ENGINEERING TRIPOS PART IA

Tuesday 12 June 2001 9 to 12

Paper 3

ELECTRICAL AND INFORMATION ENGINEERING

*Answer not more than **eight** questions, of which not more than **three** may be taken from Section A, not more than **three** from Section B, and not more than **two** from Section C.*

*The **approximate** number of marks allocated to each part of a question is indicated in the right margin.*

All questions carry the same number of marks.

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

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SECTION A

*Answer not more than **three** questions from this section.*

1 A battery, modelled as a 12 V e.m.f. in series with a resistance of 1 Ω, is being charged by a constant current source through the network shown in Fig. 1. The multi-range ammeter A_m used to measure the battery current drops a voltage of 1 V at full-scale deflection on all ranges. Here it is set to its 10 A range and it reads 1 A.

(a) What is the value of the constant current supply? [7]

(b) Determine the powers dissipated in every component in the circuit and find the input power. What fraction of the power goes into the battery, ignoring any heating effect on it? [6]

(c) What would be the current into the battery if the ammeter was replaced with a wire of zero resistance? [7]

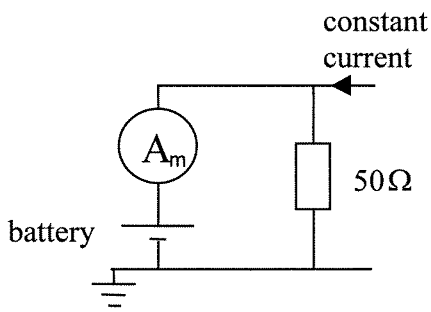

Fig.1

2 The circuit of Fig. 2 is used to drive a speaker coil, represented by L from an oscillating voltage source v_s of angular frequency ω.

(a) Find an expression for the transconductance (i/v_s) of this circuit if the operational amplifier is ideal (infinite gain; infinite input impedance; zero output impedance). [5]

(b) If instead the operational amplifier has finite gain A while otherwise remaining ideal, derive an expression for the transconductance of the form $1/(X+jY)$ in terms of R, ω, L and A. [5]

(c) Find the -3 dB point for the transconductance if the amplifier gain A varies with frequency f, and is $A = \dfrac{100}{1 + jf/f_c}$ and R and L are such that $2\pi f_c = R/L$. [10]

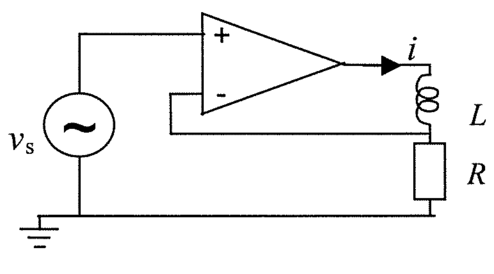

Fig. 2

3 A crane lifts a mass of 1 kg at a speed of 1 ms^{-1}. There are no power losses and the crane's 50 Hz AC motor can be modelled as an inductance L of 50 mH in series with a resistor R, where the latter dissipates a power equal to the output of the motor.

(a) If the input current is 1 A when lifting this load, what is the power factor of the circuit? [6]

(b) If the crane is driven by a higher voltage AC supply through an ideal step-down transformer with a turns ratio of 20:1, what capacitance can be placed across the transformer's high voltage terminals to give the circuit a power factor of unity? [7]

(c) If instead of needing power factor correction, the transformer's winding losses for this load are known to be 3 W and 4 VAR's, what will be the high voltage supply and what will be the input power factor? [7]

4 (a) Draw the small signal model for the circuit of Fig. 3 if the transistor has a transconductance of g_m. The drain resistance and all other transistor parameters may be ignored. [4]

(b) Show that an expression for the small signal gain of the circuit v_2/v_1 at an angular frequency ω is:

$$\frac{v_2}{v_1} = \frac{-g_m R_1}{1 + \dfrac{g_m R_2}{1 + j\omega C_2 R_2}}$$ [6]

(c) If C_2 is very large, what does the gain expression become? If the angular frequency ω tends to zero, what is the gain expression? [4]

(d) What is the gain magnitude and phase change for the circuit if the frequency equals 1 kHz, $C_2 = 300$ nF, $g_m = 0.05$ S and $R_1 = R_2 = R_3 = 1$ kΩ? [6]

