PROFESSIONAL ENGINEERS ONTARIO

National Examinations - May 2011

07-Mec-A5, Electrical & Electronics Engineering

Mechanical Engineering

3 hours duration

Name [print]: Signature:

Notes:

[1] If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

[2] Candidates may use one of two calculators, the Casio or Sharp approved models. This is a closed book examination.

[3] Any five (5) questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

[4] Each question is of equal value.

[5] Clarity and organization of answers are important.

[6] The candidate is required to sign this examination paper and submit it with the solution booklets.

[7] $\pi = 3.14159$
$1\ \text{hp} = 746\ \text{W}$
$\mu_0 = 4\pi \times 10^{-7}\ \text{H m}^{-1}$

QUESTION 1

Consider the circuit shown in Figure 1 which has been designed using ideal operational amplifiers (U_1 to U_3) with infinite bandwidth and infinite open loop gain. In the schematic, a, b and c are constants. You will note that U_3 is configured as a basic difference amplifier which has a transfer function given by:

$$E_0 = c\,(e_y - e_x)$$

where e_y and e_x are the potentials at points y and x respectively.

In the derivation of the transfer function for such circuits, one can assume:

[i] Zero differential voltage between the input terminals of the operational amplifier,

[ii] Zero current flows into either input terminal of the operational amplifier.

Applying the principle of superposition, derive an expression for the transfer function of the total circuit [E_O as a function of E_1, E_2].

Hint: Let $E_2 = 0$, and solve for the potentials at points x and y for input E_1.
Let $E_1 = 0$, and again solve for the potentials at points x and y for input E_2.
Calculate the resultant output E_0 for both E_1 and E_2 inputs.

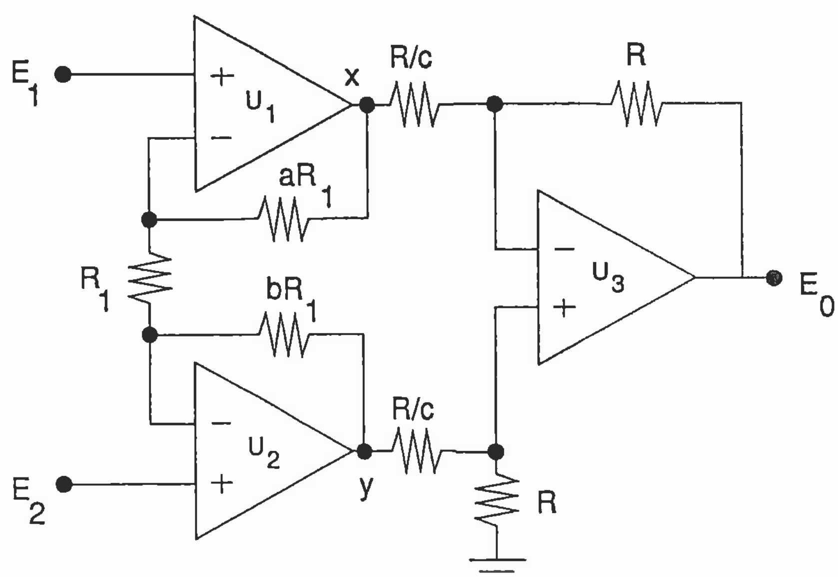


Figure 1 Circuit Schematic

QUESTION 2

Consider the transistor circuit shown in Figure 2. All transistors can be assumed to be identical with a dc current gain β.

Calculate the current transfer ratio for the circuit, I_2 / I_1, as a function of β.

