

ELECTRICAL ENGINEERING

(Paper I)

Time Allowed : Three Hours
Maximum Marks : 300

QUESTION PAPER SPECIFIC INSTRUCTIONS

(Please read each of the following instructions carefully before attempting questions)

There are EIGHT questions divided in two Sections.

Candidate has to attempt FIVE questions in all.

Question Nos. 1 and 5 are compulsory and out of the remaining, any THREE are to be attempted choosing at least ONE question from each Section.

The number of marks carried by a question/part is indicated against it.

Wherever any assumptions are made for answering a question, they must be clearly indicated.

Word limit in questions, wherever specified, should be adhered to.

SECTION 'A'

1. (a)(i) Determine the time constant for the network shown in Fig. 1:
[Figure: Fig. 1 – 10 V battery in series with switch S and resistor R; beyond R the circuit splits into two parallel branches, resistor 2R and capacitor C, each connected back to the other terminal of the battery] 5
- (a)(ii) For a 3-phase, 400 V, 50 Hz, acb system, write the voltages v_{ac} and v_{bn} in instantaneous form, assuming V_{bc} as a reference phasor. 5
- (a)(iii) The discrete time system is described by $y(n)=x(n)+nx(n-1)$. Check whether this system is causal/time variant. 5
- (b)(i) For the circuit shown in Fig. 2– 1. determine the operating point; 2. find the stability factor. Given: $V_{BE}=0.6$ V, $\beta=50$.
[Figure: Fig. 2 – NPN transistor ($\beta=50$) in voltage-divider bias: $V_{CC}=15$ V; 39 K from V_{CC} to the base, 4.7 K from the base to ground; 4.7 K collector resistor from V_{CC} to the collector; 1 K emitter resistor from emitter to ground; input terminal at the base (other input terminal at ground), output terminal at the collector (other output terminal at ground)] 10
- (b)(ii) Draw the circuit of TTL NAND gate and explain its operation. 5
- (c)(i) Draw a circuit diagram for a single-phase, full-wave, midpoint diode rectifier. Sketch waveforms for source voltage, load voltage, voltage across one diode and source current. Take turns ratio from each secondary to primary as unity. Derive expressions for average and r.m.s. output voltages. 10
- (c)(ii) Why is the air-gap length in a 3-phase induction motor kept as small as is mechanically possible? 5
- (d)(i) Determine the primary constants of a 50-ohm lossless line at 100 MHz, if it has a phase constant of 3.14 rad/m. Sketch its π -type equivalent circuit. Is this a distortionless line? 5
- (d)(ii) Determine the power density spectrum of the noise voltage across the terminals aa' of the circuit shown in Fig. 3:
[Figure: Fig. 3 – Three parallel branches connected between the top line (terminal a) and the bottom line (terminal a'): left branch 1 Ω resistor in series with 1 H inductor; middle branch 1 F capacitor; right branch 2 Ω resistor in series with 1 F capacitor] 10
2. (a)(i) Use Thevenin's theorem to find the current in 4 Ω branch of the network given in Fig. 4:
[Figure: Fig. 4 – Left: 12 V source (+ at top) with current I_1 flowing from its + terminal through a 5 Ω resistor to node X; 12 A current source from the bottom (reference) line up into node X; from node X a current-controlled voltage source $10I_1$ (diamond, + on the node-X side, – on the right) in series with the 4 Ω resistor, then a 1 Ω resistor, then a 20 V source (+ at top, – to the bottom line); the bottom line joins all the negative terminals] 10

