MADE EASY

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ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-4 : Electronic Devices & Circuits + Advanced Communication Topics [All topics]
Analog & Digital Communication Systems-1 [Part Syllabus]
Digital Circuit-2 + Microprocessors and Microcontroller-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	20
Q.4	39
Section-B	
Q.5	57
Q.6	51
Q.7	
Q.8	
Total Marks Obtained	167

Signature of Evaluator .... Cross Checked by ....

◦ Keep it up --

◦ Revise EDC & Adv. Commn

IMPORTANT INSTRUCTIONS

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

DONT'S

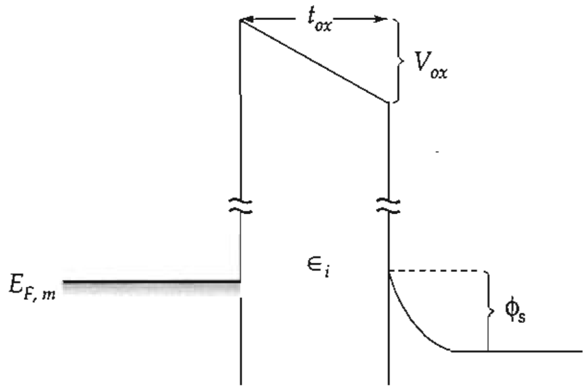
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify 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

Q.1 (a) A metal-oxide-semiconductor in equilibrium is shown below:
(Assume that the oxide is free of any charges or traps)



Given, $t_{ox} = 10$ nm, $V_{ox} = 0.4$ V, $\in_i \in_0 = 40 \times 10^{-14}$ F/cm, $\in_s \in_0 = 100 \times 10^{-14}$ F/cm.
Determine:

(i) The type of the semiconductor shown in the diagram and value of ϕ_s.

(ii) The metal-semiconductor work-function difference.

(iii) The MOS capacitance at equilibrium is determined to be

$C(V=0)_{MOS} = \frac{1}{3} \times 10^{-7}\ \text{F/cm}^2$. What is the width, $W(V=0)$?

[4 + 4 + 4 marks]

Q.1 (b) Under standard test conditions (T = 300 K), an ideal solar cell has a photogenerated current of 3.5 A, dark saturation current of 3.22×10^{-11} A, and power at the maximum power point of 1.75 W. Determine its open circuit voltage (V_{OC}) and fill factor.

[12 marks]

Q.1 (c) (i) What is meant by foliage? Define foliage loss.

(ii) How is location of cell-site and mobile unit influenced by foliage loss?

[6 + 6 marks]

Q.1 (d) Determine the propagation path loss for a radio signal at 900 MHz cellular system operating in a large urban city, with a base station *Tx* antenna height of 100 m and mobile *Rx* antenna height of 2 m. The mobile unit is located at a distance of 4 km. Use the Hata propagation path loss model.

[12 marks]

Q.1 (e) A base-station transmitter has a power output of 10 watts operating at a frequency of 250 MHz. The transmitter is connected by 20 m of an RF coaxial cable, which has a loss of 3-dB/100 m specification, to an antenna that has a gain of 9 dBi. The receiving antenna is 25 km away and has a gain of 4 dBi. There is negligible loss in the receiver feeder line, but the receiver is mismatched; the receiving antenna and feeder cable are designed for a 50-Ω impedance, but the receiver input has 75-Ω impedance, resulting into a mismatch loss of about 0.2 dB. Calculate the power delivered to the receiver, assuming free-space propagation.

[12 marks]

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Q.2 (a) Consider that a geographical service area of a cellular system is 4200 km^2. A total of 1001 radio channels are available for handling traffic. Suppose the area of a cell is 12 km^2.

(i) How many times would the cluster of size 7 have to be replicated in order to cover the entire service area? Calculate the number of channels per cell and the system capacity.

(ii) If the cluster size is decreased from 7 to 4, then does it result into increase in system capacity? Comment on the results obtained.

[10 + 10 marks]

Q.2 (b) A uniformly doped silicon npn bipolar transistor at $T = 300$ K has parameters: emitter doping, $N_E = 2 \times 10^{18}$ cm^{-3}, Base doping, $N_B = 2 \times 10^{16}$ cm^{-3} and collector doping, $N_C = 2 \times 10^{15}$ cm^{-3}. The neutral basewidth $x_{B0} = 0.85$ μm, and electron diffusion coefficient in base, $D_n = 25$ cm^2/s. Assume $x_{B0} << L_n$ where L_n : diffusion length of electron, $V_{BE} = 0.65$ V, $\in_{si} = 11.7\in_0$, $n_i = 1 \times 10^{10}$ cm^{-3}, $V_T = 0.026$ V.

(i) Determine the electron diffusion current density in the base for

1. $V_{CB} = 4$ V
2. $V_{CB} = 8$ V
3. $V_{CB} = 12$ V

(ii) Estimate the Early voltage by using the data in part (i). (Use linear approximation for current density versus $\frac{1}{x_B}$).

[14 + 6 marks]

Q.2 (c) (i) Define Linear Scattering losses in optical fiber and its types in brief.

(ii) Define and explain the following terms with respect to Telecommunication systems:

1. Grade of service
2. Offered traffic
3. Delay system
4. Loss system

[12 + 8 marks]

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Q.3 (a) (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]

Soln: 3 (a)(i)

Total pulse broadening, $\tau = 0.5\ \mu sec$

Distance, $d = 10$ km

1. Pulse Dispersion per unit length

$= \frac{\text{Total pulse Dispersion broadening}}{\text{Distance}}$

$= \frac{0.5 \times 10^{-6}}{10 \times 10^{3}} = 5 \times 10^{-8}$ sec/KM

$= 5 \times 10^{-1} \times 10^{1} \times 10^{-8} = 50 \frac{nsec}{KM}$

10

Good

2. Using NRZ pulse:

$BW = \frac{R_b}{2}$

where, $R_b = \frac{1}{2\tau} = \frac{10^6}{2 \times 0.5}$

$\therefore R_b = 1 M \frac{bits}{sec}$

$\therefore \quad BW = \frac{1}{2}$ MHZ

$\therefore$ **BW = 0.5 MHZ**

3. $BW \times L = 0.5\ MHZ \times 10\ KM$
$= 5$ MHZ-KM

Q.3.(a)(ii) length = 9 Km
core RI, $n_1 = 1.5$
cladding RI, $n_2 = 1.45$

1. RMS pulse broadening due to intermodal dispersion on the link:

MMSI: $\sigma_s = \frac{L n_1 \Delta}{2\sqrt{3} C}$

$\therefore \Delta = \frac{n_1^2 - n_2^2}{2 n_1^2} = \frac{(1.5)^2 - (1.45)^2}{2 \times (1.5)^2}$
$= 0.0327$

$\therefore \sigma_s = \frac{9 \times 10^3 \times 1.5 \times \Delta}{2\sqrt{3} \times 3 \times 10^8} = 4.25 \times 10^{-7}$ sec

$\sigma_s = 0.425$ usec

2. $\Delta t = \frac{L n_1 \Delta}{C} = \frac{9 \times 10^3 \times 1.5 \times \Delta}{3 \times 10^8}$

$\therefore$ **$\Delta t = 1.475$ usec**

Q.3 (b) (i) An n-type Si sample with $N_D = 10^{15}/cm^3$ is steady illuminated such that $g_{op} = 10^{21}$ EHP/cm^3-s. If $\tau_n = \tau_p = 1$ μsec for this excitation, calculate the separation in the Quasi Fermi levels, $(F_n - F_p)$.
(Assume for Si at 300 K, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $KT = 0.026$ eV)

(ii) A semiconductor sample is exposed to a photonic excitation for a long time ($t < 0$). Under low level injection, derive the equation governing the decay of excess carrier and life time of carrier if the excitation is removed at $t = 0$.