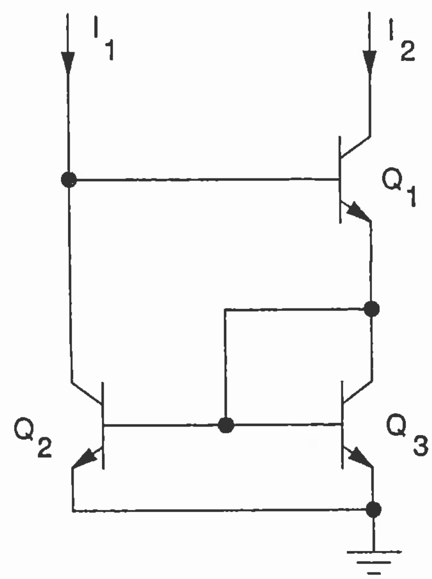


Figure 2 Transistor Circuit

QUESTION 3

A novel type of DC machine is designed using a disc type rotor of effective outer and inner diameters D and d respectively, as shown in Figure 3. A current I_2 is fed radially through the rotor via two ring shaped carbon brushes. The rotor lies in the horizontal plane and is situated in a vertical magnetic field of uniform density, B Tesla. The rotor spins at an angular speed ω rad/s.

[a] Find the magnitude of the emf e generated between the brushes.

[b] Determine the torque that the rotor will be subjected to and find the output horsepower of the machine.

HINT: As a starting point, consider an elemental annulus of radius **r** and radial length **dr**.

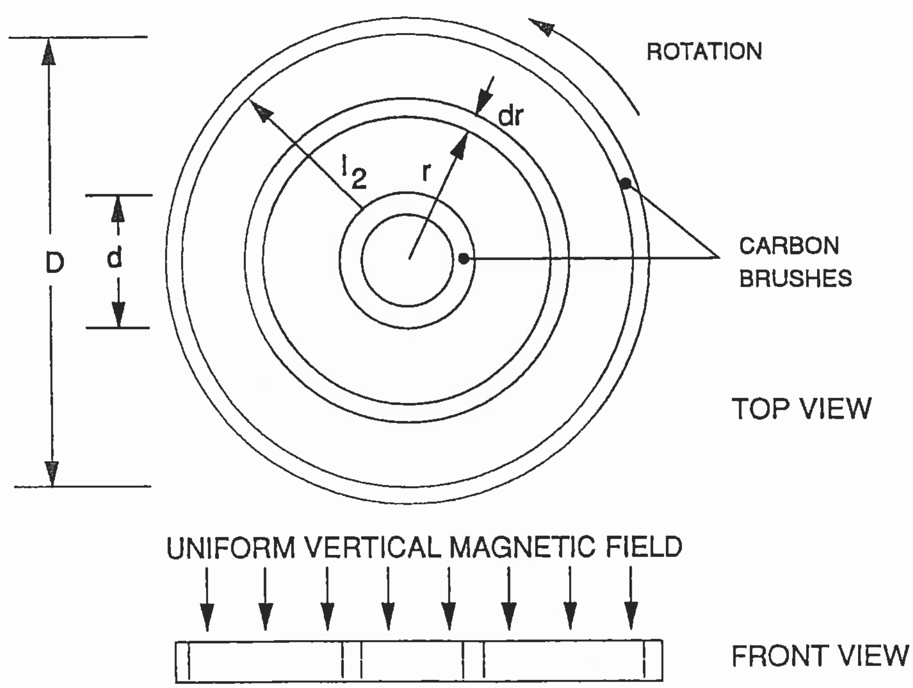


Figure 3 dc Machine

QUESTION 4

Consider the magnetic circuit of a transformer shown in Figure 4. Infinite relative permeability can be assumed for the iron core.

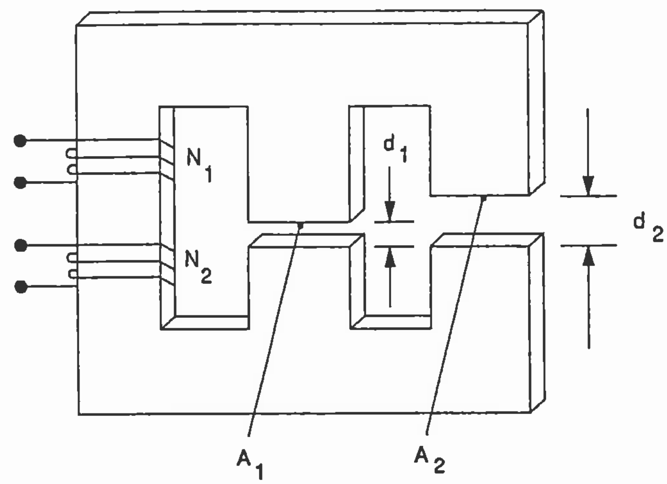


Figure 4 Transformer

The following specifications apply.