- (a)(ii) Obtain the convolution sum $y(n)=x(n)*h(n)$ for $n=2$, using the property $x(n)*\delta(n-n_0)=x(n-n_0)$. Assume $x(n)=(1/2)^n u(n)$, $h(n)=(1/3)^n u(n)$ 10
- (b)(i) Draw the circuit of a Cascode amplifier. Indicate the two configurations of transistors used. Why is this circuit preferred in high-frequency applications? 6
- (b)(ii) For the voltage series feedback amplifier shown in Fig. 5, calculate V_p feedback ratio β , voltage gain without feedback A_V and voltage gain with feedback A_{V_f} :
 [Figure: Fig. 5 – Source V_s in series with the amplifier input; input voltage of the amplifier block A_V is 5 mV (+ at top input terminal); output $V_o=2$ V across a load resistor; feedback network (dashed box) of 19 K and 1 K in series across the output: 19 K from the upper output terminal to a tap, 1 K from the tap to the lower output line; the voltage across the 1 K is V_p connected in series between the source V_s and the lower input terminal of the amplifier] 6
- (b)(iii) Design a decade counter using JK FF's (MOD-10 counter) and draw the timing diagrams. 8
- (c)(i) A d.c. battery having a constant e.m.f. E is charged through a 1-phase full converter. A resistor R limits the battery charging current. Single-phase source voltage is $V_m \sin \omega t$. Sketch waveforms for source voltage, output voltage and charging current. Derive an expression for the average charging current on the assumption that each pair of thyristors is fired continuously in each half-cycle. Take V_r as the voltage drop in each conducting pair. 16
- (c)(ii) In part (i) above, find the value of R in case battery charging current is 5 A, supply voltage is 40 V, 50 Hz; $E=12$ V and $V_r=1$ V. 4
3. (a)(i) Draw the circuit of Darlington emitter follower. Obtain the expressions for overall current gain and input impedance. You can use suitable approximations. Find the above two quantities if $R_B=2$ M Ω , $R_E=1$ k Ω . The device parameters are identical.

$$h_{fe_1}=h_{fe_2}=50, h_{ie_1}=h_{ie_2}=1 \text{ K}, h_{oe_1}=h_{oe_2}=20 \text{ } \mu\text{A/V}$$
 10
- (a)(ii) Design a binary to Gray code converter. 10
- (b)(i) Draw the exact equivalent circuit of a three-phase induction motor. Write clearly what the various parameters represent. 10
- (b)(ii) A three-phase, 400 V, 20 kW, 1440 r.p.m., 50 Hz, star-connected induction motor has rotor leakage impedance of $(0.4+j1.6) \Omega$ per phase. Stator leakage impedance and rotational losses are assumed negligible. If this motor is energized from 120 Hz, 400 V, three-phase source, then calculate– 1. the motor speed at rated load torque; 2. the slip at which maximum torque occurs. 10
- (c)(i) A plane wave has

$$\vec{E}=E_0 \cos(\omega t-\beta x) \hat{y}$$
 and

$$\vec{H}=E_0/\eta \cos(\omega t-\beta x) \hat{z}$$
 in free space, satisfying Maxwell's equations. Find the general expressions for phase constant β and intrinsic impedance η , in terms of medium parameters. Hence, calculate their values at 10 MHz. Identify the direction of propagation and type of polarization. 10
- (c)(ii) A message signal $m(t)$ containing the frequency components 100 Hz, 200 Hz and 400 Hz is applied to an SSB modulator together with a carrier at 100 kHz with only USB retained. The coherent detector employed at the receiver uses a local oscillator that gives a sine wave of frequency 100.02 kHz. 1. Determine the frequency components of detector output. 2. Determine the frequency components of detector output if only LSB is transmitted. 10
4. (a)(i) Determine the resonant frequency of the following circuit (Fig. 6):
 [Figure: Fig. 6 – Series loop: a.c. source, 10 Ω resistor, and a parallel combination of (4 H inductor in series with 1 F capacitor) and a 1 F capacitor] 6

- (a)(ii) The applied a.c. voltage and the resulting current in the following circuit (Fig. 7) are in phase. Determine the coefficient of coupling and the dot polarity of coil PQ:
[Figure: Fig. 7 – Series loop: a.c. source, capacitor $-j12$, resistor 10 , coil $j8$ (dot at its left end, the end nearer the resistor), then coil $j2$ between terminals P (left) and Q (right), back to the source; mutual coupling coefficient K shown between the $j8$ and $j2$ coils; no dot is marked on coil PQ] 4
- (a)(iii) The input (x)-output (y) relationship for the system is given by

