ENGINEERING TRIPOS PART IB

Friday 4 June 1999 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)

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

1 A reinforced concrete swimming pool is 10 m wide and 4 m deep, as shown in Fig. 1. The critical loading case for the pool is when it is empty with the water table on the outside at ground level. Uplift is resisted by ground anchors around the perimeter which provide no moment resistance.

The applied loading on the side wall (which includes soil pressures and hydrostatic effects) varies linearly from the top with magnitude of $12z$ kN/m$^2$, where $z$ is the depth from ground level. The loading on the base has uniform magnitude $w$.

The concrete used has a cube strength of 40 N/mm$^2$ and the reinforcement has a strength of 460 N/mm$^2$. Ignore the effect of axial force in the slab and the slab's own dead weight. Consider a 1 m strip across the width of the pool.

(a) What would be a reasonable value for $w$? Justify your answer. [2]

(b) Draw the bending moment diagram of the walls and the slab, indicating critical values. [6]

(c) If the base slab is to have a uniform thickness and is to be singly reinforced everywhere, determine the required thickness. [4]

(d) Design the reinforcement at the corners and at the centre of the main slab. [6]

(e) Sketch the layout of the reinforcement showing the principal reinforcement you have designed and any secondary reinforcement (whose sizes you do not need to determine) that should be provided. [2]

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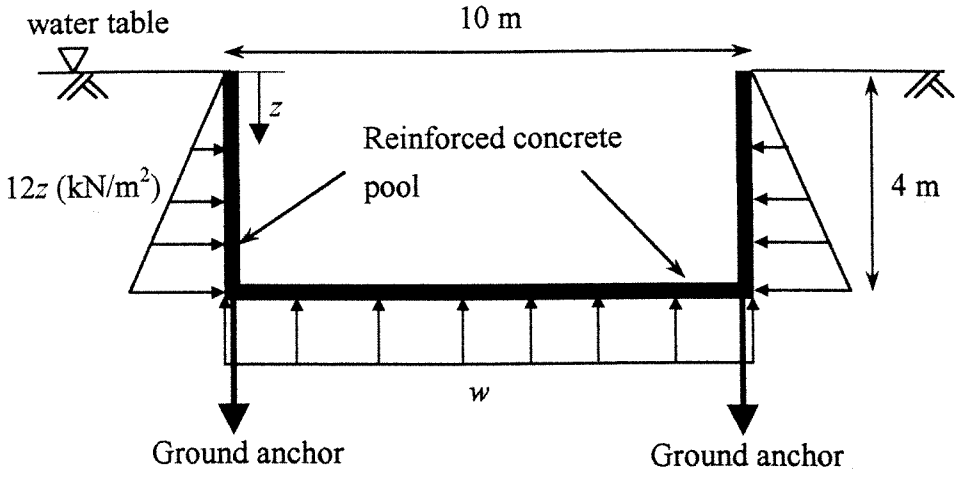
water table
10 m
z
Reinforced concrete
pool
12z (kN/m²)
4 m
w
Ground anchor
Ground anchor

**Fig. 1**

2 During construction of a cut-and-cover tunnel, a sheet pile temporary retaining wall is driven down through a dry dense sand to the top of a hard, impermeable clay stratum at a depth of 9 m below ground level, as shown in Fig. 2. Excavation is designed to be to a depth of 6 m and the wall is propped at a depth of 1 m. The critical state angle of friction of the sand is 35° and the unit weight of the sand above the water table is 17 kN/m$^3$.

