Version FT/2

EGT1
ENGINEERING TRIPOS PART IB

---

Wednesday 5 June 2019    2 to 4.10

---

**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*** *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.**

## SECTION A

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

1 (a) Define Thevenin and Norton's theorem and explain how they can be used to simplify the analysis of circuits. [3]

(b) The circuit shown in Fig. 1 is a single stage amplifier based on a single bipolar junction transistor. The amplifier is biased using the component values $R_1 = 47k\Omega$, $R_2 = 10k\Omega$, $R_3 = 5k\Omega$, $R_4 = 1k\Omega$ and $V_{cc} = 10$ V.

(i) Explain the role of each of the components in the circuit when setting up a suitable operating point. [3]

(ii) Using circuit analysis, calculate the percentage variation in $V_{CE}$ when the DC current gain, $h_{FE}$ varies from 50 to 300. [7]

(c) Sketch the small signal model for the amplifier in Fig. 1 when working at mid-band frequencies. [4]

(d) Derive an expression for the mid-band gain ($v_{out}/v_{in}$) of the amplifier, using the small signal parameters $h_{ie}$, $h_{fe}$ and neglecting the effects of $h_{re}$ and $h_{oe}$. [4]

(e) Discuss the effects of $R_4$ in the analysis of this circuit. How might the limitations it introduces be avoided? [4]

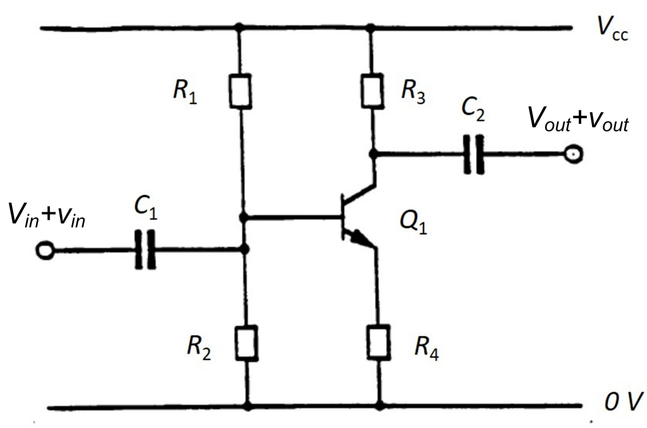


Fig. 1

2 (a) If an amplifier with a gain of A is subject to feedback from its output to its input via a network B, explain what conditions would result in an oscillatory output. [5]

(b) The circuit shown in Fig. 2 is an oscillator based around an ideal amplifier.

(i) Derive an expression for the oscillation frequency of the circuit. [8]

(ii) Explain how $R_1$ and $R_2$ can be used to control the output level of the oscillator. [5]

(c) The circuit in Fig. 2 is used to drive a low impedance ultrasonic transducer, via a power amplifier such that in Fig. 3. What class is this power amplifier and what are its limitations in amplifying a sinusoidal signal? [7]

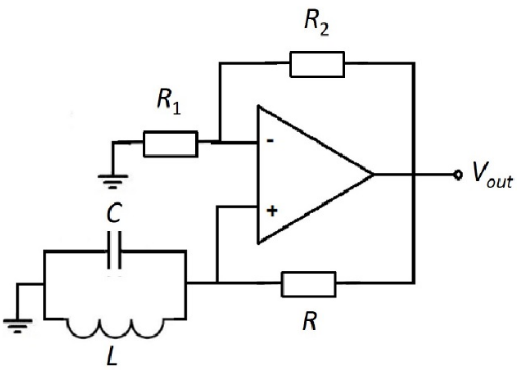


Fig. 2

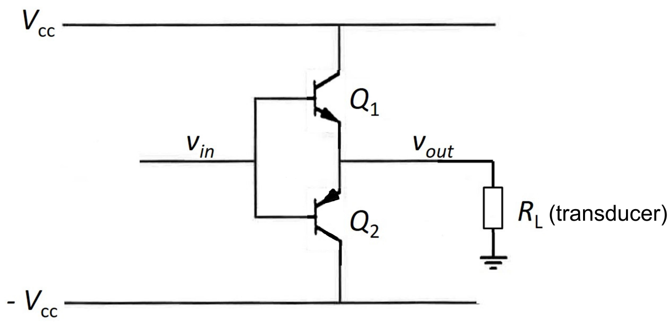


Fig. 3

## SECTION B

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

3 A three-phase 415 V, 50 Hz supply is connected to a balanced star-connected load and a balanced delta-connected load. The impedance of each leg of the delta-connected load is 300 + j150 Ω and each phase of the star-connected load consists of a 400 Ω resistor in parallel with a 10 $\mu$F capacitor.

(a) Draw the most simplified structure of the equivalent one-phase circuit. [4]

(b) Calculate

(i) the line current; [4]

(ii) the input power; [4]

(iii) the input VARs. [4]

(c) We wish to alter the power factor of the system to 0.95 lagging.

(i) Explain whether delta-connected capacitors or inductors must be used. [2]

(ii) Derive the required value of the capacitors/inductors. [5]

(iii) Explain whether each of the following parameters change after correcting the power factor: [2]

A. The total dissipated power;

B. The supply current.

4 (a) Explain why three-phase power generation is superior to any other number of phases. [4]

(b) A synchronous generator is connected to an infinite bus.

(i) What is an infinite bus? Give an example where an infinite bus assumption may not hold. [3]

(ii) What conditions must be satisfied for a synchronous AC generator to produce steady torque? Explain why these conditions must be met. [4]

(c) A synchronous star-connected generator with 4 poles and a synchronous reactance of $X_s = 0.2\ \Omega$, is connected to a 50 Hz infinite bus with a line voltage of 11 kV.

