Version SJS/3

EGT1
ENGINEERING TRIPOS PART IB

Tuesday 10 June 2025 9 to 11.10

Paper 5

ELECTRICAL ENGINEERING

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

Answer not more than ***two*** *questions from any one section and not more than* ***one*** *question from each of the other two sections.*

All questions carry the same number of marks.

The ***approximate*** *number 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 at least **one** *question from this section*

1 The circuit in Figure 1 is known as a common-base amplifier. The transistor is biased at an operating point such that V_{BE} = 0.7 V, I_B=10 μA, V_{CE} = 4.7 V and I_C = 1 mA. At this operating point h_{fe} = 200, h_{ie} = 5 kΩ and the other transistor parameters h_{oe} and h_{re} 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. [4]

(b) If the current flowing through R_2 is designed to be 100 I_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_B may be assumed to be zero). [5]

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

(i) The small-signal voltage gain. [3]

(ii) The small-signal input resistance. [3]

(iii) The small-signal output resistance. [3]

(e) Comment of the characteristics of this common-base amplifier compared to those of a common-emitter amplifier. [3]

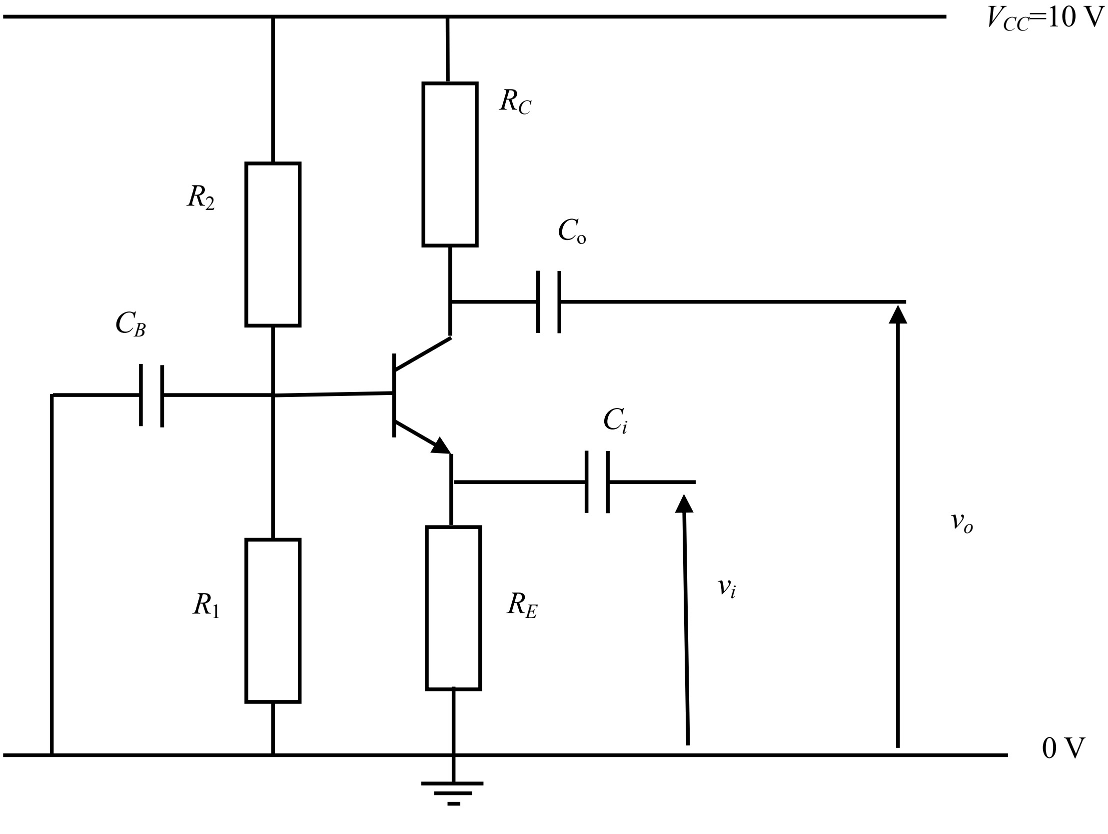

Figure 1

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2 A voltage amplifier has an input impedance r_i, gain of A and output impedance r_o.

