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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-4 : Electronic Devices & Circuits + Advanced Communication [All topics] Analog & Digital Communication Systems-1 [Part Syllabus] Signals and Systems-2 + Microprocessors and Microcontroller [Part Syllabus]

Name :

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Student's Signature

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	202

Signature of Evaluator

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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.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Electronic Devices & Circuits + Advanced Communication Topics

Q.1 (a) A Si sample with $10^{15}/\text{cm}^3$ donors is uniformly optically excited at room temperature such that $10^{19}/\text{cm}^3$ electron-hole pairs are generated per second. Find the electron concentration, hole concentration and change in conductivity upon shining the light. (Assume electron and hole lifetimes are both 10 μs, $D_p = 12\ \text{cm}^2/\text{sec}$, $\mu_n = 1300\ \text{cm}^2/\text{V-sec}$, $V_T = 0.0259$ V, $n_i = 1.5 \times 10^{10}\ \text{cm}^{-3}$.)

[12 marks]

$N_D = 10^{15}$, $n_0 \approx 10^{15}$, $p_0 = \dfrac{n_i^2}{N_D} = 2.25 \times 10^{5}/\text{cm}^3$

- Continuity equation for Holes are given by

$$\frac{d(\delta p)}{dt} = -\mu_p p \frac{dE}{dt} - \mu_p E \frac{dp}{dx} + D_p \frac{d^2 p}{dx^2} + G_p - R_p$$

Electric field Not present so $E = 0$

$$\frac{d(\delta p)}{\delta t} = D_p \frac{d^2 p}{dx^2} + G_p - R_p$$

There are No profile given so $\dfrac{d^2 p}{dx^2} = 0$

$$\frac{d(\delta p)}{\delta t} = G_p - R_p$$

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$G_p = 10^{19}/\text{cm}^3$, $R_p = \dfrac{\delta p}{\tau_p}$

$$\frac{d(\delta p)}{\delta t} = 10^{19} - \frac{\delta p}{\tau_p}$$

$$\frac{d(\delta p)}{\delta t} + \frac{\delta p}{\tau_p} = 10^{19}$$

Similarly
$\delta n = 10^{19} e^{-\frac{t}{10 \times 10^{-6}}}\ \text{cm}^3$
$\frac{d(\delta n)}{dt} =$

$$\delta p = 10^{19} e^{-\frac{t}{\tau_p}}\ \text{cm}^3 + C$$

$$\boxed{\delta p = 10^{19} e^{-\frac{t}{10 \times 10^{-6}}}\ \text{cm}^3 + C}$$

$\delta p = 10^{19} e^{-\frac{t}{10 \times 10^{-6}}}$ ~~0.0225 × 10^3~~

Q.1 (b) A typical single mode optical fiber has a core of diameter 8 μm and a refractive index of 1.46. The normalized index difference is 0.3%. The cladding diameter is 125 μm. Calculate the numerical aperture and the acceptance angle of the fiber. What is the single mode cut-off wavelength λ_c of the fiber?

[4 + 4 + 4 marks]

Given core diameter $2a = 8 \mu m \Rightarrow a = 4 \mu m$

core refractive index $n_1 = 1.46$

$\Delta = 0.3\% = 0.003$

Cladding diameter $2b = 125 \mu m$

① Numerical aperture $(N.A) = \sqrt{n_1^2 - n_2^2}$

n_2 : Refractive index of cladding

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} = \frac{(N.A)^2}{2n_1^2}$$

$$N.A = n_1\sqrt{2\Delta} = 1.46\sqrt{2 \times 0.003}$$

$$N.A = 0.1131$$

② $\sin\theta_a = N.A$

↳ acceptance angle

$$\theta_a = \sin^{-1}(N.A)$$

$$= \sin^{-1}(0.1131)$$

$$= 6.494^\circ$$

③ For single mode Normalized frequency number $V = 2.405$, and we get $\lambda = \lambda_c$

$$V = \left(\frac{2\pi a}{\lambda}\right) N.A$$

$$2.405 = \frac{2\pi \times 4 \times 10^{-6}}{\lambda_c} \times 0.1131$$

$$\lambda_c = 1.182 \times 10^{-6} m = 1.182 \mu m$$

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Q.1 (c) A cellular system operator is allocated a total spectrum of 5 MHz for deployment of an analog cellular system based on the FDMA technique, with each simplex channel occupying 25 kHz bandwidth. Compute the number of simultaneous calls possible in the system, number of simplex channels and number of duplex channels.

[12 marks]

Total spectrum = 5MHZ

Simplex channel BW = 25KHZ

$$\text{No. of simplex channel} = \frac{\text{Total BW}}{\text{Simplex channel BW}} = \frac{5\text{MHZ}}{25\text{KHZ}} = 200$$

Duplex channel will occupy twice Bandwidth so

$$\text{No. of Duplex channel} = \frac{\text{No. of simplex channel}}{2}$$

$$\text{No. of Duplex channel} = \frac{200}{2} = 100$$

For one call 1 duplex channel needed so

100 simultaneous calls will be possible

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Q.1 (d) An n-type semiconductor has excess carrier holes 10^{14} cm^{-3}, a minority carrier life time 10^{-6} sec in the bulk material, and a minority carrier lifetime 10^{-7} sec at the surface. Assume zero applied electric field and let $D_p = 10$ cm^2/sec. Determine the steady-state excess carrier concentration as a function of distance from the surface ($x = 0$) of the semiconductor.

[12 marks]

$E = 0 \;,\; G_p = 0$

~~dp~~ $\frac{d(\delta p)}{dt} = D_p \frac{d^2 p}{dx^2} + G_p - R_p$

$\cancel{\frac{d(\overset{0}{\delta p})}{\delta t}} = D_p \frac{d^2 p}{dx^2} - \frac{\delta p}{\tau_p}$

↳ with time carrier (minority) concentration not changing.

$D_p \frac{d^2 p}{dx^2} = \frac{\delta p}{\tau_p}$

$\frac{d^2 p}{dx^2} - \frac{1}{D_p \tau_p} d(\delta p) = 0$

~~$\delta p = \frac{d1}{L}$~~

$L_p = \sqrt{D_p \tau_p}$ so $D_p \tau_p = L_n^2$

$\frac{d^2 p}{dx^2} - \frac{1}{L_p^2} (\delta p) = 0$

$\delta p = A e^{-\frac{x}{L_p}} + B e^{x/L_p}$

As $x \to \infty$ then $\delta p \to 0$ Hence $B = 0$

$\delta p = A e^{\frac{-x}{L_p}}$

Given at $x = 0$ $\delta p = 10^{14}$

$\delta p = 10^{14} e^{\frac{-x}{L_p}}$

$\boxed{\delta p = 10^{14} e^{-\frac{x}{10^4}}}$

$L_p = D_p \times \tau_p$

$= 10^{10} \times 10^{-6}$

$= 10^4$ Cm

Do not write in this margin

Q.1 (e) Calculate the signal to co-channel interference ratio $\frac{C}{I}$ at the mobile receiver located at the boundary of its operating cell, under the influence of interfering signals from one co-channel interfering cell in the first tier in a cellular system designed with 6-sector-directional antenna cellular system and cluster size of $N = 7$. Comment on the results for a practical cellular system. Assume the path-loss exponent as '4'.

