ENGINEERING TRIPOS PART IB

Wednesday 8 June 2011 2 to 4

Paper 5

ELECTRICAL ENGINEERING

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

Answer at least ***one*** *question from each section.*

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.

There are no attachments

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book
	CUED approved calculator allowed

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

SECTION A

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

1 (a) Describe the key differences in the construction of a *common emitter amplifier* circuit and an *emitter follower amplifier* circuit. Give an example of an application of each of these circuits and state which type of circuit is shown in Fig. 1. [6]

(b) Draw the small-signal equivalent circuit of the amplifier shown in Fig. 1, and calculate the gain of the circuit at mid-band frequencies if the transistor has small-signal parameters of $h_{fe} = 80$, $h_{ie} = 1.5\ \text{k}\Omega$, $h_{oe} = 120\ \mu\text{S}$ and $h_{re} = 0\ \Omega$. [6]

(c) Fig. 2 shows an alternative amplifier circuit which is designed to have improved stability.

(i) Draw the small-signal equivalent circuit of the improved amplifier shown in Fig. 2 and calculate the gain of the circuit at mid-band frequencies if the transistor has the same small-signal parameters as that used in part (b). [4]

(ii) Using your answer to (c) part (i), calculate the input impedance of the circuit of Fig. 2. [2]

(iii) Explain briefly why the circuit shown in Fig. 2 will be more stable than that shown in Fig. 1. [2]

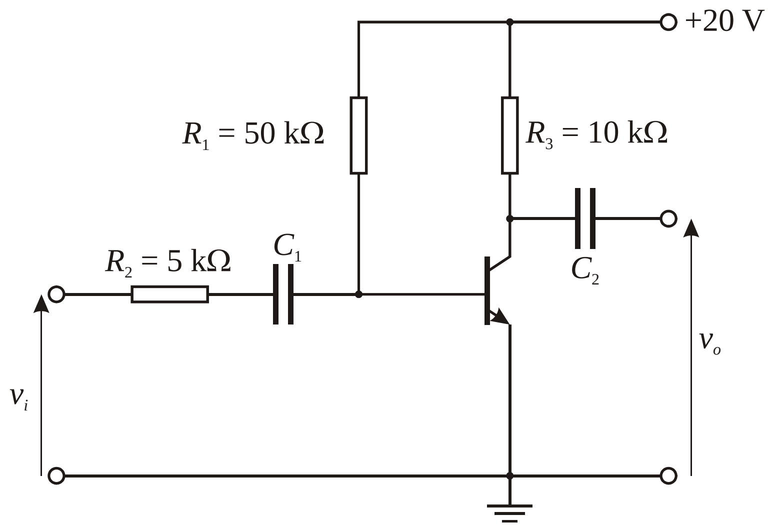
+20 V
R_1 = 50 kΩ
R_3 = 10 kΩ
R_2 = 5 kΩ
C_1
C_2
v_i
v_o

Fig. 1

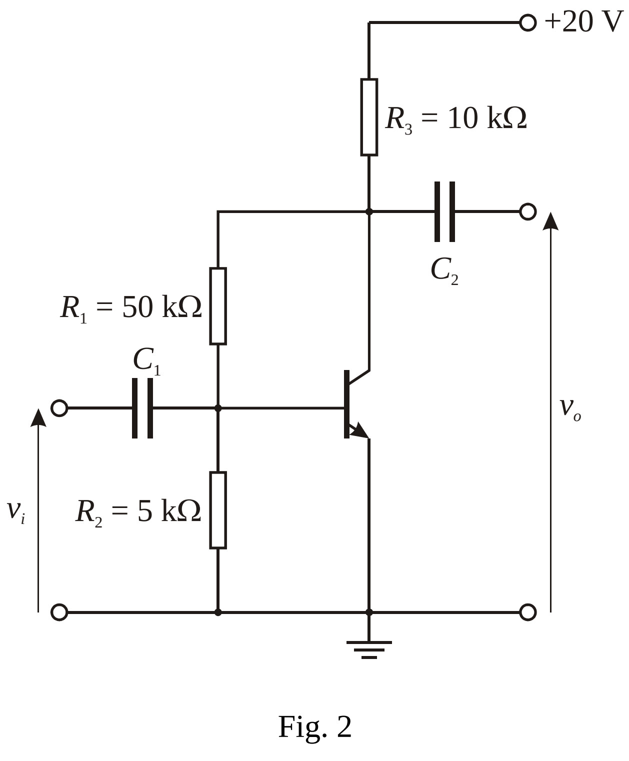
+20 V
R_3 = 10 kΩ
C_2
R_1 = 50 kΩ
C_1
v_i
R_2 = 5 kΩ
v_o

Fig. 2

2 (a) State the closed loop gain, G, for a circuit consisting of an amplifier with open loop gain, A, and for which a fraction, B, of the output is fed back to be subtracted from the input. What criteria must be satisfied if this system is to be used to provide stable oscillations without any external input? [4]

