

EGT0
ENGINEERING TRIPOS PART IA

Monday 12 June 2017 9 to 12

Paper 3

ELECTRICAL & INFORMATION ENGINEERING

Answer all questions.

*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.

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

SECTION A

1 (short) Figure 1 shows a MOSFET which is to be biased to a DC operating point of $V_S = 2\text{ V}$, $V_{GS} = 2\text{ V}$, $V_{DS} = 8\text{ V}$, and $I_D = 5\text{ mA}$.

(a) Calculate the values of R_1 and R_2 to achieve this. [5]

(b) If $r_d = 40\text{ k}\Omega$ and $g_m = 5\text{ mA V}^{-1}$ for the MOSFET, calculate the mid-band small signal voltage gain of this circuit. [5]

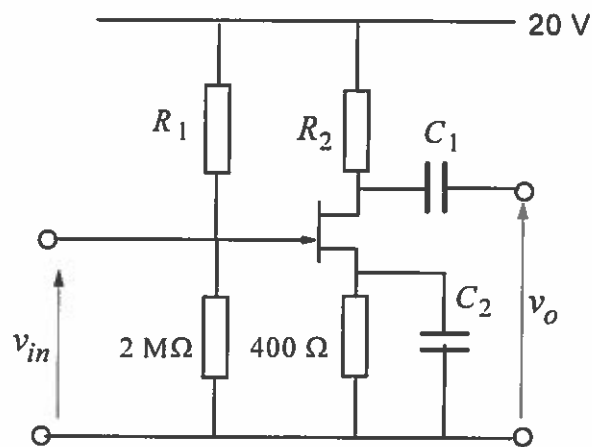


Fig. 1

2 (short) Using Thevenin's theorem or otherwise, calculate the current through the 6 V battery shown in Fig. 2. [10]

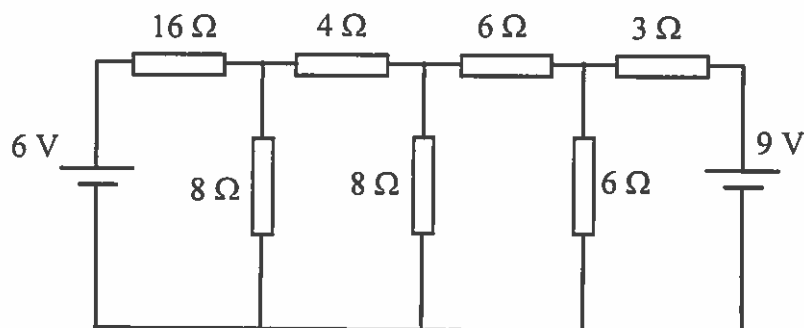


Fig. 2

3 (short) (a) Describe the advantages of *negative feedback* for amplifier design. [4]

(b) Figure 3 shows an Op Amp circuit driving a cable of resistance R_3 , and a load R_4 in parallel with capacitance C . Taking $R_1 = 4.5 \text{ k}\Omega$, $R_2 = 500 \text{ }\Omega$, $R_3 = 75 \text{ }\Omega$, $R_4 = 225 \text{ k}\Omega$, and $C = 1000 \text{ pF}$, calculate the mid-band gain and the -3 dB frequency of the output circuit [6]

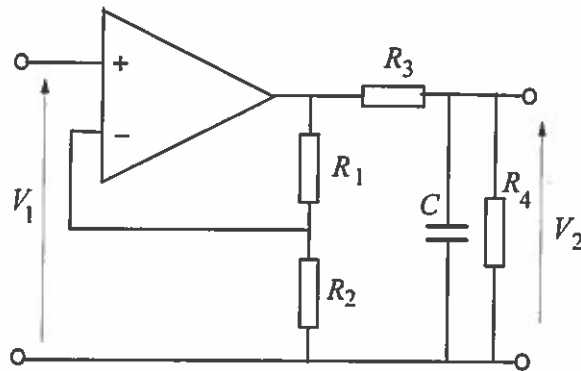


Fig. 3

- 4 (long) (a) Define Thevenin's and Norton's theorems. Illustrate these by deriving an equivalent circuit in each case for the circuit shown in Fig. 4. [10]

