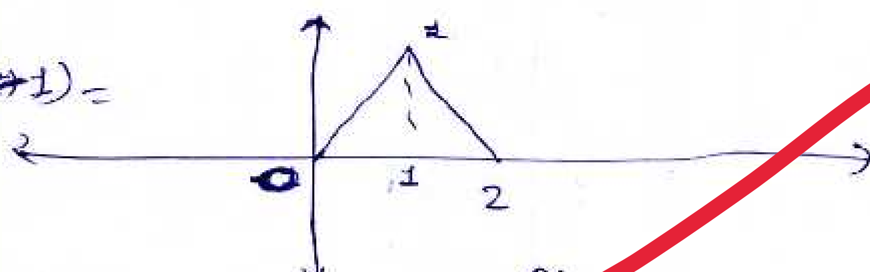
$y(t) = x(t) * h(t)$

$= [\delta(t-1) + \delta(t-2) + \delta(t-3)] * h(t)$

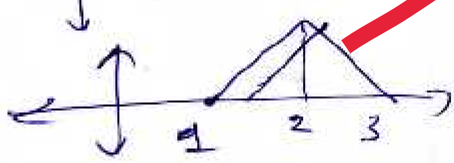
$= \delta(t-1) * h(t) + \delta(t-2) * h(t) + \delta(t-3)\, h(t)$

