ENGINEERING TRIPOS PART IB

Friday 5 June 1998 2 to 4

Paper 8

SELECTED TOPICS

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

Answer questions from **two** *sections only.*

Do not answer more than **two** *questions from any section.*

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.

(TURN OVER

SECTION A (Civil and Structural Engineering)

1 A reinforced concrete wall 9 m high, extends 6 m into the underlying soil, as shown in Fig. 1. The ultimate load on the back of the wall can be taken to be a triangularly distributed load with a maximum horizontal stress of 300 kN/m^2. A horizontal tie-rod, located 2 m below the top of the wall, extends back to an anchor block which can be assumed to be able to provide as much force as necessary.

On the front of the wall, the earth pressure is assumed to be triangularly distributed, with a maximum horizontal stress of σ.

The wall was constructed by the diaphragm walling method, and thus has constant thickness. It is made from concrete with a cube strength f_{cu} of 30 N/mm^2.

By considering a 1 m length of the wall;

(a) Determine the force in the tie rod T and the value of σ; [5]

(b) Plot the bending moment and shear force distributions in the wall and determine the position and magnitude of all the maxima; [5]

(c) Determine a suitable thickness for the wall; [5]

and

(d) Design a suitable layout for the reinforcement, assuming the steel has yield strength of 460 N/mm^2. [5]

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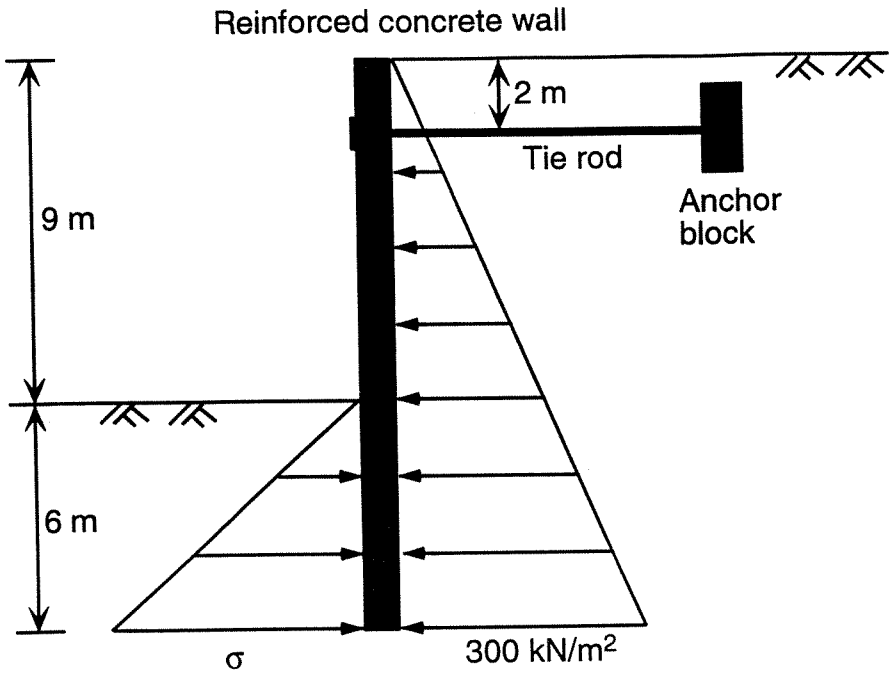
Reinforced concrete wall
2 m
Tie rod
Anchor block
9 m
6 m
σ
300 kN/m²

Fig. 1

2 (a) What is meant by the "observational method" of geotechnical design and construction? [5]

(b) Explain why the construction of a tunnel can lead to surface subsidence, and explain the purpose and practice of compensation grouting. [5]

(c) It has been suggested that compensation grouting might also be used to eliminate subsidence around a deep rectangular excavation for a basement in London Clay, constructed "top-down". Sketch the sequence of operations which might be advocated, and discuss the possible use of the observational method in this case. [10]

3 A long, reinforced concrete water tank is to be constructed below ground level, as shown in section in Fig. 2. The tank will be constructed in a de-watered excavation and then back-filled with a river sand (G_s = 2.65, ϕ_{crit} = 33°) compacted to a voids ratio of 0.60. The water table will be permitted to recover to the previous ground surface, and it has been proposed to place a 1 m high embankment of sand over the top slab, as shown in the figure. The water table can be taken to separate zones of sand which are dry and saturated, respectively. The unit weight of reinforced concrete can be taken as 24 kN/m^3.