[12 marks]

Q.2 (a) **(i)** In a certain BJT (PNP), we increase the base doping by a factor of 10 and halve the base width. Calculate approximately by what factor the collector current changes in the normal active mode, assuming that everything else stays same.

(ii) In a certain BJT (PNP), the emitter doping is 100 times greater than the base doping, the emitter width is 0.1 times the base width and assume both the base and emitter widths to be much shorter than the carrier diffusion lengths L_n and L_p. What is the emitter injection efficiency and base transport factor?

[10 + 10 marks]

Q.2 (b) (i) Write short notes on pure ALOHA and slotted ALOHA.

(ii) Determine the maximum throughput that can be achieved using pure ALOHA and slotted ALOHA protocols.

[10 + 10 marks]

Q.2 (c) **(i)** In a particular semiconductor material, the effective density of states functions are given by $N_C = N_{c0}\left(\frac{T}{300}\right)^{3/2}$ and $N_V = N_{v0}\left(\frac{T}{300}\right)^{3/2}$ where N_{co} and N_{v0} are constant and independent of temperature. Experimentally determined concentrations are found to be $n_i = 1.4 \times 10^2 \text{ cm}^{-3}$ at $T = 200$ K and $n_i = 7.7 \times 10^{10} \text{ cm}^{-3}$ at $T = 400$ K. (Assume E_g is constant over this temperature range). Determine the product $N_{c0} \times N_{v0}$ for both temperatures.

(ii) Boron is implanted into n-type Si sample ($N_d = 10^{16} \text{ cm}^{-3}$), forming an abrupt junction of square cross-section with area = $2 \times 10^{-3} \text{ cm}^2$. Assume, acceptor concentration in the p-type region is $N_a = 4 \times 10^{18} \text{ cm}^{-3}$. Calculate V_0, x_{n0}, x_{p0} and positive ionic space charge, Q_+ for this junction at equilibrium (300 K).

(Assume, $V_T = 0.0259$ V; $\epsilon_{Si} = 11.7 \epsilon_0$, $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$)

[10 + 10 marks]

Q.3 (a) Consider a city of 10 square kilometers. A macrocellular system design divides the city into square cells of 1 square kilometer, where each cell can accommodate 100 users. Find the total number of users that can be accommodated in the system and the length of time it takes a mobile user to traverse a cell (approximate time needed for a handoff) when moving at 30 km per hour. If the cell size is reduced to 100 square meters and everything in the system scales so that 100 users can be accommodated in these smaller cells, find the total number of users the system can accommodate and the length of time it takes to traverse a cell.

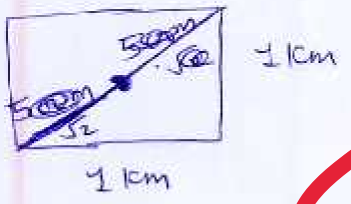
[20 marks]

(i) Given city is $10\ km^2$

One cell distance = $1\ km^2$

No. of cell Required to cover the city = $\frac{10 km^2}{1 km^2} = 10$

1 cell accomodate 100 user so 10 cell will accomodate $100 \times 10 = 1000$ user.



Minimum distance travelled by the user when call disconnected = 1 km

$$\text{Time} = \frac{1 km}{30 km/hour} = \frac{1}{30} \text{ hour} = 2 \text{ minute}$$

2 minute time

(ii) Cell size reduced to $100\ m^2$

$$\text{No. of cell required} = \frac{10 \times 10^6\ m^2}{100\ m^2} = 10^5$$

$$\text{No. of user} = 100 \times 10^5 = 10^7$$

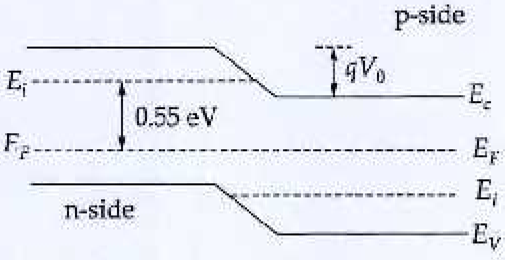
$$\text{Time} = \frac{10 m}{30 \times \frac{5}{18}\ m/s} = 1.2 \text{ sec time}$$

1.2 sec for call will be disconnected

Q.3 (b) Consider a Si n$^+$–p junction with Energy band diagram shown below. The acceptor carrier concentration, $N_a = 10^{15}$ cm^{-3}, area of junction, $A = 0.001$ cm^2.

Draw the plot $\frac{1}{C_j^2}$ vs V_R mentioning the values for reverse bias voltages (in magnitude), $V_R = 1$ V, 5 V, 10 V

(Assume, $KT = 0.025$ eV, $\epsilon_s = 11.7\,\epsilon_0$, $n_i = 1.5 \times 10^{10}$ cm^{-3})



[20 marks]

Given n+-p Junction

$$qv_0 = q\phi_1 + q\phi_2$$

Given $q\phi_1 = 0.55\,eV$

$$q\phi_2 = KT \ln\left(\frac{NA}{n_i}\right)$$

$$q\phi_2 = 0.025\,ev \ln\left(\frac{10^{15}}{1.5\times10^{10}}\right)$$

$$q\phi_2 = 0.278\,eV$$

$$qv_0 = 0.55 + 0.278 = 0.828\,eV$$

$$\boxed{\phi_{bi} = v_0 = 0.828\,V}$$

$$C_j = \frac{A\,\varepsilon_s}{w}$$

Given $A = 0.001\,cm^2$, $\varepsilon_s = 11.7\,\varepsilon_0$

$$W = \sqrt{\frac{2\varepsilon_s}{w}\left(\frac{1}{NA} + \frac{1}{ND}\right)(\phi_{bi} + V_R)}$$ (Reverse Bias)

Given n+-p Junction so $N_D \gg N_A$ and

$$\frac{1}{NA} + \frac{1}{ND} \approx \frac{1}{NA}$$

$$W = \sqrt{\frac{2\varepsilon}{q} \frac{1}{N_A} \times (\phi_{bi} + V_R)}$$

$$C_j = \frac{A\varepsilon_s}{W} = \frac{A\varepsilon_s}{\sqrt{\frac{2\varepsilon_s}{qN_A}(\phi_{bi}+V_R)}}$$

$$C_j \quad \frac{1}{C_j^2} = \frac{2\varepsilon_s(\phi_{bi}+V_R)}{qN_A \times A^2 \varepsilon_s^2}$$