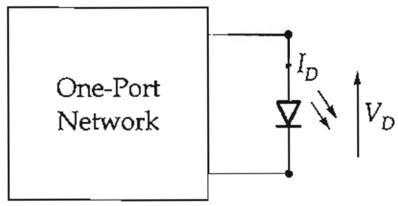
[10 + 10 marks]

Q.3 (c) (i) A light emitting diode (LED) is connected across the terminal of the one-port network as shown in the figure below.

The relationship between the current through the LED (I_D) and the voltage across the LED (V_D) can be modelled by the following piece-wise function:

$I_D = 0$ amperes, for $V_D < 1.5$ V

$I_D = 0.03 \times V_D - 0.045$ Amperes, for $V_D > 1.5$ V



Assume the LED is ON and considering the Thevenin equivalent of the network as V_{TH} and R_{TH}, calculate the value of I_D and V_D.

(ii) Consider an npn Si bipolar junction transistor which is to be designed with an emitter efficiency of $\gamma_e = 0.995$. To maintain a reasonable base resistance, the base is doped with boron for $N_A = 1.2 \times 10^{16}$ cm^{-3}. Given that diffusion length of electron and effective base width, $L_e \approx W_b = 0.7$ μm, minority carrier diffusion coefficients in emitter and base regions are 12 cm^{2}s^{-1} and 30 cm^{2}s^{-1} respectively and minority electron concentration in the base region is 1.88×10^4 cm^{-3}. Calculate the n-type doping concentration needed in the emitter.

[10 + 10 marks]

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Q.4 (a) (i) Consider a uniformly doped n-channel silicon JFET with the following parameters:

$$N_A = 10^{19}\ \text{cm}^{-3},\ N_D = 3 \times 10^{16}\ \text{cm}^{-3},\ a = 0.40\ \mu\text{m}$$

The drain-to-source voltage applied is $V_{DS} = 5$ V and $V_{GS} = 0$. If the effective channel length L' is the 90% of the original channel length L, then determine the value of L. Assume $n_i = 1.5 \times 10^{10}\ \text{cm}^{-3}$, $V_t = 0.026$ V and $\varepsilon_{si} = 1.06 \times 10^{-12}$ F/cm. Also assume that the depletion region at pinched-off portion is equally extended into the channel and drain side neutral regions.

(ii) Illumination of n-type Si($N_d = 10^{16}\ \text{cm}^{-3}$) generates $20^{21}\ \text{cm}^{-3}/\text{s}$ electron-hole pairs. Si has $N_t = 10^{15}\ \text{cm}^{-3}$ generation-recombination centers with $\sigma_n = \sigma_p = 10^{-16}\ \text{cm}^2$. Calculate equilibrium concentration of electrons and holes if $E_t = E_i$, where E_i is the fermi level of intrinsic Si, and Thermal velocity, $V_t = 10^7$ cm/s.

[10 + 10 marks]

Sol: 4(a)(i) Given:

Effective channel length L' is the 90 of the original length L.

i.e $L' = 0.90L$

The Depletion region at pinched off portion is equally extended into the channel and drain side neutral regions.

i.e $L' = L - \frac{\Delta L}{2} = 0.90L$

$L - 0.90L = \frac{\Delta L}{2}$

4

$2 \times 0.1L = \Delta L$

$\Delta L = 0.2L$

and $\Delta L = \sqrt{\frac{2\varepsilon_i}{qN_D}(V_{DS} - V_{DS\,sat})}$

$0.2L = \sqrt{\frac{2 \times 1.06 \times 10^{-12}}{1.6 \times 10^{-19} \times 3 \times 10^{16}}(V_{DS} - V_{DS\,sat})}$

$L = \frac{1}{0.2}\sqrt{4.416 \times 10^{-10}(V_{DS} - V_{DS\,sat})}$

Now, $V_{DS} = 5V$

and $V_{GS} = 0$ ∴ $V_{DS} = V_{P0}$

where, $a = \sqrt{\frac{2\varepsilon_{si}}{q}\left(\frac{1}{N_D}\right)V_{bi}}$

and $V_{bi} = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$

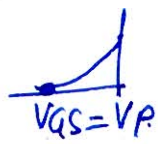
$V_{bi} = 0.026 \ln\left(\frac{10^{19} \times 3\times10^{16}}{(1.5\times10^{10})^2}\right)$

$V_{bi} = 0.905\,V$

V_{sat} ??

$a = \sqrt{\frac{2\times1.06\times10^{-12} \times 0.905}{1.6\times10^{-19}\times3\times10^{16}}}$

$a = 1.99\times10^{-5}$ cm.



∴ $L = \frac{1}{0.2}\sqrt{4.416\times10^{-10}(5 - \quad)}$

$L = 2.349\times10^{-4}$ cm

4.(a)(ii) Given: $N_d = 10^{16}/cm^3$

$G = 10^{21}/cm^3/s$

$N_t = 10^{15}/cm^3$

$\sigma_n = \sigma_p = 10^{-16}\ cm^2$

$n = n_0 + \Delta n = ?$

$p = p_0 + \Delta p = ?$

if $E_t = E_i$. $V_t = 10^7 \frac{cm}{sec}$

$$\Delta\tau_n = \Delta\tau_p = \frac{1}{\sigma_n N_t V_t}$$

$$\therefore \Delta\tau_n = \Delta\tau_p = \frac{1}{10^{-16} \times 10^{15} \times 10^{7}}$$

$$\Delta\tau_n = \Delta\tau_p = 10^{-6} \text{ sec}$$

since, $G = \frac{\Delta n}{\tau_n} = \frac{\Delta P}{\tau_p}$

$$\therefore \Delta P = \Delta n = G \times \tau_n$$

$$\Delta P = \Delta n = 10^{21} \times 10^{-6} = 10^{15}/cm^3$$

$\therefore$ Total electron generated

$$n = N_D + \Delta n = 10^{16} + 10^{15}$$

$$\boxed{n = 1.1 \times 10^{16} /cm^3}$$

since, its n type SC.

$$N_A = \frac{n_i^2}{N_D}$$

$$N_A = \frac{(1.5 \times 10^{10})^2}{10^{16}}$$

$$N_A = 22500$$

Total holes generated

$$\therefore P = N_A + \Delta P$$

$$P = 22500 + 10^{15}$$

$$\therefore \boxed{P \simeq 1 \times 10^{15} /cm^3}$$

10

Good

Q.4 (b) (i) For an MOSFET with sufficient drain voltage to be in saturation (under constant mobility condition), the drain current is 50 μA at $V_{GS} = 1$ V and 200 μA at $V_{GS} = 3$ V. Find the threshold voltage of the MOSFET.

(ii) Different parameters, with their usual notations, of an ideal n-channel MOSFET with a silicon substrate, are: $N_A = 10^{16}$ cm^{-3}, $t_{ox} = 500$ Å, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $kT = 0.026$ eV, $\varepsilon_{si} = 1.06 \times 10^{-12}$ F/cm and $\varepsilon_{ox} = 3.45 \times 10^{-13}$ F/cm. Determine the threshold voltage of the MOSFET.

