SECTION - A
There are FOUR questions in this section. Answer any THREE.

1. (a) For a one-sided junction show that the inverse capacitance squared is a linear function of applied reverse-bias voltage.
   
   (5)

(b) Consider a uniformly doped GaAs pn junction at \( T = 300 \text{ K} \). The junction capacitance at zero bias is \( C_j(0) \) and the junction capacitance with 10-V reverse-bias voltage is \( C_j(10) \). The ratio of the capacitance is \( C_j(0)/C_j(10) = 3.13 \). Under reverse-bias, the space charge width into the p region is 0.2 of the total space charge width. Determine the built-in potential barrier and the doping concentrations in the p and n regions. For GaAs the intrinsic carrier concentration is \( 1.8 \times 10^6 \text{ cm}^{-3} \).
   
   (15)

(c) Consider a silicon pn junction at \( T = 300 \text{ K} \) with the doping profile shown in Fig. for Q. No. 1(c). Calculate the applied reverse-bias voltage required so that the space charge region extends entirely through the p region. Also determine the space charge width into the n+ region and the peak electric field for this applied voltage. Consider \( \varepsilon_i = 11.7 \), \( \varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm} \), \( k = 1.38 \times 10^{-23} \text{ J/K} \).
   
   (15)
2. (a) A silicon pn junction diode is to be designed to operate at \( T = 300 \) K such that the diode current is \( I = 10 \) mA at a diode voltage of \( V_D = 0.65 \) V. The ratio of electron current to total current is to be 0.10 and the maximum current density is to be 20 A/cm\(^2\). Consider the following parameters:

\[
\begin{align*}
    n_i &= 1.5 \times 10^{10} \text{cm}^{-3} \\
    \tau_{n0} &= \tau_{p0} = 5 \times 10^{-7} \text{s} \\
    e_r &= 11.7 \\
    D_n &= 25 \text{ cm}^2/\text{s} \\
    D_p &= 10 \text{ cm}^2/\text{s}
\end{align*}
\]

(b) In the pn junction diode the reverse-bias saturation current, \( I_s \), is a function of temperature. Assuming that \( I_s \) varies with temperature only from the intrinsic carrier concentration, show that \( I_s = CT^3 \exp(-E_g/kT) \) where \( C \) is a constant and a function only of the diode parameters. Also determine the increase in \( I_s \) as the temperature increases from \( T = 300 \) K to \( T = 400 \) K for a germanium diode. The bandgap energy \( E_g \) of germanium is 0.66eV.

3. (a) What are the differences between a Schottky diode and a pn junction diode? Why the Schottky diodes are useful for fast-switching applications?

(b) A Schottky diode at \( T = 300 \) K is formed between tungsten and n-type silicon doped at \( N_d = 10^{16} \) cm\(^{-3}\). The cross-sectional area is \( 10^{-4} \) cm\(^2\). Determine the reverse-saturation current at a reserve-bias voltage, \( V_R = 2 \) V. Consider Schottky barrier lowering. Assume the following parameters.

\[
\begin{align*}
    \phi_{Bn} &= 0.68\text{eV} \\
    A^* &= 114 \text{A/K}^2 \\
    e_r &= 11.7 \\
    e_0 &= 8.85 \times 10^{-14} \text{F/cm} \\
    N_c &= 2.8 \times 10^{19} \text{cm}^{-3}
\end{align*}
\]

(c) A metal-semiconductor junction is formed between a metal with a work function of 4.3eV and a p-type silicon with an electron affinity of 4.0eV. The acceptor doping concentration in the silicon is \( N_a = 5 \times 10^{16} \) cm\(^{-3}\). Assume \( T = 300 \) K. Sketch the thermal equilibrium energy band diagram and determine the height of the Schottky barrier.

4. (a) An npn silicon bipolar transistor at \( T = 300 \) K has uniform dopings of \( N_E = 10^{19} \text{cm}^{-3} \), \( N_B = 10^{17} \text{ cm}^{-3} \) and \( N_C = 7 \times 10^{15} \) cm\(^{-3}\). The transistor is operating in the inverse-active mode with \( V_{BE} = -2 \) V and \( V_{BC} = 0.565 \) V. Sketch the minority carrier distribution through the device. Calculate the thermal equilibrium minority carrier concentrations in the emitter, base and collector. If the metallurgical base width is 1.2 \( \mu \)m, determine the neutral base width.

(b) Consider a uniformly doped npn bipolar transistor at \( T = 300 \) K with the following parameters:

\[
\begin{align*}
    N_E &= 10^{18} \text{cm}^{-3} \\
    D_E &= 8 \text{ cm}^2/\text{s} \\
    \tau_{EO} &= 10^{-8} \text{s} \\
    x_E &= 0.8 \mu\text{m} \\
    V_{BE} &= 0.6 \text{ V} \\
    N_B &= 5 \times 10^{16} \text{cm}^{-3} \\
    D_B &= 15 \text{ cm}^2/\text{s} \\
    \tau_{BO} &= 5 \times 10^{-8} \text{s} \\
    x_B &= 0.7 \mu\text{m} \\
    V_{CE} &= 5 \text{ V} \\
    N_C &= 10^{15} \text{cm}^{-3} \\
    D_C &= 12 \text{ cm}^2/\text{s} \\
    \tau_{CO} &= 10^{-7} \text{s}
\end{align*}
\]

Calculate the currents \( J_{BE}, J_{PE} \) and \( J_{BC} \). The symbols have their usual meanings.

Contd ......... P/3
There are **FOUR** questions in this section. Answer any **THREE**.

The symbols have their usual meanings.

5. (a) A semiconductor material has electron and hole mobilities $\mu_n$ and $\mu_p$, respectively. When the conductivity is considered as a function of the hole concentration $p_0$, (i) show that the minimum value of conductivity, $\sigma_{\text{min}}$, can be written as

$$\sigma_{\text{min}} = \frac{2\sigma_i (\mu_n \mu_p)^{\frac{3}{2}}}{\mu_n + \mu_p}$$

where $\sigma_i$ is the intrinsic conductivity, and (ii) find the corresponding hole concentration.

(b) The electron concentration in silicon at $T = 300$ K is given by $n(x) = 10^{16} \exp\left(-\frac{x}{18}\right)$ cm$^{-3}$, where $x$ is measured in $\mu$m and is limited to $0 \leq x \leq 25 \mu$m. The electron diffusion coefficient is $D_n = 25$ cm$^2$/sec and the electron mobility is 960 cm$^2$/V-sec. The total electron current density through the semiconductor is constant and equal to $-400$ A/cm$^2$. The electron current has both drift and diffusion current components. Determine the electric field as a function of $x$. Also, find the value of the electric field at the middle of the semiconductor.

6. (a) Two semiconductor materials have exactly the same properties except that material 'A' has a bandgap of 1.0 eV and material 'B' has a bandgap of 1.2 eV. Determine the ratio of intrinsic carrier concentration of material 'A' to that of material 'B' for $T = 300$ K.