(a) The amplifier in Figure 2(a) utilises the voltage amplifier and applies negative feedback with a proportion B_1 of the output voltage fed back. Show that:

(i) The gain G_a is given by $A/(1 + AB_1)$. [3]

(ii) The input impedance is given by $r_i(1 + AB_1)$. [3]

(iii) The output impedance is given by $r_o/(1 + AB_1)$. [3]

(b) Two of the amplifiers from part (a) are concatenated to form the amplifier in Figure 2(b). Determine, for the amplifier in Figure 2(b), using the results from part (a) or otherwise:

(i) The gain G_b of the cascaded amplifier. [2]

(ii) The input impedance of the cascaded amplifier. [2]

(iii) The output impedance of the cascaded amplifier. [2]

(c) The amplifier in Figure 2(c) cascades the voltage amplifier and then applies negative feedback, with a proportion B_2 of the output voltage fed back. Determine, for the amplifier in Figure 2(c), using the results from part (a) or otherwise:

(i) The gain G_c of this amplifier. [2]

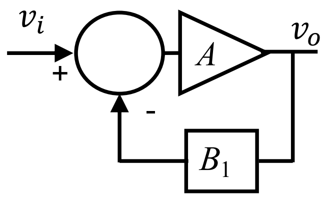
(ii) The input impedance of this amplifier. [2]

(iii) The output impedance of this amplifier. [2]

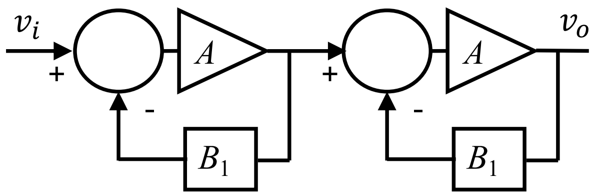
(d) The various amplifiers are designed such that $G_a \approx G_b \approx G_c \approx A$. The voltage amplifier exhibits a small gain variation δA, but is otherwise ideal, with $r_o \to 0$ and $r_i \to \infty$. Deduce which of the three amplifier configurations in Figure 2 is preferred when:

(i) The voltage gain is low such that $A \approx 1$. [2]

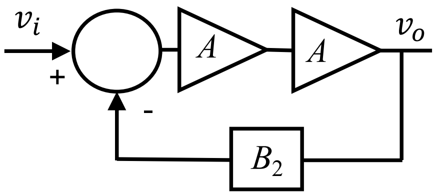
(ii) The voltage gain is high such that $A \gg 1$. [2]



(a)



(b)



(c)

Figure 2

SECTION B

Answer at least **one** *question from this section*

3 (a) Discuss the main reasons why electrical power is generated as three phase alternating voltages. [2]

(b) A 415 V, 50 Hz, three phase power line supplies two separate loads, one being star-connected with an impedance of $(32 + 24j)\Omega$ in each arm, and the other being delta-connected with an impedance of $(5 + 25j)\Omega$ in each arm.

(i) Calculate the power and reactive power supplied to each load. [3]

(ii) Calculate the total power and power factor for the combined loads. [3]

(c) A transmission line from the sub-station supplies these combined loads and has an impedance of $(0.4 + 1.6j)\Omega$ per line. Calculate the power loss in the line and the new loss if the power factor of the loads is corrected to unity. Assume that the voltage at the load is maintained at 415 V. [5]

(d) A six-pole ($p = 3$) three phase induction motor is star-connected to a 415 V (line), 50 Hz supply. The motor has a stator resistance of 0.8 Ω per phase, a referred rotor resistance of 1.0 Ω per phase, a stator leakage reactance of 2.2 Ω per phase, a referred rotor leakage reactance of 1.3 Ω per phase and a magnetising reactance of 65.0 Ω per phase. The iron loss resistance may be considered to be sufficiently large to be ignored. The power lost due to friction and windage losses is 260 W.

(i) Calculate the maximum gross torque (i.e before friction and winding power loss) that the motor can produce and the resulting motor speed. [6]

(ii) Calculate the motor output power and efficiency at the maximum gross torque. [6]

4 (a) Synchronous machines are used to supply power to the national grid.