[10 + 10 marks]

Sol: 4(b)(i) Drain current $I_{DS_1} = 50\mu A$

$V_{GS_1} = 1V$

and $I_{DS_2} = 200\mu A$

$V_{GS_2} = 3V$

Threshold voltage, $V_T = ?$

In saturation region,

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$\Rightarrow \frac{I_{D_1}}{I_{D_2}} = \frac{(V_{GS_1} - V_t)^2}{(V_{GS_2} - V_t)^2}$$

$$\therefore \frac{50 \times 10^{-6}}{200 \times 10^{-6}} = \frac{(1 - V_t)^2}{(3 - V_t)^2}$$

$$\frac{1 - V_t}{3 - V_t} = 0.5$$

$$1 - V_t = 1.5 - 0.5V_t$$

$$1 - 1.5 = -0.5V_t + V_t$$

$$-0.5 = V_t \times 0.5$$

$$\therefore \boxed{V_t = -1V}$$

10

4.b.(ii) Threshold voltage of mosfet is given by

$$V_T = \frac{\sqrt{2\varepsilon_{si} N_A \phi_F}}{C_{ox}}$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.45\times10^{-13}}{500\times10^{-10}} = 6.9\times10^{-6}\ F$$

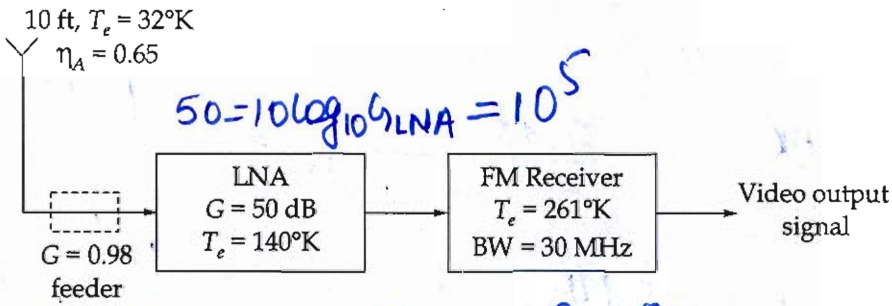
$$\phi_f = V_T \ln\left(\frac{N_A}{n_i}\right) = 0.026 \ln\left(\frac{10^{16}}{1.5\times10^{10}}\right)$$

$$\boxed{\phi_f = 0.348\ eV}$$

$$V_T = \sqrt{\frac{2\times1.06\times10^{-12}\times10^{16}\times0.348}{6.9\times10^{-6}}}$$

$$V_T = 12448254.50\ \underline{V}.$$

Q.4 (c) A typical receiver shown in figure below is used to receive the TV signals from geostationary satellite. If the above system works with satellite of EIRP + 36 dBW at 4 GHz downlink frequency, determine the carrier to noise ratio at the demodulator input. Assume slant distance of 39,500 km between the satellite and the earth station.



$50 = 10\log_{10} G_{LNA} = 10^5$

[20 marks]

Sol: The carrier to Noise ratio is

$$\frac{C}{N} = \frac{P_t G_t G_r}{\left(\frac{4\pi d}{\lambda}\right)^2 KTB}$$

where, $\boxed{EIRP = P_t G_t = 36\,dBW}$

and $d = 10\,ft$

$1\,ft = 0.34$

$d = 3.4\,m$

$A = \pi \frac{D^2}{4}$

$A = \pi \frac{(3.4)^2}{4} = 9.079\,m$

Effective Area;

$A_e = \eta_A \times A = 0.65 \times A$

$A_e = 0.65 \times 9.079$

$\boxed{A_e = 5.90\,m^2}$

$G_r = \frac{4\pi}{\lambda^2} A_e$

$G_r = \frac{4\pi}{\lambda^2} \times 5.90$; $c = f\lambda$

; $\frac{3\times10^8}{4\times10^9} = \lambda$

$G_r = \frac{4\pi}{(0.075)^2} \times 5.90$; $\lambda = 0.075\,m$

$G_r = 13180.72$

$T_{equ} = 32^\circ K + 0 + \frac{140}{0.98} + \frac{261}{0.98 \times 10^5}$

$= 174.85\,K$

$\therefore \frac{G_r}{T_e} = 18.77$ dB

$T_{equ} = 174.85\,K$

$loss = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi \times 39{,}500 \times 10^3}{0.075}\right)^2$

$loss = 196.414$ dB

$BW = 10\log_{10} 30\,MHz = 74.77$ dB

$k = 10\log_{10}(1.38\times10^{-23}) = -228.60$ dB

14

$\frac{C}{N} = EIRP + \left(\frac{G_r}{T_{eq}}\right)_{dB} - Loss - 10\log_{10}K - 10\log_{10}B$

$= 36 + 18.77 - 196.414 + 228.60 - 74.77$

$\frac{C}{N} = 12.186$

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

Q.5 (a) **(i)** The equivalent noise bandwidth of a system is defined as

$$B_{eq} = \frac{1}{2\pi} \frac{\int_0^\infty |H(\omega)|^2 \, d\omega}{|H(\omega)|^2_{max}} \text{ Hz}$$

where $|H(\omega)|^2_{max} = \max|H(\omega)|^2$

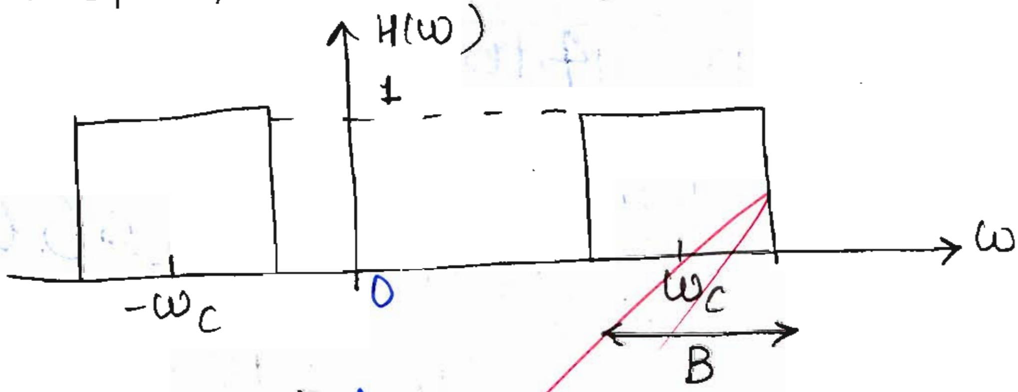
Determine the equivalent noise bandwidth of the ideal band-pass filter and that of a low pass RC filter.

(ii) Derive the expression for the probability of error of the bipolar bandband signal, assuming additive white Gaussian noise.

[6 + 6 marks]

Solu:- 5.(a)(i) Band pass filter

the transfer function of Band pass filter is:



$\therefore |H(\omega)|_{max} = 1$

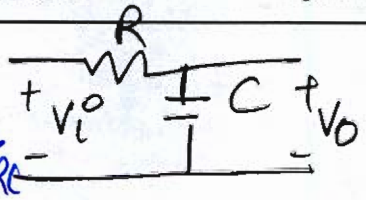
$\therefore \int_0^\infty |H(\omega)|^2 d\omega = 1^2 \times B = B$

$\therefore B_{eq} = \frac{1}{2\pi} \frac{\int_0^\infty |H(\omega)|^2 d\omega}{|H(\omega)|^2_{max}}$

$\therefore$ $\boxed{B_{eq} = \frac{1}{2\pi} \times B = \frac{B}{2\pi} \text{ Hz}}$

3

Low pass RC filter:-



$$\frac{V_o}{V_i} = \frac{\frac{1}{SC}}{R+\frac{1}{SC}} = \frac{1}{RSC+1} = \frac{1}{1+j\omega RC}$$

1

$\therefore |H(\omega)|_{max} = |H(0)| = 1$

and $H(\omega) = \frac{1}{1+j\omega RC}$; $|H(\omega)|^2 = \frac{1}{1+(\omega RC)^2}$

$$\therefore B_{eq} = \frac{1}{2\pi}\int_0^{\infty} \frac{1}{(1+(\omega RC)^2)} d\omega$$

$$B_{eq} = \frac{1}{2\pi}\left[\tan^{-1}\left(\frac{\omega RC}{1}\right)\right]_0^{\infty} = \frac{1}{2\pi}\left[\frac{\pi}{2}\right] = \frac{1}{4} HZ$$

$$\boxed{B_{eq} = \frac{1}{4} HZ}$$

5 (a) (ii) Probability of error of bipolar baseband signal:

$S_1(t) = A$ $\quad 0 \le t \le \frac{T_b}{2}$

$S_2(t) = -A$ $\quad \frac{T_b}{2} < t \le T_b$

The difference of Energy is given by:

$$E_b = \int_0^{T_b} |S_1(t) - S_2(t)|^2 dt$$

$$\therefore E_b = \int_0^{T_b} (2A)^2 dt = 4A^2T_b$$

Now, the probability of error is given by

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

6

$$P_e = Q\left(\sqrt{\frac{4A^2T_b}{2N_0}}\right)$$

$$\therefore \boxed{P_e = Q\left(\sqrt{\frac{2A^2T_b}{N_0}}\right)}$$

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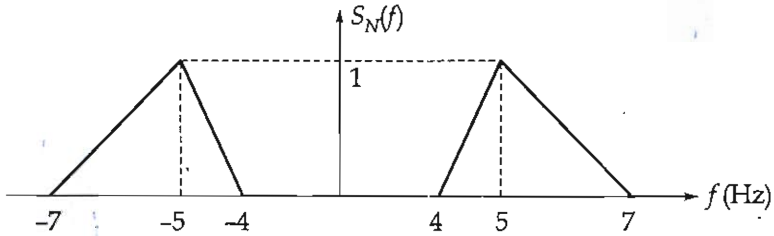
Q.5 (b) The Power Spectral Density (PSD) of a narrowband noise $n(t)$ is shown in the figure. The carrier frequency is $f_c = 5$ Hz. Assuming the peak value of PSD is 1 W/Hz.