(b) The electron concentration in silicon decreases linearly from $10^{16}$ cm$^{-3}$ to $10^{15}$ cm$^{-3}$ over a distance of 0.1 cm. Calculate the electron diffusion current. (Given, $A = 0.05$ cm$^2$ and $D_n = 25$ cm$^2$/sec)

(c) An n-type silicon sample with a donor doping density of $10^{16}$/cm$^3$ is steadily illuminated with light producing excess carriers at a generation rate of $10^{21}$ cm$^{-3}$s$^{-1}$. Find the separation of the quasi-Fermi levels and the change of conductivity upon shining light on the given sample. (Assume, $\tau_n = \tau_p = 10^{-6}$ sec, $\mu_n = 1350$ cm$^2$/V-sec and $\mu_p = 480$ cm$^2$/V-sec)

7. An n$^+$-polysilicon gate n-channel MOS transistor is made on a p-type Si substrate with a doping density of $5 \times 10^{15}$ cm$^{-3}$. The SiO$_2$ thickness is $10^{-6}$ cm and the effective interface charge is $4 \times 10^{10}$ q/cm$^2$. Given that $\phi_{\text{ms}} = -0.95$ V, find—

(i) Maximum width of the depletion region,

(ii) Flat-band voltage,

(iii) Threshold voltage,

(iv) Minimum capacitance,

(v) The channel width such that $I_{D\text{(sat)}} = 4$ mA for $V_{GS} = 5$ V. (Assume, $L = 1.25$ $\mu$m and $\mu_n = 650$ cm$^2$/V-sec) and (vi) the substrate bias that will change the threshold voltage to 0.45 V.

Contd ............ P/4
8. (a) The high frequency C-V curve of a MOS capacitor is shown in Fig. for Q. 8(a). The area of the device is $2 \times 10^{-3} \text{ cm}^2$ and $\phi_m = -0.5 \text{ V}$. The oxide is $\text{SiO}_2$ and the semiconductor is silicon with a doping density of $2 \times 10^{16} \text{ cm}^{-3}$.

(i) Is the semiconductor n or p-type?

(ii) What is oxide thickness?

(iii) What is the effective interface charge density

and (iv) determine the flat-band capacitance.

(b) The experimental characteristic of an ideal n-channel MOSFET biased in the saturation region is shown in Fig. for Q. 8(b). If $W/L = 10$, and the oxide thickness is $425 \times 10^{-8} \text{ cm}$, determine

(i) the threshold voltage and

(ii) the mobility
SECTION – A

There are FOUR questions in this section. Answer any THREE.

Symbols have their usual meanings. Semi-log papers are to be provided.

1. (a) (i) For the armature controlled dc motor and load shown in Fig. for Q. 1(a)(i), find the simplified block diagram.

![Block Diagram](image)

(ii) Find the transfer function \( T(s) = \frac{Y(s)}{X(s)} \) using block diagram reduction method for the Fig. for Q. 1(a)(ii).

![Block Diagram Reduction](image)

(b) State Mason’s rule. Find the transfer function \( T(s) = \frac{Y(s)}{X(s)} \) from the signal flow graph shown in Fig. for Q. 1(b) using Mason’s rule.

![Signal Flow Graph](image)
2. (a) Write down the state equations and output equation for electrical system shown in Fig. for Q. 2(a). Consider state variables $x_1 = v_c$ and $x_2 = i_2$.

(b) (i) Derive the state equations and output equation for the block diagram representation given in Fig. for Q. 2(b)(i).

(ii) Find the state-space representation in phase-variable form for the transfer function of the system shown in Fig. for Q. 2(b)(ii).

3. (a) (i) Compose the under-damped, critically-damped and over damped systems in terms of pole locations and damping ratio. Among these systems which one is better and why?

(ii) Neatly draw a step response for the case of an under-damped system indicating transient response specifications, such as delay time, peak time, maximum overshoot and settling time.

(b) (i) For a second order system with transfer function $T(s) = \frac{3}{s^2 + 2s + 9}$, find natural oscillation frequency, damped oscillation frequency, damping ratio, peak time, settling time, percentage overshoot and system gain.

(ii) Consider a second order system with a pole located at $A : -3 + j4$. If the pole is moved to the location $B: -5+j4$, what will be the effect on the time domain characteristics, such as peak time, settling time and percentage overshoot.
4. (a) Consider the following unity feedback system with
\[ G(s) = \frac{k}{(s+1)(s+2)(s+3)} \]
Show that the point \(-0.866 + j1.69\) lies on the root locus.
(b) For the unity feedback system, where
\[ G(s) = \frac{k(s-1)(s-2)}{s(s+1)} \]
Sketch the root locus and find the following
(i) The breakaway and break-in points
(ii) The jω-axis crossing
(iii) The range of gain to keep the system stable.

SECTION – B

There are FOUR questions in this section. Answer any THREE.
Attach constant M & N Circles Chart with your answer script (if any).
Attach Bode plots (on Semi-log papers) with your script (if any).

5. (a) When will an entire row of Zeros appear in a Routh table? What are the even and odd polynomials?
(b) 'Even polynomials of s only have roots that are symmetrical about the origin.' — Explain briefly with a diagram.
(c) For the system shown in Fig. for Q. No. 5(c), find the following by using the Routh-Hurwitz criterion:
(i) Ranges/values of K for stability, instability and marginal stability, and corresponding numbers of poles on left-half-plane, right-half-plane, jω-axis.
(ii) Frequency of oscillation when the system is marginally stable.

6. (a) A robot tool with a unity negative feedback control system is designed to have the following forward transfer function:
\[ G(s) = \frac{500(s+1)}{s(s+5)(s+7)} \]
Calculate the steady-state errors of the tool for unit step, unit ramp (slope = 1) and a parabolic inputs.
(b) A unity negative feedback control system with \( G(s) = \frac{k(s+6)}{(s+2)(s+3)(s+5)} \) is operating with a closed-loop dominant-pole damping ratio of 0.707. Design a PD controller so that the settling time is reduced by a factor of 2. Compare the steady-state and transient performance of the uncompensated and compensated systems. Describe any problem with your design. (Given initial operating point = \(-2.32 + j2.32\))
7. (a) For the system of Fig. for Q. No. 7(a), do the following:

(i) Plot the Bode magnitude and phase plots.

(ii) Find the phase margin and damping ratio, if \( k = 40 \) (assume, a 2nd-order approximation is valid)

(b) Utilizing the Nyquist-criterion, find the range of \( K \) for stability for the system shown in Fig. for Q. No. 7(b).

8. (a) The forward transfer function of a unity negative feedback control system is given by,

\[
G(s) = \frac{8000}{(s+5)(s+20)(s+50)}
\]

Plot (on Semi-log papers) the closed-loop log-magnitude and phase frequency response curves using the constant M and N circles chart (see attached with the question paper). Attach the chart along with the resultant closed-loop frequency response curves with your answer script.

(b) For the position control system shown in Fig. for Q. No. 8(b), \( K = 583.9 \) yields a 9.5% overshoot in the transient response for a step input. Use frequency response method to design a log compensator to yield a 10-fold improvement in steady-state error over the uncompensated system, while keeping the overshoot at 9.5%.
Constant M-Circles and Constant N-Circles
SECTION - A

There are FOUR questions in this section. Answer any THREE.

1. (a) A motor and generator are set up to drive a load as shown in Fig. for Q. 1(a). If the generator output voltage is \( e_g(t) = k_i f(t) \), where \( i_f(t) \) is the generator's field current, find the transfer function \( G(s) = \frac{\theta_f(s)}{E_i(s)} \). For the generator, \( k_f = 2\Omega \). For the motor, \( k_t = 1 \) N-m/A, and \( k_b = 1 \) V-s/rad.

(b) Find the transfer function \( T(s) \) using block diagram reduction method for the system shown in Fig. for Q. 1(b).

(c) State Mason's rule. Find the transfer function \( T(s) = \frac{C(s)}{R(s)} \) from the following signal flow graph using Mason's rule as shown in Fig. for Q. 1(c).

Contd ........... P/2
2. (a) Find the state-space representation of the electrical network in matrix form shown in Fig. for Q. 2(a). The output is \( v_0(t) \).

(b) Given the simplified block diagram of a HelpMate transport robot’s bearing angle control system as shown in Fig. for Q. 2(b), derive the state equations and output equation, where the input is the desired bearing angle, the output is the actual bearing angle, and the actual wheel position and actual bearing angle are among the state variables.