(a) By neglecting friction on all vertical and horizontal planes, derive design values of the total stresses which will act externally: [10]

(i) on the roof slab;

(ii) on the walls of the tank;

and

(iii) on the base slab;

when the tank is empty.

(b) Construct an equilibrium free-body diagram for the empty tank, and comment on the further steps which must be taken to achieve an acceptable design. [10]

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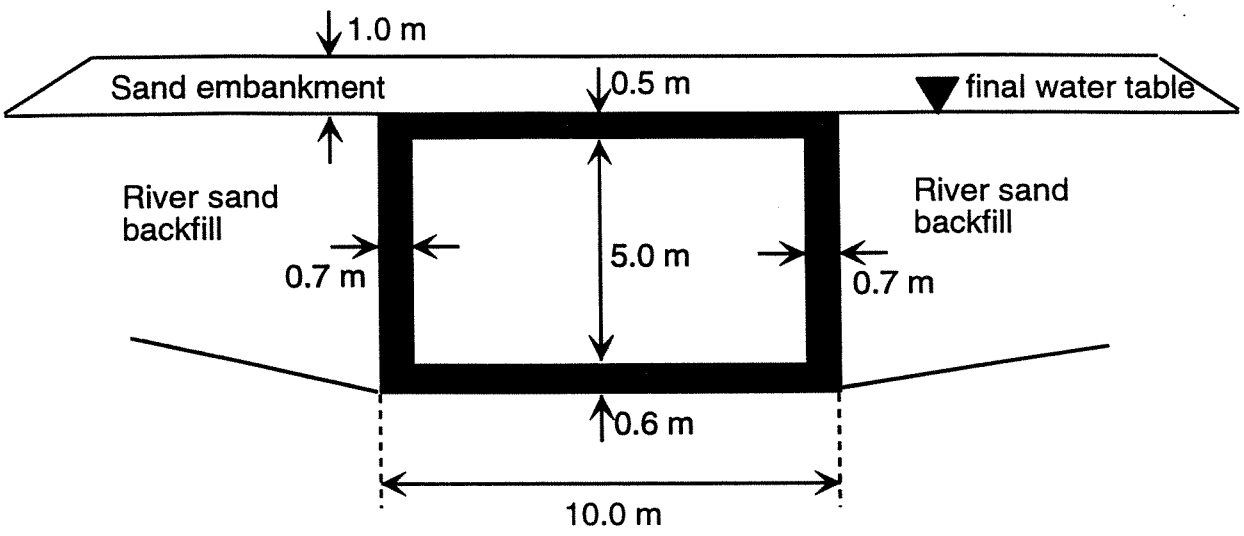
1.0 m
Sand embankment
0.5 m
final water table
River sand backfill
River sand backfill
0.7 m
5.0 m
0.7 m
0.6 m
10.0 m

Fig. 2

SECTION B (Mechanical Engineering)

4 An electromagnetic shaker is used to generate vibration in a vibrating pig and an accelerometer is used to measure the vibration response. The shaker is used in the *vertical* mode, as shown in Fig. 3, and the accelerometers measure the vibration along the axis of the shaker.

The shaker generates 5 N/A up to a maximum force of 100 N peak to peak and has an impedance of 1 Ω. It also has a suspension stiffness of 20 N/mm, a total suspended mass of 1 kg and a maximum allowable stroke of ±5 mm. The sensitivity of the accelerometer is 250 pC/g and it can measure accelerations from 0.01 mm/s^2 to 0.1 km/s^2. The pig is supported in a pipeline whose local stiffness is 20 MN/m. Sinusoidal vibration excitation is required at 10 Hz, which is well below any pipeline resonances.

