Civil Services (Main) Examination, 2006

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. Answer any three of the following:

(a)(i) State and explain Thevenin's theorem and replace the active network of the figure given below, at terminals ab with a Thevenin's equivalent.

[Figure: Voltage source V = 10∠0° (+ at top) on the left; from its + terminal a 5 Ω resistor in the top wire to node X; from node X to the bottom wire a 3 Ω [?] resistor in series with an inductive reactance j4 Ω; from node X an inductive reactance j5 Ω in the top wire to terminal a; terminal b on the bottom wire, which returns to the − terminal of the source] **10**

(a)(ii) Determine the currents i_1, i_2 and i_4 at $t=0^+$ for the circuit given below. Assume that the voltage source is applied at $t=-\infty$.

[Figure: d.c. source V_s (battery) on the left; current i_1 flows from its upper terminal through R_2 in the top wire to node P; from node P a vertical branch: R_1 (current i_2 flowing down) to node Q, then inductor L (current i_4 flowing down) from node Q to the bottom wire; from node P along the top wire to the right-hand vertical branch: capacitor C_1 from the top wire to node S and capacitor C_2 from node S to the bottom wire; a switch marked t = 0 connected between node Q and node S; the bottom wire returns to the lower terminal of V_s] **10**

(b)(i) Determine inverse Laplace transform of $H(s)=\ln(1/(s+4))$ **5**

(b)(ii) Given $\mathbf{E}=\hat{x}E_0e^{-jkz}$ in a region, where k is a constant. Find the time average Poynting vector. **5**

(b)(iii) Silicon diodes D_1 and D_2 in the circuit of the figure given below have saturation current of 1 nA and 20 nA, respectively, at 300 K. Find i_1, i_2, V_1 and V_2 Given Boltzmann constant $k=1.38\times10^{-23}$ J/K, electronic charge $q=1.6\times10^{-19}$ C and emission coefficient n = 1 for Ge and 2 for Si.

[Figure: Single series loop: 6 V battery on the left (+ at top); current i_1 flows right along the top wire through diode D_1 (anode on the left, cathode on the right; voltage V_1 across it, + on the left, − on the right); then down the right-hand side through diode D_2 drawn pointing upwards (anode at the bottom, cathode at the top; voltage V_2 across it, − at the top, + at the bottom; current i_2 marked upwards); the bottom wire returns to the − terminal of the battery] **5**

(b)(iv) Design a 2-input, 3-output circuit which can be used as half adder or half subtractor by choosing output points. **5**

(c)(i) Derive an expression for armature torque of a dc motor in terms of back emf, armature current and speed in rpm. **10**

(c)(ii) What will be the value of cosϕ at zero voltage regulation for a single phase transformer? **10**

(d)(i) Two random variables X and Y have the joint Pdf

$$f_{XY}(x,y)=\{[Ae^{-(2x+y)},\quad x,y\geq 0\ ;\ 0,\quad otherwise]$$

Where A is a constant. Evaluate A and determine the marginal pdfs and draw the corresponding graphs. **10**

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(d)(ii) At great distances from the Hertzian dipole antenna the EM fields resemble those of a uniform plane wave. Write the similarities and differences (at least five points). **10**

2. (a)(i) define a network function and explain how the poles & zeros are related to a network function. **5**

(a)(ii) Explain how an analog signal can be constructed from its samples. What are the conditions for faithful reconstruction? Give any one reconstruction circuit. **5**

(a)(iii) An airline has characteristic impedance of 75 ohms and phase constant of 3 rad/m at 100 MHz, Find the inductance and capacitance per meter of the line. **5**

(a)(iv) Input voltage to the circuit of the figure given below is v_{in}=12sin$t$ V. Determine the output voltage v_0 and sketch it, What is the name of the circuit?

[Figure: a.c. source v_{in} (+ at top); 1 kΩ resistor in the top wire from the source to node N; from node N to the bottom wire a series branch: 3 V battery (− terminal at node N, + terminal below) followed by diode D (cathode towards the battery, anode at the bottom wire); 3 kΩ load resistor from node N to the bottom wire, output v_0 across it (+ at top)] **5**

(b)(i) Draw the phaser diagram of a single–phase transformer. For a single–phase transformer of 440/ 4400 volts, 50 Hz, the no load current is 0.04 amps. Transformer input-power fed from low voltage side is 80 watts. Calculate iron loss and magnetizing component of currents and the power factor at no load. **10**