(c) Find the state-space representation in observer canonical form for the transfer function
\[
G(s) = \frac{s^3 + 2s^2 + 7s + 1}{s^4 + 3s^3 + 5s^2 + 6s + 4}
\]. Also, draw the signal flow graph.

3. (a) Find the transfer function of a second order system that yields a 12.3% overshoot and a settling time of 1 sec.

(b) For a second-order system with specifications \( T_s = 7 \) seconds and \( T_p = 3 \) seconds, find the output response to a unit step input.

(c) For the negative unity feedback system, where \( G(s) = \frac{k(s+10)(s+20)}{(s+30)(s^2 - 20s + 200)} \), find the range of gain \( k \) that makes the system stable.

4. (a) For the negative unity feedback system, where \( G(s) = \frac{k(s+2)(s+3)}{(s^2 + 2s + 2)(s+4)(s+5)(s+6)} \),

(i) Sketch the root locus.

(ii) Find the jω-axis crossing and the gain \( K \) at the crossing.

(iii) Find all break away and break-in points.

(iv) Find angles of departure from the complex poles.

(b) What rules for plotting the root locus are the same whether the system is a positive or a negative feedback system?
SECTION B

There are FOUR questions in this section. Answer any THREE.

Attach Bode plots (on Semi-log papers) with your answer script (if any).

5. (a) Find the value of K in the system of Fig. for Q. No. 5(a) that will place the closed-loop poles at the X marks shown in the jω-σ plane.

(b) The transfer function of a torque-controlled crane hoisting a load with a fixed rope length is

\[ p(s) = \frac{X_T(s)}{F_T(s)} = \frac{1}{m_T s^2 + \omega_0^2} \]

where \( \omega_0 = \sqrt{\frac{E}{L}} \), \( L \) = the rope length, \( m_T \) = the mass of the car, \( a \) = the combined rope and car mass, \( f_T \) = the force input applied to the car, and \( x_T \) = the resulting rope displacement. If the system is controlled in a feedback configuration by placing it in a loop as shown in the Fig. for Q. No. 5(b), with \( K > 0 \), where will the closed-loop poles be located?

6. (a) What are the restrictions on the feed-forward transfer function \( G_2(s) \) in the system of Fig. for Q. No. 6(a) to obtain zero steady-state error for step inputs, if:

(i) \( G_1(s) \) is a Type 0 transfer function
(ii) \( G_1(s) \) is a Type 1 transfer function
(iii) \( G_1(s) \) is a Type 2 transfer function

Contd ........... P/4
8. (a) (i) Draw the Bode log-magnitude and phase plots for a unity negative feedback system with forward transfer function \( G(s) = \frac{k(s+3)}{(s+2)(s^2+2s+25)} \). (Use semi-log papers and attach them with answer script).

(ii) Determine range of K for which the system is stable.

(b) Find the expressions of steady-state errors for different types of systems in response to a parabolic input.
(c) For the position control system shown in Fig. for Q. No. 8(c), $K = 583.9$ yields a 9.5% overshoot in the transient response for a step input. Use frequency response method to design a compensator to yield a 10-fold improvement in steady-state error over the uncompensated system, while keeping the overshoot at 9.5%.
SECTION - A
There are FOUR questions in this section. Answer any THREE.
Symbols have their usual meaning.

1. (a) Explain the atomic model of diffusion. Explain the usage of SIMS in fabrication technology. (15+10)
   (b) Calculate how much depth arsenic will diffuse in silicon in 1 hr and 2 hrs respectively, at 1000°C. [Use, \( D_0 = 0.066 \text{cm}^2/\text{s} \), \( E_a = 3.44 \text{eV} \) and \( \sqrt{Dt} \) ] (10)

2. (a) Describe, with neat diagram, the operation, advantages and disadvantages of horizontal and vertical furnaces used for any thermal processes. (15)
   (b) Discuss the various applications of oxides (e.g. SiO₂). What do you mean by 'linear growth regime' and 'diffusion limited regime' in oxide growths? (8+12)

3. (a) Explain how Boron impurities activate through rapid thermal annealing in silicon. In this respect, also discuss how the same process (RTA) improves p-type doping in GaN-crystals leading to the invention of blue LEDs. (8+9)
   (b) Compare and comment on dry and wet etching techniques. How does the presence of plasma improve etching rates? (9+9)

4. (a) A water is implanted with silicon at an energy of 150 KeV and a dose of \(10^{13} \text{cm}^{-2} \). The water is thick GaAs. Plot the extent of implantation from the surface of the wafer in the range of 900Å to 1800 Å with 100Å steps. At what depth would the concentration be highest? Use the chart in Fig. for Q. 4(a). (20)
   (b) Briefly comment on the relative advantages and disadvantages of PLD and CVD deposition techniques. Also explain what do you understand by maskless lithography. (9+6)
5. (a) What is epitaxy? Compare between MOCVD and MBE techniques of epitaxy. 
(b) Compare between CZ and float-zone techniques of crystal growth. Explain float-zone method of crystal growth with proper diagrams.

6. (a) Why wire-bonding is important? Discuss the wire-bonding techniques involving gold and aluminum.
(b) Explain, in detail, the contamination sources that may cause havoc in semiconductor industry.
Discuss the methods that are routinely undertaken in a cleanroom environment to control such contaminants.

7. (a) Explain the differences in absorption, physisorption and chemisorption. Discuss how these processes play a crucial role in CVD process.
(b) Draw and explain the Ten-Steps of conventional Lithography.

8. Write short notes on the following:
(a) Metallization
(b) Two-color pyrometry
(c) E-beam lithography
(d) Doule-patterning
(e) Implantation damage.
Projected range (solid lines and left axis) and standard deviation (dashed lines and right axis) for (A) n-type, (B) p-type, and (C) other species into a silicon substrate, and (D) n-type and (E) p-type dopants into a GaAs substrate, and several implants into (F) SiO₂ and (G) AZ111 photoresist (data from Gibbons et al.).

\[ \text{Fig. for } \alpha, \gamma(\alpha) \]
SECTION – A

There are FOUR questions in this section. Answer any THREE.
(The questions are of equal value)

1. Consider a phase-angle drive system for a universal motor. A triac is used as the switch controlled by a microcontroller. The control system must meet the following requirements:
   - Generate pulses for the triac
   - Match firing pulse time of the triac in relation with zero crossing of line voltage
   - Variable output voltage achieved by a phase shift of firing pulse
   - Speed measured by a tachometer and A/D converter
   - Protection for the motor when the shaft is blocked
   - Include START and STOP command.

   (i) How many interrupts would you suggest? Why?
   (ii) What subroutines do you propose?
   (iii) Prepare a program state diagram.

2. (a) Present a mathematical analysis of the starting and running torque in a hysteresis motor. What application you perceive for such a motor?
   (b) A small 50 Hz Hysteresis motor possesses 30 poles. The hysteresis loss in the rotor in making one complete turn is 0.8 J. Calculate (i) the hysteresis torque, (ii) the maximum power output before the motor stall, (iii) the rotor losses when the motor is stalled, and (iv) the rotor losses when the motor runs at synchronous speed.
   (c) Show that for a universal motor, for maximum efficiency, constant losses must be equal to those that vary as the square of armature current.

3. (a) Describe the operation of a simple 3-phase unipolar-operated brushless DC motor having optical sensors as position detectors. Draw a diagram showing the switching sequence and rotation of stator’s magnetic field.
   (b) Why is the commutator brushes of a permanent magnet DC motor shifted away from the mechanical neutral axis? — Explain with reference to armature reaction.
   (c) Explain under-commutation or over-commutation with reference to permanent magnet DC motor.