$y(t) = h(t-1) + h(t-2) + h(t-3)$

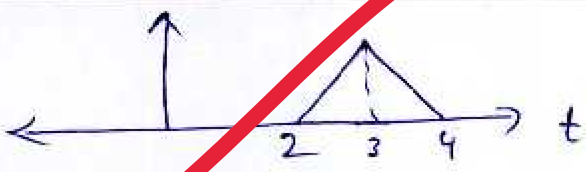
$h(t-1) =$



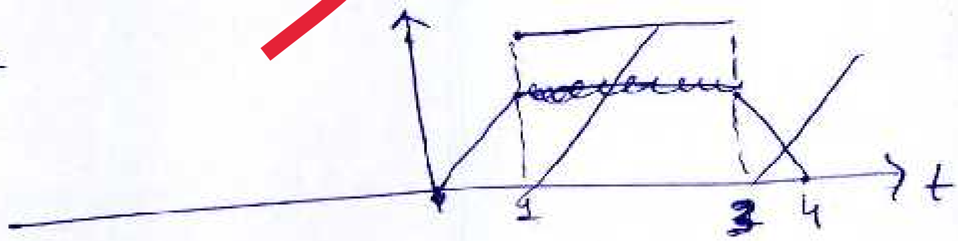
$h(t-2) =$



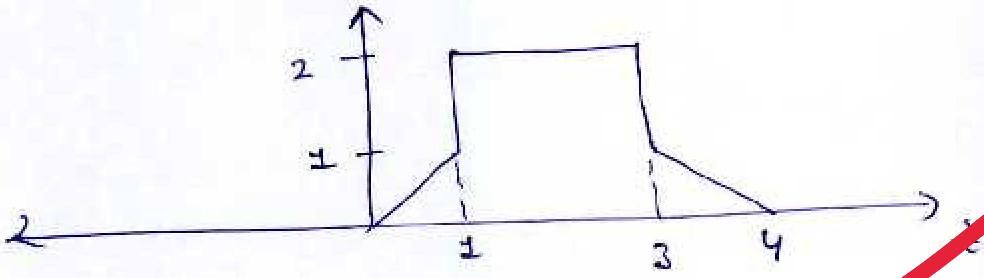
$h(t-3) =$



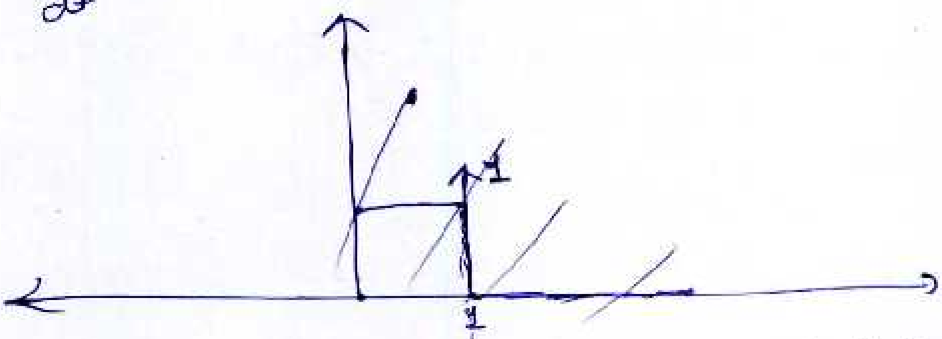
$y(t) =$



$y(t)$

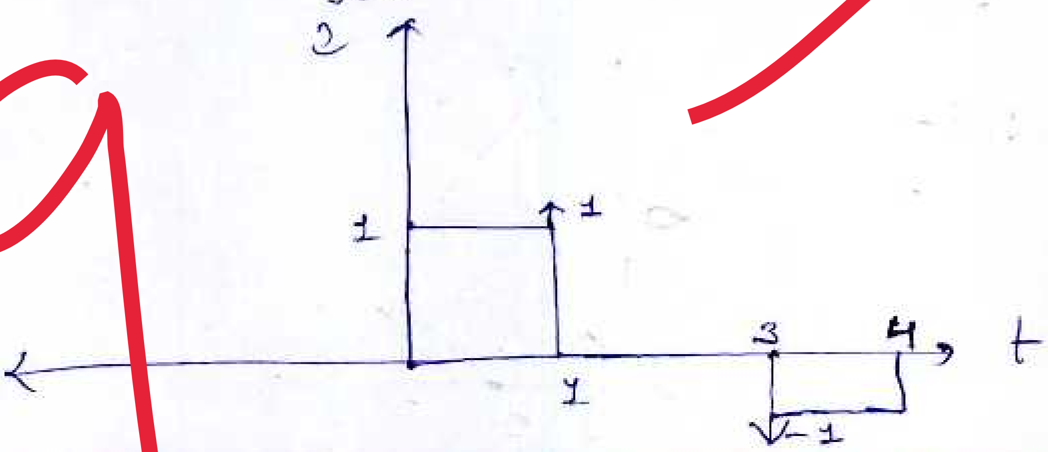


$g(t) = \frac{d}{dt} y(t) \rightarrow \frac{d}{dt}(t) = 1$



There is Jump at $t = 1$ so we have impulse function at $t = 1$, ~~change in slope present~~ ~~form 1 to 0~~ hence $-u(t-1)$ function will be present at $t = 1$

$g(t)$



(ii)

Space for Rough Work

Space for Rough Work

$$\frac{3}{(s+4)(s+2)(s+1)}$$

$$\left.\frac{3}{(s+2)(s+1)}\right|_{-4}$$

$$\frac{3}{(-4+2)(-4+1)}$$

$$\frac{3}{-2 \times -3} = \frac{1}{2}$$

$$\frac{1}{2}$$

$$\frac{3}{(s+4)(s+1)}$$

$$\frac{3}{2 \times -1}$$

$$\frac{-3}{2}$$

$$\frac{3}{(s+4)(s+2)}$$

$$\frac{3}{3 \times 1}$$

1

Space for Rough Work

$P_c\left(1+\frac{\mu^2}{2}\right)$ $\frac{Am^2}{4}$

$\frac{A_c^2}{2}\left(1+\frac{\mu^2}{2}\right)$

$\frac{\cancel{A_c^2}\,Am^2}{\cancel{A_c^2}\,4}$

$P_c \times \frac{\mu^2}{4}$. $q = CV$

$\frac{A_c^2\mu^2}{4}$

$I = C\frac{dV}{dt}$

$V = L\frac{d}{dt}I$

$L(SI(s) - I(0))$

$I = C\{SV(s) - (V0^-)\}$

$V(s) = SL - LI(0)$

$\frac{\cancel{A_c^2}}{2} \times \frac{Am^2}{\cancel{A_c^2} \times 4}$ $V(s) = \frac{1}{s}\left\{\frac{I}{C} + V(0^-)\right\}$

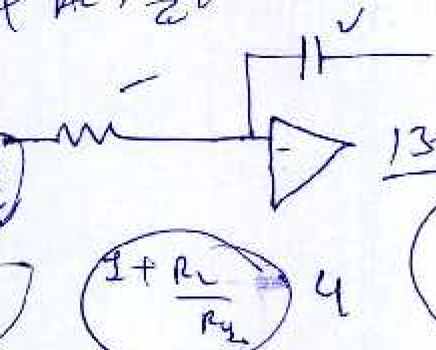
$V(s) = \frac{1}{sC}I + \frac{V(0^-)}{s}$

$\frac{Kq^2 P_m}{1+Kq^2 P_m}$

$\frac{Am^2}{8}$ $\frac{4}{8} = \frac{1}{2}$ $1+1$ $\frac{1}{2}$ $\frac{1}{8}$

$\frac{\mu^2}{2+\mu^2}$

$\frac{4}{8}$ $\frac{A_c^2\mu^2}{8}$ $+ A_c\frac{\mu^2}{2}$



$\frac{13+3s}{}$

$\frac{A_c^2\mu^2}{4}$

$\frac{A_c^2}{2} \times \frac{\mu^2}{2}$ 16

$\frac{A_c\mu}{}$ $= A \times \frac{Am}{A}$

$\frac{Am}{4}$ $1 + \frac{R_2}{R_1}$ 4

$A(s+1) + B(s+2)$

$\frac{A_c^2\mu^2}{8}$ 7 $\frac{A_c^2\mu^2}{2}$

$\left.\frac{13+3s}{s+1}\right|_{s=-2}$

$A+B=$

1 1 1

$\frac{B}{}$

$\frac{13+3s}{s+2}$ $\frac{10}{s+2}$ $s = -1$

$\frac{13-6}{-1} = \frac{7}{-7}$ $\frac{1}{2}$

$\frac{13-3}{(s+2)}$ $s = -1$

16 $\frac{13-6}{-1}$ -7

$\frac{10}{s+2} - \frac{7}{s+1}$ $10s + 10$