(i) Outline the requirements for an a.c. synchronous machine to supply power to the 50 Hz national grid. [2]

(ii) Calculate the rotational speed in radians per second for a 2-pole machine. [2]

(iii) Calculate the rotational speed in radians per second for a 20-pole machine. [2]

(iv) State the kind of application where a machine with a large number of poles is used. [2]

(b) Sketch phasor diagrams for one phase of a synchronous machine delivering power into an infinite grid at:

(i) Unity power factor. [2]

(ii) A leading power factor of 0.707. [2]

(iii) A lagging power factor of 0.707. [2]

(c) A star-connected 22 kV 500MVA synchronous generator has a reactance per phase of 0.4 Ω. Determine:

(i) The excitation phase voltage when the generator delivers 60% of the rated MVA at a leading power factor of 0.6. [4]

(ii) The line current and load angle. [2]

(d) The prime mover output power is increased by 20% with the excitation voltage held constant. Determine the new values of power and VARs delivered. [5]

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SECTION C

Answer at least **one** *question from this section*

5 (a) A coaxial transmission line cable can be modelled as having the following equivalent circuit parameters: $R = 0.164\ \Omega\text{m}^{-1}$, $G = 200\ \mu\text{Sm}^{-1}$, $C = 67.7\ \text{pFm}^{-1}$ and $L = 370\ \text{nHm}^{-1}$. Consider a cable of 1 m length driven by a source with an a.c. frequency of 100 MHz.

(i) If the cable is perfectly impedance-matched at both ends, and the source voltage amplitude is 1 V, what is the voltage amplitude at the other end? [7]

(ii) If the source voltage phase is 0°, what is the voltage phase at the other end? [3]

(b) For a lossless transmission line, the total voltage as a function of time t and distance x may be expressed as $V(x,t) = \text{Re}\left\{\tilde{V}(x)e^{j\omega t}\right\}$ where Re{·} denotes the real part, and $\tilde{V}(x)e^{j\omega t} = \tilde{V}_F\left(e^{-j\beta x} + \rho_L e^{j\beta x}\right)e^{j\omega t}$ where β is the phase constant, ω is the angular frequency, $\tilde{V}_F$ is the forward voltage wave and $\rho_L = |\rho_L|e^{j\phi}$ is the voltage reflection coefficient. Show that:

$$|\tilde{V}(x)| = |\tilde{V}_F|\sqrt{1 + |\rho_L|^2 + 2|\rho_L|\cos(2\beta x + \phi)}$$

[4]

(c) Figure 3 illustrates a load connected to a sinusoidal voltage source via a dielectric-filled transmission line with characteristic impedance of $Z_0 = 50\ \Omega$, relative permittivity $\varepsilon_r = 3$ and relative permeability $\mu_r = 1$. The amplitude of the voltage oscillations $|\tilde{V}(x)|$ on the transmission line as a function of distance x is plotted in Figure 4.

(i) Calculate the frequency of the voltage source. [4]

(ii) Calculate $|\rho_L|$, the magnitude of the voltage reflection coefficient ρ_L. [3]

(iii) Calculate ϕ, the phase of the voltage reflection coefficient ρ_L. [4]

