ENGINEERING TRIPOS PART IB

Wednesday 7 June 2006 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 hand margin.*

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

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
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 Figure 1 shows a *common-emitter* amplifier circuit operating from a 20 V supply.

(a) The transistor is biased so that I_C = 20 mA, V_{CE} = 10 V and V_{BE} = 0.7 V. The d.c. current gain of the transistor at this operating point is 250. Find suitable values for R_C and R_B. [4]

(b) What are the limitations of this circuit for establishing the operating point of the transistors, and how might the circuit be improved? Detailed calculations are not required. [2]

(c) Draw a small-signal equivalent circuit for the amplifier of Fig. 1, valid at mid-band frequencies. Determine the value of the load resistance R_L required to maximise the power transferred to the load, and with this R_L determine the mid-band voltage gain. [8]

The small-signal parameters of the transistor are: h_{ie} = $1000\,\Omega$, h_{fe} = 250, h_{oe} = 0, $h_{re} = 0$.

(d) Explain why capacitors C_1 and C_2 reduce the gain of the amplifier at low frequencies. Find an expression for the voltage gain of the circuit in part (c) including the effect of both of these capacitors, and determine the magnitude of the voltage gain at a frequency of 100 Hz if $C_1 = C_2 = 1$ µF. [6]

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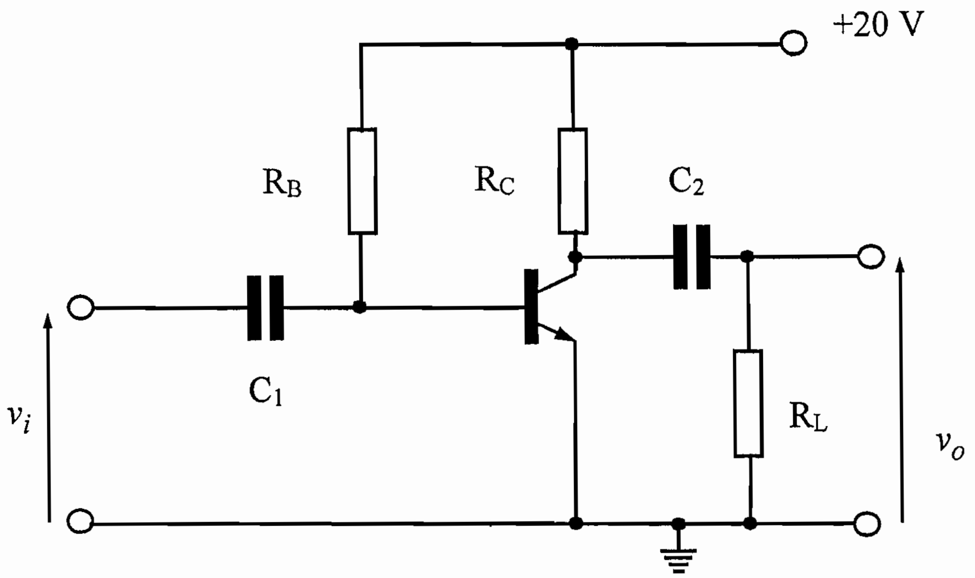

Fig. 1

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2. (a) Explain the meaning of the term *common-mode rejection ratio* used to describe the performance of a differential amplifier, and explain why it is important in the design of precision linear circuits. [3]

(b) Fig. 2 shows a differential amplifier with two inputs v_p and v_q. Assuming that the operational amplifier A1 is ideal, show that provided $R_2 / R_1 = R_4/R_3$, the output voltage v_0 is given by:

$$v_0 = \frac{R_2}{R_1} \cdot (v_q - v_p)$$ [4]

(c) This circuit is to be used to amplify signals v_a and v_b from two similar sensors A and B, as shown in Fig. 3. There is an unwanted signal v_c, independent of v_a and v_b, that arises because of interference from nearby 50 Hz power cables. Using the result of Part (b), or otherwise, show that the output voltage v_0 contains no component of the unwanted signal v_C provided the resistance ratio R_2/R_1 is equal to R_4/R_3 [3]

(d) Indicate qualitatively how non-idealities in the op-amp will affect the condition established in Part (c). [2]

(e) When sensors A and B in Fig. 3 generate equal signal amplitudes of 50 mV but opposite in phase (i.e. $v_b = - v_a$), an amplifier output of 5 V amplitude is required. If $R_1 = R_3 = 10\ \text{k}\Omega$, determine suitable values for the resistors R_2 and R_4. [2]

(f) The non-inverting amplifier of Fig. 4 uses an ideal operational amplifier A2. Draw a circuit diagram to show how the circuits of Figs. 3 and 4 may be combined and adapted to give a differential amplifier of improved performance. What are the key advantages of combining the two circuits? Calculate suitable resistor values for the non-inverting stage so the overall circuit has a differential voltage gain of 1000. [6]

