SOLUTIONS

Part IB Paper 8 (Selected Topics) 1998

SECTION A (Civil and Structural Engineering)

Questions 1,2,3

SECTION B (Mechanical Engineering)

Questions 4,5,6

SECTION C (Aerothermal Engineering)

Questions 7,8,9

SECTION D (Electrical Engineering)

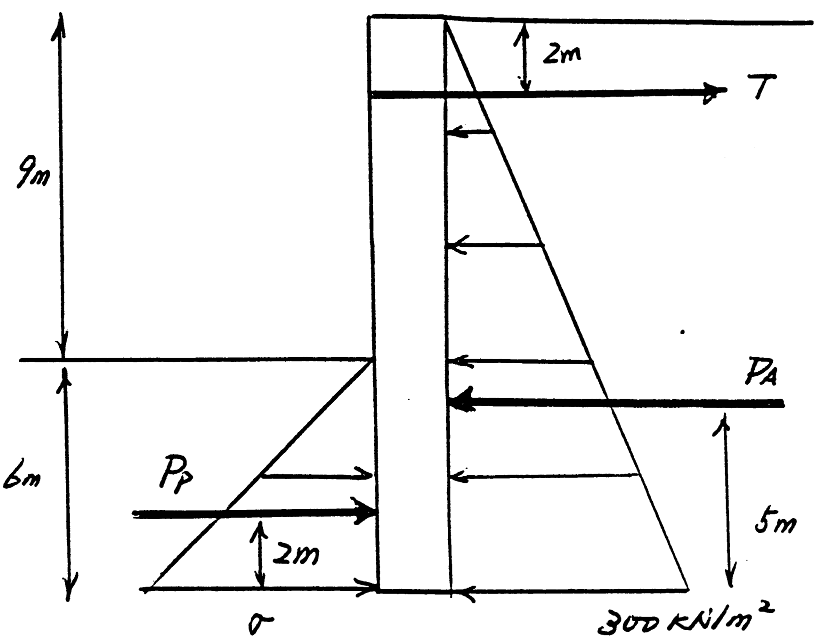
Questions 10,11,12

SECTION E (Information Engineering)

Questions 13,14,15

SOLUTIONS – SECTION A (Civil & Structural Engineering)

Q. 1



Resultant P_A
$= \frac{1}{2} \times 300 \times 15$
$= 2250$ kN/m

Resultant P_P
$= 6 \times \frac{\sigma}{2} = 3\sigma$ kN/m

(a) Take moments about line of action of T

$$2250 \times 8 = 3\sigma \times 11$$

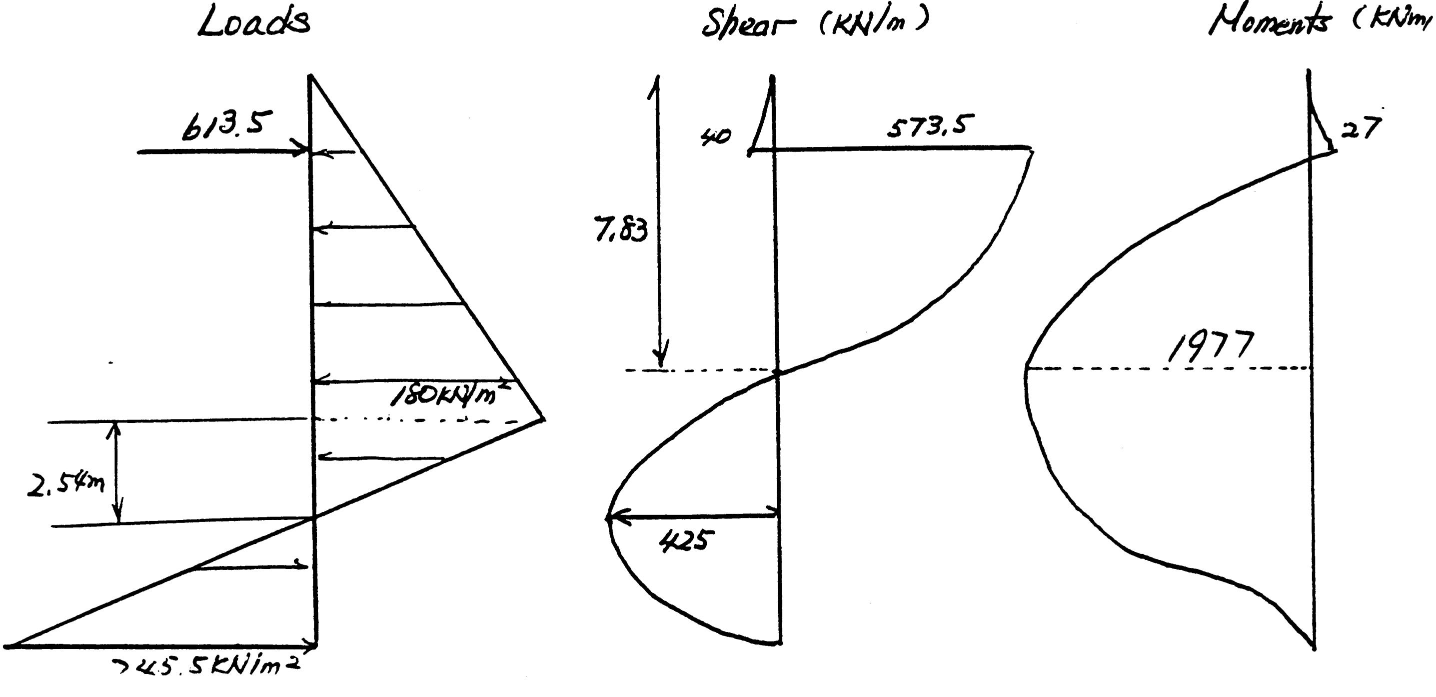
$$\underline{\sigma = 545.5 \text{ kN/m}^2}$$

Horizontal equilibrium

$$T + 3\sigma = 2250$$

$$T = 2250 - 3 \times 545.5 = \underline{613.5 \text{ kN/m}}$$

(b)



Point of zero shear

$$\text{Force} = 20x \times x \times \tfrac{1}{2} = 10x^2$$

Balances the tie force when

$$10x^2 = 613.5$$

$$x = 7.83\text{m}$$

(c) Design bending moment = 1977 kNm/m

$$0.15 f_{cu} b d^2 = 1977 \times 10^3 \times 10^3 \quad \text{N·mm}$$

$$f_{cu} = 30 \text{ N/mm}^2$$

$$b = 1000 \text{ mm}$$

$$\therefore \quad 0.15 \times 30 \times 1000 \times d^2 = 1977 \times 10^6$$

$$\underline{d = 661 \text{ mm}}$$

(d) Design for a value slightly higher than this; say $d = 700$ mm

Guess $x = 0.5$

$$M = 1977 \cdot 10^6 = 0.87 \times 460 \times A_s \times 700 \times \tfrac{3}{4}$$

$$A_s = 9410 \quad \text{mm}^2/\text{m}$$

$\therefore$ <u>8 No 40 mm bars / m</u> //

$$8 \times 1256 = 10048 \text{ mm}^2/\text{m}$$

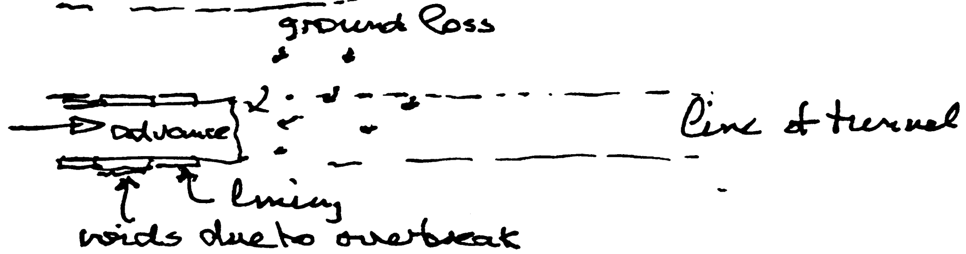
$$x = 2.175\left(\frac{460}{30}\right) \times \left(\frac{10048}{1000 \times 700}\right)$$

$$= 0.48 \quad (\text{good})$$

Q.2 a) Observational method: (Following Peck)