(b)(ii) A 1500 kVA, 6.6/1.1 kV, 3-ϕ delta-star connected transformer has the following test data, when low voltage side is short–circuited: 300 V, 30 kW, 1312 A Calculate (1) % resistance and reactance drops (2) % regulation on full load and 0.8 P.F. lag **10**

(c)(i) A battery is charged by a single–phase half–wave controlled rectifier using SCR circuit. A resistance of 10 ohms is used between rectifier and battery. An ac source voltage of 230 V, 50 Hz is used as input to rectifier. If the battery voltage is 150 V dc, find (1) average charging current (2) power supplied to battery **12**

(c)(ii) How is an SCR protected against high di/dt and dv/dt? Give circuit configuration and explain the role of each component. **8**

3. (a)(i) For the circuit given below draw the network graph and draw any three possible trees of the network. Prove that for the network graph L = B − (N − 1) where L = no. of links B = no. of branches N = no. of nodes

[Figure: Triangular network with an internal star: outer vertices T (top), BL (bottom left) and BR (bottom right) and a central node O; side T–BL: 10 Ω in series with a 10 V source (polarity marks not clearly legible); side T–BR: 10 Ω; side BL–BR: 10 Ω; 5 Ω from each of T, BL and BR to the central node O] **5**

(a)(ii) Determine impulse response of the system described by difference equation $y[n+1]-2y[n]=x[n]$ $y[0]=0$. **5**

(a)(iii) The ideal op-amp circuit of the figure given below converts voltage v_i into a current i_L. Show that if $2R_1=2R_2=R_3+R_4$ and $R_4-R_1=500$ Ω then $i_L=+v_i$ mA.

[Figure: Op-amp: input v_i through R_1 to the inverting (−) input; R_2 from the output v_o to the inverting input; R_3 from the output v_o to the non-inverting (+) input; R_4 from the non-inverting input to ground, carrying the load current i_L (downwards) with voltage v_L across it (+ at top)] **10**

(b)(i) Explain hunting phenomena in a synchronous motor operating at constant voltage and field excitation, when load on the shaft is suddenly decreased. **8**

(b)(ii) For a leading power factor load, draw phaser diagram of a synchronous motor. A motor is rated as follows: 3-ϕ, 400 V, star connected, R_a 0.2 ohm, X_s = 2 ohm. For 20 A armature current calculate excitation emf at 0.8 leading P.F. condition. **12**

(c)(i) Draw the circuit diagram of a step–up/step–down dc chopper. Write expression for the average output voltage using energy balance equation. **10**

(c)(ii) A chopper circuit is operating on Time Ratio Control strategy at a frequency of 2 kHz on 220 V dc supply. If the load voltage is 200 V dc, compute the conduction and blocking **10**

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period of SCR in each cycle.

4. **(a)(i)** Compute the quality factor of an RLC series circuit with R = 20 Ω, L = 50 mH and C = 1 μF using $Q=\omega_0 L/R$, $1/\omega_0 CR$, ω_0/β **5**

(a)(ii) Impulse response and input to a discrete time system are given as $h[n]=\alpha^n u[n]$ $0<\alpha<1$, $x[n]=u[n]$. Determine response of the system. **5**

(a)(iii) List in ascending order the frequencies of the five lowest (frequency) modes of an air–filled rectangular cavity of dimensions 5 × 4 × 2.5 cm. **5**

(a)(iv) Describe what happens to each of the following CMOS characteristics as V_{DD} is increased (i) Noise margin (ii) Power dissipation (iii) Switching speed **5**

(b)(i) Show that the signal $v(t)=\sum[\cos\omega_c t\cos(\omega_i t+\theta_i)-\sin\omega_c t\sin(\omega_i t+\theta_i)]$ is an SSB signal. Is it USB or LSB? Write an expression for the missing sideband. Obtain an expression for the total DSB-SC signal. **10**

(b)(ii) A white-noise current source having a power spectral density $G_n(f)=\eta/2$ is filtered by a narrow band, parallel single-tuned circuit having a resonant frequency at f_0 and a 3-dB bandwidth $B \ll f_0$. Find the output voltage noise power. **10**

(c) The ionosphere can be considered as a dielectric with refractive index n. Derive an expression for n. **20**

SECTION 'B'

5. Answer any three of the following:

(a)(i) A balanced three–phase system has a line voltage of 500 V. Two balanced Y-connected loads are present. One is a capacitive load with (7 − j2) Ω per phase, and the other is an inductive load with (4 + j2) Ω per phase. Find (1) the phase voltage; (2) the line current, (3) the total power drawn by the load; (4) the power factor at which source is operating. Draw the circuit arrangement also. **10**

(a)(ii) Find the voltage transfer function V_2/V_1 for the network given below.