(b) Fig. 3 shows a circuit diagram for a *Wien bridge oscillator*. If the operational amplifier may be considered to be ideal, show that the feedback fraction, B, for this circuit is given by

$$B = \frac{1}{3 + \mathrm{j}\left(\omega RC - 1/\omega RC\right)} \; . \qquad [6]$$

(c) Calculate the value of R_1 required to produce stable oscillations in the circuit of Fig. 3 if R_2 = 5 kΩ. [3]

(d) Calculate the value of C required to produce oscillations at a frequency of 15 kHz if R = 10 kΩ. [3]

(e) In selecting a real operational amplifier for this circuit, what would you consider to be the minimum acceptable input impedance and maximum acceptable output impedance? Justify your answers. [4]

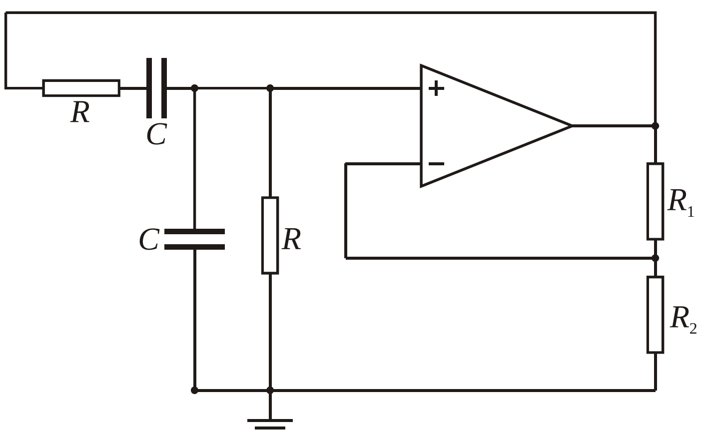

Fig. 3

SECTION B

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

3 (a) What are the two conditions that must be satisfied if a *synchronous a.c. generator* is to produce steady torque? In each case, explain why it is necessary for the condition to be met. [4]

(b) A three-phase, star-connected, synchronous a.c. generator delivers 650 MW of power to a 22 kV infinite bus with unity power factor. The generator has a synchronous reactance of 0.5 Ω per phase and negligible stator resistance. Calculate the generated excitation voltage and the load angle. [5]

(c) The power delivered by the generator to the bus is decreased to 500 MW and the excitation voltage is reduced by 12%. Calculate the new load angle and the power factor. [7]

(d) A grid connected power distribution system consists of a number of synchronous a.c. generators that are connected through a network of transformers to a number of loads. How are the generators considered mathematically when analysing such a network using the *per-unit* system? Explain your answer. [4]

4 (a) The outputs V_1, V_2 and V_3 from a balanced, three-phase generator are connected to each other in series to produce a single phase output $V_1 + V_2 - V_3$. The coils of each phase of the generator are designed with a maximum current rating of I_m.

(i) By adding phasors, calculate the amplitude of the resulting voltage in terms of $|V_1|$. [4]

(ii) Calculate the factor by which the maximum output power is reduced when the three phases are connected in series ($V_1 + V_2 - V_3$) compared with when the generator is star-connected to a three-phase load. [3]

(b) A three-phase power supply operating at 50 Hz is connected via a long feeder line to two factories which are connected in parallel with each other, as shown in Fig. 4. The first factory behaves as a star-connected load consisting of three sets of a 2 Ω resistor and 9.55 mH inductor connected in series. The second factory behaves as a delta-connected load consisting of three sets of a 15 Ω resistor and 7.1 μF capacitor connected in parallel. The line voltage is 11 kV at the factory end of the feeder line.

(i) Calculate the combined power factor of the two factories and the feeder line current from the power supply. [5]

(ii) The overall power factor of the two factories is to be corrected to 0.95 lagging by connecting three identical capacitors in a star in parallel with the two factories. What is the value of the capacitors required to achieve this? [5]

(iii) If the feeder has an impedance of (0.5 + 0.5j) Ω per line, calculate the decrease in real power dissipated in the feeder lines by introducing this power factor correction, assuming that the line voltage at the factory end of the feeder line remains 11 kV. [3]