(a) Calculate the overall factor of safety against rotation about the prop, ignoring any friction acting on the wall and assuming that the passive pressure coefficient $K_p$ would be fully mobilised in a rotational failure of the wall. [8]

(b) During construction, several mishaps occur which reduce the factor of safety. Calculate the factor of safety against rotation about the prop for each of the following separate events

(i) Stockpiling of a 2m high pile of sand of the same unit weight for a considerable distance behind the wall. [4]

(ii) Accidentally overdigging the excavation by 0.5 m. [4]

(iii) Deformations of the wall and the ground behind it cause the high pressure water main shown on Fig. 2 to burst, resulting in water completely filling the sand behind the wall up to ground level. Assume the unit weight of the saturated sand to be 20 kN/m$^3$. [4]

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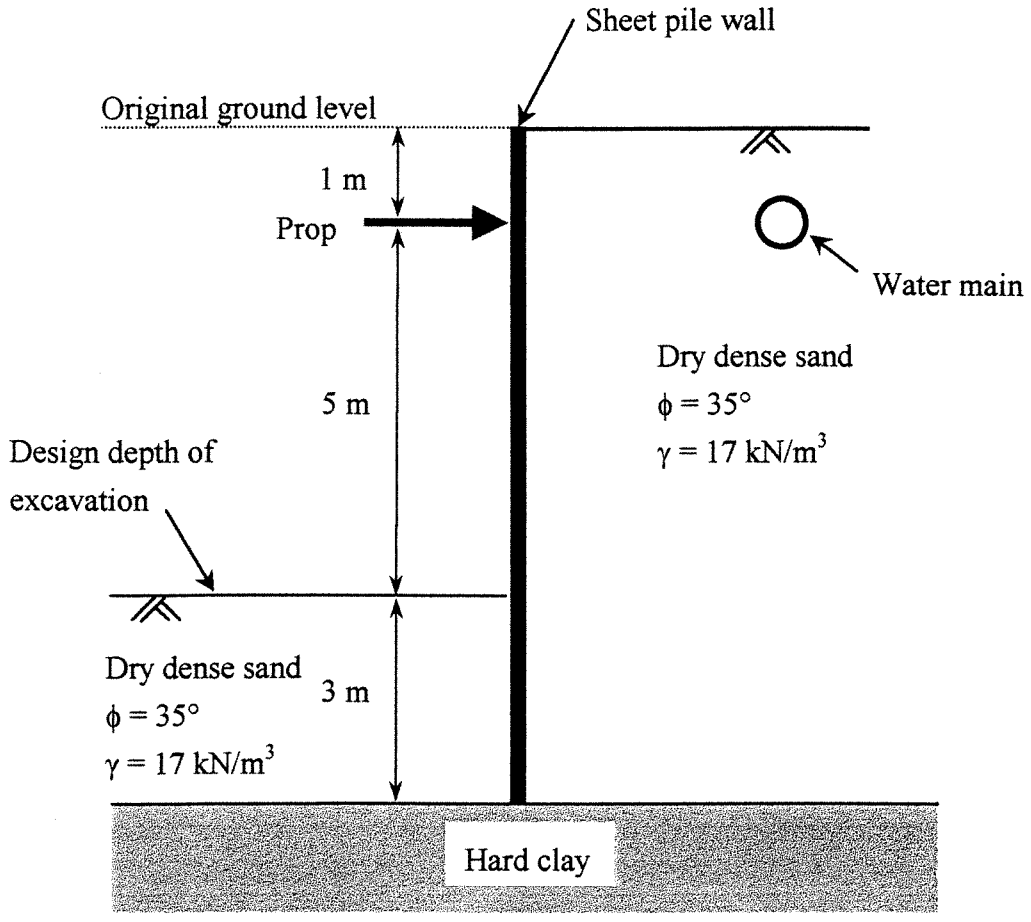


**Fig. 2**

**(TURN OVER**

3 (a) Describe the principal factors affecting the design and construction of a major bored tunnelling project in soft ground beneath a city. Your answers should consider

(i) stability,

(ii) ground movements, and

(iii) tunnel lining. [9]

(b) If there is a risk of ground movements adversely affecting a building, outline a possible range of options for protective measures that might be taken. Illustrate your answers with sketches where appropriate. [6]

(c) Describe the use of instrumentation in monitoring and controlling ground movements during tunnel construction, giving examples of the type of measurements that should be made. [5]

SECTION B (Mechanical Engineering, Manufacture and Management)

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

4. You are the Technical Director of a UK company which manufactures electro-magnetic shakers. A potential customer has requested that you develop a new shaker capable of shaking a car. The shaker is to be used in each of the customer's design and development centres (five distributed around the globe) to simulate extreme road conditions when testing new vehicle prototypes. It is envisaged that one shaker will be mounted underneath each wheel of the car. The range of shakers currently manufactured by your company has an upper force generation limit of 1000 N .