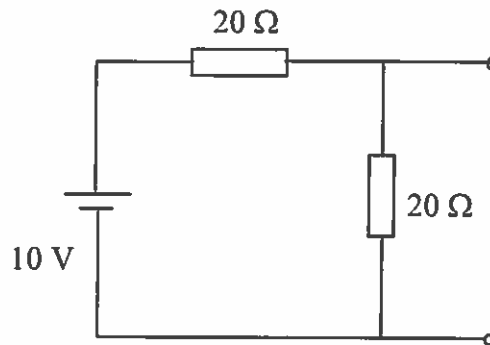


Fig. 4

- (b) Figure 5 shows a radio frequency (RF) tuner circuit connected to a 500 kHz RF voltage source.

- (i) Determine the complex impedance of the circuit and hence find the magnitude and phase of the input current with respect to the voltage source of 6 V RMS. [10]
- (ii) What would be the resonant frequency of this circuit? [5]
- (iii) What is the output voltage at this resonant frequency? [5]

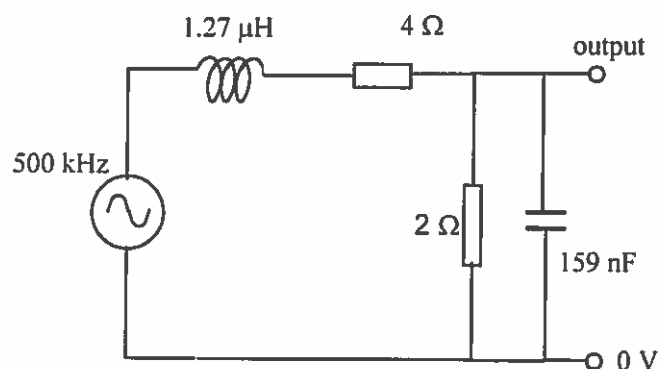


Fig. 5

5 (long) (a) Draw the small-signal circuit model for the source-follower circuit shown in Fig. 6 and derive an expression for the:

(i) input impedance;

(ii) gain when no load is connected;

(iii) output impedance.

[15]

(b) Evaluate these quantities when $g_m = 3 \text{ mA V}^{-1}$, and $r_d = 15 \text{ k}\Omega$ for the transistor and with $R_1 = 20 \text{ M}\Omega$ and $R_2 = 3 \text{ k}\Omega$.

[10]

(c) What is the main purpose of a source follower?

[5]

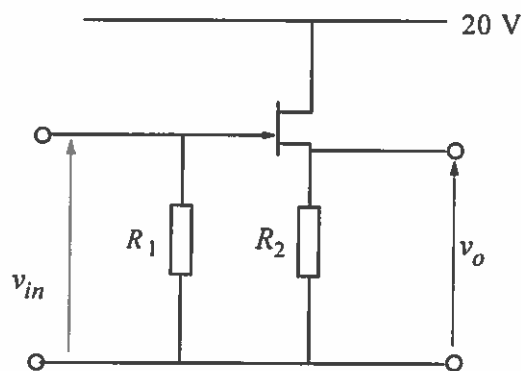


Fig. 6

SECTION B

6 (short) The Boolean expression for a two-input exclusive-OR gate can be written as $A\bar{B} + \bar{A}B$.

- (a) Using De Morgan's theorem, derive the expression for a two-input exclusive-NOR gate and implement it using only two-input NAND gates. [6]
- (b) Implement a two-input exclusive-NOR gate using only two-input NOR gates. [4]

7 (short) A 4-bit Digital to Analogue Converter (DAC) is shown in Fig. 7. Digital '1' is assumed to be 5 V and a digital '0' is assumed to be 0 V. The operational amplifier is ideal.