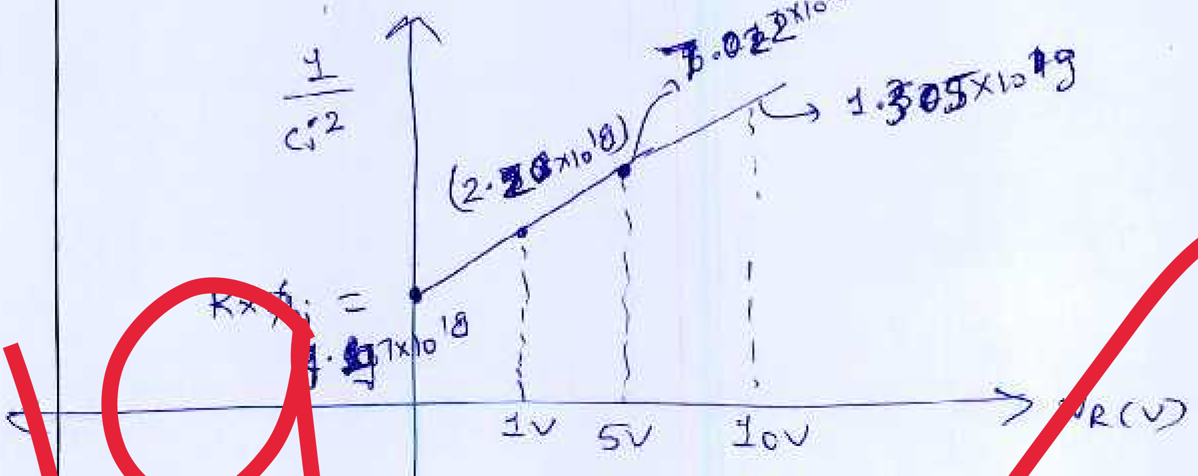
$$\frac{1}{C_j^2} = \frac{2(\phi_{bi}+V_R)}{qN_A A^2 \varepsilon_s} = K(\phi_{bi}+V_R)$$

$$= K\phi_{bi} + KV_R$$

$$\text{find } K = \underset{\downarrow}{\frac{2}{qN_A A^2 \varepsilon_s}} = \frac{2}{1.6\times10^{-19} \times 10^{15} \times (0.001)^2 \times 8.85 \times 11.7 \times 10^{-14}}$$

$$\boxed{K = 1.205 \times 10^{18} \; F^{-2} V^{-1}}$$

$$\phi_{bi} = 0.828 \rightarrow \frac{1}{C_j^2} = 9.977\times10^{19} + 1.205\times10^{18} V_R$$



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$$\frac{1}{C_j^2} = 9.977\times10^{19} + 1.205\times10^{18} V_R$$

put V_R = 1V, 5V and 10V

Q.3 (c) A satellite circuit has the following parameters:

	Uplink (in dB)	Downlink (in dB)
[EIRP]	54	34
[G/T]	0	17
[FSL]	200	198
[RFL]	2	2
[AA]	0.5	0.5
[AML]	0.5	0.5

Calculate the overall $[C/N_0]$.

[20 marks]

overall $[C/N_0]$

$$\frac{1}{(\text{overall}([C/N_0]))} = \frac{1}{(C/N_0)_{\text{uplink}}} + \frac{1}{(C/N_0)_{\text{downlink}}}$$

$$\left(\frac{C}{N_0}\right)_{\text{uplink}} = \frac{P_t G_t \; G_r}{L_{up} \; L_s \; K T_e} = (EIRP)\,dB + (G/T)\,dB - L_{up}(dB) - L_s(dB) - 10\log(k)$$

$$(C/N_0)_{\text{downlink}} = (EIRP)dB + (G/T)dB - L_{d}(dB) - L_s dB - 10\log k$$

$(C/N)_{uplink} =$ ~~54 + 200 − 2 − 0.5 − 0.5~~

$(C/N)_{uplink} = (EIRP)_{dB} + (G/T)_{dB} - 10\log(1.38\times10^{-23})$
$- (FSL)_{dB} - (RFL)_{dB} - [AA]_{dB} - [AML]_{dB}$

$(C/N)_{uplink} = 54 + 0 + 228.599 - 200 - 2 - 0.5 - 0.5$

$(C/N)_{up} = 79.599\ dB$

$(C/N)_{down} = \cancel{8}\ 34 + 17 + 228.599 - 198 - 2 - 0.5 - 0.5$

$= 78.599\ dB$

$$\frac{1}{(C/N)_{overall}} = \frac{1}{91183628} + \frac{1}{72429735}$$

$$\frac{1}{(C/N)_{overall}} = 2.477\times10^{-8}$$

$(C/N)_{overall} = 40364363$

$(C/N)_{dB} = 76.06\ dB$

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Q.4 (a) (i) A photodetector is provided with the following data:

1. Sensitivity = 0.6 A/W
2. The detector is kept at a distance of 3 cm from GaAs IR LED.
3. Output power of the LED = 0.6 mW
4. Peak emission wavelength = 850 nm
5. Active area of the photoconductor = 7.5×10^{-3} cm^2
6. Divergence angle of LED = 0.65 rad

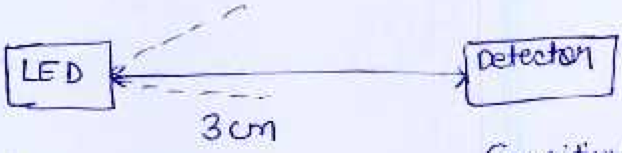
Find out the value of photocurrent.

(ii) An avalanche diode is provided with following data:

1. Quantum efficiency = 0.75
2. Wavelength = 850 nm
3. Optical power = 0.6 μW
4. Avalanche multiplied current = 11 μA

Determine the avalanche multiplication factor.

[12 + 8 marks]



$P_{in} = 0.6 \times 10^{-3}$ W

$\lambda = 850 \times 10^{-9}$ m

Divergence angle = 0.65 rad

Sensitivity = 0.6 A/W

$A_D = 7.5 \times 10^{-3}$ cm^2

$A_D = 7.5 \times 10^{-7}$ m^2

Power recieved at the detector P_r is given by

$$P_r = \frac{P_{in}}{4\pi r^2} \times \left(\frac{\theta}{2\pi}\right) \times A_D$$

where r is the distance and θ is the divergence angle

$$P_r = \frac{0.6 \times 10^{-3}}{4\pi \times (3 \times 10^{-2})^2} \times \left(\frac{0.65}{2\pi}\right) \times 7.5 \times 10^{-3} \times 10^{-4} \text{ m}^2$$

PTO

$P_r = 4.11617 \times 10^{-9}\ W$

4

$\text{Sensitivity} = \frac{I_o}{P_{in}}$

photocurrent $I_o = P_r \times \text{Sensitivity}$

$= 4.11617 \times 10^{-9}\ W \times 0.6\ A/W$

$= 2.4697 \times 10^{-9} A$

$$\boxed{\text{photocurrent} = 2.47\ nA}$$

(ii) Given $\eta_Q = 0.75$

$I_o \rightarrow$ Photo current without avalanche multiplication

$\lambda = 850 \times 10^{-9} m$

$P_{in} = 0.6 \times 10^{-6} W$

$I_{out} = 11 \times 10^{-6} A$, $E_p = \frac{hc}{\lambda}$

$$\eta_Q = \frac{\frac{I_o}{q}}{\frac{P_{in}}{E_p}} = \frac{I_o}{q} \times \frac{E_p}{P_{in}}$$

$$I_o = \frac{q\,\eta_Q \times P_{in}}{E_p} = \frac{1.6 \times 10^{-19} \times 0.75 \times 0.6 \times 10^{-6}}{\frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{850 \times 10^{-9}}} A$$

10

$I_o = 0.30829\ \mu A$

Multiplication factor $M = \frac{I_{out}}{I_o} = \frac{11 \times 10^{-6}}{0.30829 \times 10^{-6}} = 35.68$

Q.4 (b) Consider a Si n-channel MOSFET for a gate-to-substrate work function difference $\phi_{ms} = -1.5$ eV, gate oxide thickness = 100 Å, $N_A = 10^{18}$ cm^{-3} and fixed oxide charge of 5×10^{10} qC/cm^2.