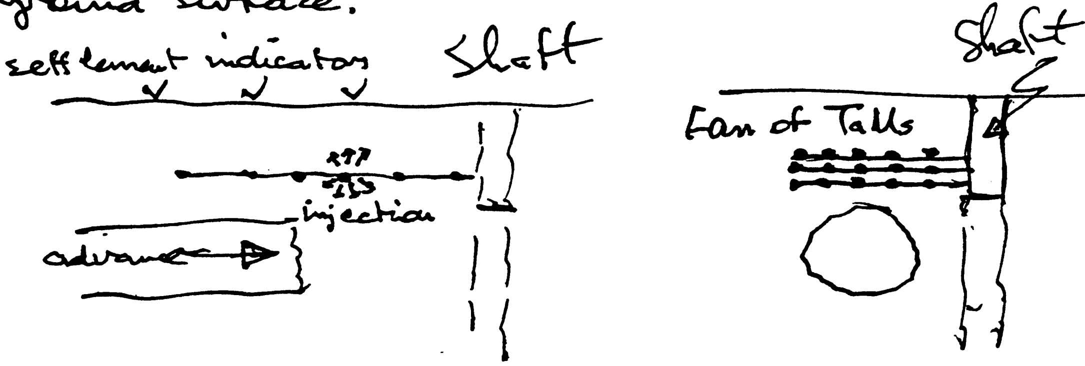
- design facility for most probable design conditions: A
- design also for "worst credible" conditions: B
- during construction of A, make observations which are sufficient to determine real conditions
- interpret observations and switch to plan B if necessary.

b) Subsidence trough



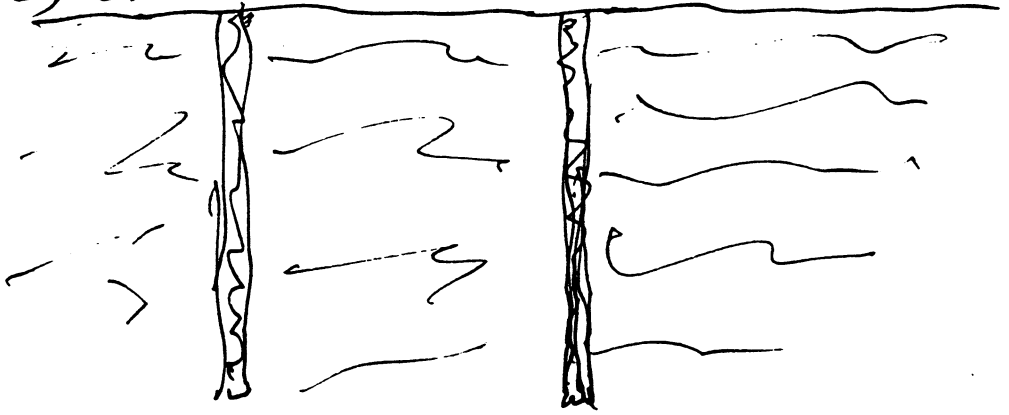
- Soil flows in at the face, creating ground loss. More soil is dug than the volume of the hole in the ground
- Voids are left outside the lining: overbreak. This can be remediated by grouting through the lining before the overbreak has chance to collapse and add to subsidence.

Compensation grouting is intended to replace ground loss during construction. Grouting tubes (TaMs) with grouting sleeves at 1m intervals (say) are placed along the line of the tunnel construction, either from purpose-built shafts, or vertically from the ground surface.



Cement grout is injected out of the ports in sequence, to control observed surface subsidence, e.g to prevent it exceeding a target such as 5mm.

c) (i) diaphragm walls cast in situ, under mud.

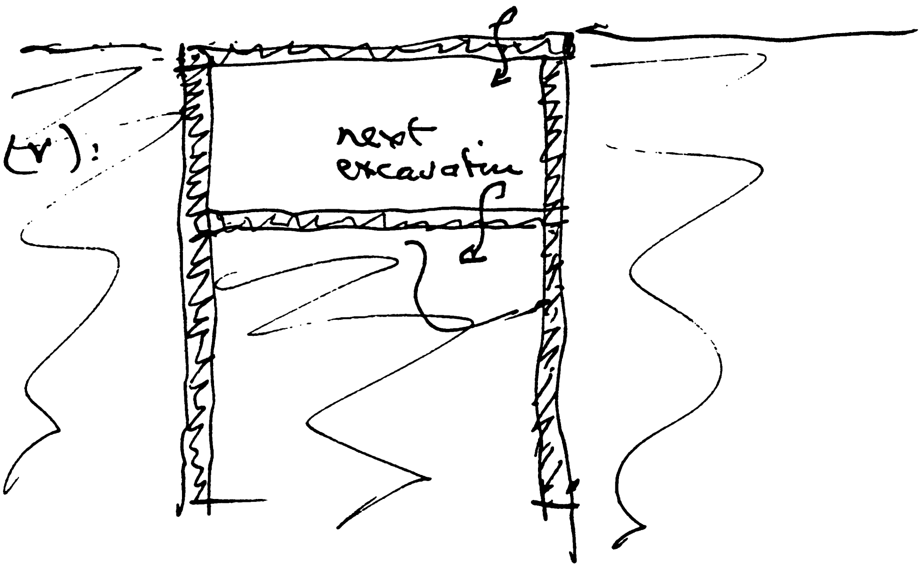


(ii) ground floor slab cast

(iii) excavation beneath slab

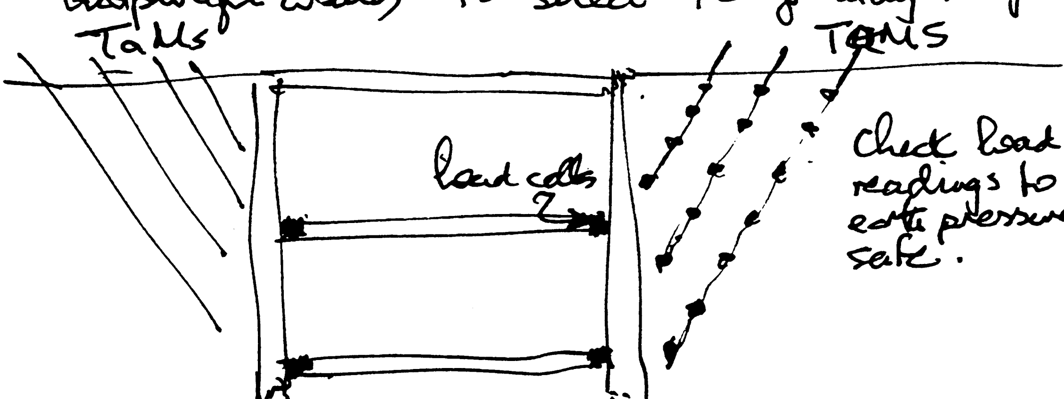
(iv) next slab cast

(v):



Ground loss may occur due to inward movement of soil, at any stage including (i). So begin by inserting TaMs before any other work.

Use surface settlement gauges and inclinometers in the diaphragm walls, to select the grouting magnitudes.



Check load cell readings to ensure earth pressures are safe.