(a) Decide whether the accelerometer and shaker are suitable for the purpose by calculating the natural frequency of the shaker, the maximum practical stroke for the shaker for a linear response and the maximum pipeline acceleration amplitude that can be generated by the shaker. [8]

(b) The shaker is to be driven by a power amplifier whose input is a 10 V rms sinusoidal voltage. Design a simple power amplifier circuit to achieve this using operational amplifiers specifying values and power ratings of all passive components used. [4]

(c) The charge output of the accelerometer must be amplified to produce a voltage of 1 V rms. Design a simple charge to voltage converter to achieve this using operational amplifiers. [4]

(d) What is the maximum practical pipeline acceleration which could be generated by the shaker if the total suspended mass were to be increased? [4]

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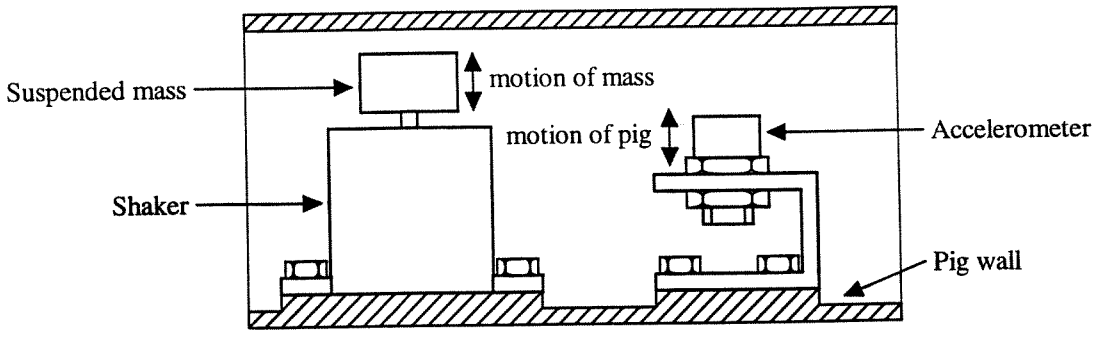
Suspended mass
motion of mass
motion of pig
Accelerometer
Shaker
Pig wall

Fig. 3

5 As the Technical Director of a small brewing company you are responsible for new product development and manufacturing. Currently the company produces keg and canned beer but has not yet broken into the lucrative 'widget' beer market. However, the Managing Director has decided that a new widget beer should be developed in ten months ready for the Christmas market. You have been assigned £10M to ensure the timely development of the widget product.

(a) Draft a project plan showing the key stages required to develop the new widget beer and its associated manufacturing equipment. [4]

(b) Sketch a possible sales vs time profile for the new widget product over the first three years of production. Note that a widget canned beer could command a 30 pence per can premium over non-widget beers. [4]

(c) Define a manufacturing strategy for the new product with reference to the issues of facilities/capacity, span of process, processes, human resources, quality, control policies and suppliers. [6]

(d) Discuss the importance of Risk Management in product development. Illustrate your answer with examples of the application of two common risk assessment techniques to the development of the new widget beer. [6]

(cont.

6 An oil pipeline has been laid on a sandy sea floor. The steel pipe has 800 mm outside diameter and 25 mm wall thickness. It is proposed to monitor the integrity of the pipeline support using a pig which generates vibration of 100 N peak to peak over a range of 2 to 100 Hz. It is hoped, through the monitoring of the pipeline displacement in response to the vibration, to distinguish between pipelines buried to a depth of 2 m, pipelines resting uncovered on the sea floor and 'spanning' pipelines.

The density of wet sand may be taken as 2500 kg/m^3, the foundation stiffness (per unit length) of a deeply buried pipe as 30 MN/m^2 and the damping factor of the vibrating pipe as 0.3. The length of the deflection bowl of a buried or uncovered pipe may be taken as 20 times the diameter of the pipe and a typical pipeline span may be assumed to be 20 m in length.

(a) Demonstrate the feasibility of this form of inspection, by calculating the resonant frequencies and static stiffnesses for the three pipeline support conditions. Use sketches of the displacement vs frequency responses to support your answer. [14]

(b) Choose an operating frequency for the vibrating pig to ensure greatest discrimination between the three support conditions. [2]

(c) Discuss the relative merits of shakers and rotating masses for generating vibrations for pipeline inspection. [4]

SECTION C (Aerothermal Engineering)