Contd ………. P/2
4. (a) Develop a simplified relationship between the torque developed in a switched reluctance motor (SRM) and the motor inductance. What does this relationship tell us about the basic SRM control strategy?
(b) Explain why current in a switched reluctance motor can be controlled to any desired value at low-speed but not at high speed.
(c) Discuss the torque ripple in an SRM and strategies to reduce it.

SECTION - B
There are FOUR questions in this section. Answer any THREE.

5. (a) With neat diagram, describe the operation of an acycic generator. What are the salient features of an acycic generator and how it differs from a conventional ac or a conventional dc generator?
(b) How a linear ac and a linear dc induction pump work? Describe their operation with neat diagrams.

6. (a) What are the losses in an MHD generator? How the Hall Effect loss in an MHD generator can be reduced? Elaborate with necessary diagrams.
(b) Describe a steam power plant which has an MHD generator in its process.
(c) Classify FUEL CELLS. How an ion membrane FUEL Cell works.

7. (a) Illustrate the following,
   (i) Equivalent circuit of a PV Cell,
   (ii) i-v and p-v characteristics of a p-v cell and
   (iii) maximum power point or peak power point operation of a solar array.
(b) Briefly discuss the components of a P-V system. How a dc-dc converter can be used for maximum power point tracking of a PV system? Explain.

8. (a) Briefly illustrate the prospect of wind energy for electricity generation in Bangladesh.
(b) Write notes on any two of the following,
   (i) Earthing of Wind farms
   (ii) Lighting Protection of Wind farms
   (iii) Power quality of Wind generated electricity
   (iv) Control scheme of a wind electricity generator.
1. (a) An infinite sheet of current with surface current density of \( J_s = J_0 \) exists on the \( z = 0 \) plane in free space. An infinite sheet of perfect conductor is placed at \( z = -\frac{\lambda}{2} \). Find the expressions of the field quantities for plane wave solutions in both \( z > 0 \) and \( z < 0 \) regions.

(b) The transmission line showed in the figure for question 1(b) is a cascade of two coaxial cable of identical length and geometry but different dielectric filling. In the associated Smith Chart, points \( P_1 \) and \( P_2 \) represent the normalized input impedance at \( z = -l \) with respect to the \( z_0 \) and \( z_1 \) values, respectively. The frequency of operation is 10 GHz and \( \varepsilon_r = 4 \) for \(-l \leq z \leq 0\). Find the value of (i) \( \varepsilon_r \) for \(-2l \leq z < -l\), (ii) \( z_1 \), (iii) minimum possible value of \( l \), (iv) \( R_L \) and (v) \( z_{in} \) at \( z = -2l \).

2. (a) A transmission line of characteristic impedance \( z_0 \) is connected to a real load \( R_L \) through a single section tuner of length \( l \) and characteristic impedance \( z_1 \). Make a neat sketch of relative reflection and transmission magnitudes at relevant interfaces. Using the approximation of small reflections, prove that overall reflection co-efficient at \( z = -l \) (assuming that the load is at \( z = 0 \)) as seen by the line is given by:

\[ \Gamma \approx \Gamma_1 + \Gamma_3 e^{-j\pi l / 2} \]

Use this relation to show that \( z_1 = \sqrt{z_0 R_L} \) when \( l = \frac{\lambda}{4} \).

(b) Design a three section binomial transformer to match a 50\( \Omega \) load to a 100\( \Omega \) line. Calculate its bandwidth if \( f_0 = 100 \text{ MHz} \) and \( T_m = 0.05 \).
3. (a) Derive the expression of cut-off frequency of TM<sub>m</sub> mode for propagating surface waves in a grounded dielectric sheet.

(b) Two identical conducting plates, infinitely long along the negative z axis, are placed as shown in the figure for question 3(b). The bottom plate is grounded and the top plate is maintained at a time varying potential \( V_0 \cos(\omega t - kz) \). Find an approximate expression for the potential and the electric field and show that \( \vec{E} \) field is normal to the surface at the top plate.

4. (a) Prove that an arbitrary lossy line will be distortionless if \( R/L = G/C \).

(b) Design a rectangular waveguide with a dielectric filling of \( \varepsilon_{r} = 4 \) so that no frequency smaller than 800 MHz can be supported by it and no more than one mode can be supported for frequencies 800 MHz \( \leq f \leq 1 \) GHz.

(c) Design a single short circuit shunt stub tuner to match a 100 + j50 \( \Omega \) load to a 50 \( \Omega \) line.

SECTION - B

There are FOUR questions in this section. Answer any THREE.

5. (a) The radiation intensity of a lossless antenna is approximated by

\[
U(\theta) = \begin{cases} 
B \cos^2 \theta & 0 \leq \theta \leq \frac{\pi}{2} \\
0 & \frac{\pi}{2} \leq \theta \leq \pi 
\end{cases}
\]

The power radiated by the antenna at a frequency of 10 GHz is 10 W. Find (i) the value of B, (ii) the maximum power density at a distance of 1000 m in W/m\(^2\) and the angle for which this value is achieved, (iii) the exact expression for its directivity and the maximum directivity, (iv) the effective aperture in m\(^2\).

(b) Calculate the vector potential \( \vec{A} \) for an infinitesimal dipole and obtain the far field expression directly from the vector components of the vector potential. Show that maximum directivity of the infinitesimal dipole is 3/2.
6. (a) Determine the electric field intensity at a distance of 10 km from an antenna having a directive gain of 5 dB and radiating a total power of 20 kW.

(b) A one way communication system, operating at a frequency of 100 MHz, uses two identical lossless infinitesimal dipoles as transmitting and receiving antennas. To detect a signal, the power level at the receiver terminals must be at least 1 µW. Each antenna is connected to the transmitter or receiver by a lossless 50 Ω transmission line. Assume that the antennas are polarization matched and so oriented that the directions of maximum radiation intensities coincide. Calculate the minimum amount of power needed to be transmitted by taking the appropriate losses into account.

7. (a) Obtain the general expression of the array factor for an N element linear array.

(b) Suppose it is required to obtain the major lobe at \( \theta = \pi / 3 \) and the first null at \( \theta = 0 \) for a 10 element linear array. What are the required values of \( \beta \) and \( d \) for design of such an array?

(c) Roughly sketch the polar plot of the field intensity due to the array factor clearly showing the positions of the major lobe, the nulls and the approximate positions of minor lobes.

8. (a) A transmission line with characteristic impedance of \( Z_0 \) is supposed to feed a load impedance of \( R + jX \). An engineer proposes a matching technique by using a shunt susceptance of \( jB \) \( \Omega^{-1} \) at the load plane and introducing a quarter wave transformer of characteristic impedance \( Z_I \) between the line and the load. Find the expressions for \( B \) and \( Z_I \) in terms of \( R \), \( X \) and \( Z_0 \).

(b) The expression of electric field for TEM wave mode in a coaxial cable is given by

\[
\vec{E}(\rho, \phi, z) = \hat{\rho} \frac{V_0}{\rho \ln(b_0)} e^{-i k z}
\]

(i) obtain the expression for characteristic impedance.

(ii) obtain the expression for attenuation constant due to conductor loss using the method of perturbation.
The Complete Smith Chart
Black Magic Design
SELECTION – A

There are FOUR questions in this section. Answer any THREE.

1. (a) Show the process sequence of fabricating the following circuit (NMOS inverter with a resistance load) in NEWLL CMOS process. You have the freedom to design the resistance either from polysilicon layer or from the N+diff/P+diff layer.

(b) You have to design a four line gray code to binary code converter in a structured way. The truth table is shown in Fig. for Q. No. 1(b).

