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UPSC ESE 2019

Main Exam Detailed Solutions

Electronics and Telecom. Engineering

PAPER-II

EXAM DATE : 30-06-2019 | 2:00 PM to 5:00 PM

MADE EASY has taken due care in making solutions. If you find any discrepency/ error/typo or want to contest the solution given by us, kindly send your suggested answer with detailed explanations at info@madeeasy.in

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Electronics and Telecom. Engineering Paper Analysis
ESE 2019 Main Examination

Sl.	Subjects	Marks
1.	Control Systems	70
2.	Electromagnetics	80
3.	Communication Systems	80
4.	Advanced Communication	100
5.	Advanced Electronics	80
6.	Computer Organization and Architecture	70
	Total	**480**

Scroll down for detailed solutions

1. (a) In a narrow band digital communication system the symbol error probability for the in-phase channel is P_{eI} and for quadrature phase channel is P_{eQ}. Prove that the probability of symbol error for the overall system is given by (P_e):

$$P_e = P_{eI} + P_{eQ} - P_{eI} P_{eQ}$$

[10 Marks]

Solution:

In a digital communication system, when a symbol is transmitted using in-phase and quadrature phase carriers, the overall symbol will be correctly detected at the output of the receiver when and only when both in-phase and quadrature phase channels detect their respective symbols correctly.

So, the probability of detecting the overall symbol correctly is,

$$P_c = (1 - P_{eI})(1 - P_{eQ}) = 1 - P_{eI} - P_{eQ} + P_{eI} P_{eQ}$$

The probability of symbol error will be,

$$P_e = (1 - P_c) = P_{eI} + P_{eQ} - P_{eI} P_{eQ}$$

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- **ESE 2019 Mains Test Series:** Q.2(c) of Test-3

End of Solution

1. (b) Consider a discrete time system with impulse response $h[n] = \left(\frac{1}{5}\right)^{2n} U[n]$. Find the value of constant A such that $h[n] - Ah[n-1] = \delta[n]$ and $\delta[n]$ is a unit impulse signal.

[10 Marks]

Solution:

$$h[n] = \left(\frac{1}{5}\right)^{2n} u[n] = \delta[n] + \left(\frac{1}{5}\right)^{2n} u[n-1]$$

$$h[n-1] = \left(\frac{1}{5}\right)^{2(n-1)} u[n-1] = 25\left(\frac{1}{5}\right)^{2n} u[n-1]$$

Given that, $h[n] - Ah[n-1] = \delta[n]$

So, $\delta[n] + \left(\frac{1}{5}\right)^{2n} u[n-1] - A25\left(\frac{1}{5}\right)^{2n} u[n-1] = \delta[n]$

$$A(25) = 1$$

$$A = \frac{1}{25} = 0.04$$

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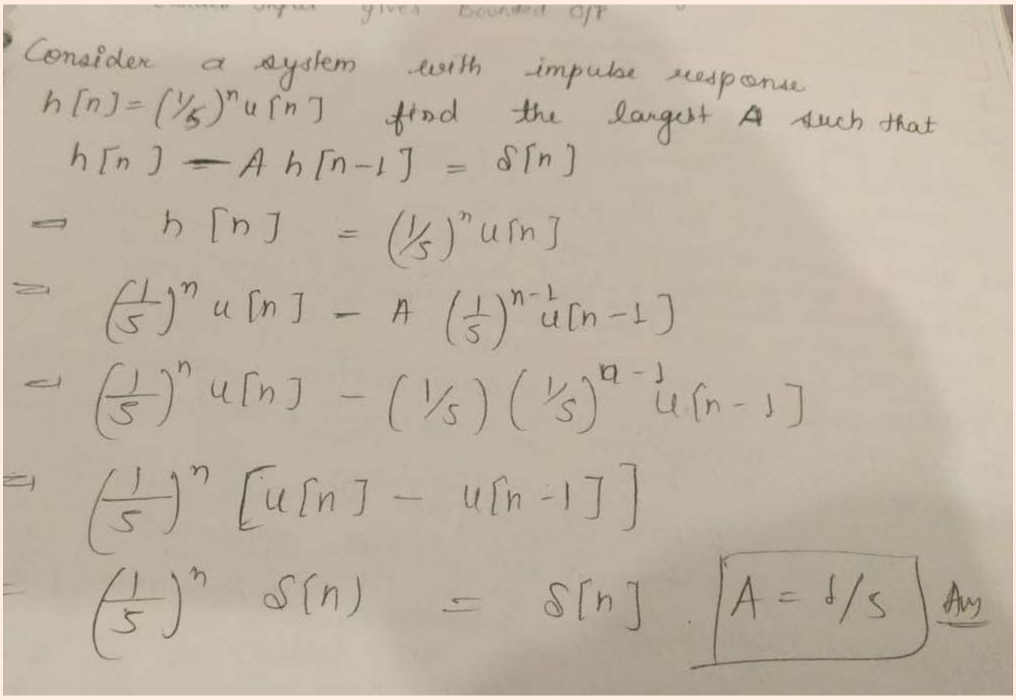
- **Theory Book 2020 :** Signal and Systems (Page No. 13)
- **MADE EASY Classnotes**



Consider a system with impulse response $h[n] = (1/5)^n u[n]$ find the largest A such that

$h[n] - A\,h[n-1] = \delta[n]$

$\Rightarrow h[n] = (1/5)^n u[n]$

$\Rightarrow \left(\frac{1}{5}\right)^n u[n] - A\left(\frac{1}{5}\right)^{n-1} u[n-1]$

$\Rightarrow \left(\frac{1}{5}\right)^n u[n] - (1/5)(1/5)^{n-1} u[n-1]$

$\Rightarrow \left(\frac{1}{5}\right)^n [u[n] - u[n-1]]$

$\Rightarrow \left(\frac{1}{5}\right)^n \delta(n) = \delta[n]$ $\boxed{A = 1/5}$ Ans

End of Solution

1. (c) A digital computer has a memory unit with 32 bits per word. The instruction set consists of 240 different operations. All instructions have an operation code part (opcode) and an address part (allowed for only one address). Each instruction is stored in one word of memory.

(i) How many bits are needed for the opcode?

(ii) How many bits are left for the address part of the instruction?

(iii) What is the maximum allowable size of the memory?

[10 Marks]

Solution:

The instruction format of the given computer can be taken as,

Opcode	Address part
(x bits)	(y bits)

Each memory word has 32-bits and each instruction is stored in one memory word.

So, $x + y = 32$

(i) Number of bits needed to represent opcode $= x$

$$x = \lceil \log_2(240) \rceil = \lceil 7.9 \rceil = 8$$

(ii) Number of bits left for the address part = y

$$x + y = 32$$

$$y = 32 - x = 32 - 8 = 24$$

(iii) The maximum allowable size of the memory is the size that can be represented using the address field of the instruction.

So, the maximum size of the memory = $2^y = 2^{24}$ words

$$2^{24} \text{ words} = 2^{24} \times 32 \text{ bits} = 64 \text{ MB (Mega bytes)}$$

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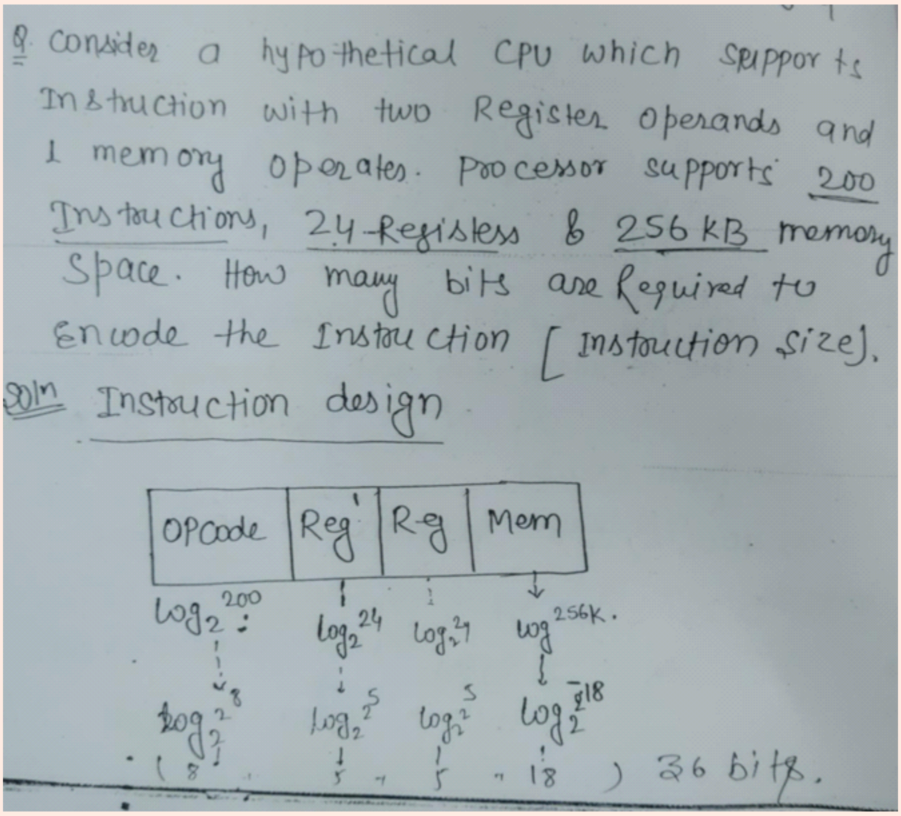
- **MADE EASY Classnotes**


Q. Consider a hypothetical CPU which supports Instruction with two Register operands and 1 memory operates. Processor supports 200 Instructions, 24 Registers & 256 kB memory space. How many bits are required to encode the instruction [Instruction size].

Soln Instruction design

Opcode	Reg	Reg	Mem
$\log_2 200$	$\log_2 24$	$\log_2 24$	$\log 256K$
$\log_2 2^8$	$\log_2 2^5$	$\log_2 2^5$	$\log_2 2^{18}$

(8 + 5 + 5 + 18) 36 bits.

End of Solution

1. (d) The Radiation intensity of an antenna is

$$U(\theta, \phi) = \begin{cases} 2\sin\theta\sin^3\phi & 0 \le \theta \le \pi, 0 \le \phi \le \pi \\ 0 & \text{elsewhere} \end{cases}$$

Determine the directivity of the antenna.

[10 Marks]

Solution:

The directivity of an antenna can be given by,

$$D = \frac{4\pi U_{max}}{\int_\phi \int_\theta U(\theta, \phi) \sin\theta \, d\theta \, d\phi}$$

Given that, $U(\theta, \phi) = 2\sin\theta\sin^3\phi$

So, $U_{max} = 2$

$$D = \frac{4\pi}{\int_{\phi=0}^{\pi}\int_{\theta=0}^{\pi} \sin^3\phi\sin^2\theta d\theta d\phi} = \frac{4\pi}{\int_{\phi=0}^{\pi}\sin^3\phi d\phi \int_{\theta=0}^{\pi}\sin^2\theta d\theta}$$

$$\int_{\phi=0}^{\pi}\sin^3\phi d\phi = \int_{\phi=0}^{\pi}\frac{1}{4}(3\sin\phi - \sin 3\phi)d\phi = \frac{1}{4}\left[-3\cos\phi + \frac{\cos 3\phi}{3}\right]_{\phi=0}^{\pi} = \frac{4}{3}$$

$$\int_{\theta}^{\pi}\sin^2\theta d\theta = \int_{\theta=0}^{\pi}\frac{1-\cos 2\theta}{2}d\theta = \frac{1}{2}\left[\theta - \frac{\sin 2\theta}{2}\right]_{\theta=0}^{\pi} = \frac{\pi}{2}$$