(a) Derive an outline specification for the new shaker identifying and quantifying the most important requirements. [8]

(b) Identify those requirements from part (a) which you expect to cause the greatest risk during the development of the new shaker. [2]

(c) Describe a generic approach to product development which will help to minimise the risks identified in part (b). [6]

(d) What is a Failure Mode and Effect Analysis (FMEA). State how it may be applied during the development of the new shaker. [4]

5. Sophisticated electronics are used in most modern pipeline inspection systems for system control, signal amplification and data-logging. Fig. 3 shows two such amplification circuits.

(a) Describe how the two circuits perform for a harmonic input over a wide frequency range. Illustrate your answer with sketches of typical gain versus frequency responses for each circuit. Derive expressions for the 3 dB frequency in each case. [6]

(b) Show how the two circuits may be combined to form a band-pass filter to convert the charge output of an accelerometer into a voltage. State any constraints which must be satisfied for the circuit component values. [3]

(c) For a mid-band frequency of 15 Hz and mid-band gain of 100 V/μC calculate possible values for $R_1$, $C_1$, $R_2$ and $C_2$, if $R_2 = 10\,R_1$ and $C_1 = 1000\,C_2$. [5]

(d) The output of the filter is to be sampled and stored digitally. What is the minimum practical sampling frequency? Give reasons for your answer. [3]

(e) Four such circuits are to be used in a particular inspection system which must discriminate signals with a maximum dynamic range in the sampled voltage of 60 dB. How much data storage is required to store data from a 20 hour logging run? [3]

**(cont.**

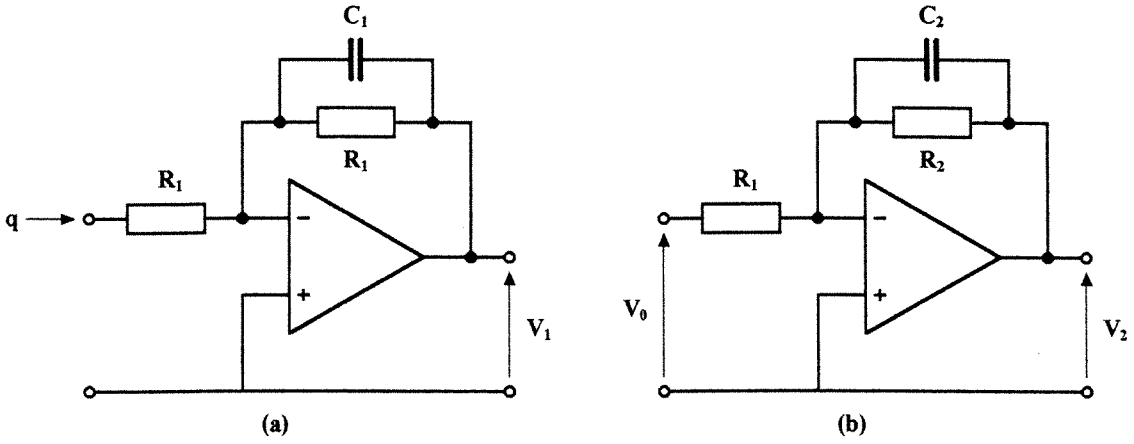


**Fig. 3**

**(TURN OVER**

6 An oil pipeline has been laid on a sandy sea floor. Legislation demands that the pipeline be regularly inspected for its depth of sand cover. A novel inspection pig which generates vibration within the pipeline is to be used, over a frequency range of 1 Hz to 50 Hz , to excite a displacement at a particular location which is to be measured.

It is hoped that this technique will allow inspectors to differentiate between sections of pipeline which are buried as intended, those which are uncovered and those which, due to the action of ocean currents, are 'spanning'. Three typical displacement versus frequency responses are shown in Fig. 4 for a steel pipe which has an outside diameter of 800 mm and wall thickness of 24 mm .