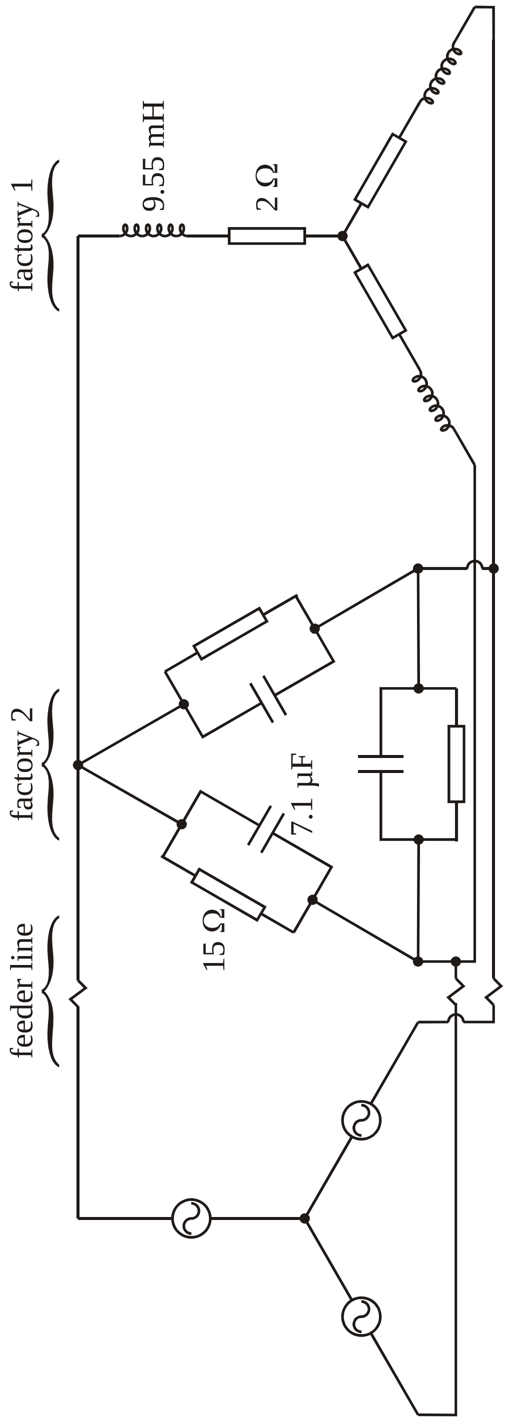

Fig. 4

5 (a) Sketch a graph of how torque varies with angular velocity for an induction motor. Identify clearly on your graph:

(i) the ranges of angular velocity corresponding to *motoring*, *generating* and *plugging*;

(ii) the points at which the *slip* is 0 and 1;

(iii) a typical motor operating point, justifying your answer. [5]

(b) 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 torque that the motor can produce and the resulting motor speed. [6]

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

(c) Explain how an induction motor can be designed so that the angular velocity at which torque is maximised may be varied during operation and why this is useful. [3]

SECTION C

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

6 (a) Explain the physical significance of the *Poynting vector*. [3]

(b) The Sandy Heath television transmitter near Cambridge broadcasts a digital multiplex signal at a frequency of 642 MHz with a power of 20 kW.

(i) Calculate the wavelength of the transmitted wave through free space. [2]

(ii) Assuming that the transmitter produces an electromagnetic wave that propagates through free space with a gain of 10 in the plane of the surface of the earth, calculate the electric field intensity, E, and the magnetic field intensity, H, at a point on the surface of the earth which is 20 km from the Sandy Heath transmitter. [5]

(iii) A television receiving antenna on the roof of a house which is 20 km from the Sandy Heath transmitter has an effective area of 0.25 m^2 . If it is connected to a matched load of 50 Ω, calculate the resulting r.m.s. current that will flow into the television receiver. [5]

(iv) The same receiving antenna is now placed inside the house which has brick walls with a relative permittivity of 4.2 and a relative permeability of 1. Estimate the new r.m.s. current that will flow into the receiver. State any assumptions that you make. [5]

7 (a) Explain what is meant by the term *characteristic impedance* when applied to a transmission line. [2]

(b) By considering an arbitrary wave on a transmission line to be composed of forward and backward components of current (I_F and I_B respectively) and voltage (V_F and V_B respectively), show that the *voltage reflection coefficient* is given by

$$\rho_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

when a transmission line of characteristic impedance Z_0 is connected to a load of impedance Z_L. [4]

(c) Fig. 5 shows a 12 V d.c. power supply with an internal resistance of 15 Ω which is connected via a switch to a 50 m long coaxial cable with a characteristic impedance of 75 Ω. The velocity of waves on the coaxial cable is 6×10^7 m s^{-1}, and it is terminated with a load impedance Z_L of 200 Ω. The switch has been left open for a sufficiently long time for the voltage and current at all points on the coaxial cable to be zero.

(i) Calculate the power of the first wave to be reflected by the load resistor after the switch is closed. [4]

(ii) How long will it take for the reflections in the coaxial cable to have reduced to less than 1% of the power input at the moment when the switch is closed? [6]

(iii) Sketch how the voltage across the load resistor will vary with time after the switch is closed. [4]

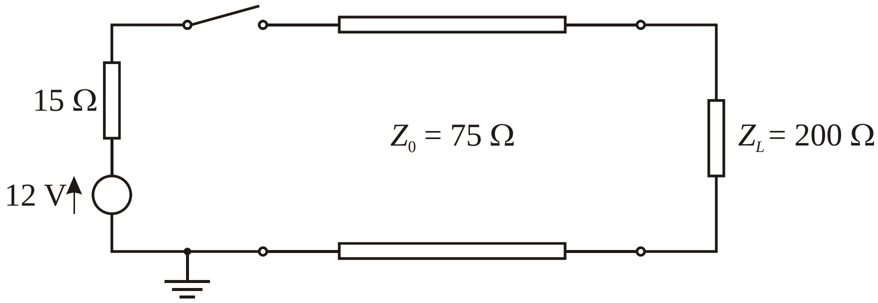

Fig. 5

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