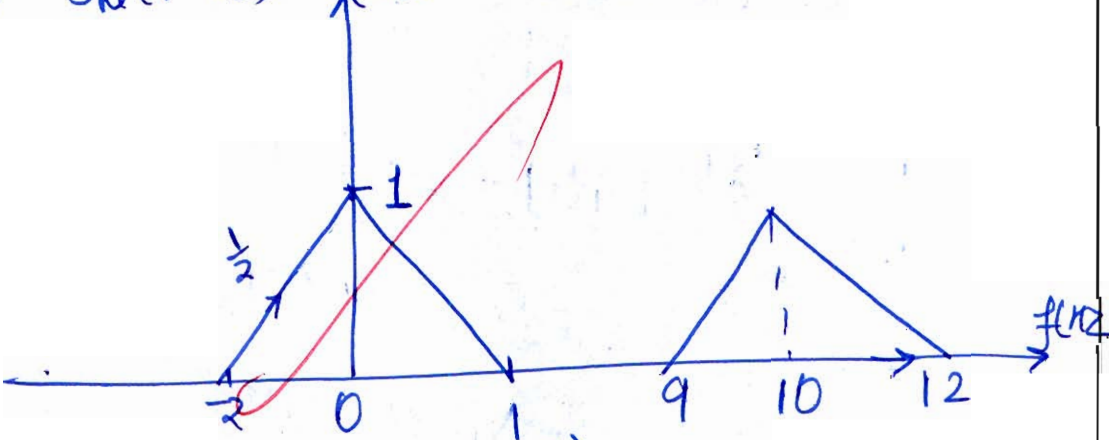
1. Find and sketch the PSDs of the in-phase component $S_{NI}(f)$ and quadrature component $S_{NQ}(f)$.
2. Calculate the total average power of the original narrow band noise $n(t)$.
3. Determine if the in-phase and quadrature components are uncorrelated by examining their cross-spectral density $S_{NI,NQ}(f)$.

[6 + 3 + 3 marks]

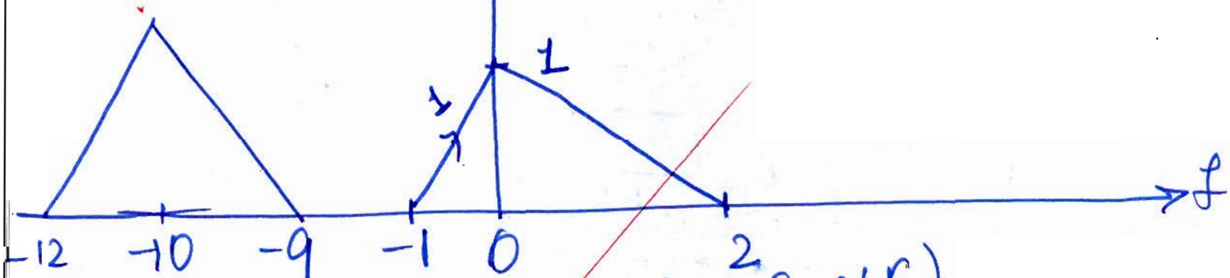
Solⁿ: 5.(b) 1. The inphase and quadrature phase PSD is given by:

$S_{NI}(f) = S_{NQ}(f) = S_N(f - f_c) + S_N(f + f_c)$

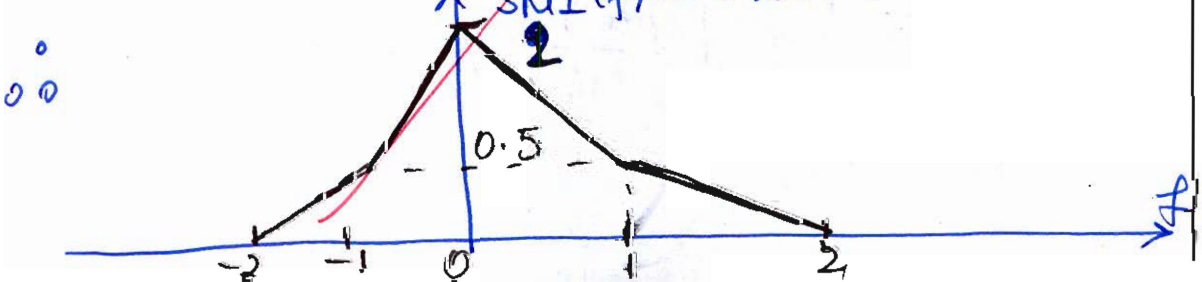
Now, $S_N(f - f_c) = S_N(f - 5)$



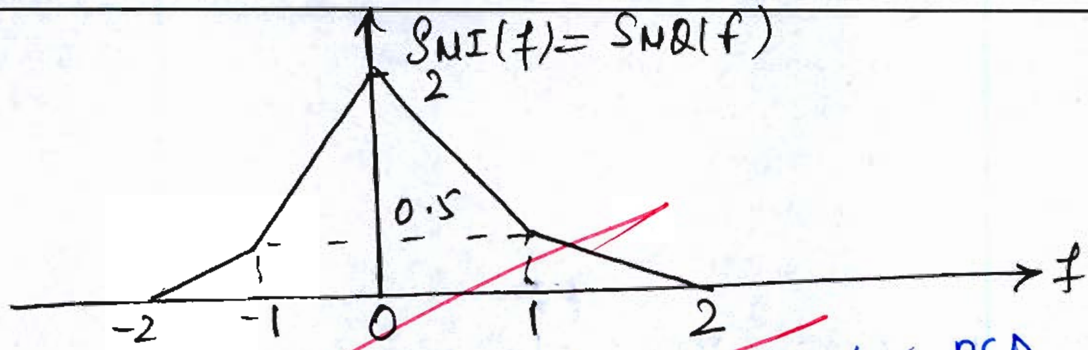
$S_N(f+5)$



$S_{NI}(f) = S_{NQ}(f)$



5(b)2.



The total average power is area under PSD.

$$\therefore \quad P_y = \int_{-\infty}^{\infty} S_{NI}(f)\, df$$

$$\therefore \quad P_y = 2\left[\int_0^{\infty} S_{NI}(f)\, df\right]$$

$$P_y = 2\left[\frac{1}{2} \times 1 \times 1.5 + \frac{1}{2} \times 1 \times 0.5 + 1 \times 0.5\right]$$

$$\therefore \boxed{P_y = 3 \text{ Watt}}$$

(b)3. The inphase and quadrature phase components are said to uncorrelated when,

$$S_{NI}(f+f_c) = S_{NI}(f-f_c)$$

i.e. $S_{NI}(f) = S_{NQ}(f) = 0.$

But, here assymtry is present between $S_{NI}(f+f_c)$ and $S_{NI}(f-f_c)$.

$$\therefore \quad S_{NI}(f+f_c) \neq S_{NI}(f-f_c)$$

The Inphase and Quadrature phase components are correlated but are not uncorrelated.

1/

Q.5 (c) What output voltage would be produced by a DAC whose output range is 0 to 10 V for the following input binary numbers?