(i) Find the speed of rotation and the torque of the prime mover if the prime mover power is set to 400 MW. [2]

(ii) If the prime mover power is kept at 400 MW and the power factor at the terminals of the machine is 0.9 lagging, find the excitation voltage. [6]

(iii) If the prime mover power reduces to 250 MW, while the excitation voltage that you obtained in (ii) remains unchanged, calculate the new power factor. [6]

5 (a) Explain why the induction motor is sometimes known as an asynchronous motor. [3]

(b) Consider an induction motor.

(i) Draw its equivalent circuit model. [2]

(ii) What is the locked rotor test? How is the equivalent circuit approximated for this test? [3]

(iii) What is the no-load test? How is the equivalent circuit approximated for this test? [3]

(c) A four-pole star-connected, three-phase induction motor is operated at 1350 rpm, when driven by a line voltage of 600 V at 50 Hz. The equivalent circuit of this induction motor has the following circuit parameters: $R_1 = R_2' = 2\ \Omega$, $R_0 = 2500\ \Omega$, $X_{\mathrm{m}} = 500\ \Omega$, $X_1 = X_2' = 6\ \Omega$.

(i) Calculate the value of slip. [3]

(ii) Stating any approximations, calculate the peak torque. [5]

(iii) Find the speed at which the maximum torque occurs. [3]

(iv) How can we maximize the starting torque of this motor? Calculate the required changes in the circuit elements of the equivalent circuit model. [3]

## SECTION C

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

6 The terminals of an AC voltage source are connected to two parallel microstrip conductors in a printed circuit board (PCB), which have specific inductance $L$ and specific capacitance $C$. The voltage source amplitude is $V$ and $x = 0$ is at the nodes of the two wires connecting to the source.

(a) Show that the telegraphers equations for the voltage $V$ and current $I$ in the parallel wires may be expressed as functions of distance $x$ along the wires at any given instant of time $t$. Hence comment on the form of the time-varying $V$ and $I$ on the microstrips. [3]

(b) Derive the general solutions for the voltage and current in the two parallel wires as functions of $x$ and $t$. [4]

(c) Using the solutions to (a) and (b) above obtain an expression for the impedance presented by the two parallel wires to the voltage source. [3]

(d) Two parallel microstrips on the PCB have values of $L$ = 4.0 x $10^{-7}$ H $m^{-1}$ and C = 2.5 x $10^{-10}$ F $m^{-1}$ and are used to connect a voltage source of 10 MHz to a load on the board. Estimate the maximum length $l$ of the parallel metal tracks which allows the following assumption to be made: the voltage at the source may be considered to be equal to that at the load connected, as the voltage difference between the source voltage and the voltage $V(x, t)$ at the load is no more than 1%. [5]

(e) A two parallel wire transmission line of length 5 m having the same $L$ and $C$ values as for the two parallel microstrips on the PCB in (d) is used to connect a load $Z_L$ = 50 + j10 Ω to an ideal (i.e. internal impedance of 0 Ω) voltage source $\hat{V}_S$ = 5 + j0 $V$ operating at a frequency of 10 MHz.

(i) What is the reflection coefficient at the load? [2]

(ii) Derive an expression for the steady state voltage as a function of distance $x$ over the transmission line (Hint: Consider the conditions imposed by the ideal voltage source on the sum of the forward and reflected waves at $x$ = 0). [5]

(iii) Hence, calculate the steady state voltage at the load. [3]

7 (a) Using Maxwell's equations, show that the time varying electric field $\underline{E}$ and the associated magnetic field $\underline{H}$ in free space give rise to electromagnetic wave propagation. [3]

(b) Based on the results from (a), how can one conclude that visible light in free space is a form of electromagnetic wave? [3]

(c) Considering $\underline{E}$ and $\underline{H}$ fields to be plane waves in the $x - y$ plane

(i) calculate the characteristic impedance of free space. [4]

(ii) In which direction is the electromagnetic power transmitted? Justify your answer. [3]

(d) A $\frac{3}{4}\lambda$ dipole antenna is used to transmit a radio signal with a carrier frequency of 100 MHz. In polar coordinates, the antenna is oriented vertically at $\theta = 0$, perpendicular to the $r,\phi$ plane with coordinates ($\frac{3}{4}\ \lambda\underline{e_{\mathrm{r}}}$, $0\underline{e_{\theta}}$, $0\underline{e_{\phi}}$). In the far field, which is a distance many wavelengths away from the antenna, the electric field $\underline{E}$ at a distance $r$ is given as

$$\underline{E} = [E_0 sin\theta sin(\omega t - 2\pi r/\lambda)]\underline{e_{\theta}}/r \quad (1)$$

where $\mathrm{E_0}$ is the rms magnitude of the electric field at the transmitting antenna and $\lambda$ is the wavelength.

(i) What is the corresponding magnetic field (make clear its orientation)? [3]

(ii) Derive an expression for the power density in the electromagnetic field at a distance $r$ from the antenna and comment on the direction of the power transmission. [4]

(iii) A receiving antenna on a radio is located a distance $100\lambda$ away in parallel with and on the same plane as the transmitting antenna at coordinates (100 $\lambda\underline{e_{\mathrm{r}}}$, $\pi/2\underline{e_{\theta}}$, $\phi\underline{e_{\phi}}$). The receiving antenna has a signal capture area extending over $\delta\theta = 0.1$ rad and $\delta\phi = 0.1$ rad. What is the average power of the signal received by the radio antenna when the strength of the transmitting electric field $\mathrm{E_0} = 40\ \mathrm{V\ m^{-1}}$. [5]

**END OF PAPER**