So, $$D = \frac{4\pi}{\frac{4}{3}\times\frac{\pi}{2}} = 6$$

In decilogs, $[D] = 10\log_{10}(D) = 7.78$ dB

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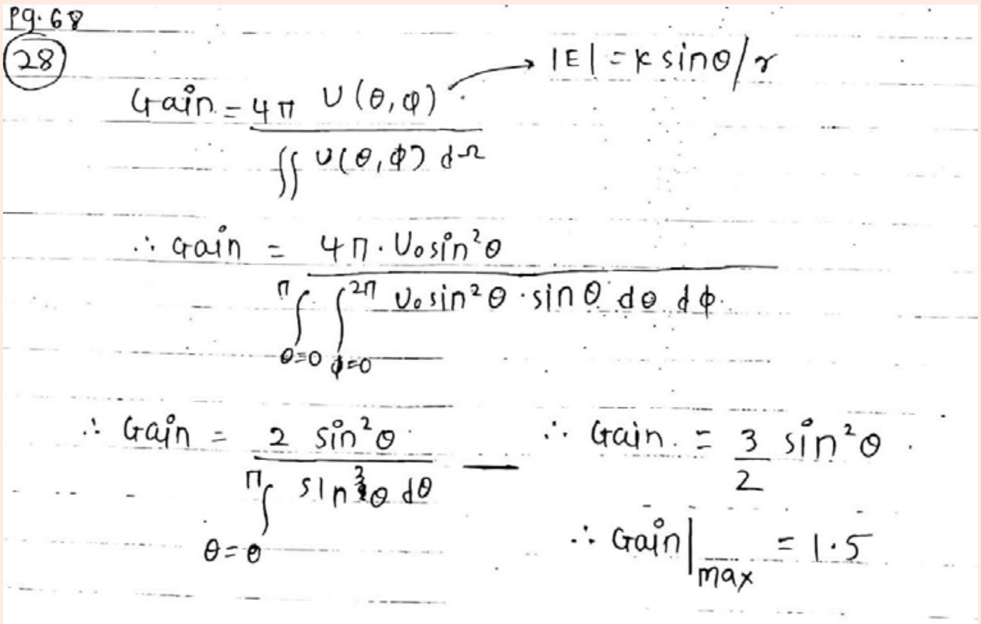
- **ESE 2018 Mains Test Series:** Q.4(b) of Test-6
- **MADE EASY Classnotes**


Pg. 68
(28)
$|E| = k\sin\theta/r$
$$\text{Gain} = \frac{4\pi\, U(\theta,\phi)}{\iint U(\theta,\phi)\, d\Omega}$$
$$\therefore \text{gain} = \frac{4\pi \cdot U_0\sin^2\theta}{\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} U_0\sin^2\theta \cdot \sin\theta\, d\theta\, d\phi}$$
$$\therefore \text{Gain} = \frac{2\sin^2\theta}{\int_{\theta=0}^{\pi}\sin^3\theta\, d\theta}$$
$$\therefore \text{Gain} = \frac{3}{2}\sin^2\theta$$
$$\therefore \text{Gain}\Big|_{max} = 1.5$$

End of Solution

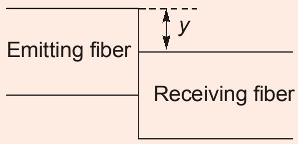
1. (e) A graded index fiber has a characteristics refractive index profile of 1.85 and a core diameter of 60 μm. Compute the insertion loss due to a 5 μm lateral offset at an index matched fiber joint assuming the uniform illumination of all guided modes.

[10 Marks]

Solution:

When there is uniform illumination of all guided modes, the loss due to lateral offset can be given by,

$$L_{lat} = \frac{2}{\pi}\left(\frac{y}{a}\right)\left(\frac{\alpha+2}{\alpha+1}\right)$$



Given that, $y = 5\ \mu m$, $a = \frac{60}{2} = 30\ \mu m$ and $\alpha = 1.85$.

So,
$$L_{lat} = \frac{2}{\pi}\left(\frac{5}{30}\right)\left(\frac{1.85+2}{1.85+1}\right) = 0.143$$

The lateral coupling efficiency can be given by,

$$\eta_{lat} = 1 - L_{lat} = 0.857$$

Therefore the insertion loss can be given by,

$$\text{Loss} = -10\log_{10}(\eta_{lat}) = -10\log_{10}(0.857) = 0.67\ \text{dB}$$

End of Solution

1. (f) A mobile network transmits data having bandwidth of 200 Hz using a carrier frequency of 800 MHz. If the maximum speed of a vehicle is 120 km/hr, calculate the bandwidth and the cut-off frequencies of the filter at the receiver input.
[10 Marks]

Solution:

Since vehicle is moving, there will be a shift in the received carrier frequency due to Doppler effect. The amount of shift is called as Doppler frequency (f_d).

Let the maximum Doppler shift is f_{dm}, then the received carrier frequencies will be in the range of $(f_c - f_{dm})$ to $(f_c + f_{dm})$.

$$f_{dm} = \frac{v_m}{c} f_c$$

$$v_m = \text{Maximum speed of the vehicle} = 120\ \text{km/hr} = \frac{100}{3}\ \text{m/s}$$

$$c = 3 \times 10^8\ \text{m/s and } f_c = 800\ \text{MHz}$$

So,
$$f_{dm} = \frac{100}{9\times 10^8} \times 800 \times 10^6 = 88.88\ \text{Hz}$$

The data have bandwidth (B) of 200 Hz. So, the filter at the receiver input should have characteristics as follows:

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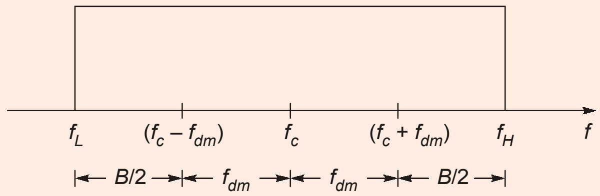

Lower cut-off frequency, $f_L = f_c - f_{dm} - \frac{B}{2} = 800\text{ MHz} - 88.88\text{ Hz} - 100\text{ Hz}$

$= 799999811.1\text{ Hz}$

Higher cut-off frequency, $f_H = f_c + f_{dm} + \frac{B}{2} = 800\text{ MHz} + 88.8\text{ Hz} + 100\text{ Hz}$

$= 800000188.9\text{ Hz}$

Bandwidth of the filter can be given by,

$$f_H - f_L = 2f_{dm} + B = 2(88.88) + 200 = 377.76\text{ Hz}$$

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- **ESE 2018 Mains Test Series:** Q.6(b) of Test-15

End of Solution

2. (a) Two speech signals $m_1(t)$ and $m_2(t)$ are used to generate a composite signal as:

$$s(t) = m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t$$

Assume both the messages are low pass in nature and have W Hz bandwidth.

(i) Draw the block diagram and show the generation scheme of $s(t)$. [8 Marks]

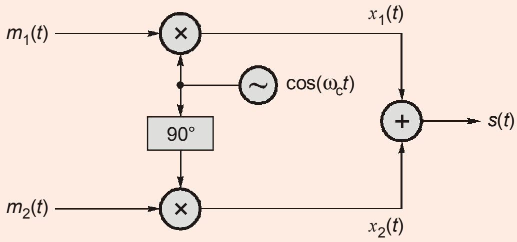
(ii) Propose a demodulation scheme in the form of block diagram and show the recovery of the two signals $m_1(t)$ and $m_2(t)$. Assume $\omega_c >> 2\pi W$. [12 Marks]

Solution:

(i) The composite signal is given by,

$$s(t) = m_1(t)\cos\omega_c t + m_2(t)\sin\omega_c t$$

This is a quadrature multiplexed signal in which we can transmit two different message signals using single carrier frequency. This composite signal can be generated by using the scheme shown below.

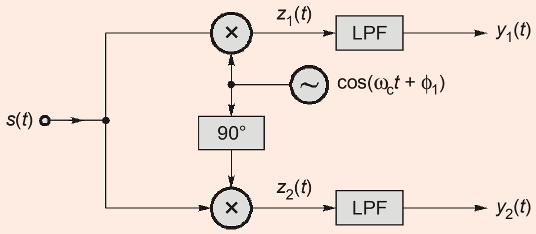


$$x_1(t) = m_1(t)\cos(\omega_c t)$$

$$x_2(t) = m_2(t)\sin(\omega_c t)$$

$$s(t) = x_1(t) + x_2(t) = m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)$$

(ii) The composite signal $s(t)$ can be demodulated to recover signals $m_1(t)$ and $m_2(t)$ using the scheme shown below:



The cut-off frequency of both the low-pass filters (LPF) is W Hz.

$$z_1(t) = s(t)\cos(\omega_c t + \phi_1) = [m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)]\cos(\omega_c t + \phi_1)$$

$$= \frac{1}{2}m_1(t)[\cos\phi_1 + \cos(2\omega_c t + \phi_1)] + \frac{1}{2}m_2(t)[\sin(2\omega_c t + \phi_1) - \sin\phi_1]$$

$$z_2(t) = s(t)\sin(\omega_1 t + \phi_1) = [m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)]\sin(\omega_c t + \phi_1)$$

$$= \frac{1}{2}m_1(t)[\sin(2\omega_c t + \phi_1) + \sin\phi_1] + \frac{1}{2}m_2(t)[\cos\phi_1 - \cos(2\omega_c t + \phi_1)]$$

After posing $z_1(t)$ and $z_2(t)$ through LPF, we get,

$$y_1(t) = \frac{1}{2}m_1(t)\cos\phi_1 - \frac{1}{2}m_2(t)\sin\phi_1$$

$$y_2(t) = \frac{1}{2}m_2(t)\cos\phi_1 + \frac{1}{2}m_1(t)\sin\phi_1$$

If $\phi_1 = 0°$, i.e. there is no phase difference between the transmitter carrier signal and the receiver local oscillator carrier signal. Then,

$$y_1(t) = \frac{1}{2}m_1(t) \propto m_1(t)$$

$$y_2(t) = \frac{1}{2}m_2(t) \propto m_2(t)$$

Hence the message signals $m_1(t)$ and $m_2(t)$ can be recovered from $s(t)$ when $\phi_1 = 0°$.

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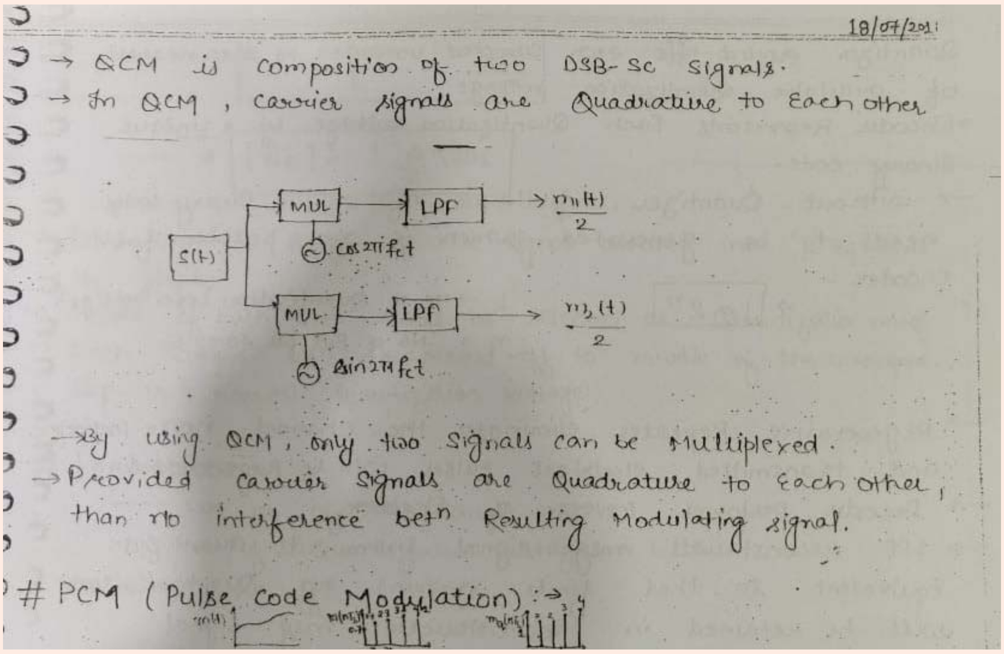
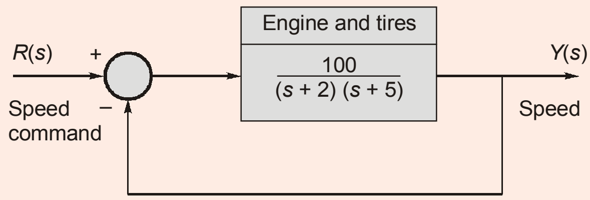
- **Theory Book 2020:** Communication Systems (Page No. 142)
- **MADE EASY Classnotes**


18/07/2019
→ QCM is composition of two DSB-SC signals.
→ In QCM, carrier signals are Quadrature to each other

→ By using QCM, only two signals can be multiplexed.
→ Provided carrier signals are Quadrature to each other, than no interference betn Resulting Modulating signal.
PCM (Pulse Code Modulation) :→

End of Solution

2. (b) The engine, body, and tires of a racing vehicle affect the acceleration and speed attainable. The speed control of the car is represented by the model as shown in the following figure.



