Civil Services (Main) Examination, 2003

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. Attempt any THREE of the following

(a)(i) For the circuit given below, Find the frequency w_0 at which the impedance across X, Y reaches a maximum.

[Figure: Source $V_s(t)=V\sin wt$ in the left vertical branch; from its top terminal, terminal X is marked on the top wire, followed by series resistor R_1; R_1 feeds three parallel branches to the bottom wire: inductor L, capacitor C and resistor R_2; the bottom wire returns to the source, with terminal Y marked on it near the source.] **10**

(a)(ii) Find the impedance across X, Y at frequency w_0 and the current through the network at that condition. **10**

(b)(i) Solve the difference function given by $y(K+2)-5y(K+1)+6y(K)=3x(K+1)+5x(K)$ If the initial conditions are $y(-1)=11/6$ and $y(-2)=37/36$ and the input function is $x(K)=2.\ u(K)$. **10**

(b)(ii) Enumerate different properties of the ROC for Laplace transform and find out the I.L.T of $X(s)=1/((s+1)(s+2))$ for the different ROC's $\mathrm{Re}(s)>-1$, $\mathrm{Re}(s)<-2$, $-2<\mathrm{Re}(s)<-1$ **10**

(c)(i) A full-pitched coil having N turns rotates with an angular velocity of w_r rad/sec with respect of field flux. Obtain an expression for the flux Linkages with the coil as a function of time t. Derive there from an expression for the emf generated in the coil. Discuss about the two components of the emf expression so obtained. **10**

(c)(ii) Show that, in case the field flux is time-invariant, the generated emf lags by 90° the flux that generates it. **10**

(d)(i) Can you detect a DSBSC signal using an envelope detector? By a suitable analysis, compare the same with coherent detection **15**

(d)(ii) A modulating signal, m(t) is given by $\cos 100t+2\cos 300t$. Determine the LSB and USB relations + LSB and ϕUSB if the carrier frequency is 1000 rad. **5**

2. **(a)(i)** The following two amplifier circuit is a generalized immitance converter (GIC). Analyze the above circuit to get an expression for Z_{in}. Assume the two op-amps to be ideal.

[Figure: Five impedances: Z_1, Z_2, Z_3, Z_4 connected in series in a horizontal chain starting at the upper input terminal (nodes: input node, node A between Z_1 and Z_2, node B between Z_2 and Z_3, node C between Z_3 and Z_4, node D after Z_4); Z_5 from node D down to the lower input terminal (bottom wire). Op-amp OA1 (drawn above the chain): + input to the input node, − input to node B, output to node C. Op-amp OA2 (drawn below the chain): − input to node B, + input to node D, output to node A. Z_{in} is the impedance looking into the two input terminals (arrow).] **10**

(a)(ii) With $Z_1=R_1$, $Z_3=R_3$, $Z_2=1/C_2s$, $Z_4=R_4$ and $Z_5=R_5$, what does the GIC circuit above realize? **2**

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(a)(iii) Z_1 and Z_5 are capacitors, Z_2, Z_3 and Z_4 are resistors. How does the input impedance Z_{in}, behave? **2**

(a)(iv) What are energy and power signals? Compute the energy and power contents of the following signals and indicate whether they are energy or power signals $x_T(n)=\{(-0.5)^n u(n)\ 0.01s\}$; $y_T(n)=\{2e^{3j\pi n}u(n)\ 0.2s\}$. **6**

(b)(i) Discuss why forward break over in a thyristor occurs at a lower anode-cathode voltage if its gate current is increased. **5**

(b)(ii) What are the advantages of IGBT over BJT, MOSFET and thyristor? **5**

(b)(iii) Discuss why the speed control with constant supply voltage and reduced supply frequency is rarely used in practice in a three-phase induction motor. **5**

(b)(iv) A dc machine has total armature ampere conductors of 4500 and total flux in the machine is 0.14 Wb. Calculate the torque developed in the machine. **5**

(c) A three-phase full-converter feeds a resistive load of 15 Ω. For a firing-angle delay of 75°, the load takes 6 kW. Find the magnitude of per phase input supply voltage to the three-phase full-converter. Derive the relevant expression used if any. **20**

3. (a)(i) A rectangular pulse g(t) exists between T = - (T/2) and t = + (T/2). Sketch the pulse obtained by convoluting g(t) with itself. The Fourier transform of g(t) is a sine function Write down the Fourier transform of the pulse obtained by the above convolution. **10**

