Data Provided:

Data and equations at start of paper

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2015-16 (3.0 hours)

EEE118 Electronic Devices & Circuits 1

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth or sixth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

You may require the following:

Electronic charge, $e = 1.6 \times 10^{-19}$ C

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ JK^{-1}

Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}$ Fm^{-1}

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

Energy of a photon = hc/λ

Poisson's Equation,

$$\frac{d^2V}{dx^2} = -\frac{ne}{\varepsilon}$$

$$E = -\frac{dV}{dx}$$

$$W_d = \left[\frac{2(V_0 - V)\varepsilon}{e}\left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{1/2}$$

$$J = eD\frac{dn}{dx}$$

$$J_0 = \frac{e\,L_e\,n_p}{\tau_e} + \frac{e\,L_h\,p_n}{\tau_h}$$

$$J = J_0\left[\exp\left(\frac{e\,V}{k\,T}\right) - 1\right]$$

$$n_i = C\,T^{3/2}\exp\left(-\frac{E_g}{2k_B T}\right)$$

$$B = 1 - \frac{1}{2}\left(\frac{l_b}{L_e}\right)^2$$

$$\alpha = \gamma B$$

$$\sigma = ne\mu_e + pe\mu_h$$

$$n_p p_p = n_n p_n = n_i^2$$

$$\beta = \frac{\alpha}{1-\alpha}$$

$$\rho = \frac{1}{\sigma}$$

$$v = \mu E$$

$$C = \frac{\varepsilon A}{d}$$

$$D = \frac{kT}{e}\mu$$

For silicon: relative permittivity $\varepsilon_r = 12$; built-in voltage = 0.7 V; electron mobility = 0.07 m^2/Vs; hole mobility = 0.045 m^2/Vs; band gap = 1.12 eV.

1. This question is about diodes and circuits that contain diodes.

a. Figure 1 shows a linear power supply circuit. The input to the transformer in figure 1 is a 50 Hz sinusoid.

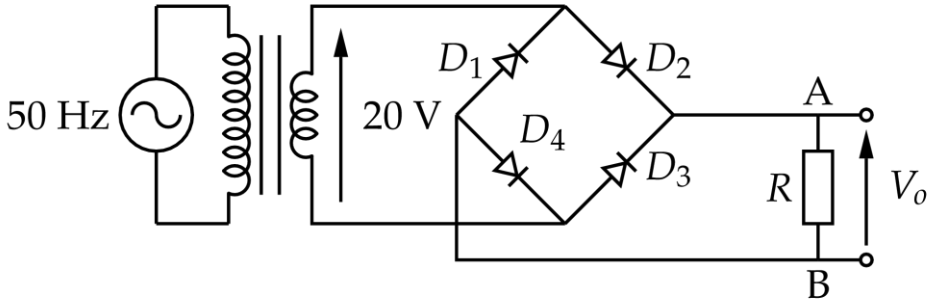

Figure 1

(i) The circuit of figure 1 has a node labelled **A** and another node labelled **B**. Draw the circuit indicating with arrows the current path through the transformer, diodes and resistor when node A is positive with respect to node B. **(1)**

(ii) Sketch the waveform you would expect to see across V_O. Your sketch should contain at least one complete cycle of the input waveform. Label times and amplitudes. **(4)**

(iii) Derive the average value of the waveform of part (ii). **(6)**

(iv) If R = 20 Ω, what is the minimum value of capacitor that can be placed in parallel with R if the ripple voltage component of V_O must not exceed 2 V peak to peak? *(Hint: Some of the marks are given for the derivation of relationships used.)* **(6)**

b. A Zener diode regulator circuit is to be used to derive a 9 V supply from the output of figure 1 which has been smoothed as described in part **d**. The load for the 9 V supply may draw a current anywhere between 5 mA and 10 mA and the Zener diode specifications recommend a minimum current through the diode of 2 mA.

(i) What is the largest value of series resistance that can be used in the regulator circuit? **(5)**

(ii) What ripple voltage would you expect to measure at the output of the regulator if the small signal Zener diode resistance in the breakdown region, r_Z, is 5 Ω and the input ripple to the regulator circuit is 2 V peak to peak? **(3)**

Assume in all parts of the question that the transformer and 50 Hz main supply are perfect and that the diodes D_1 to D_4 have zero series resistance.

2. a.