(i) Calculate the steady state error of the car to a step command in speed. [5 Marks]

(ii) Calculate the overshoot of the speed to a step command. [15 Marks]

Solution:

(i) The open-loop transfer function of the given system is,

$$G(s) = \frac{100}{(s+2)(s+5)}$$

The system is of type-0 and it has unity negative feedback. So, the steady-state error for step excitation $Au(t)$ can be given by,

$$e_{ss} = \frac{A}{1+K_p}$$

$$K_p = \text{Position error constant} = \lim_{s \to 0} G(s)$$

$$K_p = \lim_{s \to 0} G(s) = \frac{100}{2 \times 5} = 10$$

$$e_{ss} = \frac{A}{1+10} = \frac{A}{11}$$

For unit step excitation, $e_{ss} = \dfrac{1}{1+10} = \dfrac{1}{11} = 0.091$

(ii) The closed-loop transfer function of the given system is,

$$T(s) = \frac{100}{s^2 + 7s + 110}$$

By comparing the denominator of $T(s)$ with the characteristic equation of a standard second order system, we get,

$$\omega_n^2 = 110 \Rightarrow \omega_n = \sqrt{110}\ \text{rad/sec}$$

$$2\xi\omega_n = 7 \quad \Rightarrow \xi = \frac{7}{2\sqrt{110}} = 0.334$$

The maximum peak overshoot of the speed in response to a step command can be given by,

$$M_p = \frac{y(t_p) - y(\infty)}{y(\infty)} = e^{-\xi\pi/\sqrt{1-\xi^2}} = e^{-\xi(0.334)/\sqrt{1-(0.334)^2}} = 0.3285$$

$$\%M_p = 32.85\%$$

Note: The closed-loop transfer function of the given system is deviated from that of a standard second order system only by a scaling factor of $\left(\dfrac{110}{100}\right)$. But there are no zeros in the transfer function. So, the formula of M_p of standard second order system is valid to calculate M_p of the given system.

MADE EASY Source

- **GATE 2019 Online Test Series:** Q.16 of Test-26

End of Solution

2. (c) A digital computer has memory capacity of 32767 words with 48 bits per word. The instruction code format consists of 8 bits for the operation part and 16 bits for the address part. Two instructions are packed in one memory word and 48 bit instruction register IR is available in the control unit. Formulate the procedure for fetching and executing the instructions for this computer.

[20 Marks]

Solution:

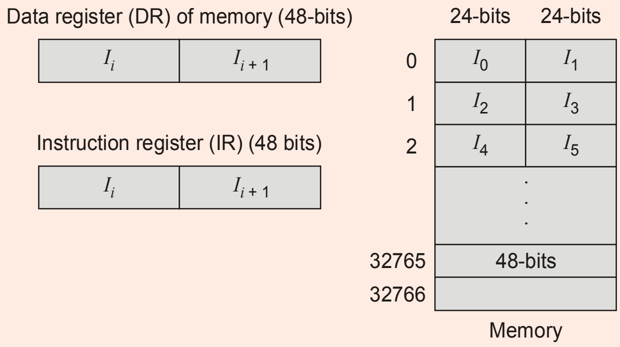
The format of the instructions can be given by

Opcode	Address	
(8-bits)	(16-bits)	$\Rightarrow$ 24 bits

Each instruction occupies 24-bits.

Each memory location can store 48-bits = 2 × 24 bits.

Two instructions can be stored in one memory location.



In each memory access, two instructions will be transferred to IR through DR. The computer hardware should be provided in such a way that the two instructions in the data word fetched must be separated and inserted into the instruction queue in the same order as they have to be executed. Then the instruction execution unit will execute the instructions one-by-one by taking them from the instruction queue.

End of Solution

3. (a) A digital communication system uses five symbols $\{S_0, S_1, S_2, S_3, S_4\}$ with their following probabilities of occurrence

S_0	S_1	S_2	S_3
0.55	0.20	0.10	0.10

(i) Compute Huffman code for these symbols by moving the combined symbol as low as possible.

[15 Marks]

(ii) Calculate the average code word length.

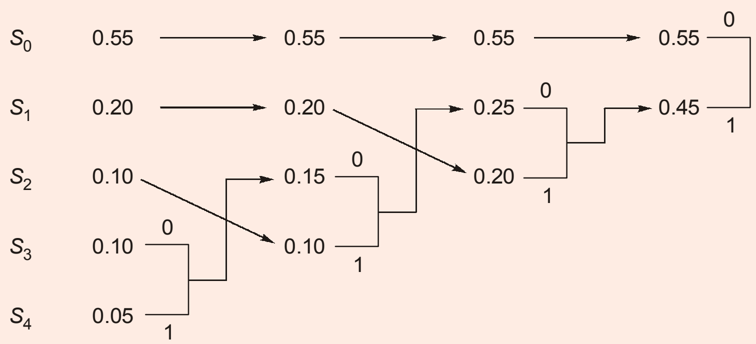
[5 Marks]

Solution:

The probability of occurrence of the fifth symbol can be given by,

$$P(s_4) = 1 - (0.55 + 0.20 + 0.10 + 0.10) = 0.05$$

(i) Huffman code construction:



The binary code words associated with each symbol can be tabulated as,

Symbol (S_i)	S_0	S_1	S_2	S_3	S_4
Probability, $P(S_i)$	0.55	0.20	0.10	0.10	0.05
Code word	0	11	101	1000	1001
Length of code word (l_i)	1	2	3	4	4

(ii) The average length of the code word can be given by,

$$\bar{L} = E[L] = \sum_{i=0}^{4} l_i P(S_i)$$

$$\bar{L} = (0.55 \times 1) + (0.20 \times 2) + (0.10 \times 3) + (0.10 \times 4) + (0.05 \times 4)$$
$$= 1.85 \text{ binary digits/symbol}$$

Entropy, $$H = -\sum_{i=0}^{4} P(S_i) \log_2 P(S_i) \simeq 1.82 \text{ bits/symbol}$$

Coding efficiency, $$\eta = \frac{H}{\bar{L}} = \frac{1.82}{1.85} = 0.984 \text{ (or) } 98.4\%$$

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.5(c) of Test-5
- **ESE 2018 Mains Test Series:** Q.3(a) of Test-15

End of Solution

3. (b) A unity feedback control system has $KG(s) = \frac{K(s+2)}{s(s+1)}$

(i) Find the breakaway and entry points on the real axis.

[10 Marks]

(ii) Find the gain and the roots when the real part of the complex roots are located at –2.

[10 Marks]

Solution:

(i) The open-loop transfer function of the given system is,

$$KG(s) = \frac{K(s+2)}{s(s+1)}$$

The characteristic equation of the system can be given by,

$$1 + KG(s) = 0$$

$$1 + \frac{K(s+2)}{s(s+1)} = 0$$

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

Solution of $\frac{dK}{ds} = 0$ yields break-away and break-in points.

$$\frac{dK}{ds} = \frac{-(s+2)(2s+1)+s(s+1)(1)}{(s+2)^2} = 0$$

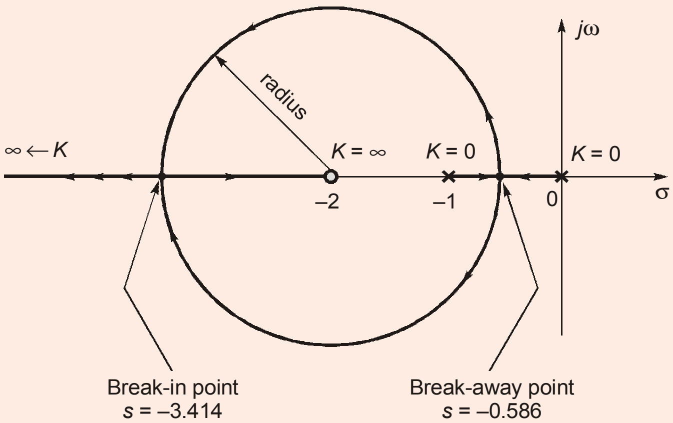
$$2s^2 + 5s + 2 = s^2 + s$$

$$s^2 + 4s + 2 = 0$$

$$s = -2 \pm \sqrt{2}$$

So, break-away point exists at $s = -2+\sqrt{2} = -0.586$

Break-in point exists at $s = -2-\sqrt{2} = -3.414$

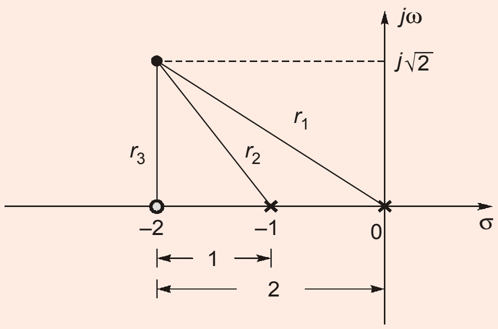


The radius of the circle = $\sqrt{2}$

Centre of the circle exists at $s = -2$

(ii) From the above root-locus diagram it is clear that, with real part as "–2", the roots exists on the root-locus at $s = -2 \pm j\sqrt{2}$

To determine gain K at $s = -2 \pm j\sqrt{2}$:



$$K = \frac{\text{Product of distances from the point of OL poles}}{\text{Product of distances from the point to OL zeros}}$$

$$K = \frac{r_1 r_2}{r_3}$$

$$r_1 = \left|2 + j\sqrt{2}\right| = \sqrt{(2)^2 + (\sqrt{2})^2} = \sqrt{6}$$

$$r_2 = \left|1 + j\sqrt{2}\right| = \sqrt{(1)^2 + (\sqrt{2})^2} = \sqrt{3}$$

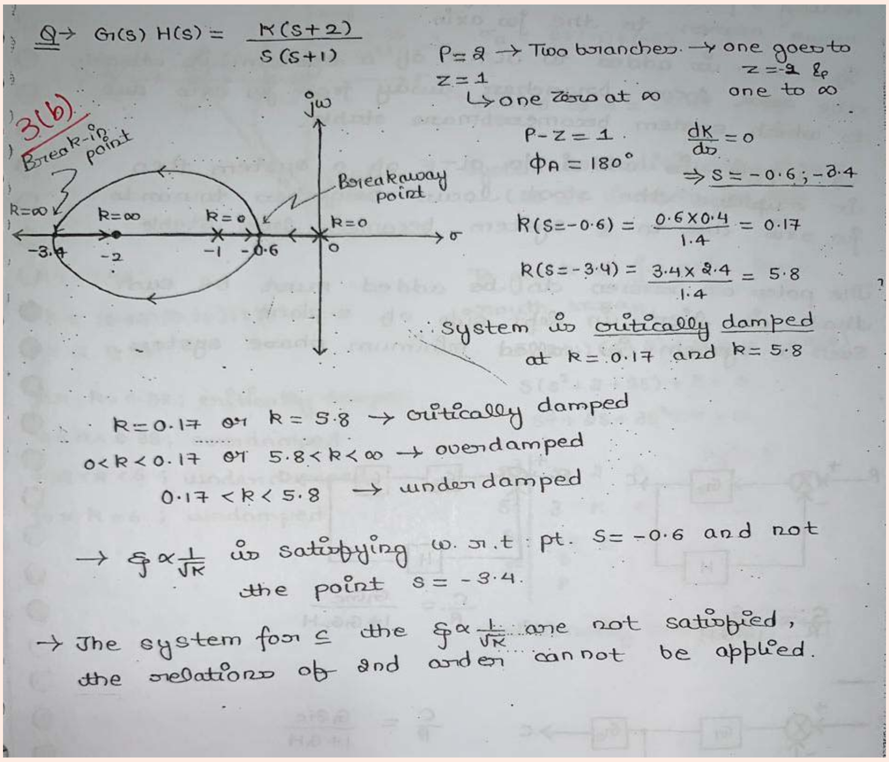
$$r_3 = \left|0 + j\sqrt{2}\right| = \sqrt{2}$$

$$K = \frac{\sqrt{6} \times \sqrt{3}}{\sqrt{2}} = 3$$

So, when $K = 3$, the roots of the characteristic equation exists at $s = -2 \pm j\sqrt{2}$.

MADE EASY Source

- **ESE 2018 Mains Test Series:** Q.7(c) of Test-2
- **Theory Book 2020:** Control Systems (Page No. 252, 256)
- **MADE EASY Classnotes**



End of Solution

3. (c) What is virtual memory? How it is different from main memory? Suppose CPU generates 32 bit virtual addresses and the page size is 16 KB. The processor has a translation look-aside buffer (TLB) which can hold a total of 512 page table entries and is 4-way associative. Calculate the size of TLB tag.