Q.3 . For sand, $\gamma_{dry} = \frac{2.65 \times 9.8}{1.6} = 16.2 \text{ kN/m}^3$

$$\gamma_{sat} = \frac{(2.65 + 0.6) \times 9.8}{1.6} = 19.9 \text{ kN/m}^3$$

K_a for design to critical angle,

$$\frac{\sigma_h'}{\sigma_v'} = K_a = \frac{1 - \sin\phi}{1 + \sin\phi} = 0.295$$

a)(i) On roof slab, $\sigma_v = 16.2$ kPa

(ii)

	σ_v	u	σ_v'	σ_h'	σ_h	
wall top (1m)	16.2	0	16.2	4.8	4.8	} trapezoidal
wall bottom (7.1m)	137.6	59.8	77.8	23.0	82.8	

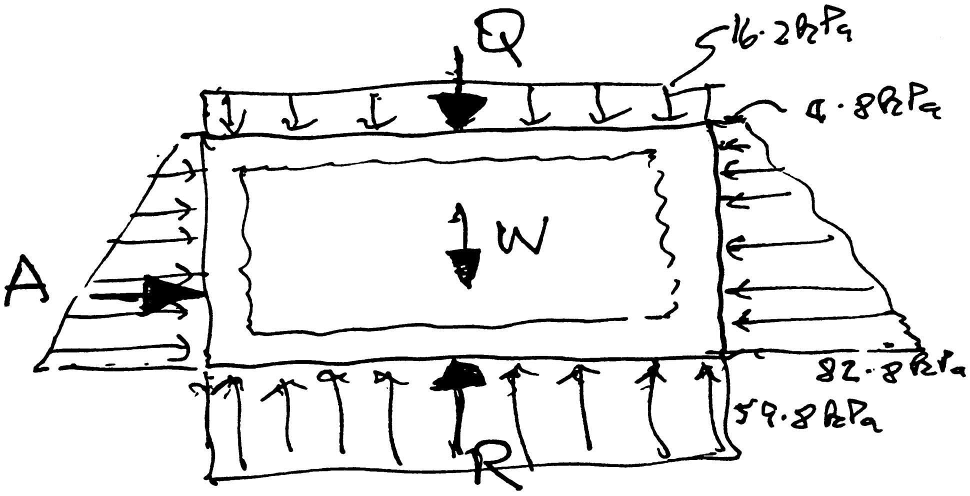
(iii) On average, σ_v must be such as to carry the 1m of sand embankment, plus the weight of the tank.

i.e. $\sigma_{v\,base} = 16.2 + (0.5 + 0.6) \times 24 + \frac{2 \times 5 \times 0.7 \times 24}{10}$

or $\sigma_{v\,base} = 59.4$ kPa

b) Unfortunately, the uplift water pressure on the base is: $u = 6.1 \times 9.8 = 59.8$ kPa
so the tank is on the point of floating. It is unsatisfactory to rely on friction, so raise the embankment by 1m (say) or anchor the tank to its underlying ground with grouted ground anchors. Finally, take bending moments and shear forces from the EFBD, attributing self-weight to the concrete where it properly arises, and allowing for some fixity at the corners.

Forces / unit length (uncorrected for buoyancy remedy)



active thrust	A = 297.7 kN/m		
overburden	Q = 162 kN/m	distributed	
weight	W = 432 kN/m		
reaction	R = 594 kN/m		

SOLUTIONS - SECTION B (MECHANICAL ENGINEERING)

4. a) i) Shaker natural resonant frequency is given by:

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{20 \times 10^3}{1}} = 141 \text{ rad sec}^{-1}$$

$$\therefore f_n = 22.5 \text{ Hz}$$

This is suitably above the operating frequency of 10 Hz

ii) The maximum allowable stroke for the shaker is given by the available stroke minus the static deflection:

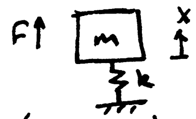
$$\text{available stroke} = \pm 5 \text{ mm}$$

$$\text{static deflection} = \frac{\text{mass} \times g}{\text{stiffness}} = \frac{9.81}{20} = 0.49 \text{ mm}$$

$$\therefore \text{allowable stroke} = \pm(5 - 0.49) = \pm 4.5 \text{ mm}$$

This soounds resonable.

iii) The maximum pipe line acceleration is given by:



$$\text{force available from shaker} = m\omega^2 X \quad (= m\ddot{x})$$

$$\text{for peak to peak force} = 2\, m\omega^2 X = 2 \times 1 \times (2\pi \times 10)^2 \times 4.5 = 35.6\text{N}$$

This is below the maximum available, ie possible. This force is transferred to the pipe:

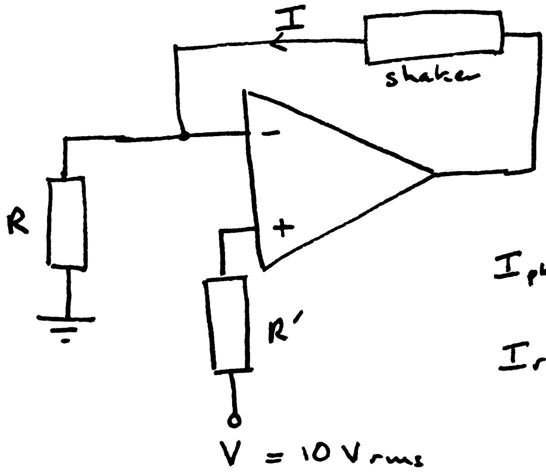
$$\text{displacement pk-pk} = \text{force pk-pk} / \text{stiffness} = \frac{35.6}{20 \times 10^6} = 1.8\,\mu\text{m}$$

$$\therefore \text{acceleration pk-pk} = \omega^2 \times \text{displacement pk-pk} = 7.0 \text{ mms}^{-2}$$

This acceleration is well within the measurable range of the accelerometer.

The shaker and accelerometer are suitable for the task.

4. b) Power amplifier: the simplest circuit might be:



$$I_{pk-pk} = T_{pk-pk}/5 = 7.12\,A$$

$$I_{rms} = \frac{I_{pk-pk}}{2\sqrt{2}} = 2.5\,A$$

Since zero current flows at op-amp input $V_- = V_+ = V$

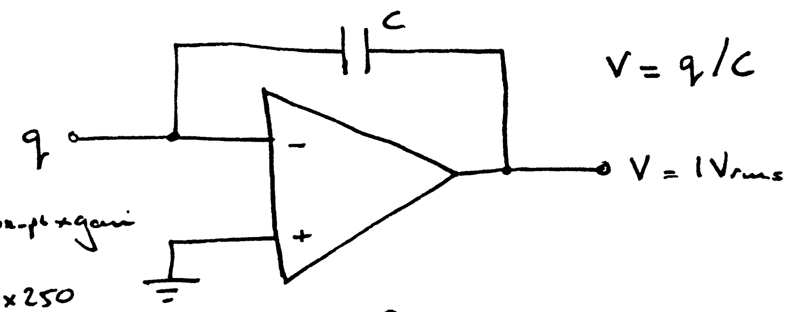
$$\therefore \quad I = V/R$$

$$R = V/I = 10/2.5 = 4.0\,\Omega$$

$$\text{Power in resistor} = I^2R = 25\,W$$

The second input resistor R' may have a higher value of say 1kΩ and consequently a much lower power rating.

c) Charge amplifier: the simplest circuit might be:



$$V = q/C$$

$$q_{pk-pk} = \text{accel}_{pk-pk} \times \text{gain}$$

$$= \frac{7.0}{9.81} \times 250$$

$$= 0.18\,pC$$

$$q_{rms} = \frac{q_{pk-pk}}{2\sqrt{2}} = 0.063\,pC$$

$$\therefore \quad C = 0.063/1 = 0.063\,pF$$

4. d) Increasing the suspended mass will increase the force generated at the expense of a reduced stroke.