(i) Calculate threshold voltage, V_T, for a substrate bias of –2.5 V.

(ii) Sketch a labelled band diagram normal to the surface at V_T showing the fermi potential, for a substrate bias of –2.5 V.

(Assume $\epsilon_{si} = 11.8\,\epsilon_0$, $\epsilon_i = 3.9\,\epsilon_0$, $\frac{kT}{q} = 0.026$ V)

[4 + 6 marks]

$$V_T = V_{FB} + \frac{|Q_{SS}|}{C_{ox}} + 2\phi_f \quad (\text{when } V_{SB} = 0V)$$

Given $N_A = 10^{18}\, cm^{-3}$, $n_i = 1.5\times10^{10}\, cm^{-3}$

$$\boxed{\phi_f = \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right) = 0.4684\ V}$$

~~$V_{FB} = (\phi_{MS} - \left(\frac{Q_{SS}'}{C_{ox}}\right)$ 5×10^{10}~~

~~No Trap Charge = 5×10^{10}~~ $q\,C/cm^2$

~~$\varepsilon_{ox} = 3.9\,\varepsilon_0$~~

~~$V_{FB} = -1.5 - \frac{5\times10^{10}}{3.9\times8.85\times10^{-14}\times1.6\times10^{-19}}$~~

$\urcorner$ No Trap Charge.

$$V_{FB} = \phi_{MS} - \frac{Q_{Trap\,Charge}}{C_{ox}} = -1.5V$$

$$V_T = V_{FB} + \frac{\sqrt{2\varepsilon q N_D}}{C_{ox}}\left(\sqrt{V_{SB}+2\phi_f}\right) + 2\phi_f$$

$$V_T = V_{FB} + \frac{\sqrt{2\varepsilon q N_D\, 2\phi_f}}{C_{ox}}\left(\sqrt{\frac{V_{SB}+2\phi_f}{2\phi_f}}\right) + 2\phi_f$$

$$Q_{SS} = \sqrt{2 \varepsilon q N_D (2\phi_f)}$$

$$Q_{SS} = 5\times10^{10}\ qC/cm^2$$

$$V_T = -1.5 + \frac{5\times10^{10}}{C_{ox}}\left[\sqrt{\frac{V_{SB}+2\phi_f}{2\phi_f}}\right] + 2\phi_f$$

$$V_T = -1.5 + \frac{5\times10^{10}}{C_{ox}}\sqrt{\frac{2.5+2\times 0.4684}{2\times0.4684}} + 2\times0.4684$$

$$C_{ox} = \frac{3.9 \times 8.85\times10^{-14}}{100\times10^{-10}} =$$

V_T (without substrate potential) $V_{SB} = 0$

$$V_T = V_{FB} + \frac{\sqrt{2\varepsilon q N_D (2\phi_f)}}{C_{ox}} + 2\phi_f$$

V_T with substrate potential

$$V_T = V_{FB} + \frac{\sqrt{2\varepsilon q N_D (V_{SB}+2\phi_f)}}{C_{ox}} + 2\phi_f$$

Q.4 (c) (i) A multimode graded index fiber exhibits total pulse broadening of 0.5 μs over a distance of 10 km.

Determine:

1. Pulse dispersion per unit length.
2. The maximum possible bandwidth on the link assuming no intersymbol interference while transmitting through NRZ pulse.
3. The bandwidth length product for the fiber.

(ii) A 9 km optical link consist of multimode step index fiber with a core refractive index of 1.5 and cladding refractive index of 1.45.

Determine:

1. The RMS pulse broadening due to intermodal dispersion on the link.
2. The Delay difference between the fastest and slowest modes at the fiber output.

[10 + 10 marks]

(i) Pulse Broadening $\tau = 0.5\,\mu s$

Distance = 10 km

Pulse dispersion per unit length $= \frac{0.5\,\mu s}{10\,km} = 0.05\,\mu s/km$

For NRZ pulse $BW = \frac{R_b}{2} = \frac{1}{4\tau}$

$BW = \frac{1}{4 \times 0.5 \times 10^{-6}} = 0.5\,MHZ$

BW Length product = BW × length = 0.5 MHz × 10 km

$= 5 \times 10^9$ Hzm

(ii) $L = 9$ km, $n_1 = 1.5$, $n_2 = 1.45$

RMS pulse Broadening for multimode fiber • ~~$\left(\frac{n_1 L}{c}\right)\frac{\Delta^2}{8}$~~

is given by $\sigma_s = \frac{\Delta t}{2\sqrt{3}}$

$\Delta t = \left(\frac{n_1 L}{c}\right)\frac{\Delta^2}{8}$ (Multimode fiber)

~~Δ~~ $\Delta = \frac{n_1^2 - n_2^2}{2 n_1^2} = \frac{1.5^2 - 1.45^2}{2 \times (1.5)^2}$

$\Delta = 0.03278$

$\Delta t = \frac{(1.5 \times 9 \times 10^3)}{3 \times 10^8} \times \frac{(0.03278)^2}{8} = 6.04$ ns

$\sigma_s = \frac{\Delta t}{2\sqrt{3}} = \frac{6.04\text{ns}}{2\sqrt{3}} = 1.745$ ns

Delay spread b/w $-\frac{\Delta t}{2}$ and $\frac{\Delta t}{2}$ so maximum delay b/w fastest and slowest mode will be $\Delta t = 6.04$ ns

Section B : Analog & Digital Communication Systems-1 + Signals and Systems-2 + Microprocessors and Microcontroller-2

Q.5 (a) A message signal $m(t) = \cos 2000\,\pi t + 2\cos 4000\,\pi t$ modulates the carrier $c(t) = 100\cos 2\pi f_c t$, where $f_c = 1$ MHz to produce the DSB signal $m(t) \times c(t)$.

(i) Determine the expression for the upper sideband (USB) of the DSB signal.

(ii) Determine and sketch the spectrum of the USB signal.