[20 Marks]

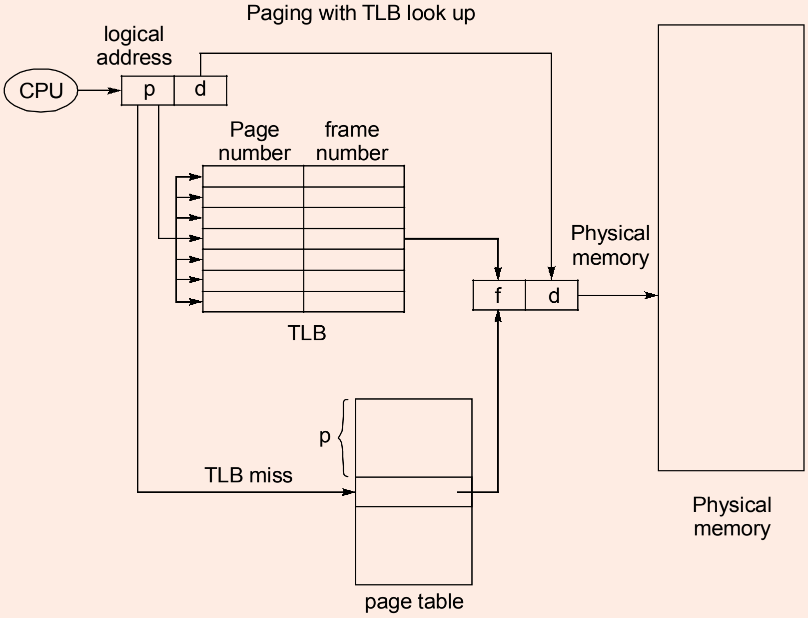
Solution:

Virtual memory is the separation of user logical memory from physical memory. This technique provides larger memory to the user by creating virtual memory space. It facilitates the user to create a process which is larger than the physical memory space. We can have more processes executing in memory at a time.

It increases degree of multiprogramming. With the virtual memory technique, we can execute a process which is only partially loaded in memory.

Paging with TLB (Translation Look-aside Buffer)

A TLB is on-chip hardware special cache which is part of memory-management unit. TLB is used in virtual-to-physical address translations so it is also called as address-translation cache. It is a cache that holds recently accessed page table entries. If address translation uses a TLB entry, access to the page table is avoided. TLB can cache only a few of page table entries. TLB is fully associative memory, so page numbers of all TLB entries are checked simultaneously for a match. TLB lookup is much faster than a memory access.



Given that, Virtual address = 32 bits

Page size = 16 kB = $2^4 \times 2^{10}$ B = 2^{14} B $\Rightarrow$ Offset field = 14 bits

Number of page table entries = 512 = 2^9 $\Rightarrow$ Set field = 7 bits

Tag	Set	Offset
x	7	14

← 32 →

$$x + 7 + 14 = 32$$

$$x = 11 \text{ bits}$$

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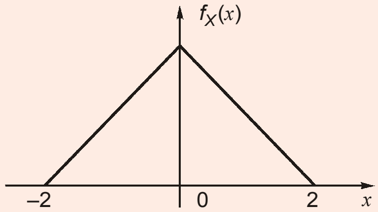
- **Theory Book 2020:** µP & Computer Org. (Page No. 254, 261)

End of Solution

4. (a)



A low pass stationary process $X(t)$ has probability density function (at any given point of time) as shown in the figure. This process has a bandwidth of 5 kHz and is to be transmitted by using a PCM system.

(i) Calculate the signal to quantization noise ratio (in dBs) if the sampling is done at the Nyquist rate and 5 bit uniform quantizer is used.

[8 Marks]

(ii) Calculate the bit rate generated.

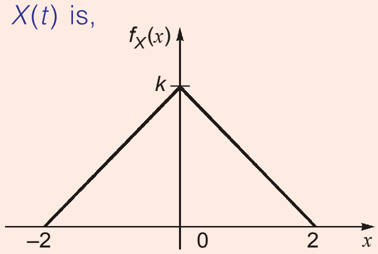
[4 Marks]

(iii) If the maximum bit rate supported by the channel is 64 kbps, calculate the possible improvement in signal to quantization noise ratio if the uniform quantizer is redesigned.

[8 Marks]

Solution:

The probability density function of the input process $X(t)$ is,



$$\int_{-\infty}^{\infty} f_X(x)dx = 1$$

$$2\left[\frac{1}{2}\times 2\times k\right] = 1$$

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

So, $f_X(x)$ can be defined as,

$$f_X(x) = \begin{cases} \frac{1}{2}-\frac{1}{4}|x| & ; \text{ for } |x|<2 \\ 0 & ; \text{ Otherwise} \end{cases}$$

(i) Signal power can be calculated as,

$$S = E\left[X^2(t)\right] = \int_{-\infty}^{\infty} x^2 f_X(x)dx$$

$$= 2\int_{x=0}^{2} x^2\left(\frac{1}{2}-\frac{1}{4}x\right)dx = \frac{1}{2}\int_{x=0}^{2}(2x^2-x^3)\,dx$$

$$= \frac{1}{2}\left[\frac{2}{3}x^3-\frac{x^4}{4}\right]_{x=0}^{2} = \frac{1}{2}\left[\frac{16}{3}-\frac{16}{4}\right] = \frac{2}{3}\text{ W}$$

Quantization noise power can be calculated as,

$$N_Q = \frac{\Delta^2}{12}$$

$$\Delta = \text{Step size} = \frac{x_{max} - x_{min}}{2^n} = \frac{2-(-2)}{2^5} = \frac{4}{32} = \frac{1}{8}$$

So, $$N_Q = \frac{(1/8)^2}{12} = \frac{1}{768}\text{ W}$$

Signal to quantization noise ratio will be,

$$\text{SQNR} = \frac{S}{N_Q} = \frac{(2/3)}{(1/768)} = \frac{2\times 768}{3} = 512$$

In decilogs, $[\text{SQNR}] = 10\log_{10}(\text{SQNR}) = 10\log_{10}(512) \simeq 27.1\text{ dB}$

(ii) The message signal $X(t)$ has a bandwidth of 5 kHz. It is sampled at Nyquist rate and quantized with a 5-bit uniform quantizer.

So, sampling rate, $f_s = 2 \times 5 = 10\text{ kHz}$

Bit rate, $R_b = nf_s = 5 \times 10 = 50\text{ kbps}$

(iii) When maximum allowed data rate is 64 kbps, the maximum number of bits/sample that can be used by the quantizer will be

$$n_{max} = \left\lfloor \frac{R_{b(max)}}{f_s} \right\rfloor = \left\lfloor \frac{64\times 1000}{10\times 1000} \right\rfloor = \lfloor 6.4 \rfloor = 6$$

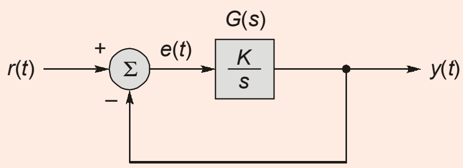
When n is increased from 5 to 6, the possible improvement in the [SQNR] is 6.02 dB.

End of Solution

4. (b) A simple unity feedback control system has a process transfer function $G(s) = \frac{K}{s}$. The system input is a step function with an amplitude A. The initial condition of the system at time t_0 is $y(t_0) = Q$, where $y(t)$ is the output of the system. The performance index of the system is defined as $I = \int_0^\infty e^2(t)dt$ where $e(t)$ is the error in the system response. Show that performance index I is given as $\frac{(A-Q)^2}{2K}$ where K is gain.

[20 Marks]

Solution:



To make the explanation simple, let us assume that input is step function excited at $t = 0$. So, $t_0 = 0$ and $y(t_0) = y(0) = Q$.

$$y(t) = K\int_{-\infty}^{t} e(t)\,dt$$

$$\frac{dy(t)}{dt} = Ke(t)$$
$$sY(s) - y(0) = KE(s)$$
$$sY(s) - Q = KE(s)$$
$$Y(s) = \frac{KE(s)+Q}{s}$$
$$E(s) = R(s) - Y(s)$$

For step excitation with an amplitude of A, $R(s) = \frac{A}{s}$.

So,
$$E(s) = \frac{A}{s} - \frac{KE(s)+Q}{s}$$
$$(s + K)\,E(s) = (A - Q)$$
$$E(s) = \frac{(A-Q)}{(s+K)}$$

By taking inverse Laplace transform, we get,
$$e(t) = (A - Q)e^{-Kt}$$
$$I = \int_0^{\infty} e^2(t)dt = \int_0^{\infty} (A-Q)^2 e^{-2Kt}dt$$
$$= (A-Q)^2\left[-\frac{e^{-2Kt}}{2K}\right]_0^{\infty} = \frac{(A-Q)^2}{2K}$$

End of Solution

4. (c) What are the advantages and disadvantages of recursion? Write a code/pseudocode (in any standard programming language) with proper statements to accept a string as a command line argument and hence find its length.

[20 Marks]

Solution:

Advantages of recursion:
- We can create a simple and easy version of programs using recursion.
- Always recursion will be written in the name of recursive definition. It can be translated into C code very easily.
- We can avoid initialization of variable inside the functions, but iterative solutions are required to be initialized.
- Some specific applications are meant for recursion such as binary tree traversal, tower of Hanoi etc. can be easily understood.

Disadvantages of recursion:
- It occupies lot of memory.
- It consumes more time to get desired result.
- Function execution is slower than iterative method because of the overhead of calling functions repeatedly.

C program to accept a string as a command line argument hence find its length:

```
# include <stdio.h>
# include <conio.h>
void main (int argc, char *argv[ ])
{
    int i, j, c = 0;
    for (i = 1; i < argc ; i++)
    {
        for (j = 0; argv[i] [j]! = NULL; j++)
        c++;
    }
    printf ("length = %d", c);
    getch();
}
```

End of Solution

5. (a) In a system if data is transmitted to remote location using 8 bit PCM encoding, find

(i) Channel capacity if Bandwidth is 300 kHz and SNR = 15 dB.

[4 Marks]

(ii) The maximum number of channels that can be accommodated in this scheme if Time Division Multiplexing is used with each channel having 5 kHz fixed bandwidth allocation.

[6 Marks]

Solution:

(i) The capacity of an AWGN channel, with bandwidth B, can be given by,

$$C = B\log_2 (1 + \text{SNR})$$

$$[\text{SNR}] = 10\log_2 (1 + \text{SNR}) = 15 \text{ dB}$$

$$(\text{SNR}) = 10^{1.5} = 31.623$$

So, $$C = 300\log_2 (1 + 31.623) = 1508.34 \text{ kbps}$$

(ii) Let the number of individual channels is N. Assuming the Nyquist sampling rate for each channel, the bit rate of the TDM signal with N channels will be

$$R_b = N \times 2 \times 5 \times 8 = 80N \text{ kbps}$$

For proper transmission of data,

$$80N \leq 1508.34$$

$$N \leq \left\lfloor \frac{1508.34}{80} \right\rfloor = 18$$

$$N_{max} = 18$$

So, at most 18 channels can be allowed.

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- **ESE 2019 Mains Test Series:** Q.4(c) (ii) of Test-11

End of Solution

5. (b) A system is described by the state equations

$$\dot{X} = \begin{bmatrix} 3 & 0 \\ -1 & 1 \end{bmatrix} X + \begin{bmatrix} -1 \\ 1 \end{bmatrix} U \text{ and } Y = [1 \quad 1]\ X.$$

Determine whether the system is controllable and observable.

[10 Marks]

Solution:

$$A = \begin{bmatrix} 3 & 0 \\ -1 & 1 \end{bmatrix};\ B = \begin{bmatrix} -1 \\ 1 \end{bmatrix};\ C^T = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

To check the controllability of the system:

$$Q_C = [B\ :\ AB] = \begin{bmatrix} -1 & -3 \\ 1 & 2 \end{bmatrix}$$

$$|Q_C| = (-1 \times 2) - (-3 \times 1) = 1 \neq 0$$

So, the given system is controllable.

To check the observability of the system:

$$Q_O = [C^T : A^T C^T]$$

$$A^T C^T = \begin{bmatrix} 3 & -1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$$

$$Q_O = \begin{bmatrix} 1 & 2 \\ 1 & 1 \end{bmatrix}$$

$$|Q_O| = (1 \times 1) - (2 \times 1) = -1 \neq 0$$

So, the given system is observable.

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- **Theory Book 2020:** Control Systems (Page No. 423, Q.12.28)

End of Solution

5. (c) An analog cellular system has a total of 33 MHz of bandwidth and uses two 25 kHz simplex channels to provide full duplex voice and control channels. What is the number of channels available per cell for a frequency reuse factor of 4 cells? If 1 MHz is dedicated to a control channel then how many voice channels will be available for reuse factor of 4 cells.