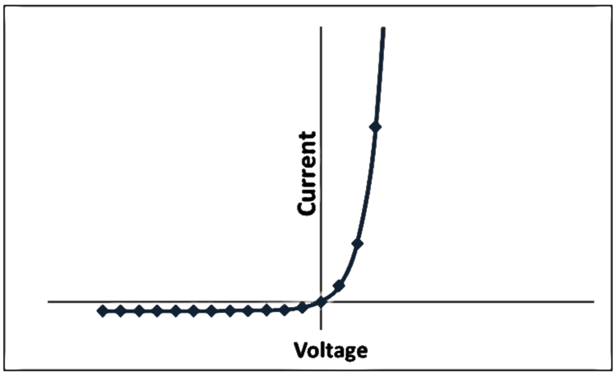

Figure 2

The graph in figure 2 shows the current voltage characteristics of a pn-diode. Draw band alignment diagrams (positions of conduction and valence bands) for the diode, and indicate the built-in voltage and applied voltages for the cases of:

(i) zero applied bias

(ii) forward bias

(iii) reverse bias

Use these diagrams to explain qualitatively the diode characteristic in the graph. **(9)**

b. (i) A p^+n diode has a forward bias current of 20 mA at 0.2 V at room temperature. If the reverse bias saturation current density is 9 Am^{-2}. Using the diode equation, calculate the cross sectional area of the diode? **(3)**

(ii) The capacitance, C, of the diode is measured as a function of applied voltage. A plot $1/C^2$ versus voltage has a slope of 1.177×10^{19} F^{-2}. Using expressions for the capacitance and depletion width at the beginning of this paper, calculate the density of donors in the n-type region using this information. **(7)**

c. Using equations found at the beginning of this paper, draw a diagram of the dependence of depletion width on donor/acceptor concentration for a symmetric diode, i.e. one where N_a and N_d are equal. **(3)**

d. At a reverse bias larger than that shown in figure 2, the diode enters the Zener breakdown region. Explain Zener breakdown using the band alignment diagrams. Outline why Zener breakdown is more likely in highly doped diodes. **(3)**

3. This question is about circuits containing transistors both as switches and amplifiers.

a. In figure 3a Q_1 is used to switch on a car headlamp, R_L. Q_1 has a static current gain, h_{FE}, of between 50 and 250 and a collector emitter saturation voltage, $V_{CE(sat)}$ of 300 mV and a base emitter saturation voltage, $V_{BE(sat)}$ of 0.7 V. The control input V_i is 12 V when the headlamp is required to be on and 0 V when off.

(i) Calculate the on-state collector current. **(1)**

(ii) Calculate the power dissipation in the load. **(1)**

(iii) Compute the largest value of R_B which will allow switching to occur irrespective of the particular h_{FE}. **(4)**

(iv) Estimate the on-state power loss in Q_1. **(1)**

(v) If Q_1 is replaced by a MOSFET, what $R_{DS(on)}$ would be required for it to dissipate the same power as the BJT? **(3)**

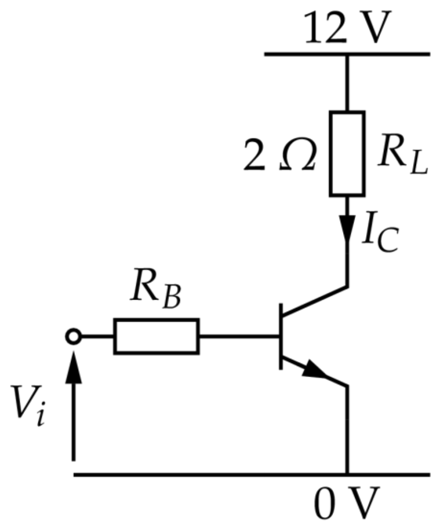

Figure 3a

b. The transistor in figure 3b has a small signal current gain, β, of 400.

(i) Work out the dc conditions V_B, V_C and I_C and the small signal parameters g_m and r_{be} for the circuit of figure 3b. **(5)**

(ii) Draw a small signal equivalent circuit of the circuit of figure 3b, labelling the components. **(4)**

(iii) State the purpose of C_1 and C_2. What effect does C_2 have on the circuit small signal parameters? **(3)**