[Figure: Source $V_1\sin\omega t$ (+ at top) on the left; inductor L_1 (dot at its left end) in the top wire to a middle node; capacitor C from the middle node to the bottom wire; inductor L_2 (dot at its left end) in the top wire from the middle node to the right; resistor R_2 from the right end of the top wire to the bottom wire, output V_2 across it (+ at top); mutual inductance M between L_1 and L_2] **10**

(b)(i) Impulse response of two systems are given as $h_1[n]=\delta[n]$ $h_2[n]=u[n-1]$ Determine which of the above systems are (1) causal, (2) memory less. **5**

(b)(ii) A lossless parallel strip line has a conducting width W. The substrate dielectric constant is 10 and has a thickness of 4 mm. Calculate the value of W to have a characteristic impedance of 75 Ω and also the line capacitance. **5**

(b)(iii) What is the impedance reflection principle as referred to FET circuits? Draw the circuit of a typical source follower and apply reflection principle to obtain its output equivalent circuit. **5**

(b)(iv) Determine (1) maximum conversion rate (2) average conversion rate (3) maximum conversion time for a 16–bit counter type A/D converter using a 1 MHz clock. **5**

(c)(i) Explain the speed-current, torque-current and speed-torque characteristics of dc series motor. **6**

(c)(ii) In case of three-phase induction motor, derive the ratio of maximum torque to full load torque as $T_m/T_{FL}=1/2(\beta^2+s_{FL}^2)/\beta.s_{FL}$ where $\beta=r_2/x_2$ **8**

(c)(iii) A fully controlled three-phase bridge is operating in inverting mode from an ac supply of 220 V, 50 Hz. The source inductance per phase is 0.32 mH. If the converter is operating with an angle of firing advance of 30°, calculate maximum current that can be commuted, allowing a recovery angle of 5°. Neglect device volt drops. **6**

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(d)(i) In an Armstrong modulator the crystal frequency is 200 kHz. The angular deviation is to be 0.2 and the system is to accommodate modulation frequencies down to 40 Hz. At the O/P the carrier frequency is to be 108 MHz and the frequency deviation be 80 kHz. Determine multiplier and mixer oscillator frequencies to accomplish this end. **10**

(d)(ii) A magnetic field strength of 15 μA/m is required at a point on θ=π/2 [?], 2 km from an antenna in air. Neglect ohmic loss. How much power would the antenna transmit if it is (1) a λ/2 dipole? (2) a 10 turn loop [?] antenna of radius λ/20? **10**

6. (a)(i) For the given network shown below driven by a current source and terminated by a resistor R_2 at port 2, calculate the transfer functions $Z_{21}(s)$, $Y_{21}(s)$ and the driving point functions $Z_{11}(s)$, $Z_{22}(s)$.

[Figure: Input current source $I_1(s)$ (arrow up) connected to port 1 (terminals 1–1′), port voltage $V_1(s)$; inside the dashed box labelled 2-Port Network: resistor R_1 (current $I_a(s)$, downwards) across port 1, then inductor L_s (current $I_L(s)$, towards port 2) in the top wire from terminal 1 to terminal 2; bottom wire straight from 1′ to 2′; port 2 (terminals 2–2′, voltage $V_2(s)$, current $I_2(s)$ flowing into terminal 2) terminated by resistor R_2 labelled Output; the source side labelled Input] **5**

(a)(ii) Prove that if at t = 0 there is a charge density ρ inside a conductor, then ε/σ seconds later the density will decrease to (1/*e*)ρ. For copper ($\sigma=5\times10^7$ S/m), calculate this time **5**

(a)(iii) Minimize and implement the following multiple-output functions $f_1(A,B,C,D)=\Sigma(1,2,3,6,8,12,14,15)$ $f_2(A,B,C,D)=\Sigma(1,2,3,5,6,7,8,12,13)$ **10**

(b) In a DSB-SC system, the carrier frequency is f_c=500 kHz and the modulating signal m(t) has a uniform PSD band-limited to 4 kHz. The modulated signal is transmitted over a distortion less channel with a noise PSD $S_n(\omega)=1/((\omega^2+a^2))$ where $a=10^6\pi$. The useful signal power at the receiver input is 1 μW. The received signal is band pass filtered, multiplied by $2\cos\omega_c t$ and then low pass filtered to obtain the output $S_0(t)+n_0(t)$. Determine the output SNR. **20**

(c)(i) Draw a neat schematic of a traveling-wave amplifier. List the elements of the tube and their constructional details. **10**

(c)(ii) Compare the salient features of O- and M-type tubes. (at least eight points) **10**

7. (a)(i) Find the current I in the circuit shown below.