[10 Marks]

Solution:

Total number of cells in a cluster = 4

Total BW assigned to each cluster = System BW = 33 MHz

BW of each simplex channel = 25 kHz

Total number of simplex channels available in each cell = $\frac{33000}{4 \times 25} = 330$

Total number of full duplex channels available in each cell = 165

If 1 MHz is dedicated to control channel:

System BW available for voice channels = 32 MHz

Total number of simplex channels available in each cell = $\frac{32000}{4 \times 25} = 320$

Total number of voice channels (full duplex) available in each cell = 160

Total number of voice channels available in the system = 4 × 160 = 640

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- **ESE 2018 Mains Test Series:** Q.3(b) of Test-9

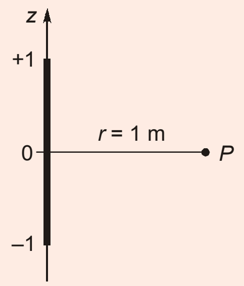
End of Solution

5. (d) Find the potential at a point P which is 1 m radial distance from the midpoint of a 2 m straight line charge of uniform density 10 nC/m in air. If this line charge is bent to form an arc of a circle of radius 1 m, find the percentage change in potential at the same point P. Give reason for this change.

[10 Marks]

Solution:

When charge is considered as a straight line:



Potential at point P,

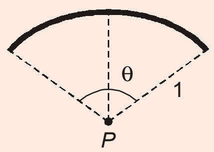
$$V_1 = \int_{-1}^{1} \frac{\rho_L dz}{4\pi\varepsilon_o \sqrt{z^2 + r^2}} \; ; \; r = 1\text{m}$$

$$= \frac{2\rho_L}{4\pi\varepsilon_o} \int_0^1 \frac{1}{\sqrt{z^2+1}} dz$$

$$= \frac{\rho_L}{2\pi\varepsilon_o} \left[\sinh^{-1}(z)\right]_{z=0}^{1} = \frac{\rho_L}{2\pi\varepsilon_o} \sinh^{-1}(1)$$

$$= \frac{10 \times 10^{-9} \times \sinh^{-1}(1)}{2\pi \times (10^{-9}/36\pi)} \simeq 158.65 \text{ V}$$

When charge is considered as an arc of circle:



$$r\theta = 2 \text{ m}$$

$$r = 1 \text{ m}$$

So, $\theta = 2$ radians

Potential at point P,

$$V_2 = \int_{\theta=0}^{2} \frac{\rho_L}{4\pi\varepsilon_o r} d\theta = \frac{\rho_L}{2\pi\varepsilon_o}$$

$$V_2 = \frac{10 \times 10^{-9}}{2\pi \times (10^{-9}/36\pi)} = 180 \text{ V}$$

% change in the potential,

$$\frac{V_2 - V_1}{V_1} \times 100 = \frac{180 - 158.65}{158.65} \times 100 \simeq 13.46\%$$

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Potential f^n of a Point charge

Reference dependent value

$V = -\int \bar{E}\cdot d\bar{l}$ $\quad \therefore V = -\int \frac{Q}{4\pi\varepsilon r^2} a_r \, dr \cdot a_r = \frac{Q}{4\pi\varepsilon r} + K$

$r = \infty, V = 0$ then $K = 0$

$\bar{E}$ – vector – $\frac{1}{r^2}$ decrease – a_r directed

V – scalar – $\frac{1}{r}$ decrease

Potential f^n of a line charge

$V = -\int E\cdot dl$ $\quad \therefore V = -\int \frac{\rho_L}{2\pi\varepsilon\rho} a_\rho \, d\rho \cdot a_\rho = \frac{\rho_L}{2\pi\varepsilon} \ln\left(\frac{1}{\rho}\right) + K$

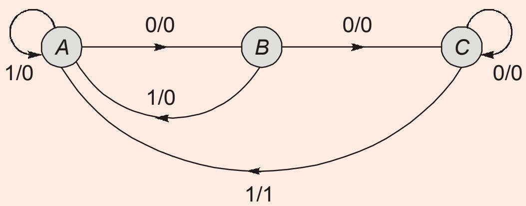
$V = 0$ at $\rho = 1 \therefore K = 0$

$\bar{E}$ – $1/\rho$ decrease – force

V – logarithmic decrease – Energy.

End of Solution

5. (e)



Mealy state diagram

Construct the state diagram for a Moore circuit from the given Mealy circuit.

[10 Marks]

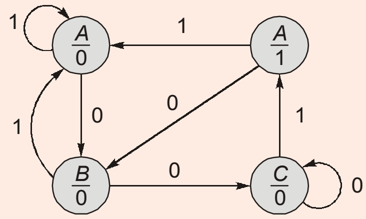
Solution:

The state table of the given Mealy state diagram is,

PS	NS		Output	
	$x = 0$	$x = 1$	$x = 0$	$x = 1$
A	B	A	0	0
B	C	A	0	0
C	C	A	0	1

x = input

The equivalent Moore circuit will have 4 states and its state diagram can be drawn as follows:



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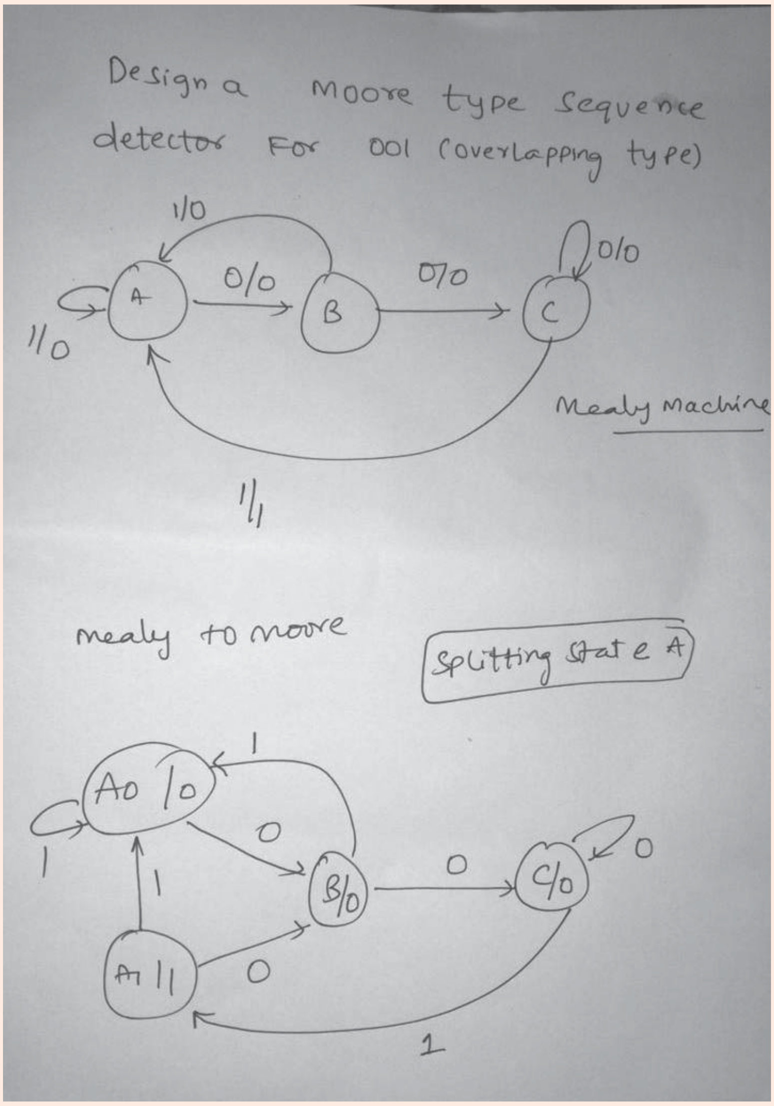
- **Theory Book 2020:** Advance Communications (Page No. 64)
- **MADE EASY Classnotes**



End of Solution

5. (f) A message consists of blocks of 8 bits. A checksum of 8 bits is added after every two blocks. If the first two blocks of a message are :

Block 1		Block 2	
0011 ↑ MSB	1010	0010 ↑ MSB	0101

(i) Find the checksum bits transmitted.

[5 Marks]

(ii) If the channel error causes bits to reverse at the MSB place of both the blocks, find the recovered bit pattern after checksum.

[5 Marks]

Solution:

(i)
Block 1 ⇒ 0011 1010
Block 2 ⇒ 0010 0101
Sum ⇒ 0101 1111 (No end carry)

1's complement of the above sum is the required checksum, which is equal to "1010 0000".

(ii) When bits at MSB place of both the blocks are reversed due to channel noise, the received data blocks will be,

Received block 1 ⇒ 1011 1010
Received block 2 ⇒ 1010 0101
(1) 0101 1111
→ 1
Sum ⇒ 0110 0000

Adding the above sum to the checksum obtained in part (i), we get,

0110 0000
1010 0000
(1) 0000 0000
→ 1
0000 0001

The recovered bit pattern after checksum will be the 1's complement of the above pattern; i.e. "1111 1110". This bit pattern is not equal to all zeros, and hence indicates that the received data blocks has errors.

End of Solution

6. (a) The relative permittivity of a dielectric material between the plates of parallel plate capacitor varies uniformly from $\in r_1 = 1$ at one plate to $\in r_2 = 4$ at other plate. The area of each plate is 1 m^2. Find the capacitance per unit length of this capacitor if d = 3 mm. Derive the equation used.

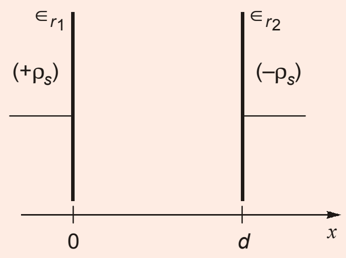
[20 Marks]

Solution:

$$\epsilon_r = \epsilon_{r_1} + \frac{(\epsilon_{r_2} - \epsilon_{r_1})}{d} x$$

$$\epsilon_{r_1} = 1 \; ; \; \epsilon_{r_2} = 4 \; ; d = 3 \text{ mm}$$

So, $$\epsilon_r = 1 + \frac{3}{3 \times 10^{-3}} x = 1000x + 1$$



The capacitance can be given by,

$$C = \frac{Q}{V} = \frac{\rho_s A}{\int_0^d \vec{E} \cdot \vec{dl}}$$

$$\vec{E} = \frac{\rho_s}{\epsilon_o \epsilon_r} \hat{x}, \; A = 1 \text{ m}^2 \text{ and } d = 3 \text{ mm}.$$

So, $$C = \frac{1}{\int_0^{3\text{ mm}} \frac{1}{\epsilon_o (1000x + 1)} dx} = \frac{1000\epsilon_0}{[\ln(1000x + 1)]_{x=0}^{3\text{ mm}}} \text{ F}$$

$$= \frac{1000 \epsilon_0}{\ln(4)} = 6.387 \times 10^{-9} \text{ F} = 6.387 \text{ nF}$$

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- **GATE 2019 Online Test Series:** Q.16 of Test-22

End of Solution

6. (b) (i) Discuss the priority of interrupts of 8086. Draw a circuit that will terminate the INTR when interrupt request has been acknowledged.

[15 Marks]

(ii) Explain Direct Memory Access (DMA) mode of data transfer.

[5 Marks]

Solution:

(i) **Priority of interrupts of 8086 microprocessor:**

As the hardware interrupts of 8086 are asynchronous in nature, so any interrupt can arise at any time. Moreover, more than one interrupt may also appear at any time. But the microprocessor can attend only one interrupt at time so there must be some priority resolving system by which microprocessor can attend the interrupt on the basis of their priority.

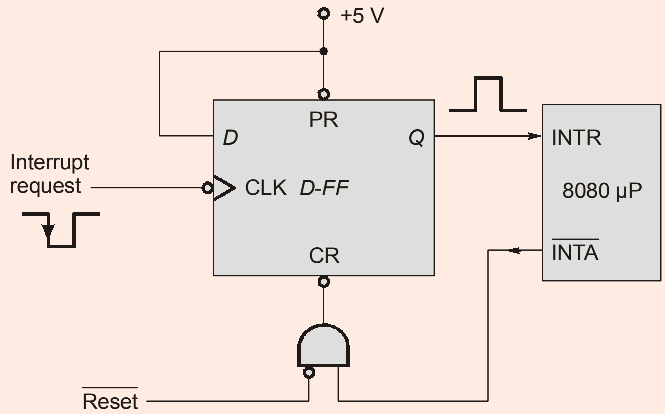
All the interrupts are serviced on the priority basis. The higher priority interrupt is served first and an active lower priority interrupt service is interrupted by a higher priority one. Lower priority interrupts will have to wait until their turns come. The section of program to which the control is passed called interrupt service routine.

In 8086 the interrupts are serviced as per the following priority order. Here interrupt types are shown with decreasing priority order.

1. Internal interrupts and exceptions
2. Software interrupt

3. Non-maskable interrupt
4. INTR
5. Single step

The following circuit can be used to terminate the INTR when interrupt request has been acknowledged:



When an external device wants to interrupt the microprocessor, the interrupt request signal goes low and the falling edge of the request triggers the *D*-flip-flop, and *Q* goes high, which interrupts the microprocessor.

After acknowledging the interrupt $\overline{\text{INTA}}$ signal goes low, which clears the *D*-flip-flop and hence a low signal will present at INTR.