$$F_{pk-pk} = 2 m \omega^2 X \quad \text{where} \quad X = X_0 - mg$$

Hence the force may be maximised when $mg = X_0/2. = 5\text{kg}$

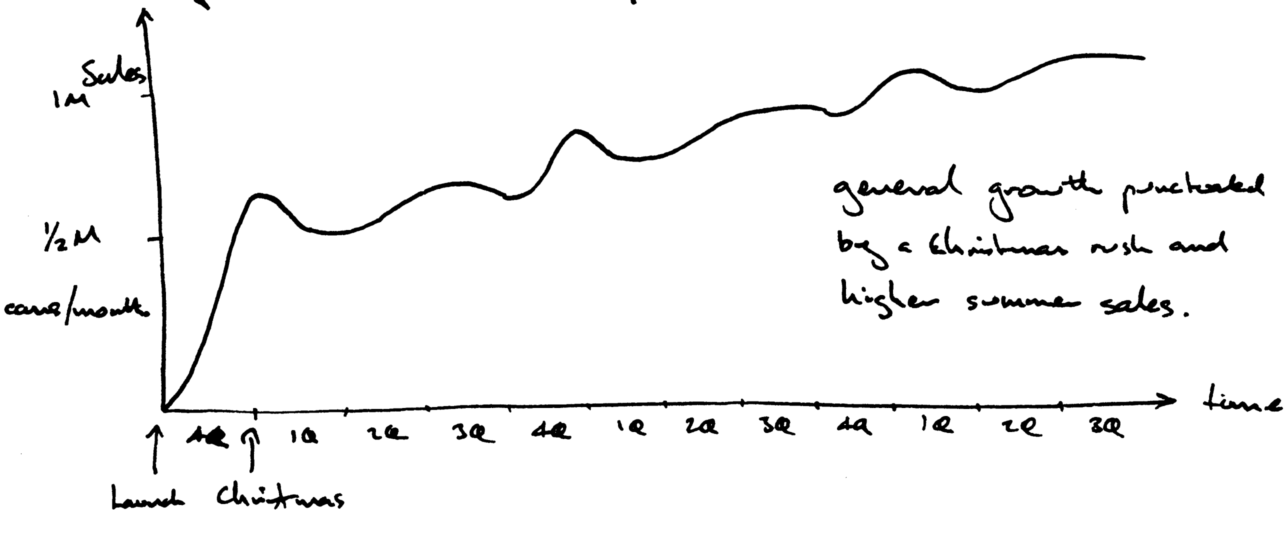
This results in a peak to peak force of 100 N ie the maximum available. However, the resonant frequency is now reduced and is 10 Hz.

This is now clearly unacceptable to operate at resonance. In practice a much more limited increase in force may be possible keeping the resonant frequency above 20 Hz (say).

5 a) The project plan should reflect the relevant stages of the BS7000 standard, namely: Design, development, production, distribution. The earlier stages are assumed to be complete or irrelevant. For example, feasibility may be assumed since other products are on the market. Likewise, operation and disposal are not as important in project planning.

Key design issues are; widget development, patent avoidance, widget insertion, widget processing, manufacturing integration. Widget and manufacturing process development will need to proceed in parallel to achieve the required timescales. Design resource is critical - may plan to buy in expertise (it is a small company). There will need to be a period of product trials, supported by early widget prototypes and small scale production. The plan should also include time to build up pre launch stocks.

b) The sales/time profile should show a peak for each Christmas market and higher summer than winter sales. A growing market would be good! Payback within 1 year would be reasonable, demanding average sales of over 400,000 cans per month.



5 c) Facilities / capacity: there is little information in the question to give a definitive answer, however, discussion of use of existing facilities and capacity would be appropriate. A small company may have only one production facility. Capacity may match existing line?

Span of process: probably better to contract out widget manufacture (mouldings or pressed metal parts), certainly can manufacture and possibly widget insertion. Decisions may depend upon location of company / suppliers.

Processes: probably use existing filling line with widget cans. May require widget pre-processing. Select number of each piece of equipment based on a technical risk assessment.

Human resources: contract out design/development. Don't forget to train staff in any new processes.

Quality:- mention of ISO9002, quality checks in production.

Control policies: probabably use just in time (JIT) and existing MRP systems.

Suppliers: as mentioned above, select moulder, can makers, transportation companies etc..

5 d) Risk management includes, risk identification, risk assessment and risk management. All product developments are risky. Risk management is essential to reduce such risks and increase the likelihood of a successful product launch.

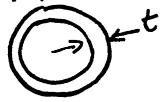
Examples may include likelihood/impact grids, Hazop studies and failure modes and effects analysis. These are well covered in the lecture notes. Phased development also reduces risk.

Risks considered should include technical, managerial, marketing, manufacturing, commercial etc..

6 a) Buried pipe: resonant frequency $\omega_n = \sqrt{\frac{k'}{m'}}$

where k' = stiffness per unit length
m' = mass per unit length

pipe



$$m' \approx \rho \times \text{area of X-section} = \rho . \pi D t$$

$$= 7800\pi(0.8)(0.025) = 490 \text{ kgm}^{-1}$$

However it is important to take account of an increased effective mass due to the movement of sand around the pipe. It is normal to assume an annulus of thickness D/4 moves with the pipe.

$$\text{mass of sand} \approx \rho \, \pi D t$$

$$= 2500\pi(1.25 \times 0.8)(0.25 \times 0.8) = 1570 \text{ kgm}^{-1}$$

$\therefore$ total effective mass = 2060 kgm^{-1}

Hence resonant frequency $\approx \sqrt{\frac{k'}{m'}} = \sqrt{\frac{30\times10^6}{2060}} = 121 \text{ radsec}^{-1}$

$$\omega_{n \text{ buried}} \approx 120 \text{ radsec}^{-1} \quad (19 \text{ Hz})$$

For the uncovered pipe assume only half the amount of sand moves and that the foundation stiffness is less than half of that for the buried pipe. Hence resonant frequency $\approx \sqrt{\frac{k'}{m'}} = \sqrt{\frac{10\times10^3}{1275}} = 89 \text{ radsec}^{-1}$

$$\omega_{n \text{ uncovered}} \approx 90 \text{ rad sec}^{-1} \quad (14.3 \text{ Hz})$$

The static stiffness may be estimated from the deflected shape of the pipe. Assume that deflection may be assumed to be rectangular over half of the 'bowl' length. Hence the pipe sees a stiffness:

$$k_{\text{buried}} \approx k' \times (10 \times \text{diameter}) \approx 30 \times 10^6 \times 8 = 240 \text{ MN/m}$$

Similarly for the uncovered pipe

$$k_{\text{uncovered}} \approx 10 \times 10^6 \times 8 = 80 \text{ MN/m}.$$

6 a) cont. Deflection of the spanning pipe may be considered with reference to a simple data book model.

$$\delta \approx \frac{WL^3}{98EI} \qquad \delta \approx \frac{WL^3}{94EI}$$

Point stiffness at centre; $k = \frac{W}{\delta} \approx \frac{100\,EI}{L^3}$

For an annulus $I \approx \frac{\pi D^3 t}{8}$, $E = 210 \times 10^9\ N/m^2$

$$\therefore k_{spanning} \approx \frac{100 \times EI}{20^3} = 13.2\ MN/m$$

For the effective mass consider half the mass acting at the midpoint since not all the mass is moving:

$$\therefore m = m' \times \frac{L}{2} = 490 \times \frac{20}{2} = 4900\ kg$$

Hence resonant frequency $\approx \sqrt{\frac{k}{m}} = \sqrt{\frac{13.2 \times 10^6}{4900}} = 52.0\ rad\,sec^{-1}$

$$\therefore \omega_{n\,spanning} \approx 52\ rad\,sec^{-1}\ (8.3\ Hz)$$

In summary:

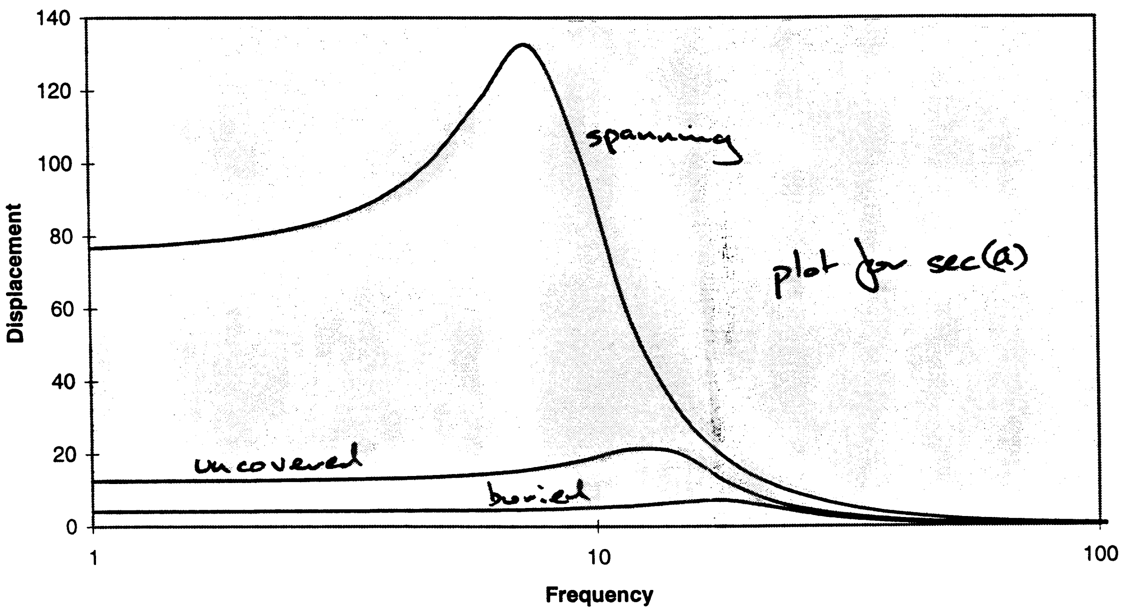
	buried	uncovered	spanning
ω_n (rad/sec)	120	90	52
k (MN/m)	240	80	13.2

The sketches of displacement vs frequency clearly show the differences in behaviour.

b) Selection from the sketches indicates that 8 Hz would be a good operating frequency. However, anything from 2 Hz to 10 Hz would work.

8 c) Shakers can generate any force waveform. However, they are generally limited to small forces and are bulky.

Rotating masses can generate large forces. However, they are limited to sinusoidal forces and need gearboxes and flywheels at low speeds.



SOLUTIONS

IB PAPER 8 : Aerothermal - SECTION C

Q7 a,

$$\frac{T_{02}^{ISEN}}{T_{01}} = \left(\frac{P_{02}}{P_{01}}\right)^{\gamma-1/\gamma} = (14.4)^{1/3.5} = 2.1427$$

$$T_{01} = 290\,K \Rightarrow T_{02}^{ISEN} = 621.38\,K$$

$$\eta_c = \frac{W_{IDEAL}}{W_{ACT}} = \frac{T_{02}^{ISEN} - T_{01}}{T_{02} - T_{01}}$$

$$\Rightarrow T_{02} = T_{01} + (T_{02}^{ISEN} - T_{01})/\eta_c = 290 + (621.38 - 290)/0.9 = \underline{658.20\,K}$$

$$\Delta h_0/U^2 = 0.4 \Rightarrow \Delta h_0 = 0.4 \times 280^2 =$$

$$\Rightarrow \Delta T_0|_{STAGE} = 0.4 \times 280^2/1005 = 31.20\,K$$

$$\frac{T_{02} - T_{01}}{\Delta T_0} = \frac{658.02 - 290}{31.20} = 11.8 \text{ STAGES} \Rightarrow \underline{\underline{12 \text{ STAGES}}}$$

b/ INLET $\Rightarrow$ $\frac{\dot m\sqrt{C_p T_{01}}}{P_{01} A} = fn(M=0.55) = 1.0205$

$$\Rightarrow A = \frac{55\sqrt{1005 \times 290}}{1\times10^5 \times 1.0205} = 0.2910\,m^2.$$

$$A = \pi(r_{TIP}^2 - r_{HUB}^2) = 3\pi/4\; r_{TIP}^2 \quad \text{SINCE } R_{HUB} = r_{TIP}/2$$

$$\Rightarrow r_{TIP} = \sqrt{4 \times 0.2910/3\pi} = \underline{\underline{0.3514\,m}}$$

$$r_{HUB} = 0.1757\,m \Rightarrow r_{MID} = (0.3514 + 0.1757)/2 = 0.2636\,m$$

$$U = r\Omega \Rightarrow \Omega = U/r = 280/0.2636 = 1062\text{ rad/s}$$

$$= \underline{\underline{10143\text{ rpm}}}$$

c/ SHAFT POWER $= \dot m \Delta h_0 = \tau\Omega$

$$\Rightarrow \tau = \frac{\dot m \Delta h_0}{\Omega} = \frac{55(658.20 - 290)1005}{1062} = \underline{\underline{19164\text{ N/m}}}$$

d/ TURBINE $r = 1.1\, r_{COMP}$ $\Rightarrow$ $U_{TURBINE} = 1.1 \times 280\text{ m/s} = 308\text{ m/s}$

$$W_{COMP} = (658.20 - 290) \times 1005 = 370\text{ kJ/kg}$$

$$\Rightarrow \frac{\Delta h_0}{U^2} = \frac{370\times10^3}{308^2} = 3.90 \qquad \left.\frac{\Delta h_0}{U^2}\right|_{MAX} = 2 \Rightarrow \underline{\underline{2 \text{ STAGES}}}$$

Turbines can achieve a much higher stage loading since primarily on accelerating flow $\Rightarrow$ favourable pressure gradient $\Rightarrow$ high flow deflection $\Rightarrow$ high work.

PAPER 8 : Aerothermal

Q8 a/ $\eta_p = \dfrac{\text{USEFUL WORK}}{\Delta KE}$.

USEFUL WORK $= V \times \text{THRUST} = V\dot{m}(V_j - V)$
$\Delta KE = \frac{1}{2}\dot{m}(V_j^2 - V^2)$

$$\eta_p = \frac{\dot{m}V(V_j - V)}{\frac{1}{2}\dot{m}(V_j^2 - V^2)} = \underline{\underline{\frac{2V}{V_j + V}}}$$

b/ V_j FIXED.

NET THRUST $= \dot{m}(V_j - V)$
ZERO THRUST WHEN $V_j = V$, ($V > V_j$ THRUST < 0 !!)

SO, $\underline{\underline{V < V_j}}$ DRAG DETERMINES DIFFERENCE.

WHEN $V = V_j$ $\eta_p = \dfrac{2V_j}{V_j + V} = \underline{\underline{1}}$

(HIGH η_p FOR SMALL $\Delta V = V_j - V$).

c/ MILITARY — HIGH MAXIMUM SPEED FOR INTERCEPTION
— V_j LARGE
— TAKEOFF $\dot{m}(V_j - V) \Rightarrow$ LOW $\dot{m}$
— LOW BYPASS RATIO OR PURE JET.