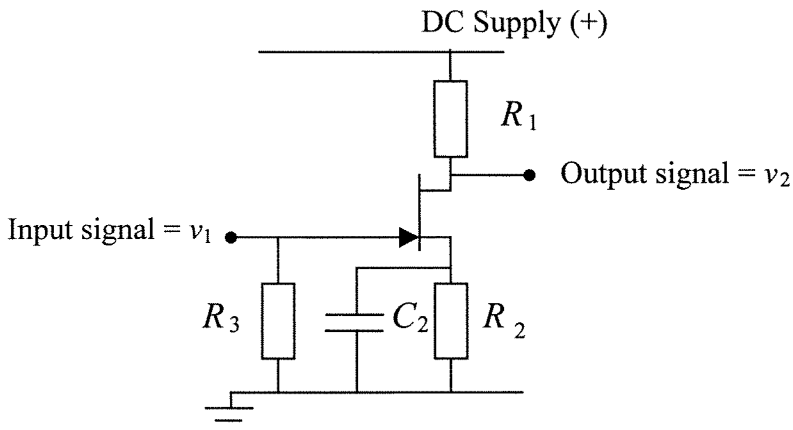

Fig. 3

SECTION B

Answer not more than **three** *questions from this section.*

5 (a) What are static hazards in digital circuits? Show how static hazards arise and how they can be eliminated using a Karnaugh map. [6]

(b) Given :

$$F = A.B.\overline{C}.D + A.C + B.\overline{C}.\overline{D} + \overline{B}.C + \overline{A}.\overline{C}.\overline{D} + \overline{A}.\overline{B}.\overline{C}.D$$

(i) Show using a Karnaugh map that F can be simplified to : [5]

$$F_1 = A.B + \overline{A}.\overline{B} + A.C + B.\overline{C}.\overline{D}$$

(ii) Show that there are a total of four possible simple expressions for F. State whether these solutions are hazard free. [4]

(iii) Show how F_1 can be implemented using 2-input NAND gates and draw the circuit. [5]

6 (a) What is meant by an unused state in the design of synchronous sequential logic? In what situations could an unused state cause improper operation to occur? [4]

(b) The state sequence for an excess-three binary counter is shown in Fig. 4.

A	B	C	D
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1
1	0	1	0
1	0	1	1
1	1	0	0

Fig. 4

The counter is to be implemented using four clocked J-K bistables.

(i) Draw a complete state table for the counter, showing the required J and K inputs at each stage. [6]

(ii) By using Karnaugh maps, find expressions for the J_B, K_B, J_C and K_C inputs. [6]

(iii) Suggest two possible general methods for returning the counter to the correct sequence if an unused state occurs. [4]

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7 (a) What are the *addressing modes* in a microprocessor? By using the ADDA instruction as an example, show the difference between the Immediate, Direct, Extended and Indexed addressing modes of the 6800 microprocessor. [4]

(b) A set of numbers in the range $00 to $7F that represent a positive half-cycle of a triangle wave are stored in a table starting at location $1000. The program fragment shown in Fig. 5 is to be used to send data from this table to a digital to analogue (D/A) converter, memory mapped at location $E000.

(i) Copy the program fragment shown in Fig. 5 and fully comment the operation performed by each line. What is the function of the instructions following LOOPC ? [5]

(ii) Find the number of microprocessor clock cycles taken to perform one pass through LOOPA. If the microprocessor clock frequency is 8 MHz, how long does this take? [5]

(iii) If the D/A converter could output the number stored at $E000 immediately it was stored, what would be the average sampling frequency of the output waveform? [2]

(iv) If it is desired to output the waveform at an 8 kHz sampling frequency, outline how the code could be modified. [4]

```
LOOPA:  LDX     #$1000
LOOPB:  LDAA     0,X
        STAA    $E000
        INX
        CPX     #$1040
        BNE     LOOPB
        LDX     #$1000
LOOPC:  CLRA
        SUBA     0,X
        STAA    $E000
        INX
        CPX     #$1040
        BNE     LOOPC
        BRA     LOOPA
```

Fig. 5

8 (a) (i) What is a shift register? [3]

(ii) The output from the final two stages of a 4-stage shift register are fed back to the input to the first stage via an exclusive-OR gate. How many steps are there in the longest sequence of shift-register states? [4]

(b) Several 64K bit memory devices, each with four data lines, are to be connected to a microprocessor with an 8-bit data bus.