7 A turbojet engine operates with an inlet stagnation temperature 290 K and inlet stagnation pressure 1.0 bar.

(a) At design operating conditions the compressor produces a stagnation pressure ratio of 14.4 with an overall isentropic efficiency of 90% (based on stagnation conditions). Given that the design stage loading factor is $\Delta h_0/U^2 = 0.4$ and the mean blade speed at design is 280 ms^{-1}, calculate the minimum number of compressor stages. [6]

(b) The compressor operates with an inlet Mach number of 0.55 and mass flow rate of 55 kg s^{-1} at design conditions. Given that the hub-to-tip ratio is 0.5 at compressor inlet, calculate the tip radius of the first blade row and the design rotational speed. [6]

(c) Calculate the torque in the shaft used to drive the compressor. [3]

(d) If the mean radius for the axial turbine is 1.1 times the mean radius for the compressor and if $\Delta h_0/U^2$ for the turbine is 2.0, find the minimum number of turbine stages. Explain why this is fewer than the number of compressor stages. [5]

(Assume that for air $R = 287$ $Jkg^{-1}K^{-1}$, $\gamma = 1.4$ and $c_p = 1005$ $Jkg^{-1}K^{-1}$)

(cont.

8 (a) For a jet engine flying at velocity V, derive an expression for the propulsive efficiency assuming that the engine produces a single jet with relative leaving velocity of V_j. (You may ignore the mass flow rate of the fuel.) [6]

(b) What is understood by the overall efficiency? Explain why the overall efficiency is proportional to the propulsive efficiency. Discuss engine properties which affect it in addition to those which determine propulsive efficiency. [4]

(c) For a fixed jet velocity, what is the maximum possible speed for the engine to produce net positive thrust? Explain your reasoning carefully. What would be the propulsive efficiency if this maximum could be achieved? [4]

(d) Discuss how the expression for propulsive efficiency affects the choice of aeroengines for both military and civil applications. Illustrate your solution with sketches of cross-sections for different types of engine, labelling key features. [6]

9 (a) In the ICAO Standard Atmosphere, for altitudes above the tropopause (in the stratosphere) the ambient temperature is assumed to be uniform at T_{trop}. Show that above the tropopause the pressure p at an altitude Z is given by the expression: [4]

$$\frac{p}{p_{trop}} = e^{-\frac{g(Z-Z_{trop})}{RT_{trop}}}$$

where p_{trop} is the ambient pressure at the tropopause and Z_{trop} is the altitude of the tropopause.

(b) An aircraft of 400,000 kg has a takeoff speed of 90 ms^{-1} at sea level. Given that the wing lift coefficient at these conditions is C_L= 1.6 calculate the necessary wing area. [3]

(c) At takeoff the aircraft has a lift-to-drag ratio of 9 and each of the four engines has a mass flow rate of 400 kgs^{-1}. Calculate the minimum net thrust for each engine to maintain constant forward speed and the necessary jet velocity. [3]

(d) At the end of cruise (which you may assume is above the tropopause) the aircraft has 50% of the takeoff mass and cruises at a Mach number of 0.85. If the lift coefficient is now C_L = 0.5 and the wing area is the same as in (b), calculate the altitude for the end of cruise. [5]

(e) At cruise conditions the aircraft has a lift-to-drag ratio of 20. Calculate the required net thrust for each engine at the end of cruise. [1]

(f) Explain, but without any explicit calculations, how the altitude and flight speed must be altered when there is an engine failure during cruise and the aircraft must continue flying on only three engines. [4]

The data in the following table may be useful.

	Altitude (m)	T (K)	p(bar)	ρ (kgm^{-3})
Sea Level	0	288.15	1.013	1.225
Tropopause	11000	216.65	0.226	0.364

(Assume that for air R = 287 $Jkg^{-1}K^{-1}$, γ = 1.4 and c_p = 1005 $Jkg^{-1}K^{-1}$)

(cont.

SECTION D (Electrical Engineering)

10 (a) Outline the main experimental evidence that light can behave like particles. [4]

(b) The time-independent Schodringer equation can be written as

$$E\psi = (T + V)\psi = -\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V\psi \qquad [7]$$

Explain the meaning of each term.

Outline some differences in behaviour between an electron which is behaving classically and a wave which obeys this equation.

