Version ACF/5

EGT1
ENGINEERING TRIPOS PART IB

Tuesday 6 June 2023 9 to 11.10

Paper 5

ELECTRICAL ENGINEERING

*Answer not more than **four** questions.*

*Answer not more than **two** questions from each section.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

SECTION A

*Answer not more than **two** questions from this section*

1 (a) If an amplifier with gain A is subject to positive feedback from its output to its input via a network B, explain what conditions would result in an oscillatory output.

[4]

(b) The circuit in Fig. 1 is an oscillator based on four ideal operational amplifiers (OP1, OP2, OP3 and OP4), where a D.C. voltage $V_{ref} = 2.5$ V is applied to OP1 to provide a D.C. offset for the signal to allow for operation with a single-ended 5 V power supply.

(i) If V_X and V_Y denote the voltages at the points X and Y marked on the circuit in Fig. 1, by considering the signal passing through OP1, show that

$$V_Y = -\frac{R_2}{R_1}\left(V_X - V_{ref}\right) + V_{ref}$$

[3]

(ii) By considering the signal passing clockwise around the circuit from Y to X, passing through OP2, OP3 and OP4, show that

$$V_X = \left(\frac{1}{1 + j\omega RC}\right)^4 V_Y$$

[4]

(iii) Derive an expression for the oscillation frequency of the circuit in Fig. 1 and the required value of R_2/R_1 for stable oscillations at this frequency.

[7]

(iv) Due to a finite number of resistor values being available, the amplifier gain is 4% higher than the ideal. Calculate the corresponding percentage change in the oscillation frequency. You may assume that this deviation has a minimal impact on the loop phase.

[7]

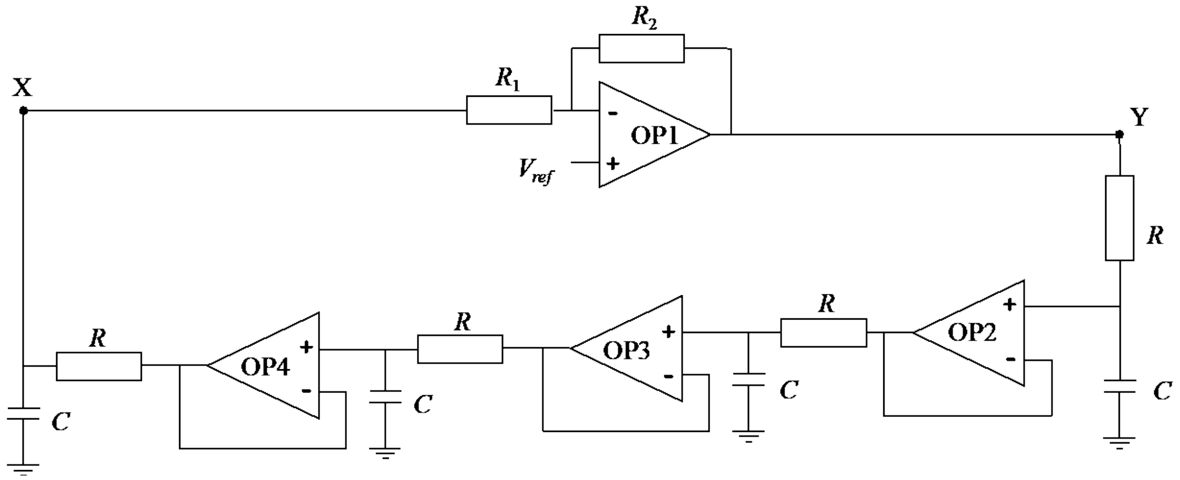

Fig.1

2 In the amplifier circuit shown in Fig. 2, the transistor is biased at an operating point such that $I_B = 10$ μA, $I_c = 2$ mA, $V_{BE} = 0.7$ V, and $V_{CE} = 5$ V. At this operating point $h_{fe} = 250$, $h_{ie} = 5$ kΩ and the other transistor parameters h_{re} and h_{oe} may be neglected.

(a) Assuming the transistor is biased to maximise the output signal before clipping occurs, i.e. $V_C = V_{CC}/2$, determine appropriate values for R_C and R_E stating any assumptions made.

[4]

(b) If the current flowing through R_2 is designed to be $10I_B$, determine appropriate values for R_1 and R_2.

[4]

(c) Draw a small-signal equivalent circuit for the amplifier valid for mid-band frequencies (where the reactance of the capacitors C_i, C_o and C_E may be assumed to be zero).

[4]

(d) Using the small-signal circuit, calculate:

(i) the small-signal voltage gain;

(ii) the small-signal input resistance;

(iii) the small-signal output resistance.

[6]

(e) If the capacitor C_E is now omitted from the circuit such that the impedance between the emitter and the ground is R_E, draw the small-signal equivalent circuit for this modified circuit and calculate:

(i) the small-signal voltage gain;

(ii) the small-signal input resistance;

(iii) the small-signal output resistance.