(i) Show the schematic diagram of the design using a suitable leaf cell.

(ii) Draw the layout diagram of the leaf cell in such a way that the VDD, GND and the intermediate signals are automatically connected when the leaf cells are butted together.

<table>
<thead>
<tr>
<th>Gray Code</th>
<th>Binary Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>G3 G2 G1 G0 A3 A2 A1 A0</td>
<td></td>
</tr>
<tr>
<td>0 0 0 0 0 0 0 0</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>0 0 0 1 0 0 0 1</td>
<td>0 0 1</td>
</tr>
<tr>
<td>0 0 1 1 0 0 1 0</td>
<td>0 0 1</td>
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<td>0 0 1 0 0 0 1 1</td>
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<td>0 1 1 0 0 1 0 0</td>
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<td>1 1 1</td>
</tr>
<tr>
<td>1 0 0 0 1 1 1 1</td>
<td>1 1 1</td>
</tr>
</tbody>
</table>

Fig. for Q. 1(a)

Fig. for Q. 1(b)

Contd ............... P/2
2. (a) Show transistor level NOR-NOR PLA implementation of a digital circuit which has three output \((Z_1, Z_2\) and \(Z_3\)) as follows:

\[
Z_1 = abc + bc; \quad Z_2 = \bar{a}bc + \bar{b}c; \quad Z_3 = b + \bar{a}bc
\]

(b) (i) Show the circuit diagram of a \(2 \times 2\) SRAM array which uses 6-transistor memory cell as basic storage cell. Clearly show the row select, column select, pre-charge and sense signal in your circuit.

(ii) Explain how the READ and WRITE operations are performed showing the first row and second column cell as an example.

(iii) Explain how sense amplifier reduces the READ time of the cell.

3. (a) Design a 8-bit Carry Select Adder such that the delay becomes minimum. Assume that the delay through one adder cell is 500 pS and the propagation delay through the multiplexer is 250 ps. Derive any equation used in your calculation and show the schematic diagram of the adder circuit. Compare the delay of this adder with that of a ripple carry adder.

(b) (i) Show the schematic diagram of a \(4 \times 4\) bit array multiplier designed in a structured way. Identify the basic cell of the multiplier and explain the operation of the circuit. Show the critical path of the signal which will experience the longest delay.

(ii) Design a general purpose I/O pad having ESD protection circuit. Explain the operation of your circuit.

4. (a) (i) Show the circuit diagram and device cross-sectional diagram of a one transistor trench capacitor DRAM Cell. By showing the timing diagram explain the READ and WRITE operation of the circuit.

(ii) To fully turn on the access MOSFET, word line of the above DRAM is driven to \(V_{DD} + V_{tn}\). The memory bit capacitance \(C_{mbit}\) is 20 fF and a '1' is stored in the capacitance by charging it to full \(V_{DD} = 1\) V. The bit line capacitance is 100 fF and before READ operation the bit line is pre-charged to \(V_{DD}/2\). What voltage will be obtained in the bit line during the read operation?

(b) In the CMOS circuit shown in Fig. for Q. No. 4(b), a bridging fault occurs between line f1 and f2. Explain how you will detect the fault and which test vector will you apply?
5. (a) (i) Show that the threshold voltage of a MOS transistor with body bias $V_{sb}$ can be approximated as $V_t = V_{to} + \gamma \sqrt{V_{sb}}$, where the symbols have their usual meanings.

(ii) When used as a pass transistor, explain why a PMOS transistor passes good '1' and bad '0'. Assume $V_{tp} = -1V$, $V_{DD} = 5V$, $V_{in} (H) = 5V$, $V_{in} (L) = 0V$.

(b) (i) An NMOS inverter with NMOS enhancement load is designed such that the output voltage becomes 0.2V when the input voltage is high (5V). Calculate the aspect ratio of the inverter. The following data are given: $\mu_nC_{ox} = 30 \mu A/V^2$, $V_{to} = 1V$, $V_{DD} = 5V$, $\gamma = 0.5$. Assume, the body of the transistors are connected with ground.

(ii) What would be the output voltage if the input voltage is 0.2V?

6. (a) Show that the dynamic power dissipation of a CMOS inverter varies directly with square of the power supply voltage whereas the delay of the circuit varies inversely with the power supply voltage.

(b) The output of a 3 input NAND gate drives 15 similar NAND gates. Calculate the worst case rise time and fall time of the NAND gate. The following data for the gate are given: $\mu_nC_{ox} = 120 \mu A/V^2$, $\mu_pC_{ox} = 40 \mu A/V^2$, $V_{ton} = 1V$, $V_{top} = -1V$, $V_{DD} = 5V$, $\gamma = 0.5$, $w_n = 10 \mu m$, $w_p = 20 \mu m$, $L_n = L_p = 1 \mu m$, source/drain length = 5um, gate oxide capacitance = 20 fF/m$^2$, source drain diffusion capacitance = 10 fF/m$^2$. Assume the body of NMOS transistor is connected with GND and the body of PMOS transistor is connected with $V_{DD}$.

7. (a) What is latch-up? A CMOS integrated circuit is designed on a PWELL process. Show the possible latch-up circuit and explain how latch-up could be induced. Explain the fabrication measures and the design measures that should be taken to prevent latch-up in CMOS circuits.

(b) An inverter buffer chain is designed in a 5V CMOS process so that each stage is four times larger than the previous stage. The first stage of the chain is designed with a minimum size inverter gate, which has an input ($C_{in}$) and output ($C_{out}$) capacitances of 0.1 pF and 0.2 pF, respectively. The chain drives 2000 minimum sized basic gates. Calculate the delay through the chain. Assume $\beta_n = \beta_p = 2 \times 10^{-5} A/V^2$ for the minimum size inverter.

If $f = 100$ MHz calculate the dynamic power consumed by the buffer chain circuit.
EEE 453

8. (a) A 3 : 2 priority encoder is defined as follows

\[ Y_0 = \overline{A}_0 \cdot (A_1 + \overline{A}_2); \quad Y_1 = \overline{A}_0 \cdot \overline{A}_1 \]  \hspace{1cm} (20)

(i) Sketch the transistor level schematics of the logic functions \( Y_0 \) and \( Y_1 \), each of which is implemented in a single CMOS complex logic gate. Assume that both true and complementary versions of the inputs are available.

(ii) If the above logic functions are to be implemented with worst case equal rise and fall times, determine the relative width of the PMOS transistors with respect to the NMOS transistors for both of the logic gates. Assume \( \mu_n = 3 \mu_p \) and gate length of NMOS and PMOS transistors are equal to the minimum allowable in the process (\( L_n = L_p = L_{\text{min}} \)).

(b) Sketch the transistor level schematic for the logic functions of \( Q_8 \) (a) in (i) pseudo NMOS, (ii) footed dynamic CMOS, and (iii) domino CMOS.  \hspace{1cm} (15)
1. (a) Describe the operation of an SCR with its two transistor model.
(b) Describe the operation of an IGBT as a semiconductor switch.
(c) Briefly differentiate the advantages and disadvantages of a BJT with that of a MOSFET as switch.

2. (a) Describe the operation of a single phase SCR current source inverter operation with emphasis on how the SCRs are commutated.
(b) Draw the inverter circuit showing all switches, diodes sources and connection for obtaining the shown output voltage wave across the resistive load of the Figure for Q 2(b). Also explain the operation of the inverter for one full cycle of the output wave.
(c) Describe the operation of a single phase voltage source full bridge sine PWM inverter with appropriate circuit, gate/base pulses and output voltage wave.