(a)(ii) Find the Laplace transform L(t) of the following function $f(t)=t\cos wt$. Given $L(\sin wt)=w/(s^2+w^2)$ Using the result of $L(t\cos wt)$, find

$$L^{-1}(1/((s^2+w^2)^2))$$

10

(b) Explain the development of electromagnetic torque in a three-phase squirrel-cage induction motor through the interaction of stator and rotor mmf waves. Hence introduce the concept of load angle. Show that rotor must rotate in the direction of rotating field. Discuss the conditions under which optimum torque is developed in a 3-phase induction motor. **20**

(c) A 12-V battery feeds a single-phase full-bridge inverter whose output is connected to an ideal 1-phase transformer. Its primary has 10 turns and the load voltage is 230 V. For a load resistance of 100 Ω, calculate (i) the number of turns in the transformer secondary winding, (ii) rms value of primary current, and (iii) rms value of thyristor current. Consider only the fundamental component of inverter output voltage. **20**

4. (a) In the circuit shown below the switch 'S' closes at t = 0, and open after 10 ms. What will be the currents in R_1 and L_1 and L_2, and voltage across C_1 8 ms after switch 'S' opens? Assume D_1 to be an ideal diode and a 0.7 V drop across D_2 whenever it conducts.

[Figure: 200 V battery in the left vertical branch; from its top terminal the switch S, then inductor L_1=0.5 H in the top wire, with diode D_2 (unlabelled in the figure) connected in parallel across L_1 (its cathode towards the switch side, anode towards the right); the top wire continues to the right and down through R_1=50 Ω to node N; from N, inductor L_2=0.5 H down to the bottom wire; also from N, a branch of capacitor C_1=1.0 μF in series with diode D_1 down to the bottom wire (D_1 anode at the bottom wire, cathode towards C_1); the bottom wire returns to the battery.] **20**

(b) Show that the field strength at a point close to the antenna (at distances of unto 200-300 miles from the transmitting antenna) in terms of the power is given by

$$\varepsilon=9.49\sqrt{P}/r \text{ volts/m}$$

Where: ε is the field strength in volts/m, P is the power radiated in watts, r is the distance in meters. Calculate the field strength at 20 km away from a transmitting station of 50 kW power **20**

(c)(i) A sine wave carrier is frequency modulated by a triangular modulating signal m(t) as shown in figure below. If the carrier frequency is 100 MHz and modulating signal frequency is 5 kHz, determine the bandwidth of the FM signal. Assume frequency **10**

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deviation constant, $K_f=10^5$ Hz/V.

[Figure: Triangular waveform m(t) versus t, starting at 0 at t = 0, rising linearly to +1.0, falling to −1.0, rising to +1.0, falling to −1.0 and returning to 0 (two full periods shown); peak values marked +1.0 and −1.0 on the vertical axis.]

(c)(ii) In a commercial FM broadcast system, the modulation index is 5, the 3 dB frequency of the pre-emphasis/de-emphasis filter is 2100 Hz and message signal frequency is 15 kHz. If the average to peak power ratio of the message signal is 05, what is the improvement in output SNR of FM with pre-emphasis and de-emphasis filtering compared to a baseband system? **10**

SECTION 'B'

5. Attempt any THREE of the following:

(a)(i) What are the criteria for a material to be an imperfect di-electric or a good conductor? Write Maxwell's equations in terms of phasors for sinusoidally varying electromagnetic fields. Consider a uniform plane wave in an isotropic and homogeneous medium, and show that the electric and magnetic field are not in time phase. **15**

(a)(ii) A uniform plane wave is traveling at a velocity of 3.0 10 m/s [?] in a non-magnetic good conductor and its wavelength is 0.35 mm. Find the frequency of the wave, and the conductivity and the intrinsic impedance of the conductor. **5**

(b) A series resonant circuit has its impedance

$$Z(s)=(20(s+1+j10)(s+1-j10))/s$$

Find (i) Resonant frequency (ii) Q factor (iii) Band width (iv) Impedance under resonance condition. **20**

(c) Two single-phase full converters are used for controlling the speed of a separately-excited dc motor. One full-converter in the field circuit has zero degree firing-angle delay. Both the converters are connected to 1-phase, 220 V, 50 Hz source. DC motor armature resistance is 0.6 Ω and field circuit resistance is 150 Ω and its constant is 0.6 V-s/A-rad. Armature and field currents are ripple free. For a firing angle delay of 40° and armature current of 40 A, determine

(c)(i) The motor speed in rpm, **6**

(c)(ii) Power factor of the armature converter, and **6**

(c)(iii) Power factor of the drive scheme. **6**

(d)(i) Define sensitivity, selectivity and fidelity with reference to a radio receiver. What is double spotting and its effects on a receiver? **8**

(d)(ii) A superhet receiver having no RF amplifier, the loaded Q of the antenna coupling circuit is 100. If the superhet is to be improved for HF reception so that its image rejection at 25 MHz is as good as at 1100 kHz, determine the loaded Q which an RF amplifier for this receiver would have to have and the new IF that would be needed in the absence of the RF amplifier. (Assume IF of 455 kHz). **12**