[Figure: Source $v_s(t)=40\sin3000t$ on the left; current I flows through a 1.5 kΩ resistor in the top wire to node A; inductor 1/3 H from node A to the bottom wire; from node A a 1 kΩ resistor in the top wire to the right-hand branch, a capacitor 1/6 μF to the bottom wire] **5**

(a)(ii) Determine the time signal represented by the DTFS coefficients given in the figure below:

[Figure: Stem plot of X[k] against k (periodic, "…" at both ends): unit-height lines at k = −1 and k = 1 (height marked 1) and a negative line of value −1/2 at k = 0, repeated with period 7 (positive lines at k = −8, −6, 6, 8, ±13 …; negative lines at k = ±7); axis labels printed −6, −4, 4, 8 [?]] **5**

(a)(iii) A plane wave is normally incident on a half-space of copper. If f = 2 GHz, calculate (1) propagation constant, impedance and skin depth for the conductor. (2) reflection and transmission coefficients. Given $\sigma=5.8\times10^7$ S/m. **5**

(a)(iv) For the circuit of the figure given below β=100, R_1=90 kΩ, R_2=10 kΩ, R_C=5 kΩ, R_E=1 kΩ and V_{CC}=20 V Determine i_B, i_C and V_{CE}.

[Figure: Voltage-divider biased NPN transistor: R_1 from $+V_{CC}$ to the base node, R_2 from the base node to ground; collector through R_C to $+V_{CC}$; emitter through R_E to ground] **5**

(b) Find the mean, the mean square, and the variance of the Gaussian random variable with the pdf $P_x(x)=1/\sigma\sqrt{(2\pi)}e^{-(x-m)^2/2\sigma^2}$ **20**

(c)(i) Draw a simple two-valley conduction band diagram for GaAs. The band structure of a semiconductor must satisfy three criterions to exhibit negative resistance for transferred electron effect to occur. State them. **10**

(c)(ii) With the help of neat sketches explain the fabrication steps for making MOSFETs. **10**

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8. **(a)(i)** Define the following terms related to electrical circuits An ideal filter SPICE Network graph d **5**

(a)(ii) Prove that $z[nx[n]]=-Zd/dzX(Z)$ where $z[x[n]]=X(Z)$ without any change in ROC. **5**

(a)(iii) What do you understand by Miller capacitance? For a CE amplifier following parameters are given r_i=10 kΩ [?], $C_{b'c}$=4 pF, R_b=1 kΩ, $C_{b'e}$=300 pF, $r_{bb'}$=20 Ω, g_m=0.5 S, $r_{b'e}$=150 Ω, R_L=300 Ω and $R_C \gg R_L$. Determine the Miller capacitance. **5**

(a)(iv) Draw the logic diagram and timing diagram of a 3-bit binary ripple up counter using positive edge triggered FF's. **5**

(b)(i) A 400 V dc shunt motor has no-load speed of 2000 rpm. It is running at 1000 rpm at full load torque, reduced armature voltage and full field. Its load torque is reduced to 50% of rated value with armature voltage and field voltage held constant at previous values; the speed increases to 1050 rpm. Find armature voltage drop at full load. Neglect effect of armature reaction. **10**

(b)(ii) A 500 V, 3-phase star connected synchronous motor has a resistance and synchronous reactance of 0.4 ohms and 3.6 ohms per phase respectively. The open circuit voltage is 600 V. If friction and core loss are 1 kW. calculate line current and power factor when motor output is 62 kW. **10**

(c)(i) Explain briefly the different control strategies of chopper. **4**

(c)(ii) An ideal single quadrant chopper operating in first quadrant is supplied with power from an ideal battery source of terminal voltage 200 V. The load voltage waveform consists of rectangular pulses of duration 1 [?] msec in overall chopper time of 3 msec. Calculate the average and rms values of the load voltage and voltage ripple factor. **6**

(c)(iii) A 200 V, 875 rpm, 150 A, separately excited dc motor has an armature resistance of 0.06 Ω. It is fed from a single phase fully controlled rectifier with an ac source voltage of 220 V, 50 Hz. Assuming continuous conduction, calculate (1) firing angle for rated motor torque and 750 rpm. (2) motor speed for α=160° and rated torque. **10**

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