CIVIL — REQUIRE VERY HIGH EFFICIENCY
— η_p HIGH
— $V_j \sim V$
— NEED LARGE $\dot{m}$ TO GET THRUST
— HIGH BYPASS RATIO (— SAY 6–9)

PAPER 8 : Aerothermal

Q9 a)

$$\frac{dP}{dz} = -\rho g \qquad \rho = \frac{P}{RT} = \frac{P}{RT_{trop}}$$

$$\frac{dP}{dz} = \frac{-gP}{RT_{trop}} \Rightarrow [\ln P] = \left(-\frac{g}{RT_{trop}}\right)[z]$$

$$\Rightarrow \underline{\underline{\frac{P}{P_{TROP}} = e^{-\frac{g(z-z_{trop})}{RT_{trop}}}}}$$

b)

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 A} \Rightarrow A = \frac{400\times10^3\times9.81}{\frac{1}{2}\times1.225\times90^2\times1.6} = \underline{\underline{494.33\ m^2}}$$

c)

$$L/D = 9 \Rightarrow D = 400\times10^3\times9.81/9 = 436\ kN \text{ (TOTAL)}$$

$$\Rightarrow \underline{\underline{\text{NET THRUST} = 109\ kN \text{ per engine}}}$$

$$\text{NET THRUST} = \dot{m}(V_j - V) \Rightarrow V_j = \frac{109\times10^3}{400} + 90 = \underline{\underline{362.5\ m/s}}$$

d)

$$M = 0.85,\ T = 216.65 \Rightarrow V = 0.85\sqrt{1.4\times287\times216.65} = \underline{\underline{250.79\ m}}$$

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 A} \Rightarrow \rho = \frac{0.5\times400\times10^3\times9.81}{\frac{1}{2}\times0.5\times250.79^2\times494.33} = \underline{\underline{0.2524\ kg/m^3}}$$

$$P = \rho RT = 0.2524\times287\times216.65 = 15694\ Pa$$

$$z - z_{trop} = \frac{RT_{trop}}{g}\ln\left(\frac{P_{trop}}{P}\right)$$

$$z = 11000 + \frac{287\times216.65}{9.81}\ln\left(\frac{0.226}{0.15694}\right) = \underline{\underline{13311\ m}}$$

e)

$$D = (0.5\times400\times10^3\times9.81)/20 = 98.1\ kN$$

$$\underline{\underline{\text{NET THRUST} = 24.5\ kN/\text{engine}}}$$

f) ENGINE FAILURE $\Rightarrow$ NET THRUST $\uparrow$ BY 4/3 FACTOR.

NET THRUST $= \dot{m}(V_j - V)$ $\qquad V_j \approx$ const

SO NEED INCREASE $\dot{m}$ & REDUCE V.

REDUCED SPEED $\Rightarrow$ LESS LIFT $\Rightarrow$ LOWER ALTITUDE.

LOWER ALTITUDE $\Rightarrow$ P HIGHER $\Rightarrow$ $\dot{m}$ INCREASED.

Solutions - Section D (Electrical Engineering)

10. (a) (1) The photoelectric effect. (2) black body readiation.

In the photoelectric effect, the frequency of light must exceed a certain value to give electron emission. The kinetic energy of the photoelectrons is found to vary as

$$E = E_0 - hv$$

where v is the light frequency, and h and E_0 are two fitting constants.

The interpretation of this equation is that light consists of packets of energy or particles called 'photons' each with energy hv, that each photon causes the emission of one electron, and that an energy E_0 is lost when the electron is emitted.

(b) E = total energy of particle. Total energy is conserved.
T = kinetic energy of particle at any position
V = potential energy of particle at any position
$\hbar$ = Planck's constant (h)/2π
The RHS equation operates on the wavefunction ψ.
d/dx = the gradient of the wavefunction
m = mass of the particle

Classical particles collide accroding the laws of Newtonian mechanics, including reflections from walls (potential barriers). Quantum particles can have evanescent waves in potential barriers and can tunnel through finite barriers to appear at the other side.

Let the box lie from x= 0 to x = L.
Schrodinger's equation for V=0 has solutions either

$$\psi = A\exp(jkx) + B\exp(-jkx) \qquad (1)$$

or

$$\psi = C\cos(kx) + D\sin(kx) \qquad (2)$$

Boundary conditions of
ψ=0 at x=0 mean that either C=0, or A=B=imaginary, and the solution is the sine, eqn (2)

Boundary condition
ψ = 0 at x=L gives
$kL = n\pi$ or $k = n\pi/L$ where n = integer.

so $E = (n\pi\hbar/L)^2/2m$

and $E = n^2\,(3.14 \times 1.1.10^{-34} / 2.5.10^{-9})^2 / 2\,.9.10^{-31}$

$= 1.06.10^{-20}$ J

$= 0.066$ eV

11. (a) $\sigma = Ne\mu$
$N = 32/(1.6.10^{-19} \times 0.1) = \mathbf{2.10^{21}\ m^{-3}}$.

(b) t= transit time, d =source-drain distance, w = source width, h=Si thickness, v_s = scattering limited velocity, V = supply voltage.

Assume $v = v_s$
Then $d = v_s t = 10^5\ 20.10^{-12} = \mathbf{2.10^{-6}\ m}$.
$E = V/d = 2/2.10^{-6} = \mathbf{10^6\ V/m}$

Critical field E_c for scattering limited velocity is where $v_s = \mu E$, $E_c = 10^5/0.1 = 10^6$ V/s. Thus we are operating at the critical field.

(c) $w = 10.\ 2.10^{-6} = 2.10^{-5}$ m
$I = w.h.N.e.v = 20.10^{-6}.2.10^{-6}.\ 2.10^{21}.\ 1.6.10^{-19}\ .10^5 = 0.64$ mA.

(d) charge density storaged in channel $Q(x) = N.e.x$, so electric field towards gate at position x above the insulator is

$E_g(x) = N.e.x/\varepsilon$
$V_g = N.e. \int x/\varepsilon\ .dx = N.e.x^2/(2\varepsilon)$

$V_g = 2.10^{21}.\ 1.6.10^{-19}.\ (10^{-6})^2\ /2.10^{-10} = 1.6$ V.

This of course is much too much but includes all they could say !!

12. (a) Silicon is the dominant semiconductor material for large scale integrated circuits which use thousands of high speed transistors. Si can be fabricated in wafers over 200 mm in diameter with bow and taper measured in the tens of micron range. It is typically available in both n and p type with resistivities for boron doped (p-type) in the range 0.0005 to 50 Ωcm material (impurity concentrations ranging respectively from $10^{26}/m^3$ down to around 5 $10^{14}/m^3$) and phosphorous doped (n-type) material ranging from 0.005 to 40 Ωcm (impurity concentrations ranging respectively from $10^{25}/m^3$ down to around $10^{14}/m^3$). The ease of doping with either p or n means that either p or n devices (complementary devices eg CMOS) can be formed. It is difficult to find resistivities higher than about 100Ω cm because of the impurities of oxygen and carbon that are extremely difficult to remove completely from silicon though fortunately they do not act directly as donors or acceptors. The band gap of silicon at 1.1 eV is sufficiently high so that the resistivity is substantially controlled by the impurity content (an *impurity* semiconductor) and transistor operation is not seriously impaired up to 80C.

The technology of silicon has been highly developed over 50 years along with many billions of pounds investment. Impurities can be inserted by (i) doping the material in growth (ii) diffusion (iii) implantation of impurity ions at high energies (iv) epitaxial growth. Specific areas can be delineated with submicron precision through various well developed lithographic techniques (photo, e-beam, x-ray see lecture notes). Silicon can be 'shaped' through cutting, and dry or wet etching. Cutting is a course procedure using for example cleaving along a dominant crystal direction, diamond saw or perhaps laser beams. Dry etching (see lecture notes) can remove areas of silicon through bombardment of the silicon in a gas discharge. Here special gases containing for example reactive ions can 'attack' and remove the silicon where it is exposed to the discharge. Alternatively it can simply be the energy of the bombarding atoms (sputtering) which removes the silicon from exposed places. Wet etching (see lecture notes) uses acids, such as nitric, hydroflouric and acetic, with buffers and moderators to attack and remove the silicon or silicon dioxide in areas exposed to the wet chemical solutions. A variety of etches are well developed which etch silicon selectively (eg will etch n-type fast but etch p-type slowly or etch Si but not SiO_2 etc.)