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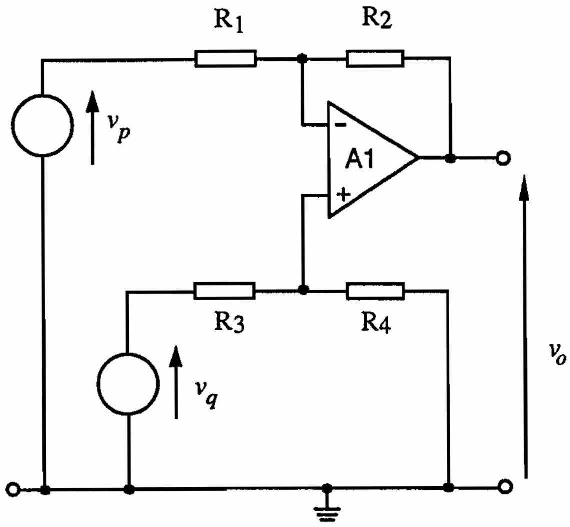

Fig. 2

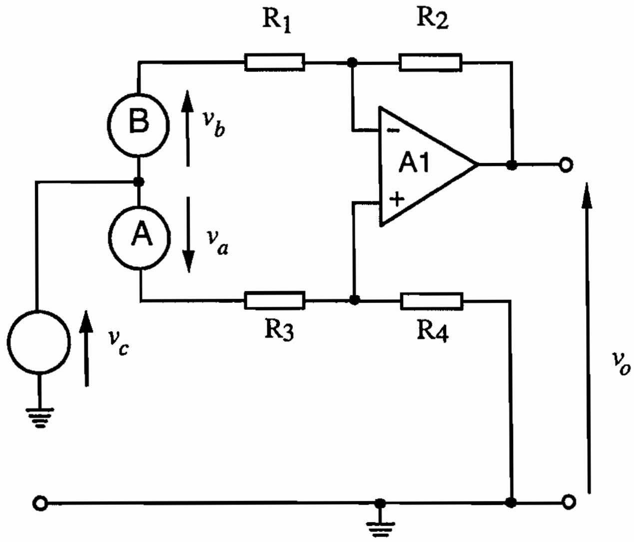

Fig. 3

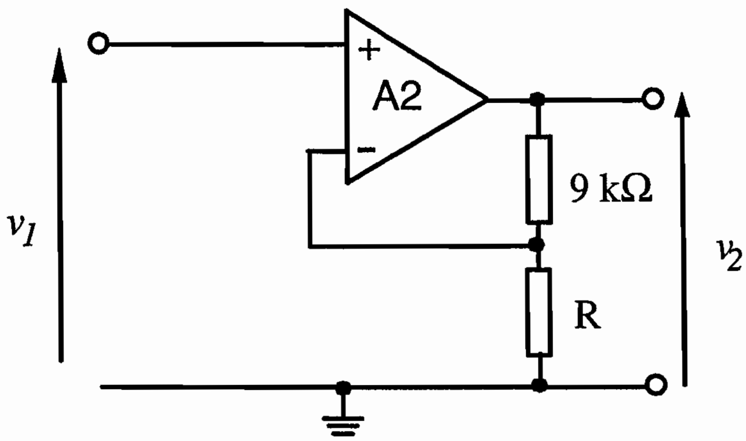

Fig. 4

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SECTION B

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

3 (a) Draw a labelled phasor diagram for a balanced, star-connected 3-phase supply and hence derive the phase and amplitude relationships between the line and phase voltages, and the line and phase currents. [3]

(b) A 415 V, 3-phase power line supplies two separate loads, one being a star-connected load with an impedance of (40 + 30 j) Ω in each arm, the other being a delta-connected load with an impedance of (60 + 80 j) Ω in each arm.

(i) Calculate the power and reactive power supplied to each load. Calculate the total power and power factor for the combined loads. [6]

(ii) The transmission line which supplies these loads has an impedance of (0.8 + 3.2j) Ω per line. Calculate the line voltage at the supply end, assuming the line voltage at the load end is 415 V. [6]

(iii) What would be the new supply line voltage, if the power factor of the combined loads were corrected to unity? [5]

4 A turbine supplies 320 MW of power to a star-connected 50 Hz synchronous generator. It is connected to a 22 kV three-phase infinite bus. The synchronous reactance of the generator is 1.2 Ω. Resistance and mechanical losses can be neglected.

(a) Draw a labelled phasor diagram showing the operating conditions of the generator when supplying a load of lagging power factor 0.8. Hence find the excitation voltage required. [7]

(b) Under other conditions the turbine power is reduced to 240 MW, while the load's power factor changes to unity. What is the new excitation voltage? [7]

(c) The generator is driven by a steam turbine of *maximum* power 350 MW. Sketch a labelled operating chart for the generator if its rating is 400 MVA and the maximum excitation is 40 kV per line. Determine the range of lagging power factors at which the rated MVA could be delivered.

[6]

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5 (a) Sketch a typical torque vs. speed relationship for an induction motor, including the synchronous speed. [3]

(b) Tests on a four-pole, 3-phase, 50 Hz, delta-connected induction motor give the following results.