[12 marks]

Given $m(t) = \cos 2000\pi t + 2\cos 4000\pi t$

$c(t) = 100 \cos 2\pi f_c t = 100 \cos 2\pi(10^6)t$

$S_{DSB}(t) = m(t) \times c(t)$

$S_{DSB}(t) = (\cos 2000\pi t + 2\cos 4000\pi t)\ 100\cos(2\pi(10^6)t)$

$= 100\cos 2000\pi t \times \cos(2\pi(10^6)t) + 200\cos(4000\pi t)\cos(2\pi(10^6)t)$

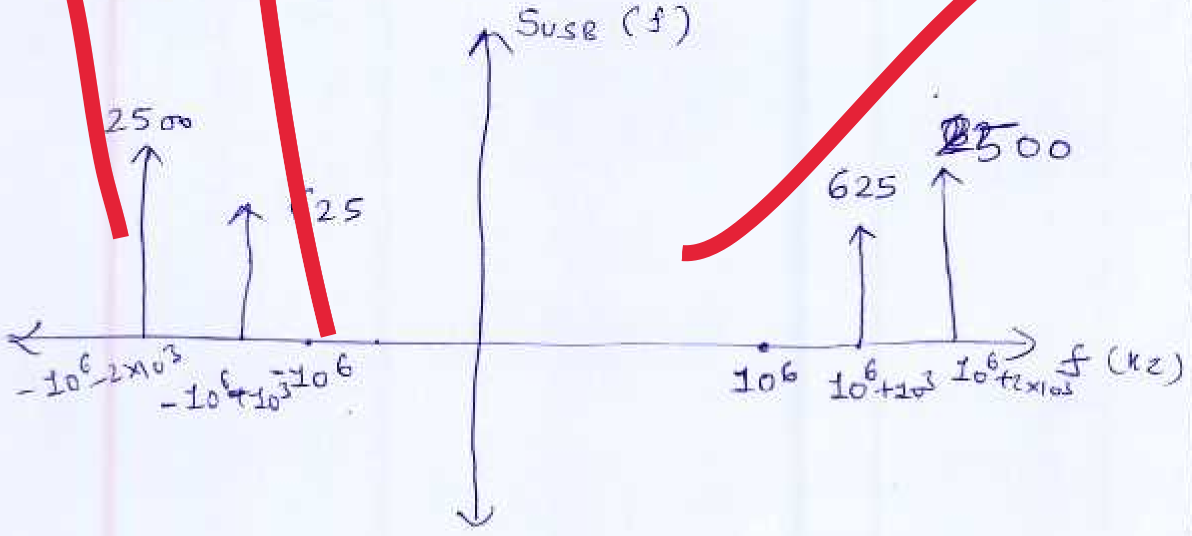
$= 50\left[\cos(10^6+10^3)2\pi t + \cos(2\pi(10^6-10^3)t)\right]$

$+ 100\left[\cos(10^6+2\times10^3)2\pi t + \cos(2\pi(10^6+2\times10^3)t)\right]$

$S_{DSB}(t) = 50\cos(2\pi(10^6+10^3)t + 100\cos(2\pi(10^6+2\times10^3)t]$

$+ 100\cos(2\pi(10^6-10^3))t + 100\cos(2\pi(10^6-2\times10^3t)$

$S_{USB}(t) = 50\cos[2\pi(10^6+10^3)t] + 100\cos(2\pi(10^6+2\times10^3t)$



Q.5 (b) Find the Z-transform of given signal and also draw ROC:

$$x[n] = \left(\frac{1}{3}\right)^n \sin\left(\frac{\pi}{4}n\right) u[n]$$

[12 marks]

$$X(z) = \sum_{n=-\infty}^{n=\infty} x[n] z^{-n}$$

write $\sin\left(\frac{\pi}{4}n\right) = \frac{e^{j\left(\frac{\pi}{4}\right)n} - e^{-j\left(\frac{\pi}{4}\right)n}}{2j}$

$$x[n] = \left(\frac{1}{3}\right)^n \sin\left(\frac{\pi}{4}n\right) u[n] = \frac{1}{2j}\left[\left(\frac{1}{3}\right)^n \left(e^{j\frac{\pi}{4}}\right)^n - \left(\frac{1}{3}\right)^n e^{(j\frac{\pi}{4})n}\right] u(n)$$

$$x[n] = \frac{1}{2j}\left[\left(\frac{1}{3}e^{j\frac{\pi}{4}}\right)^n - \left(\frac{1}{3}e^{-j\frac{\pi}{4}}\right)^n\right] u[n]$$

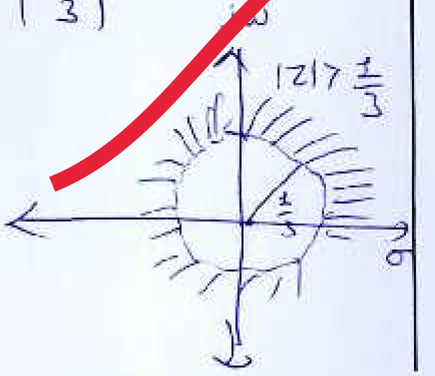
$$X(z) = \sum_{n=-\infty}^{n=\infty} \frac{1}{2j}\left[\left[\frac{1}{3}\left(e^{j\frac{\pi}{4}}\right)\right] - \left(\frac{1}{3}e^{-j\frac{\pi}{4}}\right)^n\right] z^{-n} u[n]$$

$$= \frac{1}{2j} \sum_{n=0}^{\infty} \left(\frac{1}{3}e^{j\frac{\pi}{4}}\right)^n - \left(\frac{1}{3}e^{-j\frac{\pi}{4}}\right)^n z^{-n}$$

$$= \frac{1}{2j} \times \left[\frac{1}{1 - \frac{1}{3}e^{j\frac{\pi}{4}} z^{-1}} - \frac{1}{1 - \frac{1}{3}e^{-j\frac{\pi}{4}} z^{-1}}\right]$$

ROC $|z| > \left|\frac{1}{3}e^{j\frac{\pi}{4}}\right| \cap |z| > \left|\frac{1}{3}e^{-j\frac{\pi}{4}}\right|$

ROC : $|z| > \left|\frac{1}{3}\right|$



Q.5 (c) Describe in brief about different data transfer modes of DMA controller. How are HOLD and $\overline{\text{HLDA}}$ lines used in DMA operations? **[12 marks]**

DMA controller used to directly transfer the data b/w memory and I/o devices without intervention of the CPU.

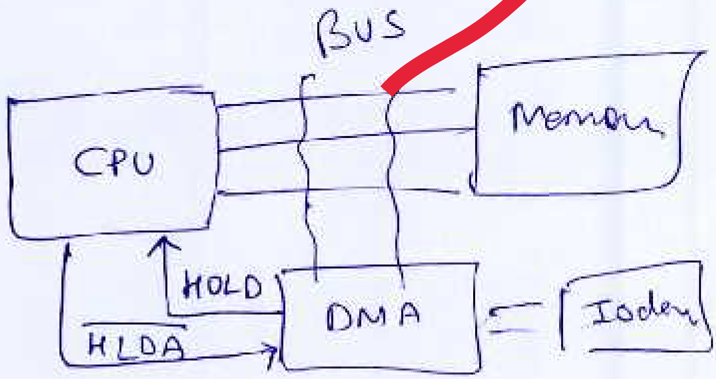
There are three transfer modes of DMA controller

① Block mode : Data transfer took place block wise one block at a time.

② Burst mode : All the data transfer takes place in single burst. CPU remain Idle for long time.