(ii) DMA Data Transfer Scheme (DMA-DTS)

- In DMA-DTS, MPU doesn't participate because data is directly transferred from an I/O device to the memory or vice-versa.
- In DMA, the MPU releases the control of the buses to a device called "DMA Controller". The controller manages data transfer between memory and a peripheral under its control, thus by- passing the MPU.
- The MPU communicates with the controller by using the chip select line, Buses and Control signals. Examples of DMA controller chips are: Intel 8237A, 8257.
- DMA-DTS is a faster scheme as compared to programmed DTS.
- It is used to transfer data from "mass storage devices" (hard disks, floppy disks etc). It is also used for high-speed printers.
- Once the controller has gained the control, it plays the role of a processor for data transfer as:
  1. The DMA controller chip puts the MPU in a HOLD state by means of the HOLD control signal. This is an active high input signal.
  2. The MPU then stops executing the program and disconnects the address, data and memory control lines from its bus by placing them on a high impedance state. The microprocessor is totally disabled during DMA.

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- **Theory Book 2020:** Microprocessor (Page No. 76)

End of Solution

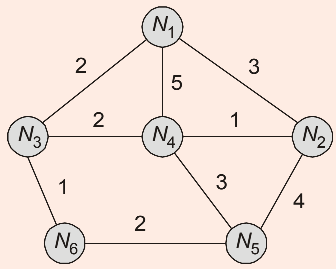
6. (c) A network with 6 nodes with associated cost function is given in the Table below. Calculate the routing table using the shortest path Dijkstra's Algorithm assuming Node 1 as the source node. NC represents no connection between the nodes.

Node Number ↓ / →	1	2	3	4	5	6
1	–	3	2	5	NC	NC
2	3	–	NC	1	4	NC
3	2	NC	–	2	NC	1
4	5	1	2	–	3	NC
5	NC	4	NC	3	–	2
6	NC	NC	1	NC	2	–

[20 Marks]

Solution:

From the given table, the network can be represented as,



The Dijkstra's algorithm always selects the shortest path possible from the source node to destination node.

So, the routing table with source node as N_1 can be given as follows:

Node	Path	Next hop to	Distance
N_1	N_1	–	0
N_2	$N_1 \rightarrow N_2$	N_2	3
N_3	$N_1 \rightarrow N_3$	N_3	2
N_4	$N_1 \rightarrow N_3 \rightarrow N_4$	N_3	4
N_5	$N_1 \rightarrow N_3 \rightarrow N_6 \rightarrow N_5$	N_3	5
N_6	$N_1 \rightarrow N_3 \rightarrow N_6$	N_3	3

End of Solution

7. (a) A lossless line with L = 0.5 μH/m and C = 150 PF/m is operated at a frequency 10 MHz. Find the shortest length of line at which it acts as
(i) 150 PF Capacitor on an open circuit and short circuit.
(ii) 2 μH Inductor on an open circuit and short circuit.

[20 Marks]

Solution:

The line is lossless.

So,

$$Z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.5\times10^{-6}}{150\times10^{-12}}} = 57.735\ \Omega$$

$$v_p = \frac{1}{\sqrt{LC}}\ \frac{1}{\sqrt{75\times10^{-18}}} = 11.55\times10^{7}\ \text{m/sec}$$

$$\lambda = \frac{v_p}{f} = \frac{11.55\times10^{7}}{10^{7}} = 11.55\ \text{m}$$

$$\beta = \frac{2\pi}{\lambda} = 0.544\ \text{rad/m}$$

Impedance at length (l) from the load end can be given by,

$$Z(l) = Z_0\left[\frac{Z_L + jZ_0\tan(\beta l)}{Z_0 + jZ_0\tan(\beta l)}\right]$$

When line is open circuited (i.e., $Z_L = \infty$),

$$Z_{OC}(l) = -jZ_0\cot(\beta l) = -j\frac{Z_0}{\tan(\beta l)}$$

When line is short circuit (i.e., $Z_L = 0$),

$$Z_{SC}(l) = jZ_0\tan(\beta l)$$

(i) To act as a capacitor of 150 pF:

$$Z(l) = \frac{1}{j\omega C} = \frac{1}{j(2\pi\times10^{7}\times150\times10^{-12})} = -j106.1\,\Omega$$

With open circuit, the minimum length of the line required is,

$$l_{min} = \frac{1}{\beta}\tan^{-1}\left(\frac{57.735}{106.1}\right) \simeq 0.916\ \text{m}$$

With short circuit, the minimum length of the line required is,

$$l_{min} = \frac{1}{\beta}\left[\pi - \tan^{-1}\left(\frac{106.1}{57.735}\right)\right] = 3.8\ \text{m}$$

(ii) To act as an inductor of 2 μH:

$$Z(l) = j\omega L = j(2\pi\times10^{7}\times2\times10^{-6}) = j125.664\ \Omega$$

With open circuit, the minimum length of the line required is,

$$l_{min} = \frac{1}{\beta}\left[\pi - \tan^{-1}\left(\frac{57.735}{125.664}\right)\right] = 4.983\ \text{m}$$

With short circuit, the minimum length of the line required is,

$$l_{min} = \frac{1}{\beta}\tan^{-1}\left(\frac{125.664}{57.735}\right) = 2.096\ \text{m}$$

The results obtained in part (i) and part (ii) can be tabulated as follows:

	l_{min} with open circuit	l_{min} with short circuit
To act as 150 pF capacitor	0.916 m	3.8 m
To act as 2 μH inductor	4.983 m	2.096 m

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- **Theory Book 2020:** Electromagentics (Page No. 170)
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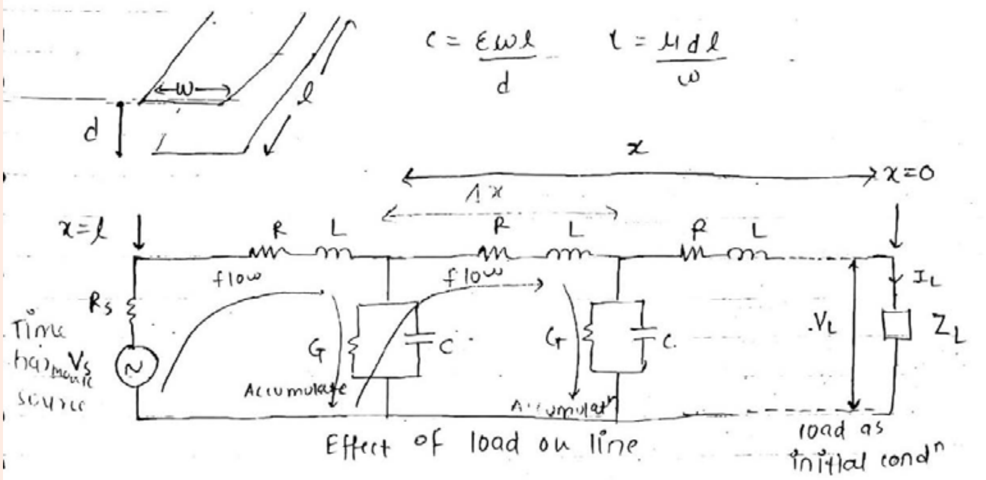
Distributed (L) × Distributed (C) = $LC = \mu\varepsilon$ For any line/geometry



Z-series of Δx length = $(R + j\omega L)\,\Delta x$

Y shunt of Δx length = $(G + j\omega C)\,\Delta x$

$\therefore \Delta V = I(x)\cdot(R + j\omega L)\,\Delta x$

$Z_{SC} = jR_0 \tan\beta l$ $Z_{OC} = \frac{-jR_0}{\tan\beta l}$

1) $0 < \beta l < \frac{\pi}{2}$ or $0 < l < \frac{\lambda}{4}$
Zin is inductive. — Zin is capacitive.

2) $l = \lambda/4$ — OC — shunt resonance ckt — series Resonance

3) $\frac{\pi}{2} < \beta l < \pi$ or $\frac{\lambda}{4} < l < \frac{\lambda}{2}$
Zin is capacitive. — Zin is inductive

4) $l = \lambda/2$ — SC — series Resonance ckt — shunt resonance

– one end of a line is short or open, the other end is purely reactive in nature such that it is resonance at $\lambda/4$ and $\lambda/2$ length.

End of Solution

7. (b) (i) Implement the following Boolean functions using PLA:

$$Sum\ (A, B, C_{in}) = \Sigma m(1, 2, 4, 7)$$
$$C_{out}\ (A, B, C_{in}) = \Sigma m(3, 5, 6, 7)$$

[10 Marks]

(ii) Explain photolithography process. Also, explain the importance of photoresists.

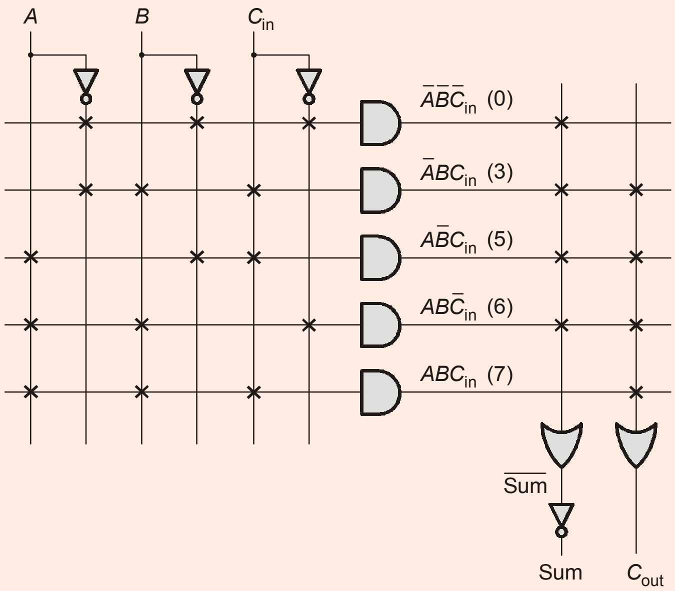
[10 Marks]

Solution:

(i)
$$Sum = \Sigma m(1, 2, 4, 7)$$
$$C_{out} = \Sigma m(3, 5, 6, 7)$$
$$\overline{Sum} = \Sigma m(0, 3, 5, 6, 7)$$

If $\overline{Sum}$ and C_{out} are designed using PLA, only 5 unique minterms are required to be produced by the AND array.

Implementation using PLA:



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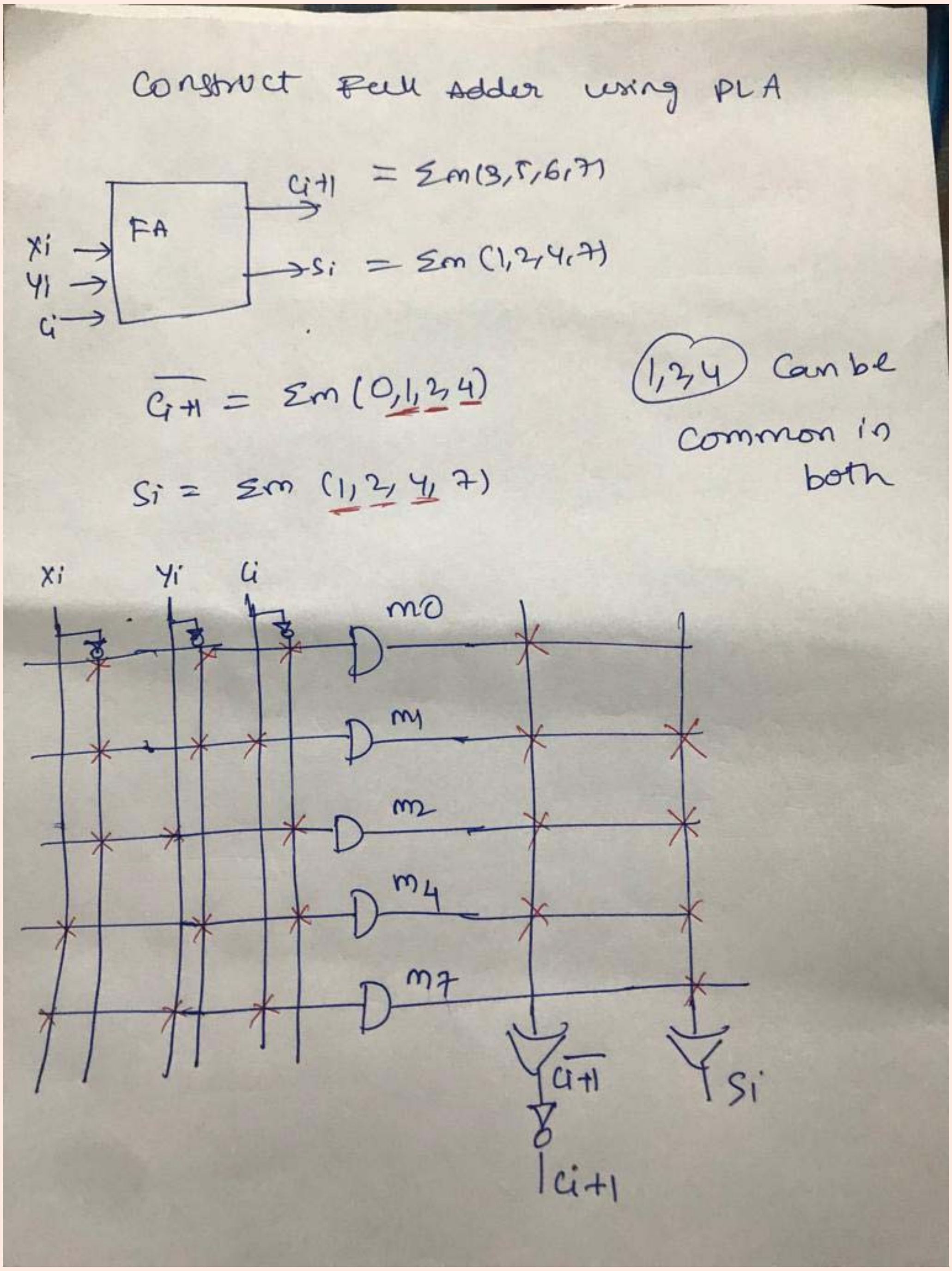
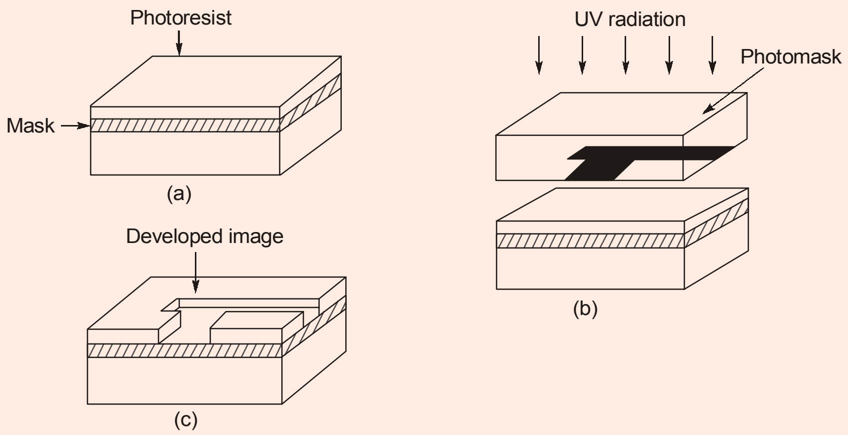
- **ESE 2019 Mains Test Series:** Q.2(c) of Test-4
- **ESE 2019 Mains Test Series:** Q.6(c) of Test-6
- **Theory Book 2020:** Advance Electronics (Page No. 106)
- **MADE EASY Classnotes**



(ii) For the fabrication of semiconductor devices, selective doping is often necessary. This means that certain regions of the wafer have to be protected against doping during diffusion or ion-implantation. In general, this is done by covering the entire sample by a protective (masking) layer and then removing this mask layer at some selected regions by a process called photolithography. Afterwards, diffusion or ion-implantation is carried out and doping takes place only in the regions not protected by the mask. The most commonly used mask material in silicon technology is silicon dioxide (SiO_2) and it can be easily grown on silicon by thermal oxidation as discussed in the previous section. For compound semiconductors, SiO_2 and/or Si_3N_4 deposited by chemical vapour deposition can be used as masks. Since ion-implantation is a relatively low temperature process, photoresist itself can be used as a mask against implantation.

Once the mask layer is grown or deposited on the semiconductor surface, it must be patterned. That is, the mask should be retained only over certain selected regions and removed from the rest of the surface. Patterning is a two-step process. In the first step, a photosensitive material (photoresist) is spin-coated on the entire sample surface. There are two types of photoresist, namely positive and negative. In optical photolithography, the photoresist-coated wafer is exposed to UV light through an appropriate mask plate (or photomask). Certain regions on the mask plate are transparent, and the rest is opaque. In case of positive photoresist, the photoresist exposed to UV light is softened and is therefore easily removed in a developer solution. In case of negative photoresist, only the exposed resist remains and the unexposed resist is removed by the developer solution. Thus, the mask pattern (or its negative) is transferred onto the resist-coated sample after the exposed (or unexposed) resist is removed in the developer solution. The following figures (a), (b), and (c) illustrate the process schematically.



Different steps in photolithography process showing the transfer of patterns

In the second step of patterning, the mask is removed (etched) from the regions no longer protected by photoresist (also called opening windows in the mask). If the masking layer is SiO_2, etching is usually done by dipping the sample in hydrofluoric acid (wet chemical etching), which etches SiO_2 in the regions which are not protected by the photoresist. After the selective removal of oxide, photoresist is removed from everywhere. The sample is then washed in de-ionized water, dried thoroughly, and is ready for diffusion/implantation. However, if photoresist itself is the mask used against ion-implantation, it is not necessary to grow and selectively etch the oxide.

Optical lithography using deep UV light is by far the most widely used lithography technique today. The minimum feature size which can be obtained by the photolithography process depends on the wavelength of the UV radiation, and lower wavelengths are used for better resolution. Electron beam lithography and X-ray lithography have also been used to reduce the minimum feature size. Electron beam lithography allows direct writing on the sample (no patterned mask plate is needed as the electron beam is directly raster-scanned on the photoresist). Due to the very small electron beam size, high resolution can be achieved. However, scanning the entire wafer is a very slow process and hence not suitable for large scale production. On the other hand, it is difficult to prepare a suitable mask plate for X-ray lithography. Thus, these techniques so far have found only limited application.

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- **ESE 2019 Mains Test Series:** Q.3(b) of Test-4
- **Theory Book 2020:** Advance Electronics (Page No. 9)
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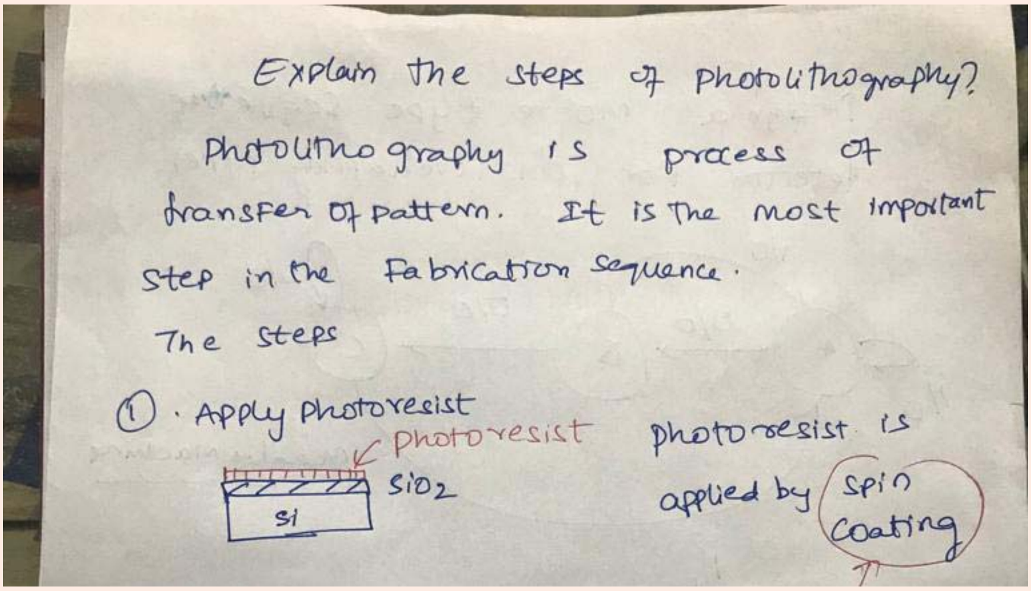

End of Solution

7. (c) (i) Calculate the degradation in the downlink $\left(\frac{C}{I}\right)$ ratio when orbital spacing between the satellites is reduced from 5° to 2°, all the other factors remaining unchanged. Assume antenna characteristics as per Federal Communications Commission (FCC) norms.

[10 Marks]

(ii) A low noise amplifier is connected to a receiver which has a noise figure of 12 dB. The power gain of the low noise amplifier is 1000 and its noise temperature referred to the low noise amplifier input.

[10 Marks]

Solution:

(i) According to the FCC antenna characteristics, the degradation in the downlink $\left(\frac{C}{I}\right)$ will be,

$$\text{Degradation} = 20\log_{10}\left(\frac{5^\circ}{2^\circ}\right) = 9.95\text{ dB}$$

(ii) **Note:** The parameter to be determined is not given clearly in the question.

$$\text{Noise figure } (F) = 10^{1.2} = 15.85$$

The noise temperature referred to the low noise amplifier input is,

$$T_e = T_o\,(F - 1) = 290\,(15.85 - 1) = 4306.5\text{ K}$$

End of Solution

8. (a) The inside dimensions of 9 GHz air filled waveguide are 2.286 cm × 1.016 cm. Find the maximum power that can be transmitted in the TE mode assuming that the breakdown electric field intensity is 3×10^6 V/m.

[20 Marks]

Solution:

The maximum power that can be transmitted through a lossless waveguide is,

$$P_{max} = \frac{E_{o(max)}^2}{4\eta_{TE(10)}}(ab)$$

$$f_{c(10)} = \frac{c}{2a} = \frac{3\times10^8}{2\times2.286\times10^{-2}} = 6.56\text{ GHz}$$

$$f = \text{Operating frequency} = 9\text{ GHz}$$

$$\eta_{TE(10)} = \frac{\eta_0}{\sqrt{1-\left(\frac{f_{c(10)}}{f}\right)^2}} = \frac{120\pi}{\sqrt{1-\left(\frac{6.56}{9}\right)^2}} = 550.65\ \Omega$$

So,

$$P_{max} = \frac{(3\times10^6)^2\,(2.286\times10^{-2})\,(1.016\times10^{-2})}{4\times550.65} \approx 949\text{ kW}$$

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- **ESE 2018 Mains Test Series:** Q.7(b) of Test-8
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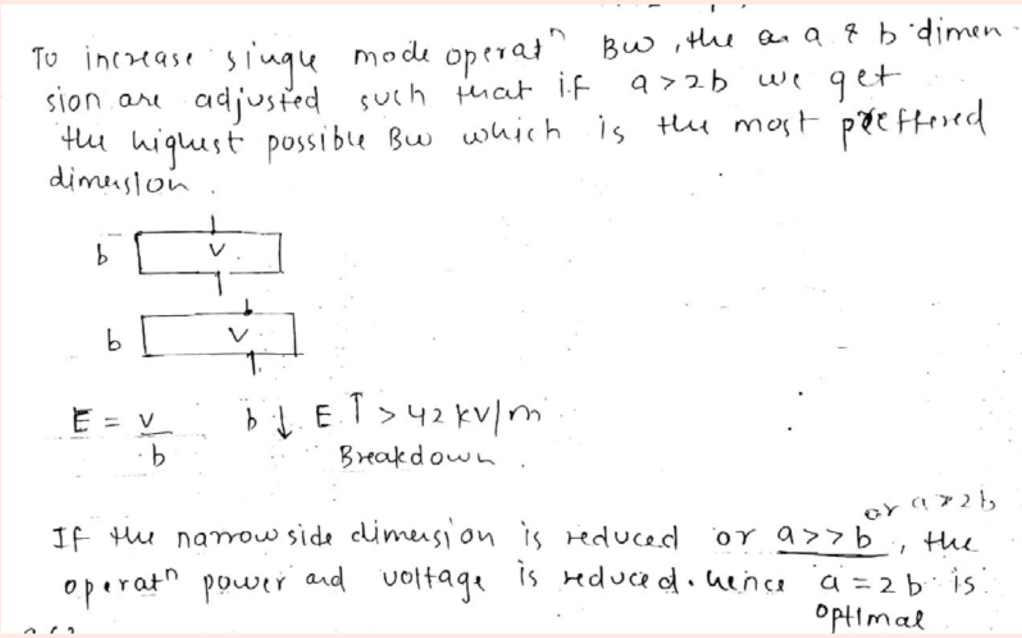

To increase single mode operatⁿ BW, the a & b dimension are adjusted such that if a > 2b we get the highest possible BW which is the most preffered dimension.

$E = \frac{V}{b}$ b ↓ E ↑ > 42 kV/m
Breakdown.