3. (a) Discuss the operation of a three phase full bridge voltage source square wave inverter with Y-connected resistance load. Provide diagrams of inverter circuit, gate/base pulses, line to line and line to neutral voltage of the output of the inverter.
(b) Derive the Fourier series of the line to neutral output voltage waveform of a three phase square wave voltage source inverter with Y-connected resistive load.
4. (a) Describe the operation of a single phase voltage controller of Fig. for Q. No. 4(a) with input voltage, output voltage, input current, output current, SCR voltage for $\alpha = 90^\circ$.

![Image of circuit diagram](image)

(b) Draw and illustrate the operation of a three phase voltage controller ($\alpha = 60^\circ$) with Y connected resistive load. Provide the diagrams of the circuit, input voltages, gate pulse of six SCRs, line to neutral output voltages and line to line output voltages.

**SECTION - B**

There are **FOUR** questions in this Section. Answer any **THREE**.

The figures in the margin indicate full marks.

5. (a) Draw the circuit diagram of a Cuk converter. Deduce the condition for minimum inductance values for this converter.

(b) Consider the dc-dc converter topologies shown in figures below. Comment on the relationship between input and output voltages for each topology.

![Figures for Q. no. 5(b)](image)

6. (a) "For a non-ideal boost converter voltage gain as predicted by ideal voltage gain expression in not attainable" – explain with necessary derivations.

(b) Describe the operation of a push-pull type isolated converter.

(c) Draw the circuit diagram of a SEPIC converter and the component currents during continuous conduction mode. What make the SEPIC converter superior over buck-boost and Cuk converters.

Contd .......... P/3
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

Sub: EEE 455 (Compound Semiconductor and Hetero-Junction Devices)

Full Marks : 210 Time : 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION - A

There are FOUR questions in this section. Answer any THREE.
Symbols have their usual meanings.

1. (a) Why is lattice constant of semiconductor important for heterostructured device fabrication? Discuss the effect of biaxial strain on valance band structure and conduction mechanism.

(b) Compare low field mobility of polar and non-polar semiconductors. How effective temperature of carrier differs to that of lattice temperature? Explain differential negative resistance in some semiconductors.

2. (a) Discuss the effect of InAs and GaAs thin film growth on InP substrates in terms of structure and electronic properties. Estimate the bandgap of In\textsubscript{x}Ga\textsubscript{1-x}As lattice matched to InP. Necessary data are given in Table for Q. 2(a).

<table>
<thead>
<tr>
<th>Materials</th>
<th>lattice constant (Å)</th>
<th>Eg (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs</td>
<td>5.6533</td>
<td>1.43</td>
</tr>
<tr>
<td>InAs</td>
<td>6.0584</td>
<td>0.36</td>
</tr>
<tr>
<td>InP</td>
<td>5.8686</td>
<td>1.35</td>
</tr>
</tbody>
</table>

(b) Why are optical absorption of amorphous, crystalline and polycrystalline semiconductors different? Explain experimental procedure to estimate bandgap of direct/indirect semiconductors.

3. (a) What is superlattice structure? How is it possible to modify opto-electronic properties in such structures? Explain with necessary diagrams. Discuss the advantages and disadvantages of graded heterostructures.

(b) What are the assumptions made in Anderson's model? Determine $\Delta E_c$, $\Delta E_v$ and $V_{bi}$ for an ideal n-Ge/p-GaAs heterojunction.

Given that:

- Electron affinity of Ge = 4.13 eV
- Electron affinity of GaAs = 4.07 eV
- $n_i = 2.5 \times 10^{13}$ /cm$^3$ (for Ge)
- $N_d = 1.2 \times 10^{16}$ /cm$^3$
- $N_a = 1 \times 10^{16}$ /cm$^3$  

Contd ......... P/2
4. (a) Write the conditions necessary to form rectifying contacts in metal-semiconductor junctions. What is Fermi level pinning? Explain a method to estimate doping concentration from Schottky junction. 

(b) Sketch the energy-band diagram of an abrupt Al$_{0.3}$Ga$_{0.7}$As/GaAs heterojunction for:

(i) N$^+$ AlGaAs, intrinsic GaAs

(ii) P$^+$-AlGaAs, n GaAs

Assume $E_g = 1.85$ eV for Al$_{0.3}$Ga$_{0.7}$As and $\Delta E_c = \frac{2}{3} \Delta E_g$ 

(Make necessary assumptions if needed).

5. (a) Using Gummel-Poon model, derive the equation for the electron current density in the base of an npn transistor biased in the active mode. What is emitter Gummel number?

(b) In the Ebers-Moll model, assume $V_T = 0.98$, $I_{E} = 10^{-13}$ A and $I_{CS} = 5 \times 10^{-13}$ A at $T = 300 \, ^\circ$K. Calculate $I_C$ for $V_{CS} = 2$ V and $V_{BE} = 0.4$ V.

6. (a) Draw the small-signal equivalent circuit of a JFET and derive the expression for maximum cut-off frequency considering simplified equivalent circuit.

(b) Calculate the small signal output resistance at the drain terminal due to channel length modulation effects. Consider an n-channel depletion mode GaAs JFET with a channel doping of $N_d = 3 \times 10^{15}$ cm$^{-3}$. Calculate $r_{ds}$ for the case when $V_{DS}$ changes from $V_{DS} (1) = V_{DS} (sat) + 2.0$ to $V_{DS} (2) = V_{DS} (sat) + 2.5$. Assume $L = 10 \, \mu$m and $I_{P1} = 4.0$ mA.

7. (a) Draw the energy band diagrams for zero, negative and positive voltage biases in a AlGaAs-GaAs HEMT. (Only energy band diagrams are required).

(b) With quantum well structure describe the operation of HEMT.

(c) In a HEMT structure, consider an abrupt n-Al$_{0.3}$Ga$_{0.7}$As - intrinsic GaAs heterojunction. The n-AlGaAs is doped to $N_d = 2 \times 10^{18}$ cm$^{-3}$. The Schottky barrier weight is 0.85 V and the heterojunction conduction band edge discontinuity is 0.22 eV. Determine the thickness of AlGaAs layer so that $V_{OFF} = -0.3$ V. The relative dielectric constant of AlGaAs layer is 12.2 and GaAs is 13.1.

8. (a) What is bandgap narrowing? Discuss the effects of high emitter doping on the characteristics of Bipolar Junction Transistor.

(b) The following currents are measured in a uniformly doped npn bipolar transistor:

\[
\begin{align*}
I_{nE} & = 1.20 \, mA \\
I_{pE} & = 0.10 \, mA \\
I_{nC} & = 1.18 \, mA \\
I_{R} & = 0.20 \, mA \\
I_{C} & = 0.001 \, mA \\
I_{PC} & = 0.001 \, mA
\end{align*}
\]

Determine (i) $\alpha$ (ii) $\beta$ (iii) $\alpha_T$ (iv) $\delta$ and (v) $\beta$, where the symbols have their usual meaning.
SECTION – A

There are FOUR questions in this section. Answer any THREE.

1. (a) Considering environmental impact discuss the criterion for selection of plant location of a steam power plant.
   (b) With a block diagram explain the operating principle of a coal fired steam power plant.

2. (a) Explain with a neat diagram how the steam flow and fuel input are controlled when real power varies in a steam power plant.
   (b) How does the reactive power (VAR) transfer take place between two alternators operating in parallel?

3. (a) With a block diagram explain the operation of a closed cycle gas turbine power plant. What are its advantages and disadvantages?
   (b) Explain combined cycle power plant operation with a layout diagram.

4. (a) What are the two criteria for capacity scheduling? Prepare a plan for capacity scheduling of 7 units with different thermal efficiency.
   (b) Explain briefly the functions of superheater, reheater and economizer in a steam power plant and show their locations in the layout of the plant.