③ Interleaved mode : In this mode when CPU does not use BUS at that time DMA uses CPU bus to transfer the data.

When DMA controller require to perform DMA operation It generate HOLD (active high) signal on CPU pin. When CPU complete It's current instruction execution it sends $\overline{\text{HOLDA}}$ (active low) signal to DMA. Bus control will pass to DMA to perform the memory operation when transfer completed DMA will make active signal to low and CPU start using the BUS.



Q.5 (d) The carrier $C(t) = A \cos 2\pi 10^6 t$ is angle modulated (PM or FM) by the sinusoid signal $m(t) = 2 \cos 2000\,\pi t$. The deviation constants are $K_p = 1.5$ rad/V and $K_f = 3000$ Hz/V.

(i) Determine the modulation index, β_f and β_p.

(ii) Determine the bandwidth in each case using Carson's rule.

[12 marks]

(i) $\beta_f = \dfrac{\Delta f}{f_{max}}$

$f_{max} = 1000$ Hz (message freq)

$\Delta f = K_f \, A_{max} = 3000 \times 2 = 6000$ Hz

$\beta_f = \dfrac{6000}{1000} = 6$

$\beta_p = \dfrac{\Delta f}{f_m} = \dfrac{K_p A_m f_m}{f_m} = K_p A_m$

$\beta_p = 1.5\text{rad/V} \times 2V = 3$

(ii) By carson's rule $BW = 2(\beta + 1) f_{max}$

$(BW)_{PM} = 2\,(\beta_{PM} + 1) f_m$

$= 2\,(3+1)\,(1\,kHz)$

$= 8\ kHz$

$(BW)_{FM} = 2\,(\beta_{FM} + 1) f_m$

$= 2\,(6+1)\,(1\,kHz)$

$= 14\ kHz$

Q.5 (e) An FIR system is characterized by $y[n] = 0.2x[n-2] + 0.2x[n] + 0.4x[n-3]$. If the input sequence {–1, 1, 0, –1} is applied to this system, find the summation of output $y[n]$.

[12 marks]

$y[n] = 0.2x[n-2] + 0.2x[n] + 0.4x[n-3]$

Apply Z transform both sides

$Y[z] = 0.2z^{-2}X[z] + 0.2X[z] + 0.4z^{-3}X[z]$

$$\frac{Y[z]}{X[z]} = 0.2 + 0.2z^{-2} + 0.4z^{-3}$$

System $H[z] = 0.2 + 0.2z^{-2} + 0.4z^{-3}$

Input $x[n] = \{-1, \underset{\uparrow}{1}, 0, -1\}$

$X[z] = -1 + z^{-1} + 0z^{-2} - z^{-3}$

$X[z] = -1 + z^{-1} - z^{-3}$

$Y[z] = X[z]\,H[z]$

$= (-1 + z^{-1} - z^{-3})(0.2 + 0.2z^{-2} + 0.4z^{-3})$

$= -0.2 - 0.2z^{-2} - 0.4z^{-3} + 0.2z^{-1} + 0.\cancel{2}z^{-3}$

$+ 0.4z^{-4} - 0.2\cancel{z^{-3}} - 0.2z^{-5} - 0.4z^{-6})$

10

$Y[z] = -0.2 + 0.2z^{-1} - 0.2z^{-2} - 0.4z^{-3} + 0.4z^{-4}$

$- 0.2z^{-5} - 0.4z^{-6}$

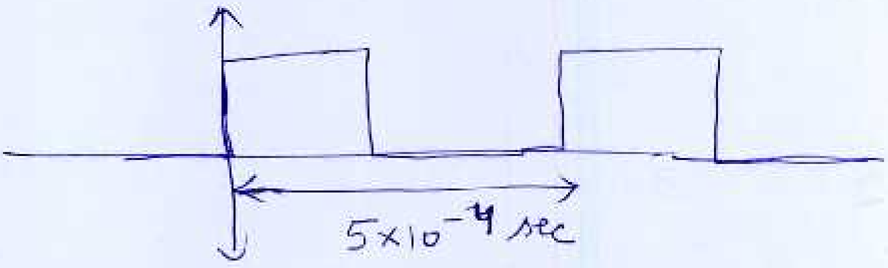
$y[n] = [\underset{\uparrow}{-0.2}, 0.2, -0.2, -0.4, 0.4, -0.2, -0.4]$

$\sum_{l=0}^{n} y[n] \xrightarrow{Z\,\cancel{\text{transform}}} y[n] * u[n]$

$y_1(z) \longleftrightarrow Y[z] \times \frac{1}{1-z^{-1}}$

Q.6 (a) Write a program to generate a square wave of frequency 2 kHz on ports pins P1.0 using timer 0, assuming that the clock frequency of the 8051 system is 12 MHz. Explain it in detail.

[20 marks]



$T_{ON} = 2.5\times10^{-4}$ sec

$T_{OFF} = 2.5\times10^{-4}$ sec

clock frequency = 12 MHz

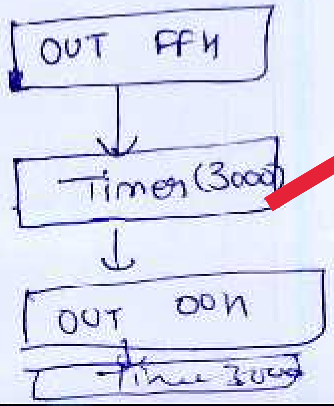
So $T_{clk} = \frac{1}{12MHz} = 8.33\times10^{-8}$ sec

Timer count for ON → $\frac{2.5\times10^{-4}}{8.33\times10^{-8}} = 3000$

Timer count to generate Logic 0 → $\frac{2.5\times10^{-4}}{8.33\times10^{-8}} = 3000$

We have to send Logic 1 or ACC = [FF] H for 3000 Timer cycle and ACC = [00] h for 3000 Timer cycle.

Logic flowchart

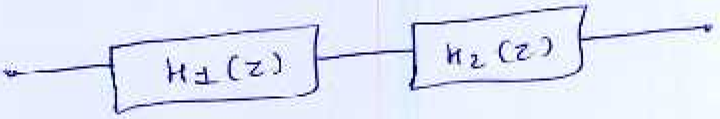


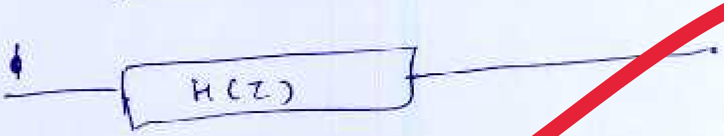
Q.6 (b) Determine the cascade and parallel realizations for the system described by the system function

$$H(z)=\frac{10\left(1-\frac{1}{2}z^{-1}\right)\left(1-\frac{2}{3}z^{-1}\right)\left(1+2z^{-1}\right)}{\left(1-\frac{3}{4}z^{-1}\right)\left(1-\frac{1}{8}z^{-1}\right)\left[1-\left(\frac{1}{2}+j\frac{1}{2}\right)z^{-1}\right]\left[1-\left(\frac{1}{2}-j\frac{1}{2}\right)z^{-1}\right]}$$