If the narrow side dimension is reduced or a >> b (or a > 2b), the operatⁿ power and voltage is reduced. hence a = 2b is optimal

End of Solution

8. (b) (i) For given discrete time systems, where $y[n]$ and $x[n]$ are the output and the input sequences, respectively. Determine, whether or not the system is - linear, causal, stable and time-invariant.

(A) $y[n] = n^2x[n]$ (B) $y[n] = x[n-5]$

[10 Marks]

(ii) Develop two different cascade canonic realization of given causal IIR transfer function.

$$H(z) = \frac{(0.3 - 0.5z^{-1})(2 + 3.1z^{-1})}{(1 + 2.1z^{-1} - 3z^{-2})(1 + 0.67z^{-1})}$$

[10 Marks]

Solution:

(i) (A) $y[n] = n^2x[n]$:

- $$x[n] \xrightarrow{T(\cdot)} y[n] = n^2x[n]$$

$$x_1[n] \longrightarrow y_1[n] = n^2x_1[n]$$

$$x_2[n] \longrightarrow y_2[n] = n^2x_2[n]$$

$$ax_1[n] + bx_2[n] \longrightarrow y_3[n] = n^2(ax_1[n] + bx_2[n])$$

$$y_3[n] = an^2x_1[n] + bn^2x_2[n] = ay_1[n] + by_2[n] \Rightarrow \text{Linear}$$

- Present output of the given system depends only on the present input. So, it is a causal system.
- As $n \to \infty$, $y[n] \to \infty$ even if $x[n]$ is finite. So, the output can be unbounded for a bounded input and hence the given system is unstable.
- $$T(x[n-n_0]) = n^2 x[n-n_0]$$
  $$y[n-n_0] = (n-n_0)^2 x[n-n_0]$$
  $$y[n-n_0] \neq T(x[n-n_0]) \Rightarrow \text{time-variant}$$

  So, the system defined as $y[n] = n^2 x[n]$ is linear, causal, unstable and time-variant.

(B) $y[n] = x[n-5]$:

- $$x[n] \xrightarrow{T(\cdot)} y[n] = x[n-5]$$
  $$x_1[n] \longrightarrow y_1[n] = x_1[n-5]$$
  $$x_2[n] \longrightarrow y_2[n] = x_2[n-5]$$
  $$ax_1[n] + bx_2[n] \longrightarrow y_3[n] = ax_1[n-5] + bx_2[n-5]$$
  $$y_3[n] = ay_1[n] + by_2[n] \Rightarrow \text{Linear}$$
- Present output of the given system depends only on the past values of the input. So, it is a causal system.
- For finite values of $x[n]$, the corresponding value of $y[n]$ also will be finite. So, the system is stable.
- $$T(x[n-n_0]) = x[n-5-n_0]$$
  $$y[n-n_0] = x[n-n_0-5]$$
  $$y[n-n_0] = T(x[n-n_0]) \Rightarrow \text{time-invariant}$$

  So, the system defined as $y[n] = x[n-5]$ is linear, causal, stable and time-invariant.

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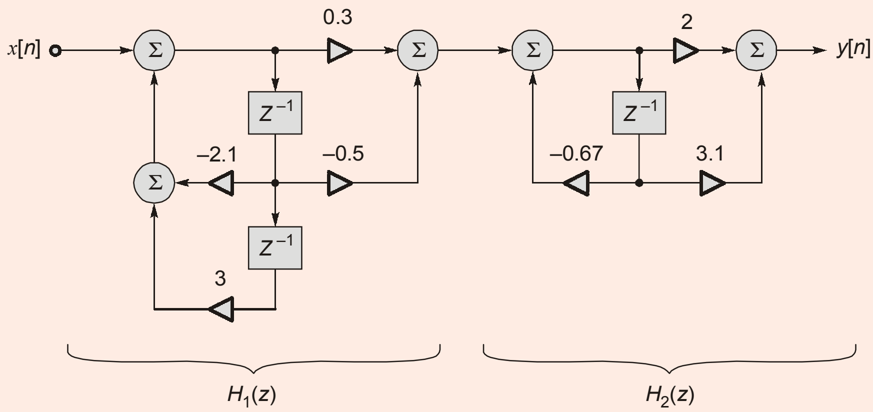
(ii) Method-I:

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

$$H_1(z) = \frac{(0.3 - 0.5z^{-1})}{(1 + 2.1z^{-1} - 3z^{-2})}$$

$$H_2(z) = \frac{(2 + 3.1z^{-1})}{(1 + 0.67z^{-1})}$$

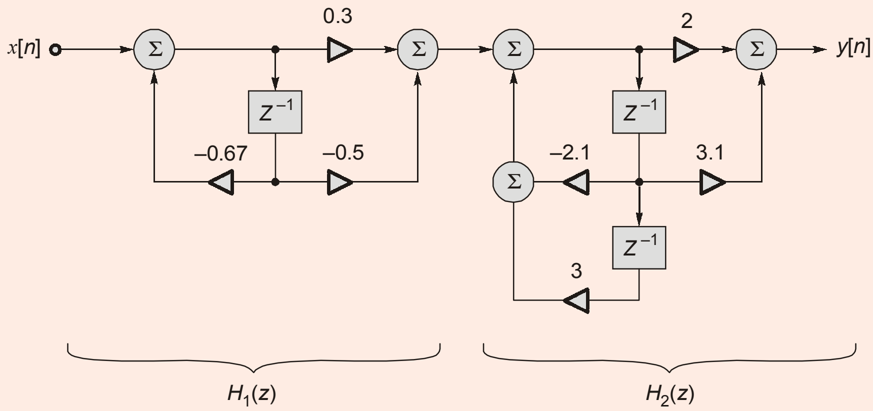


Method-II:

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

$$H_1(z) = \frac{(0.3 - 0.5z^{-1})}{(1 + 0.67z^{-1})}$$

$$H_2(z) = \frac{(2 + 3.1z^{-1})}{(1 + 2.1z^{-1} - 3z^{-2})}$$



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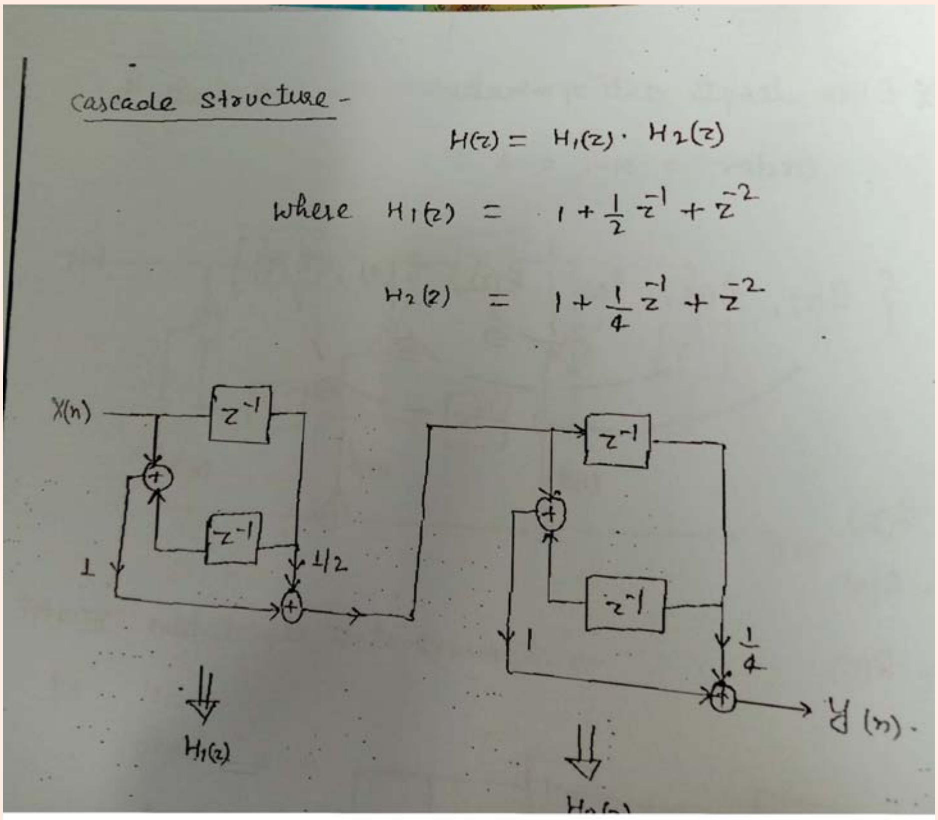


End of Solution

8. (c) Describe the mechanism of intermodal dispersion in a multimode step index fiber. Show that the total broadening of a light pulse δT_s due to intermodal disperse a multimode step index fiber may be given as :

$$\delta T_s \approx \frac{L(NA)^2}{2n_1C}$$

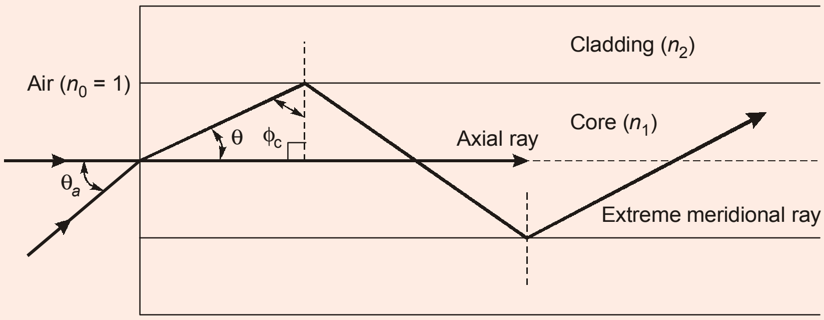
where L is the fiber length, NA is the numerical aperture of the fiber, n_1 is the core refractive index and C is the velocity of light is a vacuum.

[5+15 Marks]

Solution:

Pulse broadening due to intermodal dispersion (sometimes referred to simply as modal or mode dispersion) results from the propagation delay differences between modes within a multimode fiber. As the different modes which constitute a pulse in a multimode fiber travel along the channel at different group velocities, the pulse width at the output is dependent upon the transmission times of the slowest and fastest modes.

Using the ray theory model, the fastest and slowest modes propagating in the step index fiber may be represented by the axial ray and the extreme meridional ray (which is incident at the core-cladding interface at the critical angle ϕ_c) respectively. The paths taken by these two rays in a perfectly structured step index fiber are shown in figure below.



The delay difference between these two rays when traveling in the fiber core allows estimation of the pulse broadening resulting from intermodal dispersion within the fiber. As both rays are traveling at the same velocity within the constant refractive index fiber core, the delay difference is directly related to their respective path lengths within the fiber.

The time taken for the axial ray to travel along a fiber of length L gives the minimum delay time T_{min} and:

$$T_{min} = \frac{\text{Distance}}{\text{Velocity}} = \frac{L}{(c/n_1)} = \frac{Ln_1}{c} \quad \text{...(i)}$$

where n_1 is the refractive index of the core and c is the velocity of light in a vacuum. The extreme meridional ray exhibits the maximum delay time T_{max} where:

$$T_{max} = \frac{L/\cos\theta}{c/n_1} = \frac{Ln_1}{\cos\theta} \quad \text{...(ii)}$$

Using Snell's law of refraction at the core-cladding interface,

$$\sin\phi_c = \frac{n_2}{n_1} = \cos\theta \quad \text{...(iii)}$$

where n_2 is the refractive index of the cladding. Furthermore, substituting into equation (ii) for $\cos\theta$ gives:

$$T_{max} = \frac{Ln_1^2}{cn_2} \quad \text{...(iv)}$$

The delay difference δT_s between the extreme meridional ray and the axial ray may be obtained by,

$$\delta T_s = T_{max} - T_{min} = \frac{Ln_1^2}{cn_2} - \frac{Ln_1}{c}$$

$$= \frac{Ln_1^2}{cn_2}\left(\frac{n_1 - n_2}{n_1}\right) \quad \text{...(v)}$$

$$\simeq \frac{Ln_1^2\Delta}{cn_2} \text{ when } \Delta << 1 \qquad ...(vi)$$

where Δ is the relative refractive index difference.

However, when $\Delta << 1$, $$\Delta \simeq \frac{n_1 - n_2}{n_2} \qquad ...(vii)$$

Hence rearranging equation (v):

$$\delta T_s = \frac{Ln_1}{c}\left(\frac{n_1 - n_2}{n_2}\right) \simeq \frac{Ln_1\Delta}{c}$$

Δ also can be related to numerical aperture (NA) as,

$$(NA) = n_1\sqrt{2\Delta} \Rightarrow \Delta = \frac{(NA)^2}{2n_1^2}$$

So, $$\delta T_s \simeq \frac{L(NA)^2}{2n_1 c}$$

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- **ESE 2019 Mains Test Series:** Q.8(a) of Test-13
- **Theory Book 2020:** Advance Communications (Page No. 71)

End of Solution

■■■■