(i) What other connections will there be on each memory device? [3]

(ii) How many devices are needed to make 32K bytes of memory? [2]

(iii) How should the chip-select lines on the devices be connected if the memory is to appear in the address range \$0000 to \$7FFF ? [4]

(iv) Draw a circuit diagram showing the connection of the devices to microprocessor address, control and data buses. [4]

SECTION C

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

9 Two spherical, insulating balloons, each with a diameter of 20 cm, are rubbed all over with a woollen sleeve to a voltage of 100 kV, then placed against each other. You may assume that the total charge on each balloon acts as if concentrated at the centre of the balloon.

(a) What is the charge on each balloon? [5]

(b) What is the force between the balloons? [5]

(c) One of the balloons is placed alone against a conductive ceiling coated with insulating paint. If the mass of the balloon is 5 g and charge leaks at a uniform rate from all points on it into the air at a rate of 1 nCs^{-1}, after what time will the balloon fall from the ceiling? [10]

10 A bar with a cross-sectional area of 5 mm^2 and a relative permeability of 1000 is curved into a C shape with a gap of 10 mm between its tips and remaining dimensions as shown in Fig. 6. A straight bar with the same permeability and cross-section as the other is allowed to slide along the axis of symmetry of the C shape, and the two bars are held in contact by 500 turns of a current carrying wire.

(a) If the separation of the straight bar from the C shape is negligible, what H field is created in the central bar by a current of $I = 0.5$ A through the wire? [6]

(b) If a space is opened up by pulling the end of the straight bar 1 mm back from its original position, what is the energy per unit volume of the magnetic field in the space? [7]

(c) The bar is returned to its original position. Ignoring gravity, what force will pull the bar out of the C shape? [7]

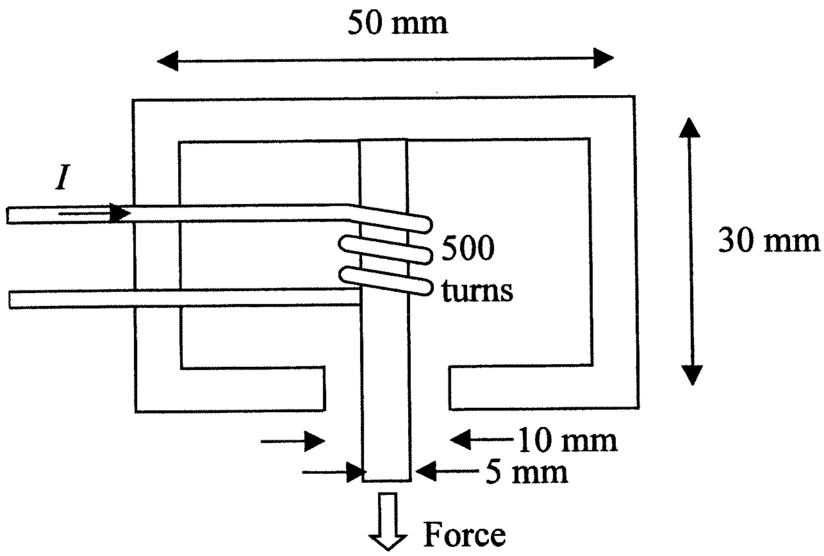

Fig. 6

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11 An air-filled co-axial cable, a unit length of which is shown in half-section in Fig. 7 has an inner conductor of radius a and an outer conductor of radius b, and a current I flows down the inner conductor and back up the outer conductor.

(a) Find an expression for the H-field between the two conductors at radius r from the centre. [5]

(b) The current I steadily increases so as to cause a rate of change of flux through the dotted loop of $d\phi/dt$. Find an expression for the e.m.f. around the dotted loop. [5]

(c) Find the inductance per unit length of an air-filled co-axial cable with an inner radius of 1 mm and an outer radius of 3 mm. [10]

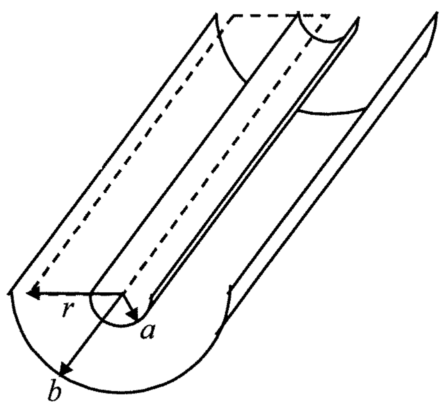

Fig. 7

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