Perhaps most important of all the features of silicon is that silicon 'dioxide' can be grown over the surface of silicon by heating in steam or in oxygen (see lecture notes). The interface between this 'native' oxide and the silicon has sufficiently low interface charges from unpaired valence electron bonds (dangling bonds) that high quality MOSFETs can be made. It is the only known semiconductor where one can envisage a commercial production of MOSFETs.

It is not easy to make high quality Schottky Barriers on Si with well defined potential barriers. Compound metallic layers appear to be required and rarely seem to be as succesful as those formed using GaAs (see below).

So much is known about the technology of silicon that complex manufacturing processes with around 100 different steps can be made with overall yields > 90%.

Germanium was the first major semiconductor but with the bandgap around 0.67eV it was found that transistors made from Ge were too sensitive to temperature. It is this temperature sensitivity which limited the applicability of Ge technology and inhibited large scale investment in this technology ensuring that Ge fell further behind in the 'race' against Si. Although it may appear, on a linear scale, that the band gap E_g = 0.67 eV is not much different from E_g =1.1 eV for silicon the real physics is concerned with the value of $\exp(-E_g/kT)$ which gives a factor of $\exp(0.43/0.025) \sim 30$. There is therefore a sense in which Ge is some 30 times more sensitive to temperature variations than Si.

Gallium Arsenide (GaAs) is a more recent material to be developed than Si. Silicon technologist make the unfair jibe that GaAs is, was and always will be the material of the future! Superficially the crystalline lattice of GaAs is similar to that of Si but the alternating different Ga and As atoms make the details, and certainly the chemistry, very different. Despite the complexity, high quality n-type material is available with dislocations and defects as low as those for Si. The wafer sizes are typically 100 mm or less so that numbers of devices per wafer are usually fewer making costs per device greater. It is a more expensive material than Si though often material expense is insignificant compared to the processing costs. The band gap (1.4 eV) of GaAs is higher than Si so that it is less sensitive electronically to temperature changes.

GaAs is the fore-runner of complex compound semiconductors using different 'quaternary' mixtures of Gallium, Aluminium, Arsenic, Indium and Phosphorous which are specially important in optical devices. Some sophisticated compound semiconductor materials with very high scattering limited velocities (4×10^5 m/s) can be formed for high speed field effect transistors. GaAs also has some fascinating specialised properties that lie outside this present course (microwave oscillations using the Gunn effect and laser diodes with 0.75μm optical wavelength emission).

Substrates with 10^8 Ω cm resistivities are found to be possible through clever technology and this can greatly help in insulating transistors from one another and in giving low capacitances to ground. Such high resistivity substrates are called 'semi-insulating'.

Several metals (mercury, nickel are two examples) readily form Schottky Barrier contacts with GaAs and these Schottky Barriers are ideal for high speed MESFETs. Some of the fastest switching transistors have been made using n-type GaAs on semi-insulating substrates.

GaAs has several processing deficiencies: (i) it is not easy to use diffusion because as one elevates the temperature the arsenic dissociates from the gallium at the surface. This means that selective doping of GaAs is more difficult (epitaxy or ion-implantation has to be used). The disparity between electron and hole mobilities ($\mu_e \sim 0.8$ m²/Vs $\mu_h \sim 0.05$ m²/Vs) in GaAs means that n-type devices are greatly preferred. In general one cannot make complementary (ie p and n) transistors with GaAs technology.

(ii) the 'native' oxide has such a high level of charges at the interface between the oxide and the semiconductor that the electric fields which arise as a result of Gauss's theorem render any MOSFETs quite useless .

Semiconductor materials: three examples

Name of element or compound	**germanium**	**silicon**	**gallium arsenide**
Chemical symbol	Ge	Si	GaAs
Group in the periodic table	IV	IV	III-V
Importance in technology	earliest	dominant	poor oxide
Comment	high leakage	: of good oxide	"material of the future?"

Properties

Semiconductor bandgap Eg ($k_B = 0.025$ eV at ambient)	0.66 eV (indirect)	1.12 (indirect)	1.42 (direct)
Intrinsic carrier concentration	$2.4 \times 10^{19}\ m^{-3}$	1.45×10^{16}	1.8×10^{12}
Mobility μ_n (electrons)	.39	.15	.85
μ_p (holes)	.19	.048	.04
Element that dopes it n-type	P	P, As, Sb	Si
group	V	V	IV
Element that dopes it p-type	Al	Al, B, Ga	Zn
group	III	III	II
Electron effective mass m_e/m_0	1.64	0.98	0.067
Hole .. .. m_p/m_0	0.04	0.16	0.082
Relative permittivity	16	11.9	~ 13

TABLE 1

12b) In order to produce a good ohmic contact - it is more difficult to produce high quality ohmic contacts to low doped semiconductors.

(i) Arsenic (ii) Boron (most common), Ga, Al.

(c) Si substrate 3×10^{22} acceptors $/m^3$ $= 3 \times 10^{16}/cm^3$

1100°C 70 mins

From graph for Phosphorus at 1100°C

$C_s \sim 1.3 \times 10^{27} /m^3$ i.e. $\sim 1.3 \times 10^{21}/cm^3$

From Diffusion coeff. graph

D for P at 1100°C $\sim 2 \times 10^{-13}$ cm^2/s

$$\frac{C(x,t)}{C_s} = \frac{3 \times 10^{16}}{1.3 \times 10^{21}} \sim \frac{3}{1.3} \times 10^{-5}$$

From erfc tables or graph

get $\dfrac{X}{2(Dt)^{\frac{1}{2}}}$ & then substitute

to get $X \sim 1.5 - 2.5\ \mu m$ dependent upon what is read from graphs.

12 contd

Alternative dopant for n-type is As

at 1100° C $\quad C_s \sim 2 \times 10^{27}$ atoms/m^3

D for As at 1100° C $\sim 3 \times 10^{-14}$ cm^2/s

$$\Rightarrow \quad \frac{C(x,t)}{C_s} = 1.5 \times 10^{-5}$$

From erfc table or graph get $\dfrac{x}{2(Dt)^{\frac{1}{2}}}$

$\Rightarrow x$ exact value again dependent upon reading from graphs but junction should be slightly shallower due to lower diffusion coeff. for As.

Q13.

a) [bookwork]

The seven layers in the ISO/OSI reference model are, starting with the top layer:

Application - The user application, eg file transfer, remote login.

Presentation - Data format conversion (eg ASCII to EBCDIC character code) and encryption

Session - Ensures the integrity of a session (eg a long file transfer) even if the transport layer fails.

Transport - The lowest layer to operate end-system to end-system, it provides basic data transfer between end-systems and typically much of the in end-system addressing (eg selection of a particular application).

Network - The highest layer to operate on a per subnetwork (ie end-system to router) basis, it provides basic data transfer between machines on the same physical network. The network (layer) address identifies the end-system.

DataLink - The lowest "software" (as opposed to hardware) layer, it defines a simple packet format suitable for hardware transmission and reception including, if required, an addressing scheme for the local physical network, the DataLink or MAC address identifying a hardware interface.

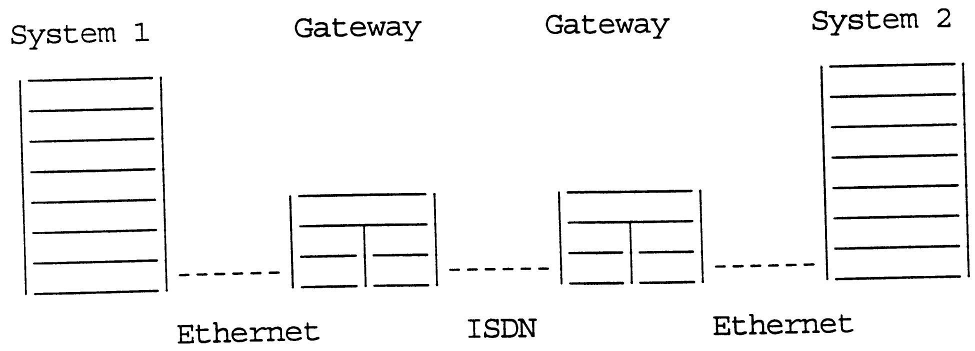
Physical - Defines the electrical components, signal levels, cabling, connectors etc, ie the physical network.

b) [bookwork]

The Service Provider - Service User model views the communication process within a single system and describes the way in which adjacent layers in the system communicate to provide transfer of data from an application across a physical network: down through the stack, each layer N provides a data transfer service for layer N+1 above. A complete packet (protocol header + data) from layer N+1 forms the data for the layer N packet with this layer adding its own protocol header to form the data for layer N-1, etc. Successive layers through the stack may provide multiplexing of data (and addressing information to identify separate data streams) thus overall allowing many applications to communicate over a single physical connection.