(a) Identify which of the responses A, B and C is for the buried pipe, which is for the exposed pipe and which is for the span. Also deduce the probable type of vibration excitation employed by the pig. Give reasons for your answers. [5]

(b) For response A estimate the natural frequency of the pipe. [6]

(c) By considering the deflection of a simply-supported beam of given length, estimate a value for the length of span that is consistent with the measured data. [6]

(d) Discuss the practicality of using the displacement versus frequency response as a means of pipeline inspection. [3]

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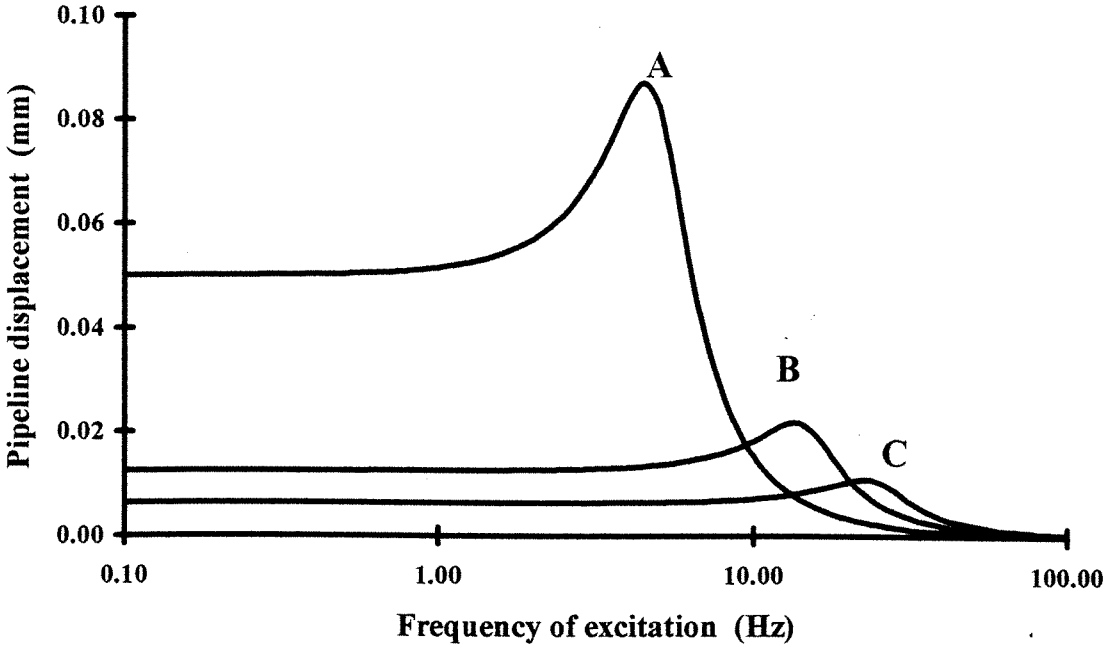


Fig. 4

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SECTION C (Aerothermal Engineering)

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

7 Fig. 5 shows, schematically, one stage of a multistage low pressure turbine that is used to power the fan of a high bypass ratio civil aircraft engine. All the stages are geometrically similar. The directions of the *absolute* velocities at inlet to and exit from every stator row are shown. The directions of the *relative* velocities at inlet to and exit from every rotor are also shown. The axial velocity and the blade speed are constant throughout the turbine.