(c) It is desired to design a one-dimensional quantum well in a material like GaAs. An electron of mass 9×10^{-31} kg moves within such a 1-D well of length L and potential 0, bounded by barriers of infinite potential. Find an expression for the energy level of the electron in the well. [9]

Evaluate the energy of the lowest level in electron volts for $L = 2.5$ nm.
($\hbar = 1.1 \times 10^{-34}$ Js)

11 A MESFET with a transit time of 20 ps is to be designed using a 1 μm thick layer of n-type silicon on an insulating substrate. The supply voltage is to be 2 V. The silicon has a conductivity of 32 $\text{ohm}^{-1}\text{m}^{-1}$, a scattering limited velocity of 10^5 ms^{-1} and a mobility of 0.1 $\text{m}^2\ \text{V}^{-1}\text{s}^{-1}$.

(a) Determine the donor density in the silicon. [2]

(b) Determine the electric field and source-drain separation for this transit time, justifying any assumptions you make. [5]

(c) The ratio of the width to length of the MESFET channel is 10. Determine the source current which flows for a gate-source voltage of zero. [6]

(d) Determine the gate voltage required to turn the transistor off, assuming the dielectric constant of silicon is 12. [7]

12 (a) Compare and contrast the use of gallium arsenide, silicon and germanium for the manufacture of high speed MOSTs. [7]

(b) In order to produce a high speed silicon based n-channel MOST, n^+ doped source and drain regions must be produced. Why? Give one example, other than phosphorus, which can be used as a dopant to produce the n^+ regions and another that can be utilised to dope the substrate p-type. [4]

(c) The required n^+ regions in a silicon n-channel MOST are produced by diffusing phosphorus from an impurity saturated vapour. The p-type Si substrate contains 3×10^{22} acceptors/m^3. Using Figs 4(a) and 4(b) estimate the depth of the n^+ p junction if the diffusion is performed at 1100°C for 70 mins. [5]

Using the data for the only alternative n-type dopant shown in Figs 4(a) and 4(b) estimate the junction depth attainable under the same diffusion conditions. State any assumptions made in your estimations. [4]

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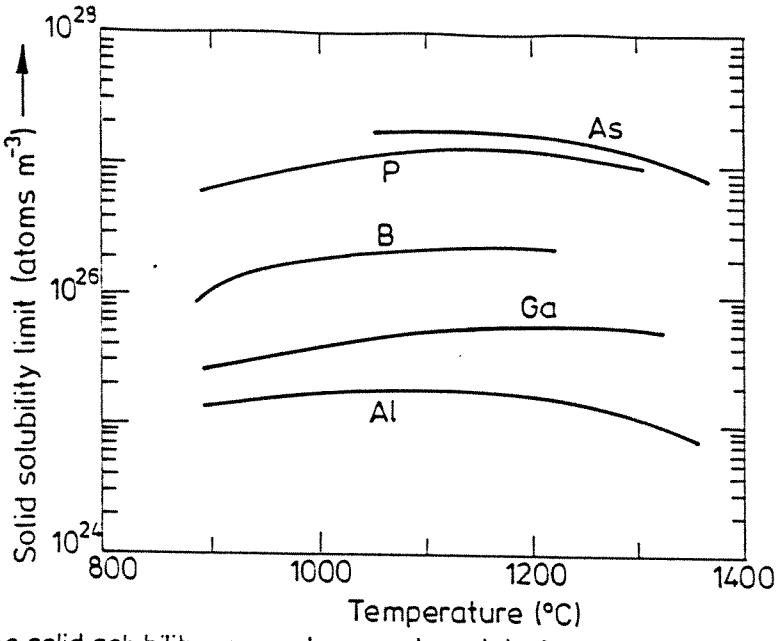

The solid solubility versus temperature data for a range of atoms on silicon

Fig. 4 (a)