SECTION – B

There are FOUR questions in this section. Answer any THREE.

5. (a) What are the different types of hydraulic turbines? Explain with a neat sketch the operation of Kaplan Turbine.
   (b) A hydro-electric power plant is supplied from a water reservoir of capacity $3 \times 10^7 \text{ m}^3$ at a head of 140 m. Determine the total energy available in kWh, if the overall efficiency is 85%. Density of water is 1000 kg/m$^3$.

Contd ........... P/2
6. (a) What are the different processes of initiation of nuclear reaction? Explain the Fission Reaction of Uranium-235.
(b) Explain with a diagram, the operating principle of a Sodium-Graphite Reactor (SGR).

7. (a) What are the components of a general rate form of electricity pricing? Discuss how the rates are adjusted?
(b) A residential consumer living in Dhaka city having single-phase connection uses 330 units of electricity per month. Assume that the present unit charges for first, second, third, fourth, fifth and sixth steps are Tk. 3.53, Tk. 5.01, Tk. 5.19, Tk. 5.42, Tk. 8.51 and Tk. 9.93 respectively. Sanctioned load of the consumer is 3 kW. Demand charge and service charges are Tk. 15.00 per kW of sanctioned load and Tk. 10.00 per month respectively. Minimum charge is Tk. 115.00 per month. The value added tax (VAT) is 5% of the bill. Calculate the monthly electricity bill of the consumer.

8. (a) What are the different methods of electrical load forecasting? Explain any two methods.
(b) What are the two methods of calculating 'C' charge of electricity tariff?
There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) Describe an ARMA(p,q) model based spectral estimation technique of a random process \( x(n) \) from its noisy observations \( y(n) = x(n) + v(n) \), where \( v(n) \) is a zero-mean white noise un-correlated with \( x(n) \). Assume that the model order and additive noise power \( \sigma_v^2 \) are known and the input to the model is a zero-mean white noise \( u(n) \) of variance \( \sigma_u^2 \).

   \[
   \sigma_v^2 = \begin{cases} 
   18 & \text{marks} \\
   \end{cases}
   \]

   (b) Suppose that you are given the autocorrelation values \( r_y(0) = 2 \), \( r_y(1) = \frac{\sqrt{3}}{2} \), and \( r_y(2) = 0.5 \) for a process consisting of a single sinusoid in additive white noise. Using the MUSIC algorithm estimate the frequency of the sinusoid. Also determine its power and the variance of the additive noise.

   \[
   \sigma_v^2 = \begin{cases} 
   17 & \text{marks} \\
   \end{cases}
   \]

2. (a) Explain the conceptual difference between STFT and CWT using the filterbank approach.

   (b) Show that the two level wavelet expansion coefficients are related as

   \[
   c_{j+1}(k) = \sum_m c_j(m) h_0(k - 2m) + \sum_m d_j(m) h_1 (k - 2m)
   \]

   where notations have their usual meanings. Also show the multirate implementation of the above interscale relationship of the wavelet transform coefficients.

   (c) A noisy frame of a speech signal \( s(n) \) is given by

   \[
   y(n) = s(n) + v(n)
   \]

   where \( v(n) \) is a zero-mean white noise. Describe the VisuShrink wavelet shrinkage denoising method for estimating \( s(n) \) from \( y(n) \).

   \[
   \sigma_v^2 = \begin{cases} 
   10 & \text{marks} \\
   15 & \text{marks} \\
   \end{cases}
   \]

3. (a) Show that the minimum variance spectrum estimate of a zero-mean WSS random process \( x(n) \) is

   \[
   \hat{S}_x^e(\omega) = \frac{P + 1}{e^{H} \hat{R}_x^{-1} e}
   \]

   where \( \hat{R}_x \) is the autocorrelation function of \( x(n) \), \( P \) is the order of the optimum filter and

   \[
   e = [1, e^{j \omega}, e^{2j \omega}, \ldots, e^{Pj \omega}]^T.
   \]

   (b) (i) What modifications were made to the Bartlett method to obtain the Welch estimate of power spectrum?

   (ii) Describe the Welch method of spectrum estimation of a zero-mean WSS random process \( x(n) \) and then comment on its performance in terms of mean, variance and frequency resolution.

   \[
   \sigma_v^2 = \begin{cases} 
   17 & \text{marks} \\
   2 & \text{marks} \\
   16 & \text{marks} \\
   \end{cases}
   \]
4. (a) What is an Lth band filter? Show that for an Lth band filter with frequency response function $H(e^{j\omega})$, 

$$ \sum_{k=0}^{L-1} H_k e^{j(\omega - \frac{2\pi k}{L})} = 1. $$

What is the impulse response $h_{LP}(n)$ of an ideal lowpass linear phase Lth band filter with a cutoff at $\pi/L$?

(b) Show that the structure of Fig. for Q. 4(b) is alias-free, and determine the overall transfer function $T(z) = \frac{Y(z)}{X(z)}$ in terms of $H_0(z)$ and $H_1(z)$. Also determine the expression for $T(z)$ if $H_0(z^2) = \frac{1}{2} [H(z) + H(-z)]$ and $H_1(z^2) = \frac{1}{2} z [H(z) - H(-z)]$.

(b) ![Diagram for Q. 4(b)]

5. (a) Explain the following terms in the context of linear adaptive filter: (i) rate of convergence, (ii) misadjustment, (iii) tracking, and (iv) robustness.

(b) Draw the schematic diagrams of adaptive filters applicable for (i) system identification (ii) inverse modeling (iii) prediction and (iv) interference cancellation.

(c) Consider the schematic diagram of a linear optimum filter as shown in Fig. for Q. 5(c). Determine the coefficients of the Wiener filter that reshapes the input signal $x(n)$ to match the desire signal $d(n)$.

(c) ![Diagram for Q. 5(c)]

Contd .......... P/3
6. (a) Consider a two-tap Wiener filter with the following statistics:

\[ E[d^2(n)] = 10, \quad R = \begin{bmatrix} 1 & 0.5 & 0.25 \\ 0.5 & 1 & 0.5 \\ 0.25 & 0.5 & 1 \end{bmatrix}, \quad P = \begin{bmatrix} 3 \\ 1 \\ 0 \end{bmatrix} \]

(i) Evaluate the tap weights of the Wiener filter.

(ii) What is the minimum mean-square error produced by the Wiener filter.

(b) Discuss the effect of eigenvalue spread on the convergence of the steepest-descent algorithm. Show that the optimum value of the step-size parameter of the steepest-descent algorithm is

\[ \mu_{\text{opt}} = \frac{1}{\lambda_{\text{min}} + \lambda_{\text{max}}} \]

where, \(\lambda_{\text{min}}\) and \(\lambda_{\text{max}}\) are the minimum and maximum eigenvalues of the correlation matrix \(R\), respectively.

(c) Consider a Wiener filtering problem characterized by the following parameters:

\[ R = \begin{bmatrix} 1 & 0.8 \\ 0.8 & 1 \end{bmatrix} \quad \text{and} \quad P = \begin{bmatrix} 2 \\ 1 \end{bmatrix} \]

(i) Find the range of step-size parameter, \(\mu\), that ensures convergence of the steepest-descent algorithm.

(ii) Using a suitable value of \(\mu\), perform two recursions for computing the tap-weight vector \(W(r)\). Assume initial values \(W_1(0) = W_2(0) = 0\).

7. (a) Formulate the LMS algorithm for a one-step-ahead N-step linear predictor, i.e., a filter that predicts \(x(n)\) based on a linear combination of its previous samples, \(x(n-1), x(n-2), \ldots, x(n-N)\).