[20 marks]

cascade system $H(z) = H_1(z)\ H_2(z)$





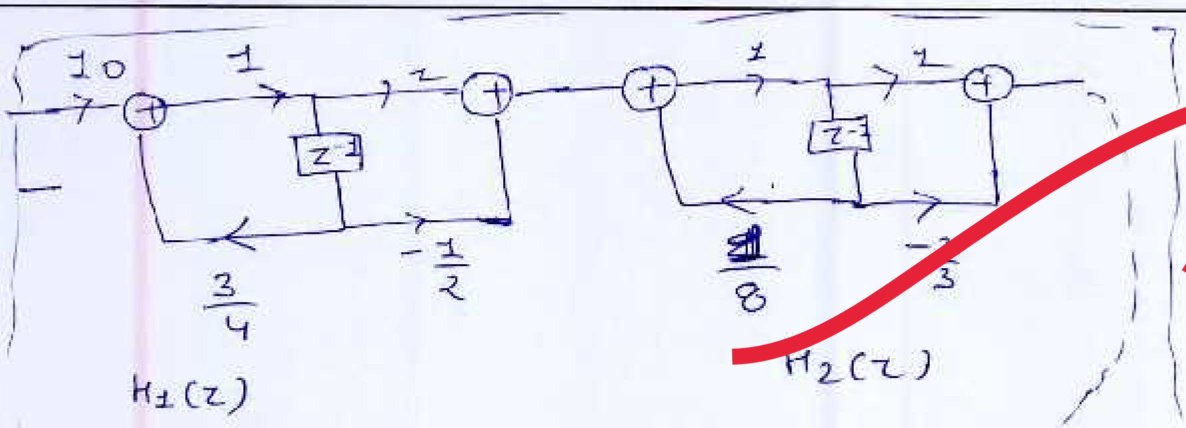
$$H(z)=\frac{10\left(1-\frac{1}{2}z^{-1}\right)\left(1-\frac{2}{3}z^{-1}\right)\left(1+2z^{-1}\right)}{\left(1-\frac{3}{4}z^{-1}\right)\left(1-\frac{1}{8}z^{-1}\right)\left(1-\left(\frac{1}{2}+j\frac{1}{2}z^{-1}\right)\right]\left[1-\left(\frac{1}{2}-j\frac{1}{2}\right)z^{-1}\right]}$$

$$\left[1-\left(\frac{1}{2}+j\frac{1}{2}z^{-1}\right)\right]\times\left[1-\left(\frac{1}{2}-j\frac{1}{2}z^{-1}\right)\right]=1-z^{-1}+\frac{1}{2}z^{-2}$$

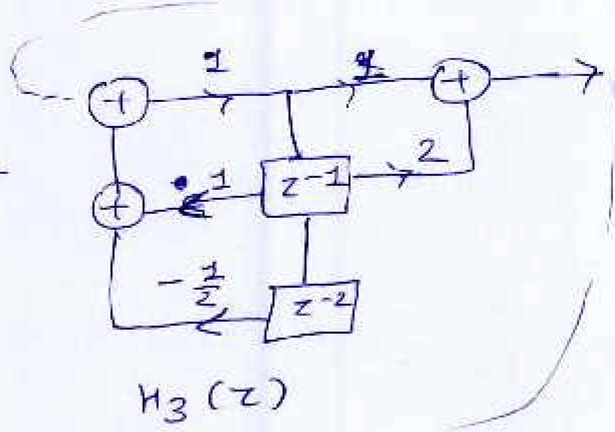
$$H(z)=H_1(z)\ H_2(z)\ H_3(z)$$

$$H_1(z)=\frac{10\left(1-\frac{1}{2}z^{-1}\right)}{\left(1-\frac{3}{4}z^{-1}\right)},\quad H_2(z)=\frac{\left(1-\frac{2}{3}z^{-1}\right)}{\left(1-\frac{1}{8}z^{-1}\right)}$$

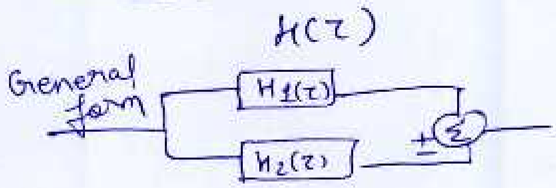
$$H_3(z)=\frac{\left(1+2z^{-1}\right)}{\left(1-z^{-1}+\frac{1}{2}z^{-2}\right)}$$



$$H_3(z) = \frac{1+2z^{-1}}{1-\left(z^{-1}-\frac{1}{2}z^{-2}\right)}$$



Parallel system



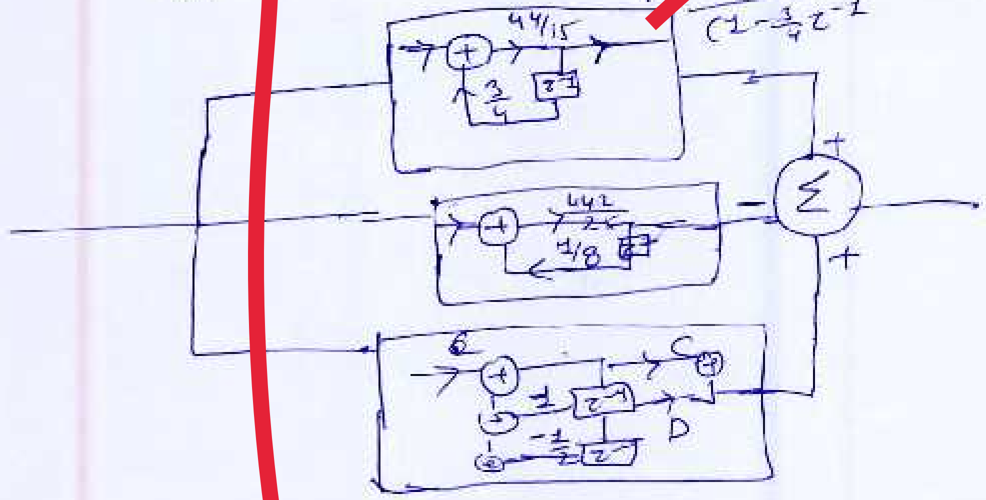
$H(z) = H_1(z) \pm H_2(z)$

$$H(z) = \frac{A}{\left(1-\frac{3}{4}z^{-1}\right)} + \frac{B}{\left(1-\frac{1}{8}z^{-1}\right)} + \frac{C + Dz^{-1}}{\left(1-z^{-1}+\frac{1}{\ }\right)}$$

Find the value of A, B and C, D

$A = \frac{44}{15}$, $B = -\frac{442}{25}$, $C =$

$\frac{44/15}{(1-\frac{3}{4}z^{-1}}$



Q.6 (c) A random process provides measurements x between the values 0 and 1 with a probability density function (PDF) given as

$$f_X(x) = 12x^3 - 21x^2 + 10x \; ; \quad \text{for } 0 \le x \le 1$$
$$= 0 \quad ; \quad \text{otherwise}$$

Determine the following:

(i) $P\left[X \le \frac{1}{2}\right]$ and $P\left[X > \frac{1}{2}\right]$.