6. (a) Discuss the criteria for a circuit to oscillate. Explain the operation of a phase shift oscillator and derive an expression for the frequency of oscillation of an RC phase shift oscillator. **20**

(b)(i) A rectangular hollow metal waveguide of internal cross-section 7366 cm × 3.556 cm carries a 3 GHz signal in the TE_{10} mode. Calculate the maximum power handling capability of the waveguide assuming the maximum permissible electric field inside the waveguide to be 30 kV/cm. **10**

(b)(ii) Explain how a PLL can be used for demodulation of FM signals. Define capture range and lock range of a PLL. **10**

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(c)(i) White Gaussian noise of two sided spectral density 10^{-12} V^2/Hz is applied to a low pass (RC) filter having a 3 dB cut-off frequency of 1 kHz. Find the output noise power. **5**

(c)(ii) The received signal is r(t) = s(t) + n(t) where s(t) is the signal and n(t) is the noise signal. The signal process is random with an autocorrelation $R_s(\tau)=2e^{-|\tau|}$. The noise is a sample function of a random process with auto-correlation $R_n(\tau)=e^{-2|\tau|}$. If the two processes are having zero mean value and are independent of each other determine the autocorrelation and total power of r(t). **15**

7. (a) What is uniform plane wave? Define all the parameters associated with it. What is meant by group velocity? A uniform plane electro-magnetic wave travelling in region 1(ε_1, μ_1, σ_1) is incident normally on a plane boundary separating the region 2(ε_2, μ_2, σ_2), How are the reflected and the transmitted waves at the interface related to the incident wave? **20**

(b) Distinguish AM and NBFM signals. Obtain an expression for NBFM and WBFM signals. Determine the approximate band of frequencies occupied by an FM wave with carrier frequency of 5 kHz, K_f=10 Hz/V and $f(t)$=100cos200πt volts. **20**

(c) Distinguish between envelope detection and synchronous detection. Explain a Costas loop receiver for demodulating a DSBSC signal. Explain how the squaring circuit can also be used for synchronous detection. **20**

8. (a)(i) Using multiplexers, implement a full adder circuit. **10**

(a)(ii) It is desired to generate the following three Boolean functions $F_1=a\bar{b}\bar{c}+\bar{a}bc\bar{c}+bc$; $F_2=a\bar{b}\bar{c}+ab+\bar{a}bc\bar{c}$; $F_3=\bar{a}\,\bar{b}\,\bar{c}+abc+\bar{a}\bar{c}$ By using an OR gate array as shown in Figure, where P_1 to P_5 are the product terms in one or more of the variables, $a,\bar{a},b,\bar{b},c$ and $\bar{c}$. Write down the terms P_1, P_2, P_3, P_4 and P_5.

[Figure: OR array with five horizontal product-term lines P_1 to P_5 (top to bottom) and three vertical output lines F_1, F_2, F_3; connections (dots) at: $F_1 - P_1$ and P_2; $F_2 - P_2$ and P_3; $F_3 - P_4$ and P_5.] **10**

(b) A 50 kW, 440 V, 50 Hz, star-connected synchronous generator with per phase impedance of 0.8 + j 4.5 Ω is working with rated terminal voltage. It is required to supply a power of 25 kW to the bus. Estimate the minimum excitation emf. Find out the corresponding stator current. **20**

(c) Consider the circuit shown below. Main thyristor T1 and auxiliary thyristor TA are off and capacitor is charged to voltage V_s with upper plate positive. Sketch the waveforms for i_o, i_c, i_{T1}, v_c and v_{T1} (assuming constant load current), after (i) thyristor T1 is turned on (ii) steady state is reached in part (i) and then thyristor TA is turned on From these waveforms, obtain the expressions for circuit turn-off time for both SCRs. In case V_s=220 V, R = 10 Ω and maximum value of current through main SCR is 3 times the load current, calculate the value of commutating inductance L for C = 20 μF and the circuit turn-off time for the auxiliary SCR.

[Figure: d.c. supply V_s (+ at the top input terminal, − at the bottom). From the top terminal (node P): main thyristor T1 (anode at P, gate G; voltage v_{T1} marked + at anode, − at cathode) to node K, current i_{T1}; from K the load current $i_o=I_0$ flows through load resistor R to the bottom (return) wire. Capacitor C connected from node P (upper plate, +, voltage V_c) down to node M, with current i_c. From M to K two parallel branches: auxiliary thyristor TA (anode at M, cathode at K) and a diode in series with inductor L (diode cathode towards M, i.e. conducting from K towards M through L).] **20**

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