(i) 10 (for a 2-bit D/A converter)

(ii) 0110 (for a 4-bit DAC)

(iii) 10111100 (for a 8-bit DAC)

[12 marks]

Sol:- 5(C)(i) $V_{out} = \frac{V_{fs}}{2^n}\left[2^{-1}B_n + 2^{-2}B_{n-1} + - - -\right]$

∴ 10 [for 2 bit D/A converter]

$V_{out} = 10\left[\frac{1}{2}\times 1 + \frac{1}{4}\times 0\right] = 5V$

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5.C (ii) For 0110 (4 bit DAC)

$V_{out} = 10\left[\frac{1}{2}\times 0 + \frac{1}{4}\times 1 + \frac{1}{8}\times 1 + \frac{1}{16}\times 0\right]$

∴ $V_{out} = 10\left[\frac{1}{4} + \frac{1}{8}\right] = 3.75\ V$

5.C (iii) For 10111100 (8 bit DAC)

$V_{out} = 10\left[\frac{1}{2}\times 1 + \frac{1}{4}\times 0 + \frac{1}{8}\times 1 + \frac{1}{16}\times 1 + \frac{1}{32}\times 1 + \frac{1}{64}\times 1 + 0 + 0\right]$

$V_{out} = 7.343V$

C

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Q.5 (d) Design a *J-K* flip-flop using a *D* flip-flop and a 4 × 1 MUX. Write various steps involved in the process.

[12 marks]

Sol: Designing of J-K FF using a D FF:-

Excitation table of J-K FF:

	Q_n	J	K	Q_{n+1}	D
0	0	0	0	0	0
1	0	0	1	0	0
2	0	1	0	1	1
3	0	1	1	1	1
4	1	0	0	[illegible]	[illegible]
5	1	0	1	0	0
6	1	1	0	1	1
7	1	1	1	0	0

Since, $D = Q_{n+1}$

K Map for D-FF

Q_n \	$\bar{J}\bar{K}$	$\bar{J}K$	JK	$J\bar{K}$
$\bar{Q}_n$	0	1	1 (3)	1 (2)
Q_n	1 (4)	5	7	1 (6)

$D = \bar{Q}_n J + J\bar{K}$

$D = J\bar{Q}_n + J\bar{K}$

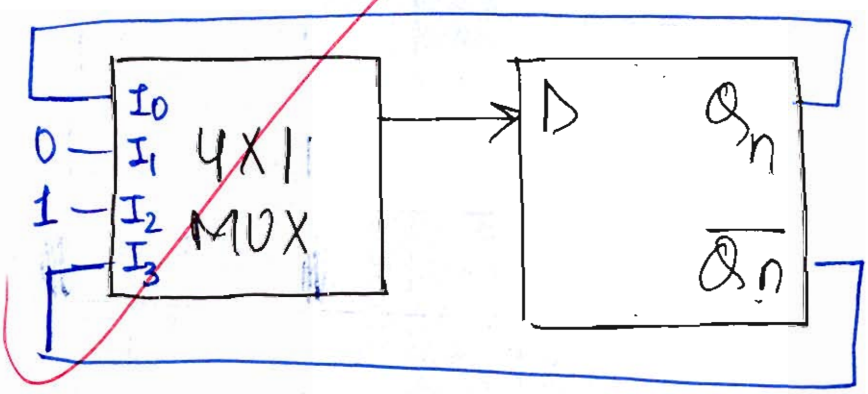
	$\bar{J}\bar{K}$	$\bar{J}K$	JK	$J\bar{K}$
$\bar{Q}_n$			1	1
Q_n	1			1

$$D = J\bar{Q}_n + \bar{K}Q_n$$

JK FF using a 4X1 MUX:

	$\bar{J}\bar{K}$	$\bar{J}K$	$J\bar{K}$	JK
$\bar{Q}_n$	0	1	1 (3)	1 (2)
Q_n	1 (4)	5	1 (6)	7
	↓ Q_n	↓ 0	↓ 1	↓ $\bar{Q}_n$

using J-K as S_1, S_0 select lines:



Q.5 (e) Implement the following functions using PLA.

$$F_1 = \Sigma m(2, 4, 5, 10, 12, 13, 14)$$

and $F_2 = \Sigma m(2, 9, 10, 11, 13, 14, 15)$

[12 marks]

Sol: PLA.

K Map for F_1:

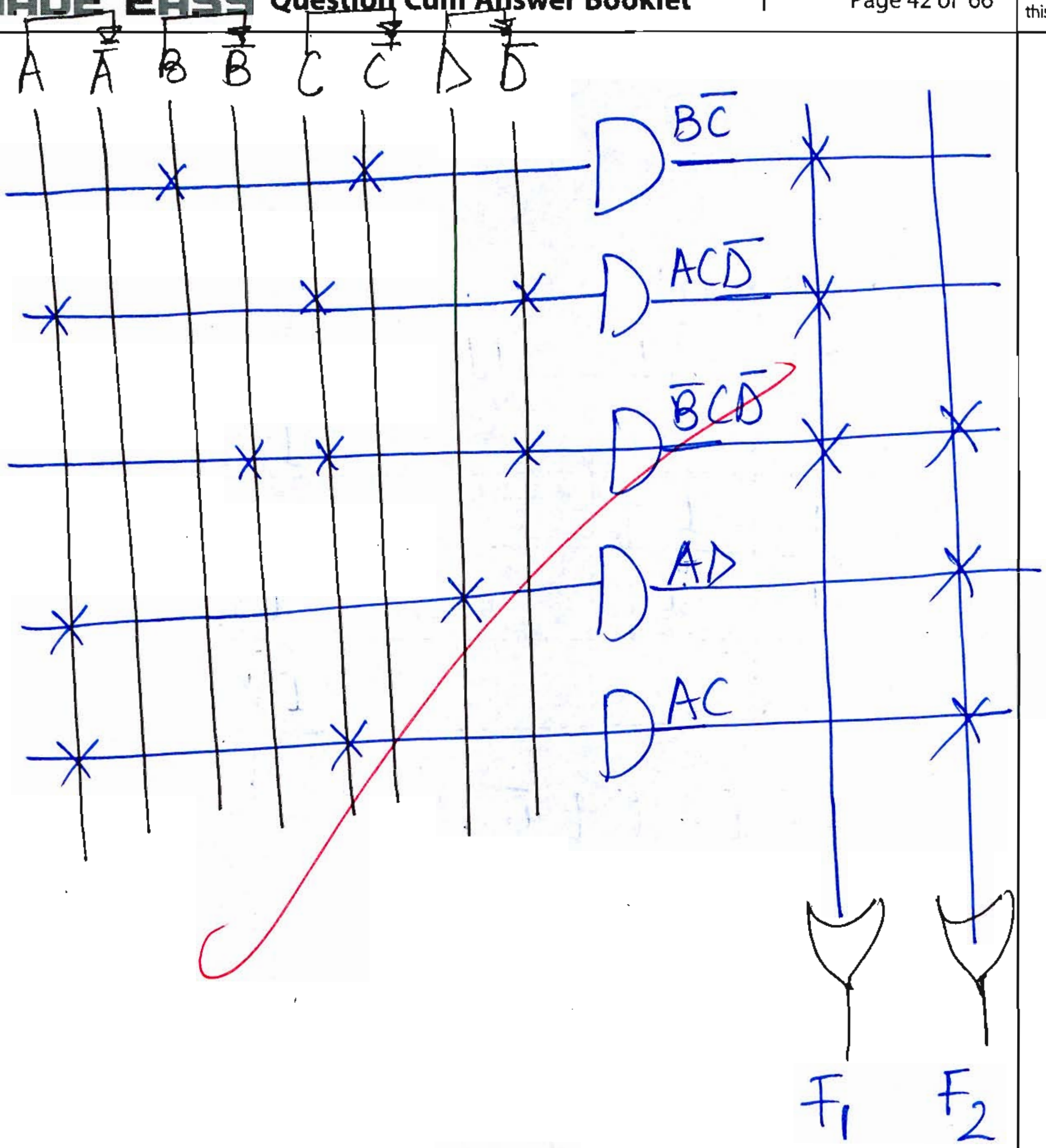
AB\CD	00	01	11	10
00	0	1	3	1 (2)
01	1 (4)	1 (5)	7	6
11	1 (12)	1 (13)	15	1 (14)
10	8	9	11	1 (10)