(a) Explain why the static pressure falls across both the stator and the rotor blades. [4]

(b) Sketch the velocity triangles for a stage. [5]

(c) The blade speed $U$ is 156 $ms^{-1}$. Find the axial velocity $V_x$. [2]

(d) For a stage, the work output per unit mass flow $w_x$ is given by Euler's Work Equation

$$w_x = U(V_{\theta 2} - V_{\theta 3})$$

where $(V_{\theta 2} - V_{\theta 3})$ represents the change in tangential velocity across the rotor blades. Find the work done per unit mass flow and the decrease in stagnation temperature for each stage. [3]

(e) The stagnation temperature at inlet to the low pressure turbine is 950 K. The mass flow rate is 400 $kgs^{-1}$. The fan requires that the low pressure turbine produces a power output of 145 MW. Find the number of stages required. Determine the overall stagnation pressure ratio of the low pressure turbine if its isentropic efficiency is 0.92. [4]

(f) Explain why the low pressure turbine has many more stages than the fan. [2]

**(cont.**

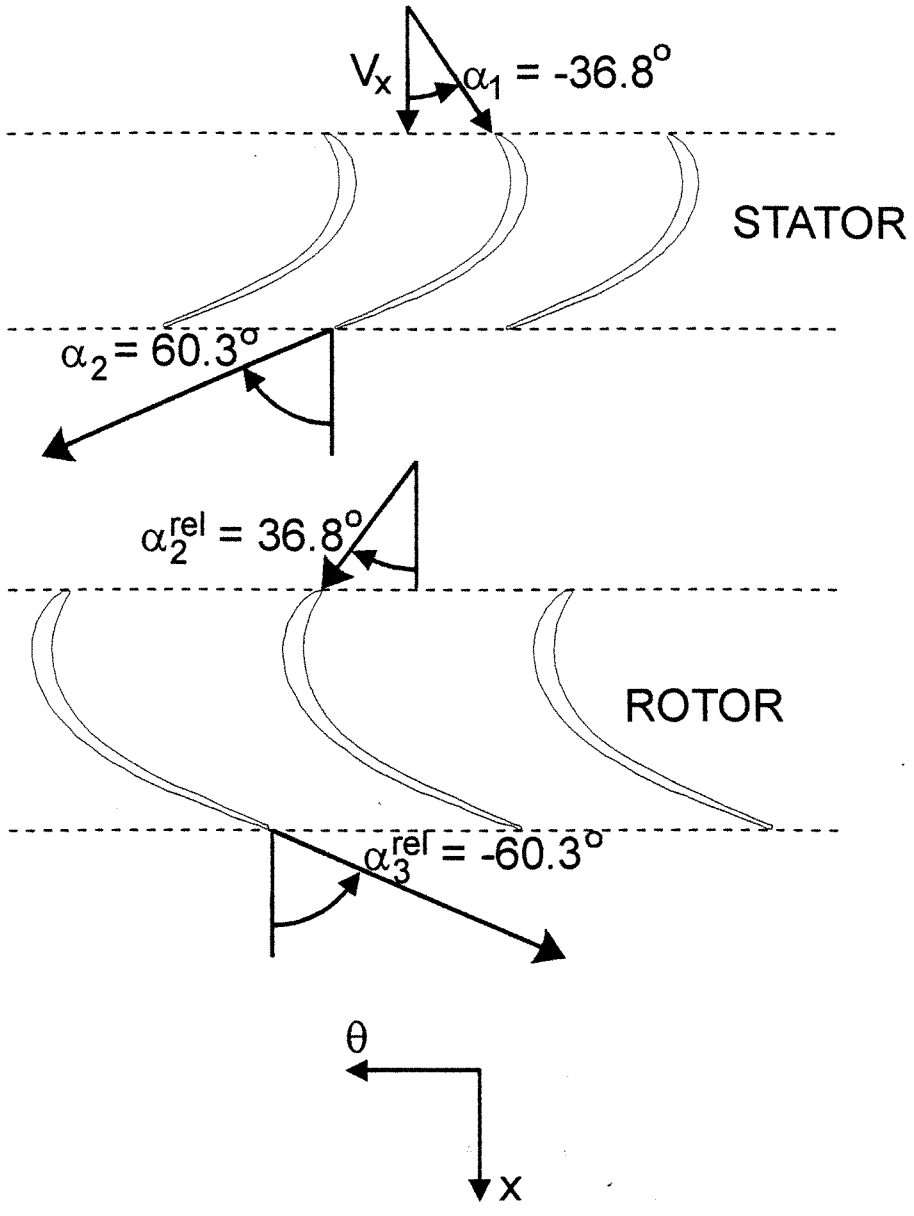


**Fig. 5**

**(TURN OVER**

8 (a) Sketch the general arrangement of a single-shaft turbojet engine, labelling each component. Sketch the temperature-entropy diagram for the engine. Indicate the changes in thermodynamic states on the temperature-entropy diagram which correspond to the components labelled in your sketch of the engine. [6]