(b) The LMS algorithm is used to adapt an adaptive filter with tap-weight vector \(W(n)\). Define \(\tilde{V}(n) = E(W(n) - W_o)\), where \(E[\cdot]\) denotes statistical expectation and \(W_o\) is the optimal value of the filter tap-weight vector. Show that if the step-size parameter, \(\mu\), is properly selected, \(\tilde{V}(n)\) will approach zero, as \(n\) increases. Does the convergence of \(\tilde{V}(n)\) guarantee the convergence of the LMS algorithm?

(c) Consider the least-square cost function

\[ J(n) = \sum_{k=1}^{n} e_n^2(k) \lambda^{n-k} \]

Use this cost function to derive the RLS algorithm.

8. (a) Consider two different ways to cascading a decimator with an interpolator as shown in Fig. for Q. 8(a). Show that the outputs of the two configurations are different, hence, in general, the two systems are not identical.
(b) Consider an arbitrary digital filter with transfer function

\[ H(z) = \sum_{n=-\infty}^{\infty} h(n) z^{-n} \]

Perform a two-component polyphase decomposition of \( H(z) \) by grouping the even-numbered samples \( h_0(n) = h(2n) \) and the odd-numbered samples \( h_1(n) = h(2n + 1) \). Show that \( H(z) \) can be expressed as

\[ H(z) = H_0(z^2) + z^{-1} H_1(z^2) \]

and determine \( H_0(z) \) and \( H_1(z) \).

(c) Determine a two-stage decimation for the following specifications

\[ D = 100 \quad \text{Input sampling rate: } 10,000 \text{ Hz} \]
\[ \text{Passband: } 0 < F < 50 \quad \text{ripple: } \delta_1 = 10^{-1}, \delta_2 = 10^{-3} \]
\[ \text{transition band: } 50 \leq F \leq 55 \]
SECTION – A

There are FOUR questions in this section. Answer any THREE.

The questions are of equal value.

1. (a) State the merits and limitations of optical fiber. What are the mechanisms which cause attenuation in a silica fiber? Discuss and show the dependance of attenuation with wavelength. What are the windows suitable for Fiber Optic Communications?

(b) Classify optical fibers and mention their relative merits, demerits and applications.

(c) Discuss the mechanism of pulse dispersion in a fiber and explain how does it limit the propagation length and bit rate.

2. (a) Distinguish between intra-modal and inter-modal dispersion. Derive the expression of the rms pulse width at the output of a single mode fiber due to material dispersion.

(b) Compare the dispersion characteristics of SMF, DSF, NZDSF, DFF and DCF. How dispersion compensation in a fiber optic link is carried out?

(c) A MMF has a core index of 1.56 and cladding index of 1.52 at a wavelength of 1310 nm. The material dispersion coefficient is 16 ps/km-nm at this wavelength. The source is an LED of FWHM linewidth of 10 nm. Determine:

(i) rms pulse width due to material dispersion at 1 km distance;

(ii) rms pulse width due to intermodal dispersion at 1 km distance;

(iii) bandwidth of 10 km of fiber;

(iv) maximum achievable bit rate through 10 km fiber with NRZ linecoding.

3. (a) With a neat schematic, discuss the principle of operation of a electro-optic directional coupler. Explain how a coupler can be used as a (2x2) optical switching element and can be used to develop (4x4) and (8x8) switching blocks.

(b) What are the different types of multiplexers/demultiplexers for WDM? Explain their operation and state their limitations.

(c) What is Kerr effect? Explain the mechanism of self-phase modulation (SPM), cross-phase modulation (XPM) and four wave mixing (FWM). How they impose limitations on a multichannel optical transmission system.

4. A fiber-optic link consists of SMF spans of length 50 km each. The operating wavelength is 1550 nm. The source and photodetectors have following parameters:

Source: SLD, FWHM linewidth = 0.05 nm
Rise time of driver ckt = 10 ns

PD: PIN, Quantum efficiency = 0.65
Rise time of PD = 15 ns
Receiver load resistance = 50 ohm

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EEE 435
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The SMF has a dispersion coefficient of 17 ps/km-nm. The loss coefficient of the fiber is 0.2 dB/km.
The fiber spans are connected through connectors of loss 1 dB each and source to fiber and fiber to detector coupling loss 1.2 dB each. Determine:

(i) System rise time for a fiber link of length 250 km;
(ii) Maximum allowable bit rate for 250 km transmission length;
(iii) If the required SNR is 20 dB, and the LPF of the receiver has a bandwidth equal to bit rate, the required received power and the transmitting laser power. Consider thermal noise limited operation of the receiver with noise temperature 300°K. Assume any missing data (if required).

SECTION – B

There are FOUR questions in this section. Answer any THREE.

The figures in the margin indicate full marks.

5. (a) Why do lasers must operate away from thermal equilibrium? State necessary conditions for laser operation.

(b) Show the band diagram, index profile and mode profile of a double heterostructure semiconductor laser. How do the double heterostructure and fiber like index profile benefit the semiconductor laser?

(c) Draw the typical input-output characteristics and spectral characteristics of an injection laser diode (ILD) and an LED.

Compare and contrast the applications of laser with LED in context of optical fiber communication.

6. (a) What are the rare-earth elements for doped fiber amplifiers? Why Erbium is chosen for such amplifiers as rare-earth element? Briefly explain the pumping schemes of EDFA and show its gain spectrum.

(b) Derive the expression of Noise Figure \( F_n \) for an optical amplifier and show that \( F_n > 3 \text{ dB} \) for a practical amplifier.

(c) With necessary figures explain how the limitations in PN PD are mitigated in PIN PD and APD.

Derive the expression for the responsivity of an intrinsic photodetector and determine the wavelength at which the quantum efficiency and the responsivity are equal. An APD with multiplication factor of 150 operates at a wavelength of 1.52 μm. Calculate the output current from the device if its quantum efficiency at this wavelength is 62% and \( 10^{10} \) photons of wavelength 1.52 μm are incident upon it per second.

Contd ........... P/3
7. (a) What is receiver sensitivity? Show that the receiver sensitivity for an APD receiver is given by

\[ P_r = \frac{Q}{R} \left( q F_A Q \Delta f + \frac{\sigma_T}{M} \right) \]

where the symbols have their usual meanings.

Find the value of \( P_r \) in dBm for a PIN receiver if thermal noise dominates. Consider it as a 1.55 \( \mu \)m receiver with \( R = 0.8 \) A/W and \( \sigma_T = 100 \) nA to achieve a BER of \( 10^{-9} \).

(b) Define the sources of power penalty in transmitter/receiver of optical communication system. Show the block diagram of a phase modulated optical fiber transmission system. Why PSK with differential scheme is promising for next generation optical fiber transmission system?

(c) A silicon photodiode incorporated into an optical fiber receiver working at a wavelength of 1550 nm. When the incident optical power at this wavelength is 2 \( \mu \)W and the quantum efficiency of the device is 60\%, shot noise dominates in the receiver. Determine the SNR in dB at the receiver when the post-detection bandwidth is 100 MHz. If the bit rate is twice the bandwidth, also calculate the number of photons contained in bit "1". To obtain the same SNR in thermal noise limit, calculate the number of photons required for bit "1". The dark current in the device is negligible and the load is 4 k\( \Omega \) at operating temperature of 25\(^\circ\)C. Assume the noise figure of the following amplifier at this temperature as 2 dB.

8. (a) What are the advantages of using external modulator over direct modulation of semiconductor laser to achieve OOK modulated signal? Differentiate between the structure and operating principle of EOM and EAM.

(b) Briefly explain how OOK signal is generated using MZM.

(c) Write short note on (ANY TWO):

(i) WDM
(ii) SOA
(iii) SONET/SDH

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