$F_1 = B\bar{C} + AC\bar{D} + \bar{B}C\bar{D}$

K map for F_2

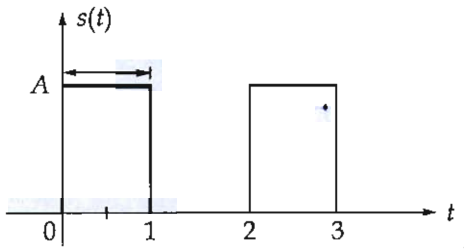
AB\CD	00	01	11	10
00	0	1	3	1 (2)
01	4	5	7	6
11	12	1 (13)	1 (15)	1 (14)
10	8	1 (9)	1 (11)	1 (10)

$F_2 = AD + AC + \bar{B}C\bar{D}$



Implementation of PLA

Q.6 (a) The received signal in a binary communication system that employs antipodal signals is $r(t) = s(t) + n(t)$, where $s(t)$ is shown in the figure below and $n(t)$ is AWGN with power spectral density $\frac{N_0}{2}$ W/Hz.



(i) Sketch the impulse response of the filter matched to $s(t)$.

(ii) Sketch the output of the matched filter when the input is $s(t)$.

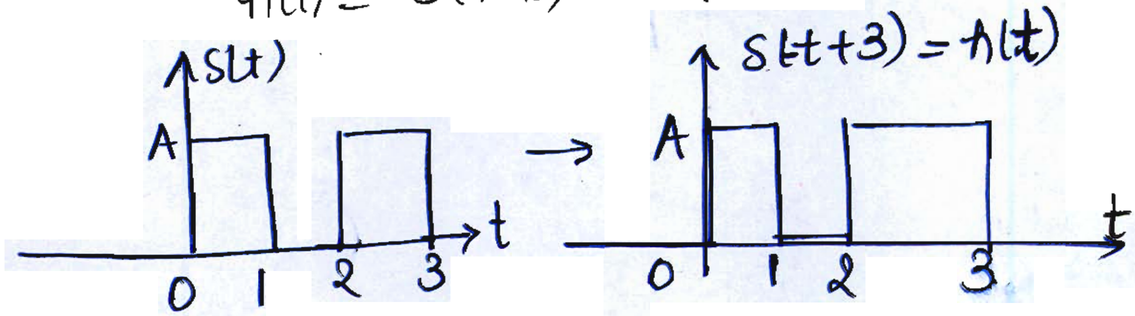
(iii) Determine the variance of the noise at the output of the matched filter at $t = 3$.

(iv) Determine the probability of error as a function of A and N_0.

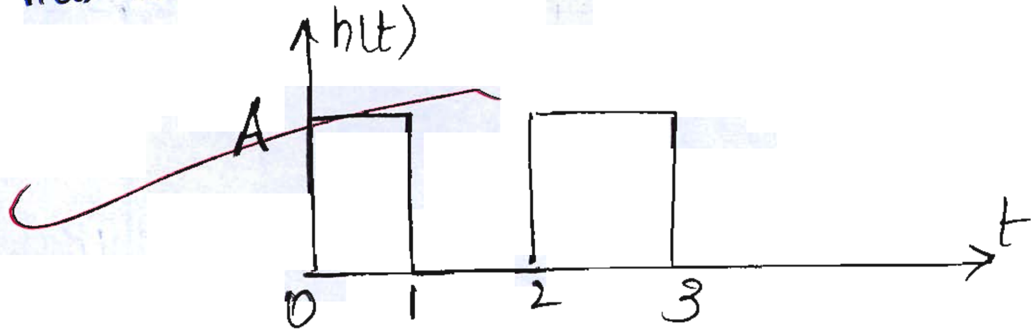
[20 marks]

Solⁿ: (a)(i) The impulse response of the filter is

$h(t) = s(T-t) = s(3-t)$



∴ $h(t)$ is same as $s(t)$

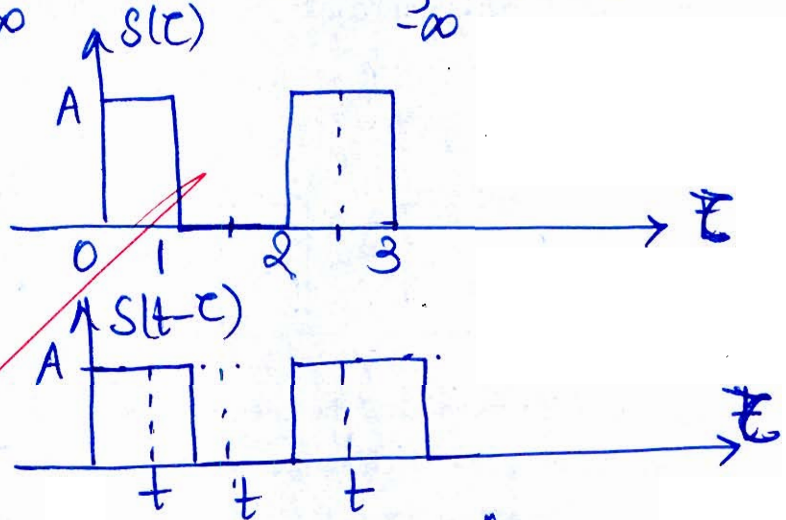


6(a)(ii) The output of matched filter is given by

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

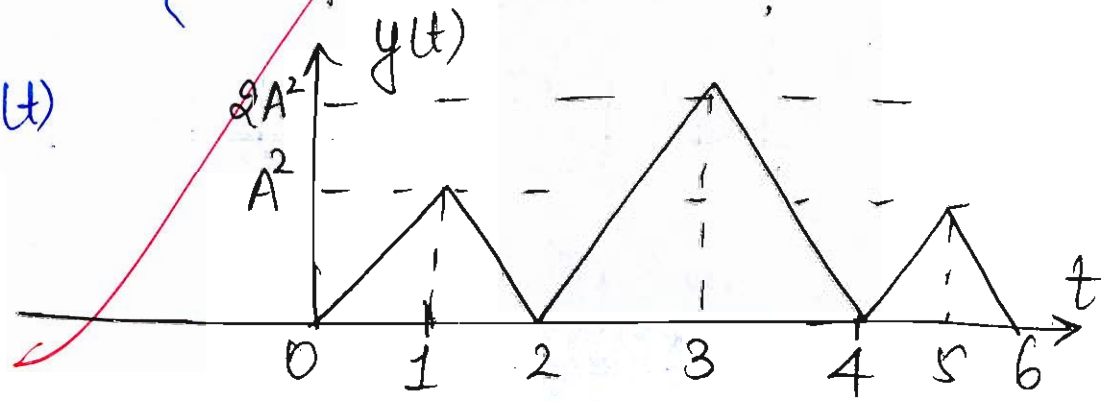
$$y(t) = \int_{-\infty}^{\infty} h(\tau)\, s(t-\tau)\, d\tau = \int_{-\infty}^{\infty} s(\tau)\, s(t-\tau)\, d\tau$$

$y(t) \Rightarrow$



$$y(t) = \begin{cases} 0 & t < 0 \\ A^2 t & 0 < t < 1 \\ A^2 t & 1 < t < 2 \\ A^2 t + A^2(t-2) & 2 < t < 3 \end{cases}$$

y(t)



6(a)(iii) At $t=3$, peak of the match filter is present.