(ii) Obtain the value of K such that $P[X \le K] = \frac{1}{2}$.

[10 + 10 marks]

$$P[x \le a] = \int_{-\infty}^{a} f_X(x)\,dx$$

(i) $f_X(x) = 12x^3 - 21x^2 + 10x$; for $0 \le x \le 1$

$= 0$ otherwise

$$P[x \le \tfrac{1}{2}] = \int_{-\infty}^{\frac{1}{2}} f_X(x)\,dx$$

$$P[x \le \tfrac{1}{2}] = \int_{0}^{\frac{1}{2}} (12x^3 - 21x^2 + 10x)\,dx$$

$$P[x \le \tfrac{1}{2}] = \frac{9}{16}$$

$$P[x > \tfrac{1}{2}] = 1 - P[x \le \tfrac{1}{2}] = 1 - \frac{9}{16} = \frac{7}{16}$$

(ii) $P[x \le k] = \frac{1}{2}$ and we have to find k

$$P[x \le k] = \int_{-\infty}^{k} f_X(x)\,dx$$

$$= \int_{0}^{K} (12x^3 - 21x^2 + 10x)\,dx$$

$$= (3x^4 - 7x^3 + 5x^2)_0^k$$

$$P[x \le k] = 3k^4 - 7k^3 + 5k^2$$

$3k^4 - 7k^3 + 5k^2 = \frac{1}{2}$

on solving the equation we get

$k = 0.451758 \approx 0.4518$

$\boxed{k = 0.4518}$

20

Q.7 (a) A pair of noise processes $n_1(t)$ and $n_2(t)$ are related by

$$n_2(t) = n_1(t)\cos(2\pi f_c t + \theta) - n_1(t)\sin(2\pi f_c t + \theta)$$

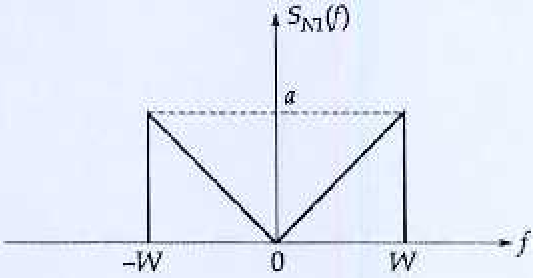
where f_c is a constant and θ is the value of a random variable θ whose probability density function is defined by

$$f_\theta(\theta) = \begin{cases} \dfrac{1}{2\pi}, & 0 \le \theta \le 2\pi \\ 0, & \text{else} \end{cases}$$

$n_1(t)$ and θ are independent.

The noise process $n_1(t)$ is stationary and its power spectral density is shown in figure below.

Find and plot the corresponding power spectral density of $n_2(t)$.

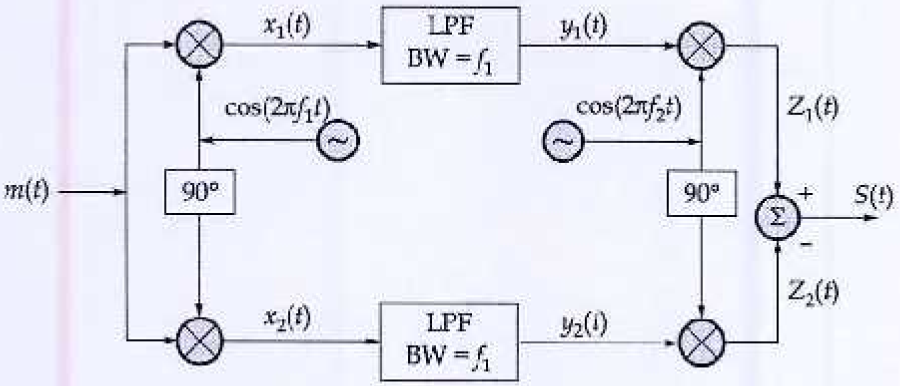


[20 marks]

Q.7 (b) Explain features and architecture of 8259 programmable interrupt controller (PIC) in details with block diagram.

[20 marks]

Q.7 (c) (i) The message signal applied to the Weaver's SSB modulator shown below is $m(t) = \cos(2\pi f_m t)$.



If $f_1 = 2f_m$ and $s(t)$ is an USSB signal with a carrier frequency of 1 MHz, then determine the value of the frequency "f_2".

(ii) Explain in brief about Quadrature-Carrier Multiplexing with its transmitter and receiver block diagram.

[10 + 10 marks]

Do not write in this margin

Q.8 (a) Explain in detail about envelope detector used in demodulation of AM with circuit diagram and waveform. Also, derive equation for the optimum value of time constant (RC) of the detector circuit.

[20 marks]

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Q.8 (b) **(i)** Explain the operation of phase locked loop (PLL) using block diagram.

(ii) Derive the expression for PLL detection of FM signals.

[20 marks]

Q.8 (c) Determine the variance of the round-off noise at the output of the two cascade realization of filter with system function

$$H(z) = H_1(z)\, H_2(z)$$

where $$H_1(z) = \frac{1}{1 - \frac{1}{2}z^{-1}}$$

$$H_2(z) = \frac{1}{1 - \frac{1}{4}z^{-1}}$$

[20 marks]

OOOO

Space for Rough Work

$\underline{q N_D \times x_n}$

$q \times N_D \times \sqrt{\frac{2\varepsilon}{q} \times \frac{1}{N_D} \times (2\phi_f)}$

$\sqrt{2 \varepsilon q \; N_D \; (2\phi_f)}$

$$\frac{dn}{dt} = G_p - R_p$$

$$\boxed{\frac{\delta n}{\delta t} = G_{pn} - \frac{\delta n}{\tau_n}}$$

$\tau_n = 10\mu s$

$\tau_p = 10\mu s$

A $\frac{\epsilon}{\omega}$

$$\frac{\delta n}{\delta t} + \frac{\delta n}{\tau_n} = G_n$$

$(n-a)\ (n-b)$

$\frac{G_n}{S + \frac{1}{\tau}}$

$G_n e^{-t/\tau_n} + C$

$t \infty$

z^{2}

$1 + z^{-1} + z^{-2}$

$\frac{dn}{dt} + \frac{n}{\tau_n} = G_n$

$n = G_n e^{-t/\tau_n} + C$

$\frac{8.85\times10^{-12}}{m}$

$\frac{1}{2}$

$\frac{8.85\times10^{-12}}{10^2 cm}$

$n = \frac{n_i^2}{10^{18}}$

$\frac{8.85\times10^{-12}}{10^2}$

Sum of the roots

$1 + \frac{1}{2}z^{-2} + z^{-1}$

$1 - z^{-1} + \frac{1}{2}z^{-2}$

$$\frac{\epsilon}{\sqrt{\frac{2\epsilon}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V}}$$

$$\frac{\epsilon^2}{\frac{2\epsilon}{q}\left(\frac{1}{N_A}\right)V_0}$$

$$\frac{1}{C/m} = \frac{q\epsilon N_A}{2V}$$