(b) A small turbojet is run in a stationary test on the ground. The engine is run at simulated cruise conditions. The ambient pressure is 101 kPa and the ambient temperature is 288 K. The mass flow rate of air through the engine is 5 kg $s^{-1}$ and the turbine entry temperature is 1200 K. At cruise conditions in flight, at entry to the compressor, the stagnation pressure is 36 kPa and the stagnation temperature is 248 K. Show that the stagnation temperature $T_{04}$ at turbine entry is approximately 1033 K at cruise conditions in flight. Hence find the mass flow rate of air $\dot{m}$ at the same conditions. [3]

(c) The compressor has a stagnation pressure ratio of 10 and an isentropic efficiency of 0.80. Find the stagnation pressure $P_{03}$ at exit from the compressor at cruise conditions in flight. Show that the stagnation temperature $T_{03}$ at exit from the compressor is 536 K at the same conditions. [3]

(d) The turbine has an isentropic efficiency of 0.85. Determine the stagnation temperature $T_{05}$ and the stagnation pressure $P_{05}$ at entry to the propelling nozzle at cruise conditions in flight. [2]

(e) The engine has a *convergent-divergent* propelling nozzle. The pressure at nozzle exit is equal to the ambient pressure of 22.5 kPa at cruise conditions in flight. Explain why the nozzle is choked. Assuming that the flow is isentropic through the propelling nozzle, determine the gross thrust of the engine at cruise. [4]

(f) The ambient temperature is 216.5 K. Determine the net thrust of the engine at cruise. [2]

In the above analysis neglect the mass flow rate of the fuel and assume that the combustion products behave as a perfect gas with the same properties as air. Neglect also any losses in the ductwork and the propelling nozzles.

9 (a) Explain the importance of the Propulsive Efficiency of an engine. Show that it may be given by the approximate expression

$$\eta_p = \frac{2V}{V + V_j}$$

where $V$ is the flight speed and $V_j$ is the jet velocity. Explain why large civil aircraft use bypass engines. [6]

(b) Give two important reasons why the takeoff speed of a large civil aircraft is limited to approximately 90 $ms^{-1}$. [2]

(c) A 4-engine civil aircraft of 620,000 kg has a takeoff speed of 90 $ms^{-1}$. It has a wing area of 766 $m^2$. If the air density is 1.225 $kg\,m^{-3}$, determine the lift coefficient of the wings. [2]

(d) Explain why the aircraft must cruise at high altitude. [4]

(e) At the top of climb, the ambient pressure is 29 kPa and the ambient temperature is 227 K. It must arrive at the top of climb with sufficient thrust to enable it to climb at 1.5 $ms^{-1}$ while travelling at Mach 0.85 horizontally. Assume that the initial cruise weight is equal to the takeoff weight. The lift-drag ratio of the wings is 20. Find the net thrust from each engine at this condition. [4]

(f) The mass flow through each engine is 510 $kg\,s^{-1}$. Find the jet velocity at the top of climb. Hence determine the propulsive efficiency. [2]

SECTION D (Electrical Engineering)

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

10 (a) Copper has a face-centred cubic lattice with a lattice constant of 3.61 Å. It has effectively one valence electron per atom and its conductivity is $6 \times 10^7$ $\Omega^{-1}m^{-1}$. If a semiconductor has the same mobility as copper, what is its conductivity if it is doped to a donor concentration of $10^{21}$ $m^{-3}$? [6]