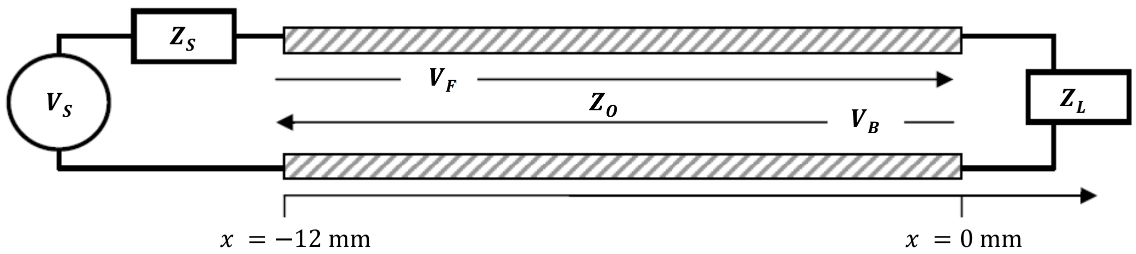

Figure 3

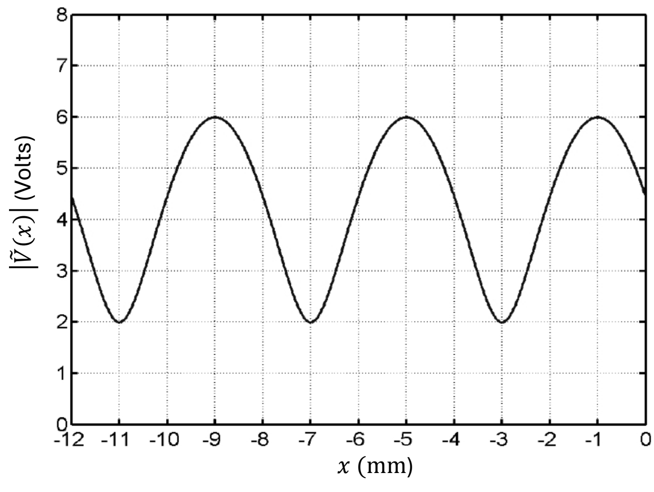

Figure 4

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6 (a) Consider a plane-polarized wave (free-space wavelength λ_0) with electric field parallel to the plane of incidence, incident on a boundary between two semi-infinite media (Region I, n = 1 and Region II, n = 2) at normal incidence as shown in Figure 5(a), where n is the refractive index. Assume that both media are non-magnetic dielectrics. If the incident electric field at $z = 0$ in Region I is given by E_0,

(i) What is the transmitted electric field E_2 at $z = 0$ in Region II in terms of E_0? [5]

(ii) What is the reflected electric field E_1 at $z = 0$ in Region I in terms of E_0? [5]

(b) We now consider what happens when a thin dielectric slab of thickness d (Region II, n = 2) is interposed between the two half spaces (Region I, n = 1 and Region III, n = 4) as shown in Figure 5(b) below. Ignore multiple internal reflections within Region II (i.e., there is a maximum of only one reflection at each interface). E_0 is the incident electric field at $z = 0$ in Region I, E_1 is the total reflected electric field at $z = 0$ in Region I and E_3 is the total transmitted electric field at $z = d$ in Region III. For the following questions, give your solutions in the simplest fractional form:

(i) What is the transmitted electric field E_3 in Region III in terms of E_0 ? [5]

(ii) What is the reflected electric field E_1 in terms of E_0? [7]

(iii) If we assume $d = \lambda_0/8$, what is E_1 in terms of E_0 ? Write one sentence explaining the engineering significance of your answer. [3]

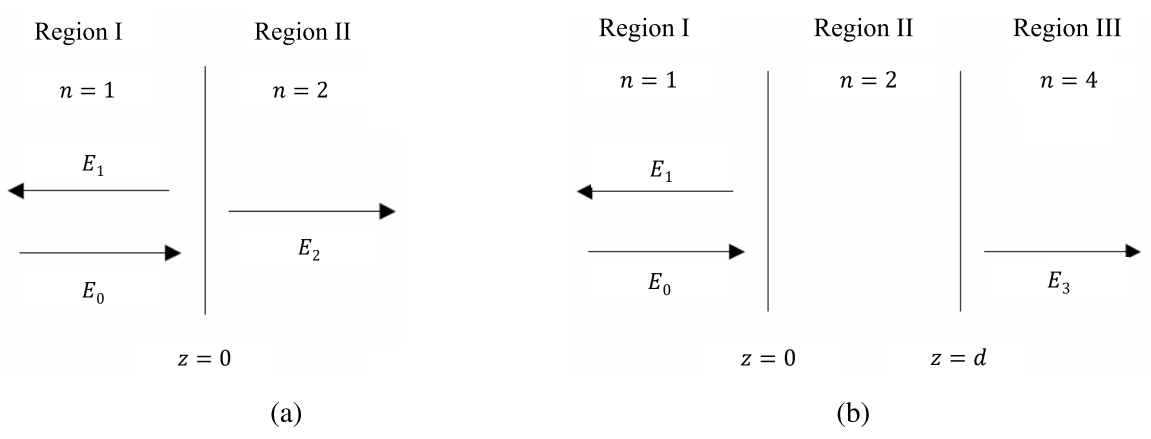

Figure 5

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