$$y(n+2)+3y(n+1)+2y(n)=x(n)$$

$$y(0)=1 \text{ and } y(n)=0 \text{ for } n<0$$

Determine $y(n)$ for unit step sequence input. 10
- (b)(i) Discuss how volts/hertz control for a three-phase induction motor is similar to armature-voltage control of a d.c. motor. 8
- (b)(ii) A 10 kW, 50 Hz, 6-pole polyphase induction motor has a full-load slip of 0.04. If its friction and windage losses are 4% of the output, then compute– 1. rotor ohmic loss at full load; 2. full-load electromagnetic torque; 3. rotor efficiency. 12
- (c)(i) Find the reflection coefficient and VSWR of a 75Ω rf line terminated in each case with a load of (1) short circuit, (2) open circuit, (3) $+j75 \Omega$ and (4) $-j75 \Omega$, and compare the results with those of matched load. What is the shortest length of such a line to produce an input reactance of $+j75 \Omega$, if its propagation constant is $(0+j1.25)$? 7
- (c)(ii) A lossless coaxial cable has the two-conductor diameter ratio of 2.0. Find its inductance, capacitance and Z_0 , assuming a filling of dielectric with $\epsilon_r=2.25$. 3
- (c)(iii) For the probability density function $f(x)=ae^{-4|x|}$ of a random variable X with x ranging between $-\infty$ to $+\infty$, find the distribution function value of a and the probability that X lies between 0 and 1. 6
- (c)(iv) For the angle-modulated signal given by

$$v(t)=5\cos\{\pi \times 10^7 t + 2\sin 500\pi t\}$$

find the maximum phase deviation and frequency deviation, and bandwidth. Is this an FM signal or a PM signal? 4

SECTION 'B'

5. (a)(i) Sketch the following function and find its Laplace transforms:

$$f(t)=r(t)-r(t-3)$$

 $r(t)$ is unit ramp function. 5
- (a)(ii) Sketch the following function and determine the energy or power contained in a signal:

$$x(t)=u(t)+5u(t-1)-6u(t-2)$$
 5
- (a)(iii) In the circuit shown below (Fig. 8), the switch S is in position '1' long enough to establish steady-state conditions and at $t=0$ is switched to position '2'. Draw 's-domain' network:
[Figure: Fig. 8 – Switch S at the top left has its common terminal connected along the top line to a 25Ω resistor in series with a 2 H inductor down the right side to the bottom line; position 1 connects to a 50 V battery (long plate, i.e. + terminal, towards the switch) whose other end goes to the bottom line; position 2 connects to a 100 V battery (drawn with the long plate, i.e. + terminal, towards the bottom line) whose other end goes to the bottom line; switch shown at position 1 with an arrow indicating movement to position 2] 5
- (b)(i) Draw the circuit of an opamp integrator. Sketch the output waveform, when the input is a symmetrical square wave of amplitude $\pm 3 \text{ V}$ and the repetition frequency is 1 kHz . 4
- (b)(ii) Determine the reading of the ideal voltmeter connected across a silicon diode shown in Fig. 9: Assume the forward voltage of diode to be 0.7 V . Find also the current through the diode.
[Figure: Fig. 9 – Series loop: 5 V battery (+ at top) – 1 K resistor – silicon diode D (anode on the resistor side, cathode on the right, i.e. forward biased by the battery) – back along the bottom line (grounded) to the – terminal; ideal voltmeter V connected directly across the diode] 4