The Peer - Peer model views the communication between systems in the network. A given layer in one system may be viewed as communicating with its peer layer (eg transport layer to transport layer) in the other system. These peer layers exchange protocol header information which can be used to provide such services as flow control and error handling.

c)



Experts might show the above ISDN physical connection split by a cloud representing the telephone network.

As can be seen from the above, the top four layers operate end to end and are thus the same on both the Ethernet and ISDN bits of the network being unaltered by th gateways. The bottom two layers are split in the gateways with separate versions for the two types of network interface, ie Ethernet and ISDN are physically different and have different datalink layers to support the different physical layer. In the gateways, the network layer (IP in this case) provides the connection between the Ethernet and ISDN datalink layers and it is thus the same protocol on both network types.

d) The only addressing information which can be used in this case is that of the network layer - here the IP address. The MAC address cannot be used directly since on either Ethernet the MAC addresses in the packets of interest will be those of the end-system and the gateway on that Ethernet not the remote end-system. The best that MAC address based filtering could achieve is to select all packets between a given local end-system and any system on the other side of the ISDN link.

Normal, simple Ethernet interfaces like the LANCE chip described in the lectures can only filter based on the MAC address (essentially they are designed to select only those packets addressed to that interface, ie to that MAC address). If this type of chip is used in a network monitor, the filtering required here must be provided in software. Since in such a scheme, the hardware must be set to receive all packets (irrespective of MAC address), the software must be capable of running fast enough to cope with this rate of incoming packets. This is potentially difficult, so more specialised hardware capable of filtering based on the IP address might be designed for a commercial system.

Q14.

a) Doubly linked list uses

```
TYPE Link = ^Cell;
     Cell = RECORD
               mac: MacAddress; {whatever this needs to be}
               count: integer;  {count of packets received}
               succ, pred: Link {forward and backward pointers}
            END;
```

If have

```
VAR hd: Link;     { the head of the list }
    c: Link;
```

then to allocate a new cell at the head of the list (assuming sentinels)

```
PROCEDURE NewCell(addr:MacAddress);
   VAR c: Link;
BEGIN
   New(c);
   c^.mac := addr;
   c^.count := 1;
   c^.pred := hd^.pred; { using the sentinel }
   hd^.pred^.succ := c;
   hd^.pred := c;
   c^.succ := hd;
   hd := c;
END;
```

The advantage of using sentinels is that you can always deference the pred/succ pointers for all active cells and don't need to have special code for this.

b) [exchange sort routine in lectures using arrays:

```
      FOR i := 2 TO N DO
         FOR j := N DOWNTO i DO
            IF a[j] < a[j-1] THEN
               Swap(j-1,j);
]
```

Exchange (bubble) sort routine using sentinels and checking for complete pass with no exchanges:

```
{ assume sentinels are marked by a zero value of c^.count};
PROCEDURE sortList(Var hd:Link)
  VAR tl,c1,c2: Link;
      sorted,swapped: Boolean; {two variables just for clarity}
      tmpCount: integer;
      tmpMac:   MacAddress;
BEGIN
  tl := hd; { find the tail }
  WHILE (tl^.next^.count <> 0 ) DO    {find the last cell}
     tl := tl^.succ;
  sorted := FALSE;
  c1 := hd;
  WHILE ((c1 <> tl) AND (NOT sorted)) DO
  BEGIN
     swapped := FALSE;
     c2 := tl;
     WHILE (c2 <> c1) DO
     BEGIN
        IF (c2^.count > c2^.pred.count) THEN   { swap the contents }
        BEGIN                                 { more complex to swap cells! }
           tmpCount := c2^.count; tmpMac := c2^.mac;
           c2^.count := c2^.pred^.count; c2^.mac := c2^.pred^.mac;
           c2^.pred^.count := tmpCount; c2^.mac := tmpMac;
           swapped := TRUE
        END;
        c2 := c2^.pred
     END;
     c1 := c1^.succ;
     sorted := NOT swapped
  END
END;
```

Problem with exchange sort is that (in worst case) can lead to (N^2)/2 compare operations (and the same number of swaps), although can operate in N compare operations for a pre-sorted list.

As N gets large it will be better to use a more complex algorithm such as QuickSort which use scales with N log_2 N compare operations. However it should be noticed that there is extra setup time for QuickSort and it may be slower than exchange sort for small or nearly sorted lists.

Q15.

a)

ACIA control and status registers.

Using the information in the Microprocessor Data Book for the MC6850

First

```
TYPE Divide = (div1, div16, div64, reset);
     WordFormat = ( bit7stop2evenpar, bit7stop2oddpar, bit7stop1evenpar,
                    bit7stop1oddpar, bit8stop2nopar, bit8stop1nopar,
                    bit8stop2nopar, bit8stop1nopar, bit8stop1evenpar,
                    bit8stop1oddpar);
```

```
    TxCtl = (intoff_rtslow, inton_rtslow, intoff_rtshigh, intoff_sendbreak);

    ACIAControl = PACKED RECORD
                      clkDiv:  Divider;
                      format:  WordFormat;
                      txmode:  TxCtl;
                      rxien:   Boolean
                  END;

    ACIAStatus  = PACKED RECORD
                      rxFull:  Boolean;
                      txEmpty: Boolean;
                      notDCD:  Boolean;
                      notCTS:  Boolean;
                      frameErr: Boolean;
                      overRun: Boolean;
                      ptyErr:  Boolean;
                      intReq:  Boolean
                  END;

TYPE  Byte   = 0..255;
VAR   ctl: ACIAControl@0FFE0000H;
      stat: ACIAStatus@0FFE0000H;
      dataByte: Byte@0FFE0001H;
```

b)

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

VAR  ctlcp: ACIAControl; {copy of ACIA control }
     outBuff: Buffer;

PROCEDURE InitACIA;
BEGIN
   ctlcp.clkDiv := div16; {whatever is needed for tx rate }
   ctlcp.format := bit8stop1evenpar;
   ctlcp.txmode := inton_rtslow;
   ctlcp.rxien := false; { no reception }
   ctl := ctlcp;
END;

INTERUPPT PROCEDURE ACIATxInt@aciavec;
BEGIN
   { assume interrupts automatically disabled }
   IF stat.frameErr OR stat.overRun THEN
      outBuff.error = TRUE; { do error reporting /recovery }
   IF outBuff.idx = packetSize THEN  { finished with the packet }
   BEGIN
      ctlcp.txmode := intoff_rtshigh;
      outBuff.done := TRUE
   END
   ELSE BEGIN
      outBuff.idx := outBuff.idx+1;
      dataByte := outBuff.data[outBuff.idx];
   END
   { assume interrupts re-enabled}
END;
```

c) Could use the ACIA in either a ring system (with packets passed until they reach the destination) or via a broadcast bus system similar to ethernet & using RTS to control the driver. One major limitation would be speed using the byte-by-byte interrupt driver transfer and the relatively low speed (compared with ethernet) that the ACIA can support.

[Note ACIA networking not covered in lectures]