(b) Sketch the velocity-field diagrams of electrons in Si and GaAs. Explain the meaning and cause of the scattering limited velocity. If the scattering limited velocity of the doped semiconductor is part (a) is $5 \times 10^4$ $ms^{-1}$, what is the relevant phonon energy in electron volts if the electron mass is $9.1 \times 10^{-31}$ kg? [6]

(c) If the doped semiconductor in part (a) is used to make an FET operating at 2 V with a channel that has a width/length ratio of 50, at what length does the conduction become scattering limited and what $f_T$ does this correspond to? [8]

11 A process engineer wishes to make a fast FET from a low mobility semiconductor whose properties are,

| | | |
|---|---|---|
| mobility | = | $0.01\ m^2V^{-1}s^{-1}$ |
| scattering limited velocity | = | $10^5\ ms^{-1}$ |
| solubility limit for the n-type dopant | = | $10^{24}\ m^{-3}$ |
| breakdown field | = | $2 \times 10^7\ Vm^{-1}$ |
| dielectric constant | = | $10^{-10}\ Fm^{-1}$ |

The design technology has a limit on device dimension of 0.3 $\mu$m minimum lateral feature size, and a width/length ratio maximum of 10.

(a) What is the maximum thickness of the semiconductor layer in the FET channel if the gate voltage magnitude must be less than 2 V? [7]

(b) What is the optimum dopant concentration for this, and does it exceed the maximum permissible? [3]

(c) What is the shortest transit time which can be achieved for this material and device design? [5]

(d) What is the minimum source-drain voltage and maximum source-drain current for these design rules? [5]

**(TURN OVER**

12 A designer has to produce a MOST to perform at GHz frequencies. Compare and contrast two methods of producing the doped source and drain regions in order to produce the required ohmic contacts. [6]

As part of the overall process, impurities are implanted into the top $0.08\ \mu m$ of a device. During a subsequent 60 minute anneal at 1000°C the impurities diffuse until their concentration profile is given by

$$C(x,t)=\frac{A}{\sqrt{t}}\exp\left[\frac{-Bx^2}{t}\right] \qquad (1)$$

where $A$ is a constant $t$ is the diffusion time in hours, $x$ is the diffusion distance in microns and, for the above temperature and time, $B = 1$.

Show that the function $C(x,t)$ is a solution of the diffusion equation [4]

$$D\frac{\partial^2 C}{\partial x^2}=\frac{\partial C}{\partial t}$$

and express the diffusion constant $D$ in terms of the above constants. [4]

If the diffusion process is thermally activated with an activation energy of 1.1 eV, estimate the new anneal time required to obtain the same doping profile as that in equation (1) but at an annealing temperature of 900°C. [6]

SECTION E (Information Engineering)

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

13 (a) List some intrinsic properties of wearable computers. [4]

(b) What is an *active badge* and how can it be used to locate personnel, pets and equipment? [8]

(c) Describe four approaches to power management in wearable computers. [8]

14 (a) Describe the data structures used by an operating system (such as Unix) to keep track of process state. [6]

(b) For a *Location Event Logging Service*, describe how accessing the local file system, and thus the disk, would cause a running process' thread to block. What effect does this have on the operating system data structures described in part (a)? What else might cause a process thread to block? [7]

(c) What operating system mechanisms cause the blocked process' thread to wake up and recommence running? How are the data structures from part (a) used here? [7]

15. You are required to build a *Pet Location Service* (PLS) using the CORBA distributed object software. The pets wear active badges. Sensors are installed around the home. Software and hardware to collect pet location events is already installed.

The PLS will provide up-to-date information on the locations of your pets around the home. Requests made to the service return the current location for a named pet. If a pet is not seen for one minute and the pet was last seen near the pet flap, it is assumed that the pet has gone out.

The IDL definition for the service is as follows:

```
Interface PLS {
     String PetLocation (in string PetName)
}
```

(a) How is the IDL interface processed to enable distributed clients to communicate with the PLS service? [7]

(b) How will distributed clients initially locate and bind to the PLS service? [6]

(c) How might you extend your architecture to deliver notification to interested clients immediately it is detected that a pet has gone out? [7]

**END OF PAPER**