since, we know,

$$\sigma^2 = \frac{N_0}{2} \int_0^t |s(t)|^2 dt$$

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$$\sigma^2 = \frac{N_0}{2} \times \left[A^2 \times 1 + A^2 \times 1\right] = \frac{N_0}{2} \times 2A^2$$

$$\boxed{\sigma^2 = N_0 A^2}$$

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6(a)(iv) The probability of error as a function of A and N_0 is:

$$P_e = Q\left(\sqrt{\frac{E_b}{2N_0}}\right) \quad \text{where } E_b = A^2 \times 1 + A^2 \times 1$$

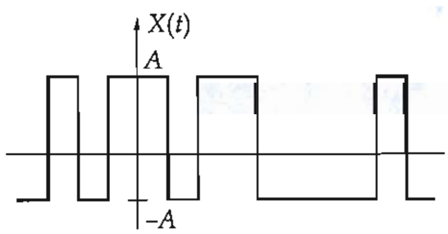
$$E_b = 2A^2$$

$$\therefore \boxed{P_e = Q\left(\sqrt{\frac{2A^2}{2N_0}}\right) = Q\left(\sqrt{\frac{A^2}{N_0}}\right)}$$

Q.6 (b) **(i)** A certain sinusoid at a frequency f_m Hz is used as the modulating signal in both a conventional AM system and a FM system. When modulated, the peak frequency deviation of FM system is set to three times the bandwidth of the AM system. The magnitudes of those sidebands spaced at $\pm f_m$ Hz from carrier in both systems are equal and the total average powers are equal in both systems (Given $J_1(6) = 0.28$). Determine the

1. modulation index of the FM system
2. modulation index of the AM system.

(ii) Consider a random process $X(t)$ that assumes the values $\pm A$ with equal probability. A typical sample function of $X(t)$ is shown in figure. The average number of polarity switches (zero crossings) per unit time is α. The probability of having exactly k crossing in time T is given by the Poisson distribution $P(z = k) = e^{-\alpha T}\frac{(\alpha T)^k}{k!}$, where τ is the random variable representing the number of zero crossings. The process $X(t)$ is known as the telegraph signal. Find the auto correlation and PSD of $X(t)$.



[6 + 14 marks]

6(b)(i) Given:-

The peak frequency Deviation of FM system is 3 times the bandwidth of AM system.

i.e $[\Delta F]_{FM} = 3[BW]_{AM}$

$$\Delta f = 3 \times (2 f_m) = 6 f_m \quad \text{---(1)}$$

The magnitude of side bands spaced at $\pm f_m$ Hz from carrier in both system are equal.

i.e $S_{FM} = A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos(2\pi(f_c + n f_m))$

$$S_{AM} = A_c \cos 2\pi f_c t + \frac{A_c \mu}{2} \cos 2\pi (f_c + f_m) + \frac{A_c \mu}{2} \cos 2\pi (f_c - f_m)$$

given, $\boxed{A_c J_n(\beta) = \frac{A_c \mu}{2}}$ ——— (2)

from (1), $\Delta f = 6 f_m$

$$\boxed{\beta = \frac{\Delta f}{f_m} = 6}$$

The total average powers are equal in both system:

$$[P_t]_{FM} = P_c = \frac{A_c^2}{2}$$

$$[P_t]_{AM} = P_c \left(1 + \frac{\mu^2}{2}\right)$$

$$\therefore \quad P_c = P_c \left(1 + \frac{\mu^2}{2}\right)$$

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b(i) 1. Modulation index of FM system i.e

$$\boxed{\beta = 6}$$

2. Modulation index of AM system:

From (2) equation,

$$J_n(\beta) = \frac{\mu}{2}$$

$$2 J_1(6) = \mu$$

$$\therefore \mu = 2 \times 0.28$$

$$\boxed{\mu = 0.56}$$

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6. (b) (ii) $R_X(t_1 t_2) = A^2 E[X(t_1) X(t+\tau)] - A^2 E[X(t) X(t+\tau)]$

$$R_X(K) = A^2 e^{-\alpha T} \frac{(\alpha T)^K}{K!} \text{ (given)}$$

$$\therefore R_X(\tau) = A^2 e^{-\alpha T} \sum_{K=\text{even}} \frac{(\alpha T)^K}{K!} - A^2 e^{-\alpha T} \sum_{K=\text{ODD}} \frac{(\alpha T)^K}{K!}$$

$$R_X(\tau) = A^2 e^{-\alpha T} \sum_{K=0}^{\infty} \frac{(\alpha T)^K}{K!} (-1)^K$$

$$\therefore R_X(\tau) = A^2 e^{-\alpha T} \sum_{K=0}^{\infty} \frac{(-\alpha T)^K}{K!}$$

$$\therefore R_X(\tau) = A^2 e^{-\alpha T} \left[1 + \frac{(-\alpha T)^1}{1!} + \frac{(-\alpha T)^2}{2!} + \cdots \right]$$

exponential series

$$\therefore R_X(\tau) = A^2 e^{-\alpha T} \cdot e^{-\alpha T} = A^2 e^{-2\alpha T}$$

For considering both sides:

$$R_X(\tau) = A^2 e^{-2\alpha |T|} \longleftrightarrow A^2 \times \frac{2\alpha}{4\alpha^2 + \omega^2}$$

$S_X(\omega) =$ PSD

Q.6 (c) A particular 6-bit DAC has a full-scale output rated at 1.260 V. Its accuracy is specified as ±0.1% full scale, and it has an offset error of ±1 mV. Consider the measurements made on this DAC in the table below:

Input code	Output
000010	41.5 mV
000111	140.2 mV
001100	242.5 mV
111111	1.258 mV

Check all the above measurement(s) and identify which are within (or) out of the device's (DAC's) specifications.

[20 marks]

Solu:- 6 (c) A 6 bit DAC has full scale output $V_{FS} = 1.260V$

$$\text{Accuracy} = \pm \frac{0.1}{100} \times V_{FS}$$

i.e $$\text{Accuracy} = \pm \frac{0.1}{100} \times 1.260 = 1.26 \times 10^{-3}$$

OFFset error = ±1 mV

∴ $V_{total} = \pm(\text{offeset error} + \text{Accuracy})$

$V_{total} = \pm(1 + 1.26)\,mV = \pm 2.26\,mV$

Now, $$|V_{measured} - V_{ideal}| \leq 2.26\,mV$$

For input code of 000010, output is 41.5 mV.

$$V_{measured} = \frac{V_{FS}}{2^n - 1} \times \text{Decimal equivalent}$$

$$V_{measured} = \frac{1.260}{2^6 - 1} \times \text{Decimal equivalent}$$

∴ $$V_{measured} = 0.02 \times \text{Decimal equivalent}$$

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2

	Input code	Ideal output	Measured output
case1	$(000010)_2 = (2)_{10}$	41.5 mV	~~[illegible]~~ 40 mV
case2	$(000111)_2 = (7)_{10}$	140.2 mV	~~137.2 mV~~ 140 mV
case3	$(001100)_2 = (12)_{10}$	242.5 mV	~~236.2 mV~~ 240 mV
case4	$(111111)_2 = (63)_{10}$	1.258 mV	~~1.2348 V~~ 1.26 V

case I: $|V_{measured} - V_{ideal}| \le 2.26\,mV$

$|41.5 - 40| = 1.5 \le 2.26\,mV$

It is within the specified limit.

Case 2: $|140.2 - 140.0| = 0.2 \le 2.26\,mV$

It is within specified limit.

Case 3: $|242.5 - 240.0| = 2.5 \ge 2.26\,mV$

It is out of specified limit

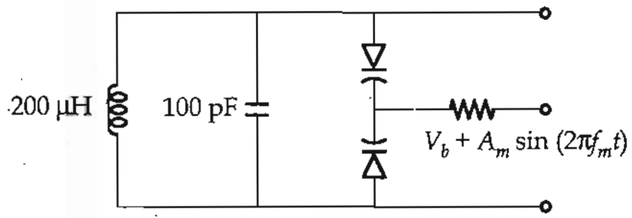
Case 4: $|1.258 - 1.26| \ge 2.26\,mV$

It is out of specified limit.