L_1	3.77×10^{-2} m	A_1	0.02 m^2
L_2	7.54×10^{-2} m	A_2	0.02 m^2
N_1 [primary]	200 turns	N_2 [secondary]	20 turns

When a dc voltage equal to 10 mV is applied to the primary, the measured primary current is 100 mA. When a dc voltage of 0.1 mV is applied to the secondary winding, the measured secondary current is 100 mA.

Assume that leakage inductances and eddy current and hysteresis losses are negligible; consider an operating frequency of 1000 Hz.

[a] Draw the equivalent circuit of the transformer referred to the primary and calculate component values.

[b] A transducer with an impedance of 0.078 Ω is connected across the secondary of the transformer; an amplifier is connected to the primary. Calculate the output impedance of the amplifier to give maximum power transfer to the load.

QUESTION 5

This question consists of two parts which are not necessarily related.

Part I

A combinational logic circuit is shown in Figure 5.

[a] Write a general Boolean algebra expression for the output F as a function of the inputs A, B.

[b] Using DeMorgan's theorems and other Boolean identities, simplify the expression obtained in [a]. Is there a single gate which can replace the network shown?

[c] Generate a truth table giving the logic levels at points C, D, E and F for inputs A,B.

Part II

Design a 2-input exclusive or (EOR) gate using only 2-input NOR gates.

[d] Develop the truth table for the gate.

[e] Write a general Boolean algebra expression for the output as a function of the inputs.

[f] Using DeMorgan's theorems and other Boolean identities, modify the expression obtained in [e] to provide a solution which can be implemented with NOR gates.

[g] Draw the circuit diagram for the final gate array.

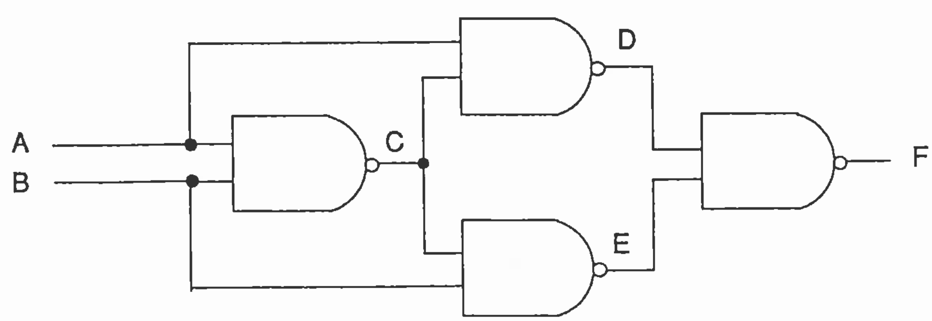


Figure 5 Combinational Logic Circuit

QUESTION 6

Consider the RC circuit shown in Figure 6[a]. The switch S_1 is closed at time t=0 connecting the dc supply V_I to the network.

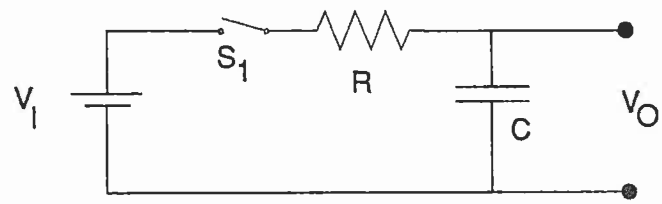
[a] Derive an expression for the transfer function of the circuit, V_o/V_I, in the time domain.