- (b)(iii) Realize an Astable Multivibrator using 555 timer to produce a square wave of frequency 1 kHz with duty cycle of 50%. Mention three applications of timer. 7
- (c)(i) In three-phase transformers, discuss the use of tertiary windings. 10
- (c)(ii) A three-phase star-delta transformer has its secondary delta open-circuited. A voltmeter is placed across open-circuited terminals. Will the voltmeter read zero? Discuss. 5
- (d)(i) A 50-ohm lossless line is terminated with a dipole of input impedance $(73+j42) \Omega$. Find the reflection coefficient, VSWR, and estimate the reflected and transmitted powers, if the input power to the line is 10 W. Also calculate the maximum and minimum impedances on the line, and suggest two methods of matching such a load to the line appropriately. 10
- (d)(ii) Determine the noise bandwidth of the first-order RC integrator with cut-off frequency f_c . Define the term noise bandwidth. 5
6. (a)(i) Using Fourier transform method, obtain expression for $v(t)$ in the following network (Fig. 10):
[Figure: Fig. 10 – Current source $e^{-t}u(t)$ (arrow upwards) in parallel with a 0.5Ω resistor and a 1 F capacitor; $v(t)$ is the voltage across the parallel combination (top terminal positive)] 6
- (a)(ii) The z -parameters of a symmetrical two-port network (consisting of passive elements only) are given by $z_{11}=2/3 \Omega$ and $z_{21}=1/3 \Omega$. Obtain equivalent T-network. If this network is excited by a 2-volt source having internal resistance of 1 ohm, determine the load resistance to be connected across port-2 which will receive maximum power. 10
- (a)(iii) State the differentiation property of Fourier transforms. Hence, obtain the Fourier transform of a Signum function. Sketch its magnitude spectrum. 4
- (b)(i) Design an opamp second-order Butterworth low-pass filter (LPF) for a cut-off frequency of 2 kHz. Compare the response curve with that of first-order LPF. 10
- (b)(ii) With the aid of circuit, draw $R/2R$ ladder DAC and discuss its operation. 6
- (b)(iii) With $V_{REF}=5 \text{ V}$ for the DAC, find the resolution and full-scale output of this converter. 4
- (c) Write voltage equations governing the performance of type-A chopper during on-period T_{on} and off-period T_{off} for the RLE type load. Hence, obtain therefrom, using Laplace transform, the expressions for the maximum and minimum currents taken by the load. Assume continuous conduction. 20
7. (a)(i) Using an opamp and RC network, explain the working of a Wien bridge oscillator. For a frequency of 1 kHz, design a Wien bridge oscillator. 10
- (a)(ii) Convert a clocked SR Flip-Flop to a clocked JK FF. 10
- (b)(i) Speed control of a three-phase induction motor with constant supply voltage and reduced supply frequency is rarely used in practice. Justify this statement. 6
- (b)(ii) Describe stator frequency control for the speed control of a three-phase induction motor. Derive expressions for motor torque, maximum torque and the slip at which it occurs. State the various assumptions made. 14
- (c)(i) A lossy non-magnetic medium has $\epsilon_r=4.0$ and a phase constant of 0.10 rad/m at 2.0 MHz . Determine its loss tangent, conductivity, propagation constant, intrinsic impedance and skin depth. 10
- (c)(ii) An FM system uses pre-emphasis and de-emphasis filters having the following transfer functions:

$$H_p(f)=k[1+jf/f_0]$$

$$H_d(f)=1/k[1/(1+j(f/f_0))]$$

1. Find the scaling factor k so that the average power of the emphasized signal is same as that of original signal $m(t)$. 2. Find the corresponding value of improvement factor I 10

produced by using this pair of pre-emphasis and de-emphasis filters.

8. (a)(i) A linear network has a driving-point admittance $Y(s)$ given by
- $$Y(s) = \frac{12(s+1)}{(s+2)(s+3)}$$
- Determine current in the network supplied by unit impulse voltage. What would be the current in the circuit when a unit step voltage is applied? 10
- (a)(ii) Write the node equations for the network shown in Fig. 11. Assume node ② as a reference node:
- [Figure: Fig. 11 – Nodes ① and ② on the top line and node ③ the bottom line. Left: source $50\angle 0^\circ$ (+ at top) from node ③ through a $5\ \Omega$ resistor to node ①; inductor $j2$ from node ① to node ③; $4\ \Omega$ resistor between nodes ① and ②; capacitor $-j2$ from node ② to node ③; $2\ \Omega$ resistor from node ② to the + terminal of source $50\angle 90^\circ$, whose other terminal goes to node ③] 10
- (b)(i) The primary winding of a single-phase transformer is energized from a fixed sinusoidal voltage with secondary open-circuited. If a small portion of iron core is removed, discuss what would happen to the magnitudes of its exciting current, core flux and the no-load power factor. 7
- (b)(ii) Explain why transformer rating is expressed in VA or kVA. Describe the significance of all the items mentioned on the nameplate of a single-phase transformer. 6
- (b)(iii) Derive an expression for the per unit voltage regulation of a single-phase transformer. Show that magnitude of per unit voltage regulation is equal to per unit value of equivalent leakage impedance of the transformer. 7
- (c)(i) A plane wave having
- $$\vec{E} = 110 \cos(\omega t - 4\pi x) \hat{z} \text{ V/m}$$
- is normally incident on a medium of $\epsilon_r = 9$, $\mu_r = 4$ and $\sigma = 0$, from a perfect dielectric medium of $\epsilon_r = 4.0$. Find the reflection and transmission coefficients, phase constants and list out the time-domain expressions for incident, reflected and transmitted electric fields. 10
- (c)(ii) Establish the time-domain expression for the AM signal at 60% modulation level with modulating signal as $5 \cos(200\pi t)$ and carrier as $50 \cos(10^4 \pi t)$, and list out its Fourier transform. Find out the amplitude sensitivity constant, side-band powers and efficiency. 10