(iv) Estimate the small signal voltage gain, V_C/V_s. **(3)**

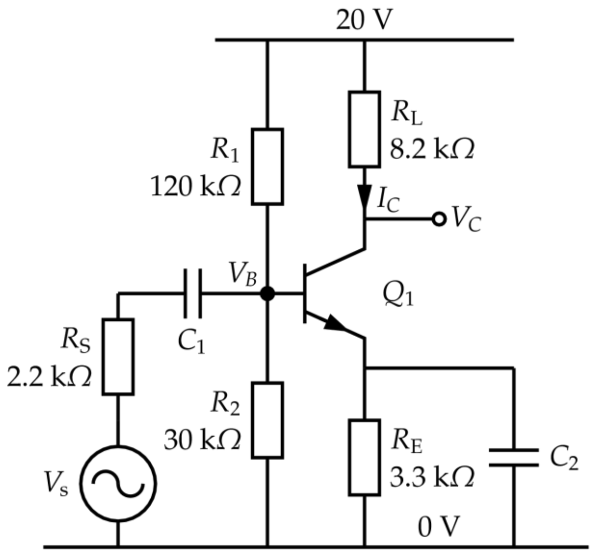

Figure 3b

4. **a.** Describe the bias conditions for the two junctions in an n^+pn bipolar transistor in order for it to exhibit gain. **(2)**

Using a diagram showing a cross section of the device, indicate the electron and hole current flow in an n^+pn bipolar transistor and describe the effects occurring at the emitter base junction. Indicate what effects in the base region can reduce the current gain of the device. **(6)**

Describe the main design considerations required to maximise the gain in the device. **(2)**

b. A n^+pn bipolar transistor in a common emitter amplifier has its collector connected to a 150 Ω load resistor. If the voltage measured across the load resistor is 45 V when the base current is 3 mA, what is the current gain in the device?

Calculate the base transfer factor and the current transfer ratio in the transistor. **(7)**

c. Due to restrictions on the fabrication process, a semiconductor engineer now has to design the transistor with a base length that is twice that of the original. If the emitter injection efficiency remains the same, $\gamma = 0.997$, calculate the new value for gain in the device. **(8)**

5. **a.** Explain the concepts of the conduction band, valence band and band gap in a semiconductor **(6)**

b. Explain the concept of the hole in a semiconductor and state if it is found in the conduction or valence band **(2)**

c. Explain the difference between an intrinsic and extrinsic semiconductor **(4)**

d. The intrinsic electron density in Silicon at room temperature is 1×10^{16} m^{-3}. What is the electron density at 350 K?

Does the conductivity of the semiconductor increase or decrease with temperature? Why? **(6)**

e. Using the formula given at the beginning of this paper, and assuming the variation of the electron concentration due to the term $T^{3/2}$ can be neglected, at what temperature would the intrinsic electron concentration in Silicon increase by a factor of 1000 over the room temperature value?

If the Silicon was heated to this temperature, what would the actual electron concentration be? **(7)**

6. This question is about operation amplifiers and circuits made from opamps.

a. (i) Draw the circuit diagram of an amplifier with a voltage gain of -10V/V using only one (ideal) opamp and two resistors. Include suitable component values on your diagram. **(4)**

(ii) Draw the circuit diagram of an amplifier with a voltage gain of +l0V/V using only one (ideal) opamp and two resistors. Include suitable component values on your diagram. **(4)**

b. (i) State the opamp equation and define the terms. **(4)**

(ii) Why is it important for op-amps to have high input resistance, low output resistance and high gain? **(5)**

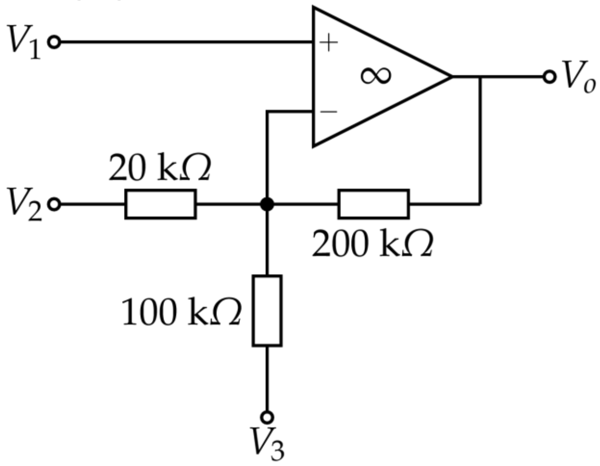

Figure 6.

c. Figure 6 shows an amplifier with three inputs, V_1, V_2 and V_3. V_1 is a d.c. voltage. $V_2 = 0.5\sin(\omega t)$ V and $V_3 = -6.0$ V

(i) What is the pk - pk value of the a.c. component of the amplifier output voltage? **(3)**

(ii) What value of V_1 will give a d.c. component of output voltage of zero? **(5)**

JEG/JH/MH