- (a) Briefly explain the principle of operation of this DAC. What are the drawbacks of this type of DAC? [5]
- (b) What is the resolution of this DAC expressed as a percentage of the output voltage when all the inputs are set? Determine the change in the output voltage V_{out} if the input digital signal is changed from 1001 to 1011. [5]

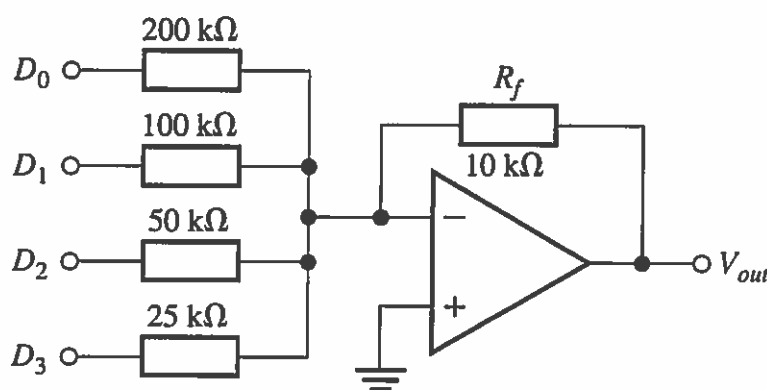


Fig. 7

8 (short) The following PIC12F629 code is executed:

```
main    movlw 111 ;  
        movwf 0x33 ;  
        movf 0x30, W ;  
        call label ;  
        movwf 0x32 ;  
        btfsc 0x32, 2 ;  
        clrf 0x33 ;  
.....  
label   subwf 0x31, W ;  
        return ;
```

(a) Explain each of the operations. [4]

(b) If the contents of 0x30 and 0x31 are decimal numbers 20 and 30, respectively, what will be the content of the memory locations 0x32, 0x33 and bit 2 in the status register after the code is executed? [6]

9 (long) A 3-bit synchronous counter is to be designed using JK bistables with the following sequence: 000, 001, 011, 010, 110, 111, 101, 100, 000 (recycle). The counter should count up when the control input $\overline{\text{UP/DOWN}}$ is 1 and count down when it is 0.

- (a) Allocating the 3-bit word as the state variables, draw the state diagram for the system. [3]
- (b) Derive the state-transition table. [6]
- (c) With the aid of Karnaugh maps, develop simplified Boolean expressions for the J and K inputs of the bistables. [15]
- (d) How many logic gates and JK bistables would be required to implement the complete design? With combinational logic gates for inputs, draw the design for the most significant bit JK bistable. [6]

SECTION C

10 (short) (a) A long straight wire carries a current of 3 A. What is the strength and direction of the magnetic flux density \mathbf{B} at a distance of 100 mm from the wire? [3]

(b) A second wire is positioned parallel to the first wire at a distance of 100 mm. The second wire carries a current of 1 A in the opposite direction to that of the first wire. Calculate the strength and direction of the magnetic flux density \mathbf{B} at a point 30 mm from the first wire and 70 mm from the second wire. [7]

11 (short) The magnetic circuit shown in Fig. 8 consists of 4% silicon-iron with a coil of 1000 turns carrying a current of 2 A. The square cross-sectional area of the magnetic circuit is 100 mm^2 .