Speed	Total input power	Line current	Line voltage
1500 rpm	600 W	4 A	415 V
0 rpm	333 W	8 A	30 V

Calculate the slip s at both speeds in the table above. An equivalent circuit with $R_1 = 2\,\Omega$ and $X_1 = X_2'$ is shown in Fig 5. Determine the other equivalent circuit parameters, making any necessary assumptions. [9]

(c) A different 4-pole, 3-phase, 415 V, delta-connected induction motor has the following circuit parameters:

$R_1 = 2\,\Omega$, $R_2' = 2\,\Omega$, $X_m = 100\,\Omega$, $X_1 = 1\,\Omega$, $X_2' = 1\,\Omega$. R_i is very large.

For a speed of 1480 rpm, calculate

(i) the slip,

(ii) the complex input impedance per phase,

(iii) the stator line current. [8]

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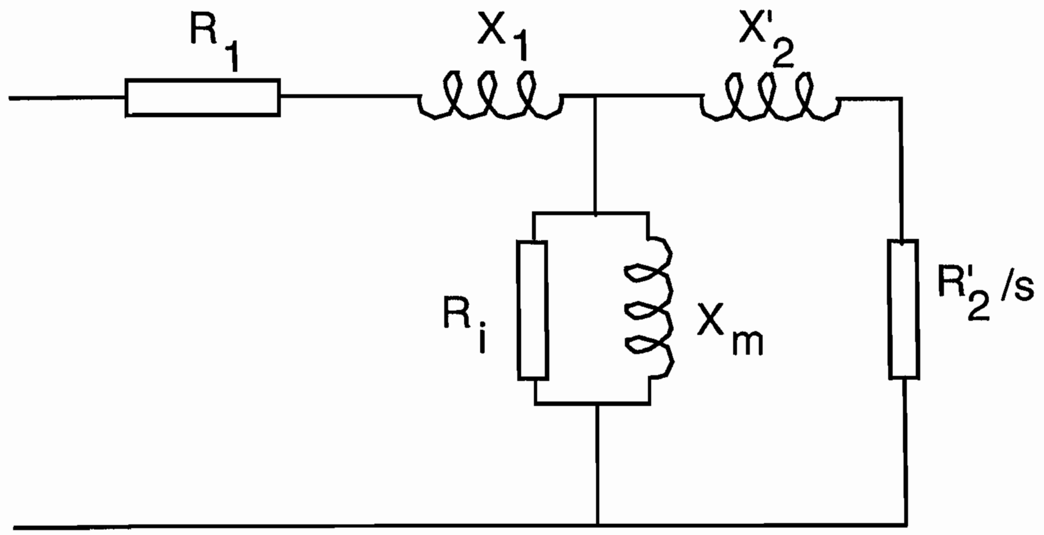

Fig 5

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SECTION C

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

6 (a) Define briefly the characteristic impedance of a transmission line.

A 20 m long coaxial cable has a capacitance per unit length of 80 pF/m, and an inductance per unit length of 0.2 μH/m. Calculate the characteristic impedance Z_0 of the cable and the phase velocity. Estimate the transmission frequency at which transmission line effects become significant. [5]

(b) A circuit consists of a 16 V voltage source with internal resistance of 150 Ω, an ideal switch and a 20 m long, loss-free transmission line having a characteristic impedance of 50 Ω. The wave velocity along the line is $v = 2 \times 10^8$ m/s. The line is terminated by a load impedance Z_L. At time $t = 0$, the switch is closed and remains closed thereafter. Calculate the value of the voltage of the first incident wave that travels from source to load.

(c) Calculate the reflected power from the load, in each of the following cases:

(i) $Z_L = \infty$

(ii) $Z_L = 0$

(iii) $Z_L = Z_0$ [9]

(d) For $Z_L = 150\ \Omega$, plot the time variation of the voltage at the midpoint of the transmission line, for up to 0.4 μs after the switch has been closed. Mark on the plot the times and voltages. [6]

7 (a) A satellite antenna transmits a radio wave through free space, without power loss. The peak power of the wave is 25 W. If the gain of this antenna is 2000, calculate the peak power intensity at a distance of 25000 km from the antenna. [6]

(b) A receiving antenna is placed 25000 km from the satellite. The receiving antenna has an area of 2 m^2 and is connected via a 50 Ω coaxial cable to an amplifier which is perfectly matched to the cable. Calculate :

(i) the peak power received by the antenna

(ii) the RMS current that flows into the receiver. [7]

(c) The magnetic field strength of a plane electromagnetic wave propagating through free space in the z-direction is given by

$$H(z,t) = \hat{e}_y H_0 \exp[j(\omega t - \beta z)]$$

Using Maxwell's equations or otherwise, show that the electric wave is given by

$$E(z,t) = \hat{e}_x \eta_0 H_0 \exp[j(\omega t - \beta z)]$$

where ω is the angular frequency, β is the wave-vector or propagation constant, $\hat{e}_y$ and $\hat{e}_x$ are unit vectors, H_0 is the amplitude of the magnetic field and η_0 is the impedance of free space. [7]

END OF PAPER