[7]

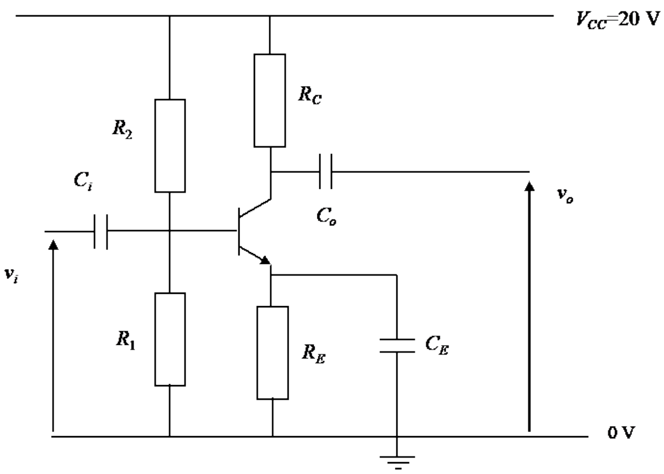

Fig.2

(TURN OVER

3 (a) A three-phase supply with 415 V and 50 Hz feeds two loads connected in parallel. The first load (called Load D) uses a delta-configuration with a parallel connection of a 12 Ω resistor and an 8 V A^{-1} inductive reactance in each branch. The second load (called Load Y) has a star configuration with the star point connected to the ground. Two arms of this star contain a 20 Ω resistor in series with a 10 V A^{-1} capacitive reactance. The third arm comprises a 10 Ω resistor in series with 5 V A^{-1} capacitive reactance. The load is unbalanced.

(i) Calculate the power dissipated in each load.

(ii) Which minimum additional star-connected compensation load (named Load C) needs to be connected in parallel to the others to achieve balanced load conditions? Provide its resistive and reactive properties. (Hint: think first about the easiest compensation so that all arms are equally loaded.)

(iii) How large would an equivalent star-configured load R need to be (with resistive and reactive components), replacing the parallel connection of Loads Y and C?

[8]

(b) Now assume that the line is loaded with the parallel connection of Loads D and R (thus balanced load from now on).

(i) Calculate the total line current.

(ii) Calculate the power factor.

[8]

(c) The power factor of the combined Loads D and R can be adjusted by balanced star-connected capacitors in parallel with the load. Determine the value of the capacitance required for:

(i) unity power factor;

(ii) 0.95 lagging power factor.

[6]

(d) Calculate the line-current reduction for each of the cases of Part (c).

[3]

SECTION B

*Answer not more than **two** questions from this section*

4 (a) Draw the typical relationship between torque and speed for an induction machine, including the motor, generator, and braking range. Label the ranges and characteristic points where the curve touches or cuts through any of the axes. What slip s does the induction machine have at these points? At which point does it reach synchronous operation? Explain why the induction machine is mechanically braking in the braking range. What slip does the electrical machine have there?

[5]

(b) You receive a two-pole three-phase induction machine (50 Hz) with a delta-configured winding. A colleague further provides the following two measurement results on a dynamometer:

Blocked rotor: 667 W total active input power, 16 A line current, 30 V line voltage.
3000 rpm: 1200 W total active input power, 8 A line current, 415 V line voltage.

Your colleague also removed the rotor once and could measure 22.6 V line voltage when the stator winding is loaded with 16 A of line current.

(i) Calculate the slip for both load points on the dynamometer.

(ii) Sketch the full equivalent circuit of the induction machine. Name each component and explain its physical meaning.

(iii) Assume that the inductance active in the measurement of the stator winding with removed rotor is mostly the stator winding's leakage inductance X_1 and X_1=X_2'. Calculate five component parameters of the equivalent circuit. State any assumptions made.

[12]

(c) The rotor is re-installed, and the motor is now highly overloaded so that it only reaches 2700 rpm at 415 V line voltage.

(i) Split the total rotor resistance into two components, one representing the electrical rotor loss and the remainder modelling the power transfer from the electrical to the mechanical domain.

(ii) Calculate the slip.

(iii) Calculate:

the electrical rotor loss P_r;

the (resistive) stator winding loss P_s.

Hint: You may neglect X_m and R_i for this approximation; sketch which current path is left in the equivalent circuit

[8]

5 (a) A transmission line has a series inductance of 400 nH m^{-1} and a shunt capacitance of 100 pF m^{-1}. Calculate the velocity of propagation of electromagnetic waves down the transmission line and its characteristic impedance. Estimate the relative permittivity of insulation of the line, stating any assumptions.

[8]

(b) The line is terminated by a short circuit and is driven by a voltage generator with an output resistance equal to the characteristic impedance of the line. At a frequency of 250 MHz, calculate the shortest length of lines which will:

(i) present an open circuit at its input;

(ii) present a short circuit at its input.

[5]

(c) The line of part (b)(ii) is bridged exactly half way along its length by a 150 Ω resistor. Calculate the reflection coefficient at the resistor, and the voltage standing wave ratio (VSWR) in the line on the input side of the resistor.

[7]

(d) The generator EMF is 150 V rms. Determine the power dissipated in the resistor. [5]

6 (a) A satellite antenna transmits a radio wave through free space without any power loss. The peak power output of the wave is 30 W. If the gain of the antenna is 2,500, calculate the peak power intensity at a distance of 30,000 km from the antenna in the direction of maximum gain.

[5]

(b) A receiving antenna is placed 30,000 km away from the satellite antenna in the direction of maximum gain. The receiving antenna has a receiving area of 3 m^2 and connects via a 50 **Ω**, lossless coaxial cable to an electronic receiver perfectly matched to the cable.

Calculate:

(i) the power received by the antenna; [3]

(ii) the rms current that flows into the receiver. [3]

(c) Consider a signal which is broadcast isotropically from a fixed station. The carrier frequency is 900 MHz and the total radiated power is 10 kW. The receiver is a loop antenna with an effective area 0.03 m^2, and it requires a minimum signal power of 10^{-9} W for good reception. Estimate the maximum distance between the transmitter and receiver, stating any assumptions made.

[8]

(d) In part (c), the receiver is placed at 85% of the maximum distance from the transmitter. Calculate by how many degrees the loop antenna can be misoriented and still receive adequate reception of the signal.

[6]

END OF PAPER

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