[b] Sketch the transfer function for a time interval of 5 time constants.

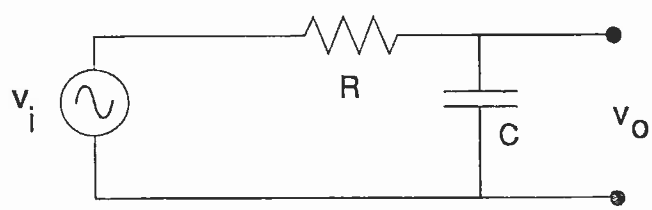
The RC circuit is reconfigured as shown in Figure 6[b]. An ac voltage source of variable frequency v_i is connected to the input.

[c] Derive an expression for the transfer function of the circuit, v_o/v_i, in the frequency domain.

[d] Sketch the magnitude of the transfer function for a frequency range of 4 decades centered at the corner frequency of the circuit.



[a]



[b]

Figure 6 RC Circuit: [a] dc test; [b] ac test

QUESTION 7

This question consists of two parts which are not necessarily related.

Part I

A 3 phase, 300 hp, 12 pole wound rotor induction motor is operated from a 60 Hz source. The per phase rotor resistance r_2 was measured and found to be 0.04Ω. At full load, the speed of the motor is 582 rpm.

At full load, determine:

[a] The speed of the magnetic field in revolutions per minute.

[b] The slip of the rotor.

[c] The frequency of the rotor currents.

[d] The angular velocity of the stator field with respect to the stator.

[e] The angular velocity of the stator field with respect to the rotor.

[f] The angular velocity of the rotor field with respect to the rotor.

[g] The angular velocity of the rotor field with respect to the stator.

Part II

In the normal operating region of an induction motor, torque is a linear function of slip. A test was performed on a 3 phase, 8 pole squirrel cage induction motor which is operated from a 60 Hz source and it was found that it developed a torque of 3 N.m at a speed of 810 rpm.
The induction motor is used to drive a load which requires a torque which is a linear function of speed. In another test, it was found that the torque required by the load was 0.5 N.m at a speed of 435 rpm.

[a] Sketch the speed-torque characteristics for the motor and load.

[b] Calculate the operating point for the motor-load system.

QUESTION 8

An industrial load is represented in Figure 8 by R = 6Ω and X_L = 8Ω. The load voltage is 250∠0° V.

[a] Calculate the load current, power, reactive power and power factor.

[b] Calculate the generator voltage V_G required at the input end of the transmission line (represented by the series impedance $Z_T = (1 + j3)\Omega$ and the power lost in transmission P_T.

[c] If capacitor X_C = 12.5Ω is connected in parallel by closing switch S, calculate I_C, the new load current I, and the new power factor. Show V, I_L, I_C, and I on a phasor diagram.

[d] Calculate the new generator voltage and the new transmission power loss.

[e] What two advantages do you see for improving the power factor by adding a parallel capacitor?

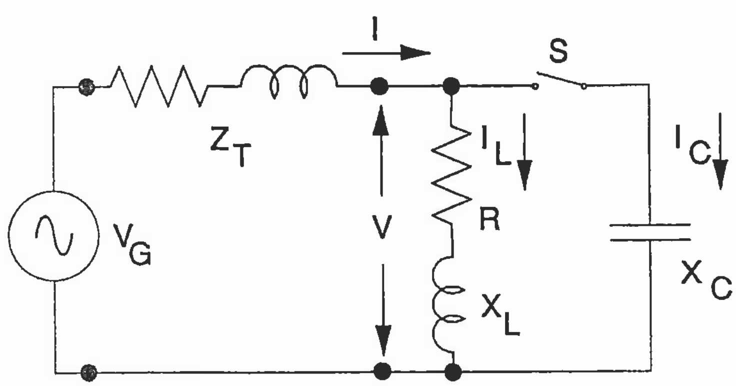


Figure 8 Industrial Load