Q.7 (a) **(i)** The below figure shows the frequency determining network of a voltage - controlled oscillator. Frequency modulation is produced by applying the modulating signal $A_m \sin 2\pi f_m t$ plus a bias V_b to a pair of varactor diodes connected across the parallel combination of a 200 μH inductor and 100 pF capacitor. The capacitor of each varactor diode is related to the voltage V (in volts) applied across its electrodes by $C = 100\ V^{-1/2}$ pF.

The unmodulated frequency of oscillations is 1 MHz. The VCO output is applied to a frequency multiplier to produce an FM signal with a carrier frequency of 64 MHz and a modulation index of 5. Determine:

1. The magnitude of the bias voltage V_b and
2. The amplitude A_m of the modulating wave, given f_m = 10 kHz.



(ii) An angle-modulated signal is described by

$$x_c(t) = 10\cos[2\pi(10^6)t + 0.1\sin(10^3)\pi t]$$

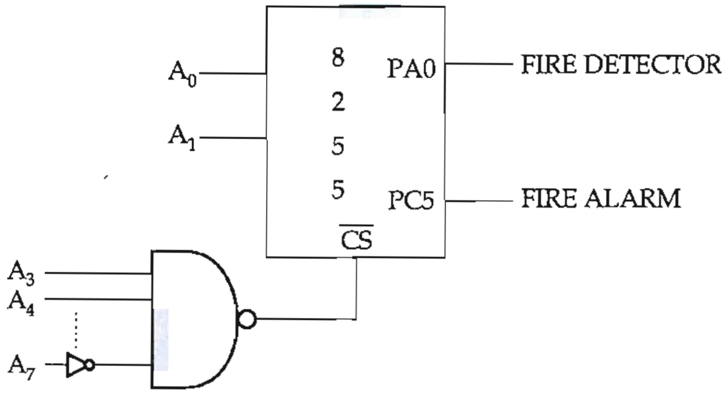
1. Considering $x_c(t)$ as a PM signal with k_p = 10 rad/V, find $m(t)$
2. Considering $x_c(t)$ as a FM signal with $k_f = 10\pi$ Hz/V, find $m(t)$

[12 + 8 marks]

Q.7 (b) For the 8255 programmable peripheral interface (PPI) shown in figure, the address of Port A, B, C and control register are 40 H, 41 H, 42 H and 43 H respectively.

(i) Determine the control word to detect the fire and on/off the alarm.

(ii) Develop an 8085 assembly language program to read from the detector and control the alarm.



[10 + 10 marks]

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Q.7 (c) **(i)** A 100 kΩ resistor is connected in parallel with a 100 pF capacitor. Determine the effective noise bandwidth and the noise voltage appearing at the terminals of the combination at 27°C.

(ii) Consider a phase-locked loop (PLL) consisting of a multiplier, loop filter and voltage controlled oscillator (VCO). Let the signal applied to the multiplier input be defined as $s(t) = A_c \cos[2\pi f_c t + k_p \cdot m(t)]$, where k_p is the phase sensitivity and data signal $m(t)$ is having value +1 for binary symbol 1 and –1 for binary symbol 0. The VCO output is $r(t) = A_u \sin[2\pi f_c t + \theta(t)]$. Evaluate the loop filter output, assuming that the filter removes the modulated components with frequency $2f_c$. Show that the loop filter output is proportional to the data signal $m(t)$, when the loop is phase-locked, that is $\theta(t) = 0$. Illustrate your answer with a neat sketch.

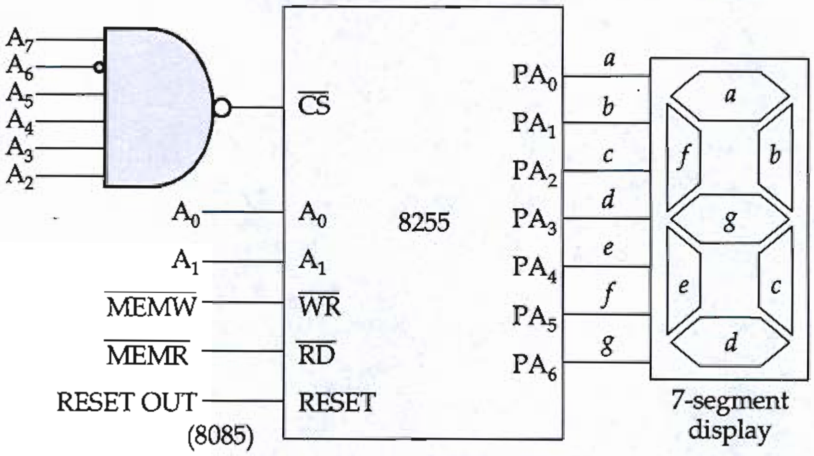
[8 + 12 marks]

Q.8 (a) **(i)** Explain with a block diagram, the working principle of a dual-slope A/D converter. Derive the expression for the output and maximum conversion time of the circuit.

(ii) A dual-slope A/D converter has a resolution of 4 bits. If the clock rate is 3.2 kHz, then calculate the maximum sampling rate with which the samples can be applied to the A/D converter.

[15 + 5 marks]

Q.8 (b) An 8085 microprocessor is interfaced with 8255 programmable Peripheral Interface (PPI) to control the seven-segment display as shown in figure.



Write an assembly language program to display the last six digits of your mobile number with each digit being displayed after some delay.

Assume I/O Addressing as

PORT A = 00 H

PORT B = 01 H

PORT C = 02 H

CONTROL = 03 H

[20 marks]

Q.8 (c) (i) When a superheterodyne receiver is tuned to 555 kHz, its local oscillator provides the mixer with an input at 1010 kHz. What is the image frequency? The antenna of this receiver is connected to the mixer via a turned circuit whose loaded Q is 40. What will be the rejection ratio for the calculated image frequency?

(ii) In an Armstrong modulator, the crystal oscillator frequency is 200 kHz. The angular deviation is set to 0.2. The system is to accommodate modulation frequencies between 50 Hz and 15 kHz. The carrier frequency at the output is 108 MHz and the maximum frequency deviation is 80 kHz. Draw the block diagram of the modulator showing the details and select multiplier and mixer oscillator frequencies to accomplish this.

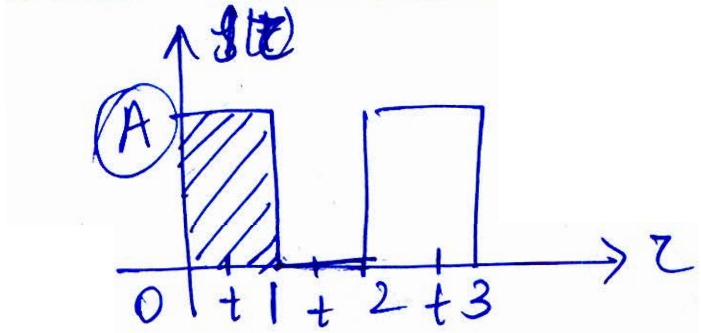
[6 + 14 marks]

OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work



s(t − τ)   t = τ

s(t − τ) = s(−τ + t)

τ = t

−∞ < τ < t

for t < 0. = 0.

$0 < t < 1$

$y(t) = \int_0^t A^2 dt$

$= A^2 t$.

$1 < t < 2$.

$= \int_1^t A + \int_1^t 0.$

$\Rightarrow A^2 \times t +$

$1 A^\circ = 10^{-10} m$

$10^{-10} m$

$1 cm = 10^{-2} m$

$10^2 cm = 1m$

$10^2 \times 10^{-10} cm = 1m$

10^{-8}

$J\bar{Q} + \bar{K} Q_n$.

$\bar{J}Q_n + J\bar{K}$

2, 3, 6

	$\bar{J}\bar{K}$	$\bar{J}K$	$J\bar{K}$	JK
$\bar{Q}_n$	0	1	1 2	1 3
Q_n	4	5	1 6	7
	0	0	1	$\bar{Q}_n$

001

010

$e^{-a|t|} \leftrightarrow \frac{2a}{(2a)^2 + \omega^2}$