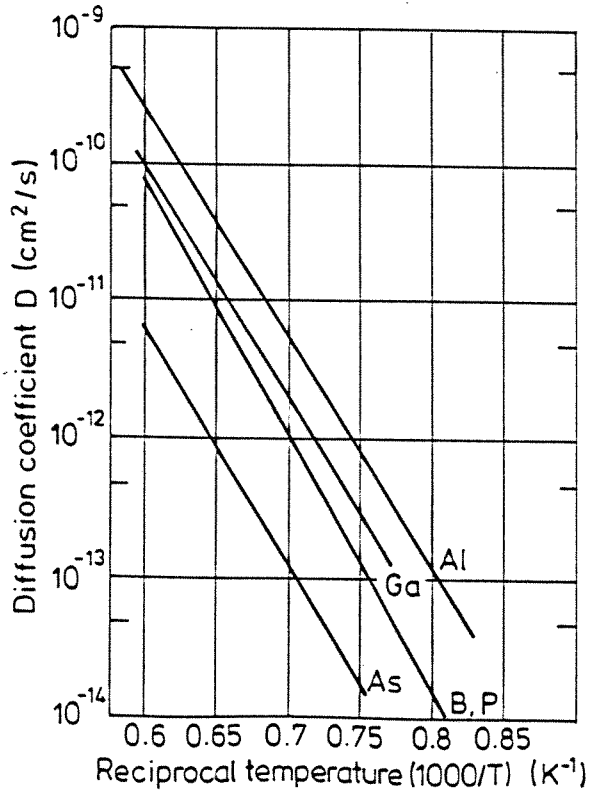

Fig. 4 (b)

(TURN OVER

SECTION E (Information Engineering)

13 (a) Name, in order, and briefly describe the purpose of each of the layers in the ISO/OSI Reference Model for computer networks. [5]

(b) In terms of the ISO/OSI Reference Model, explain the "Service Provider - Service User" and "Peer – Peer" models of network communication. [4]

(c) A company has an Ethernet local area network at a branch office which it wants to connect to its main Ethernet at its central site using ISDN (a form of digital telephone line). Each site is to have an IP router with one network interface connected to the local Ethernet and the other to an ISDN line. These are to enable any network communications based on IP to operate between the two sites.

With the aid of a diagram showing the ISO/OSI Reference Model layer structure in two communicating end systems and the intervening gateways, explain which layers are the same on the Ethernet and ISDN networks, and which are specific to the particular network. [6]

(d) Discuss which layer's or layers' addressing information could be used by a network monitor on one of the Ethernets to select all the network traffic between a pair of machines, one at either site, in the network system described in (c) above. In a typical network monitor, would this address-based filtering be most likely to be performed in hardware or software? [5]

(cont.

14 Software is to be designed for a network monitor unit to accumulate statistics on network traffic by recording the number of packets received from each MAC address. The statistics are to be maintained as a doubly linked list with one cell per MAC address.

(a) Design a Pascal datatype (`TYPE Cell`) to represent the cells in the doubly linked list and a procedure `NewCell(addr:MacAddress)` which creates a new cell at the head of the list. The type `MacAddress` representing a MAC address may be assumed. Explain why it is often an advantage to use sentinel cells in lists like this. [7]

(b) The traffic statistics are to be sorted using an Exchange Sort (Bubble Sort) algorithm for display on the network monitor.

Outline a Pascal procedure to sort traffic statistics stored in a doubly linked list so that the highest traffic MAC address is at the start of the list. [9]

Comment on the performance of the exchange sort algorithm if the traffic on the network comes from a large number of different addresses. [4]

15 An embedded computer system uses an MC6850 ACIA for serial communications.

(a) Using an extended Pascal notation, define data types to represent the ACIA control and status registers. The ACIA has its control/status register at memory address 0FFE0000H and its data register at 0FFE0001H. Give suitable variable declarations to represent the ACIA registers. [8]

(b) An ACIA, as in (a) above, is to be used to send packets of length `PacketSize`, stored in an output buffer of type `Buffer`, along a serial line under interrupt control using 8 data bits, 1 stop bit and even parity. The type `Buffer` is defined as

```
TYPE Buffer = RECORD
                  data: PACKED ARRAY[1..PacketSize] OF Byte;  {the data}
                  idx: 0..PacketSize;  {index into data}
                  done: Boolean;  {set when whole packet has been sent}
                  error: Boolean;  {set if an error occurs}
              END;
```

Using an extended Pascal notation, write a Pascal procedure to initialise the ACIA and design an interrupt process to transmit the packet under interrupt control. [8]

(c) Discuss how the ACIA could be used to connect together a number of such computer systems in a simple network. What limitations would this solution have compared to one using an Ethernet network interface? [4]

END OF PAPER