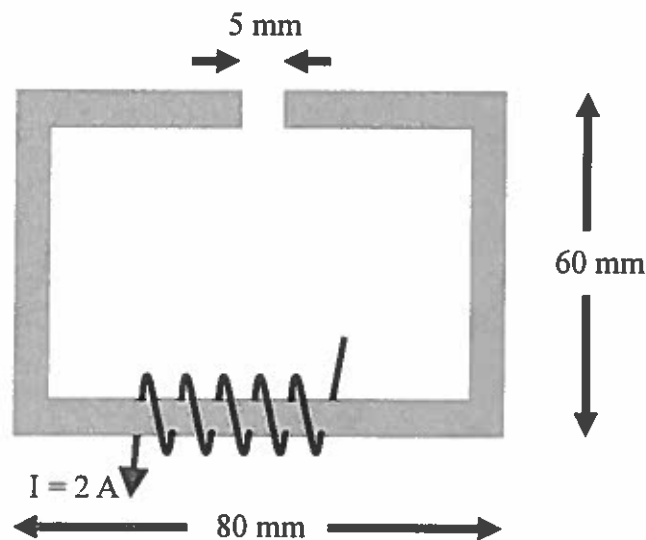


Fig. 8

(a) Calculate the magnetic flux density in the air gap stating any assumptions made. [4]

(b) A 2 mm thick square plate of an ideal magnetic material with relative permeability of 1000 measuring 10 mm on each side is inserted symmetrically into the air gap so that it is equally spaced between the surfaces of the magnetic circuit. What is the value of the magnetic flux density in the air gaps? [6]

12 (long) (a) Explain the principle of virtual work as applied to the estimation of electrostatic forces between charged conductors. [4]

(b) A capacitor shown in Fig. 9 consists of two conductors of arbitrary shape with charges $+q$ and $-q$ respectively. A constant potential V is maintained between the two conductors. Using the principle of virtual work show that the force between the conductors is

$$F = \frac{1}{2} V^2 \frac{dC}{dx}$$

where C is the capacitance of the conductors [10]

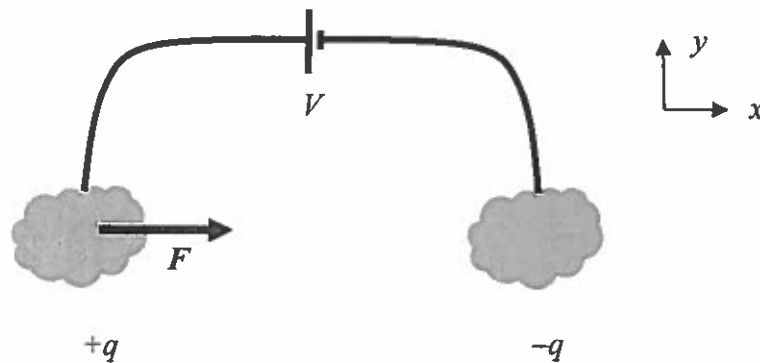


Fig. 9

(c) Consider the parallel capacitor of Fig. 10. By considering the electrostatic energy stored in the capacitor as a function of charge q and assuming that the bottom plate is stationary, show that the force on the upper plate of the capacitor is

$$F = \frac{CV^2}{2d}$$

where d is the spacing between the capacitor plates, V is the voltage applied between the plates and C is the capacitance. [8]

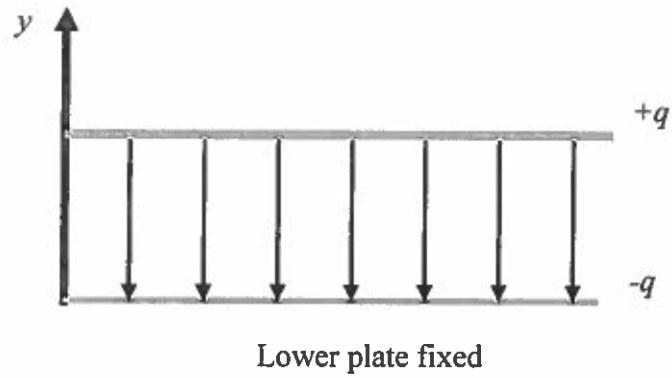


Fig. 10

(d) The principle of virtual work can also be applied to determining the force between two inductors. Explain why this force is only a function of the mutual inductance between the two coils.

[8]

END OF PAPER

THIS PAGE IS BLANK