Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2016-17 (3.0 hours)

EEE118 Electronic Devices and Ciruits

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth 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

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

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

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

Energy of a photon = hc/λ

Speed of light, $c = 3 \times 10^{8}$ ms^{-1}

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

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

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

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

$$J = J_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$$

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

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

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

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

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

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 the use of diodes in circuits.

a. Figure 1a shows a diode resistor and capacitor circuit which is driven by a pulse provided by the voltage source. The graph of the pulse waveform is shown in figure 1b. Assume that the diode is ideal.

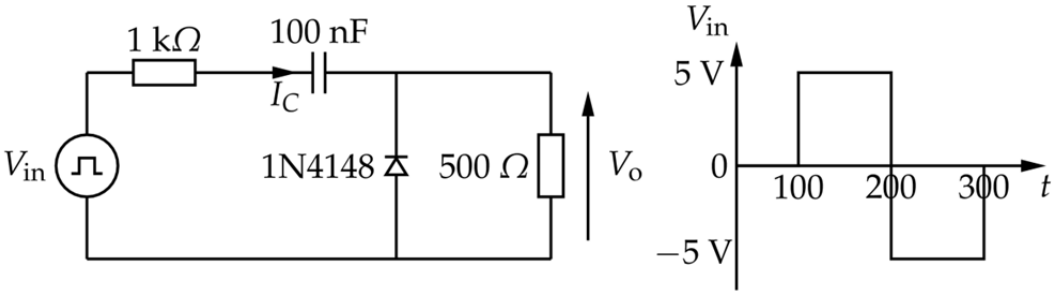


Figure 1a

Sketch, on labeled axes, the capacitor current, I_C, the capacitor voltage, V_C, and the output voltage, V_o as a function of time. Find all relavent time constants and amplitude peaks. **(13)**

b. Figure 1b shows a circuit that may be used to clamp the negative voltage of the input waveform at -0.7 V assuming that the time constant $R_1 \cdot C_1$ is much greater than period of the input signal.

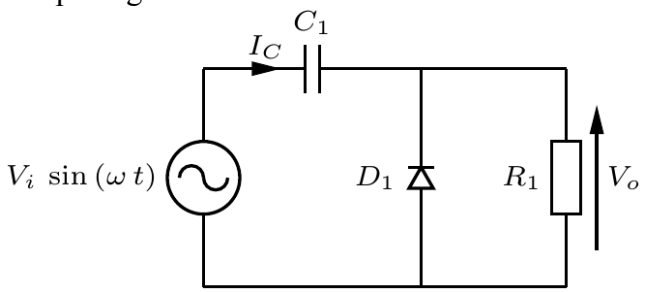


Figure 1b

i) Sketch, on labelled axes, the input voltage V_i, the output voltage V_o, the capacitor current, I_C. Pay attention to the timing alignment of the waveforms and note any salient amplitudes on your sketch. **(5)**

ii) The circuit of Figure 1b may be connected to a peak detector circuit to form a peak to peak detector. Sketch this new circuit. **(3)**

iii) Assuming the peak detector has a sinusoidal input, sketch on labelled axes, the input voltage, the output voltage and the capacitor current. **(4)**

2. This question is about light emission from semiconductors.

a. **i)** Explain how light may be emitted from a semiconductor diode and state, with justification, if this happens under reverse bias or forward bias. **(4)**

ii) State the normal spectral range for visible light. Give your answers in both wavelength (nanometres) and energy (electron volts). **(2)**

b. **i)** Outline the most common method of making white light LEDs and sketch a graph of the emission spectrum of these LEDs (the light output versus the wavelength). **(3)**

ii) Suggest an alternative method of creating white light from LEDs. **(2)**

c. **i)** Using appropriate diagrams where necessary, explain the difference between spontaneous emission and stimulated emission of photons in semiconductors. **(5)**

ii) Which one of these processes is dominant in an LED? **(1)**

d. **i)** Sketch a graph of the L-I curve for a typical semiconductor laser diode i.e. the amount of light emitted versus the current injected into the laser. Indicate the threshold current on the graph and identify the region where stimulated emission dominates the light output of the device. **(3)**

ii) Explain why a laser emits a beam of light whereas an LED emits its light in all directions. **(2)**

iii) Give three common applications for semiconductor lasers. **(3)**

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

a. Figure 3a shows a transistor switching circuit. Using the information provided in the diagram find,

i) the load current **(1)**

ii) the power dissipated in the load **(1)**

iii) the power dissipated in the switch **(1)**

iv) the range of possible base currents **(2)**

v) the maximum base resistance, R_B **(1)**

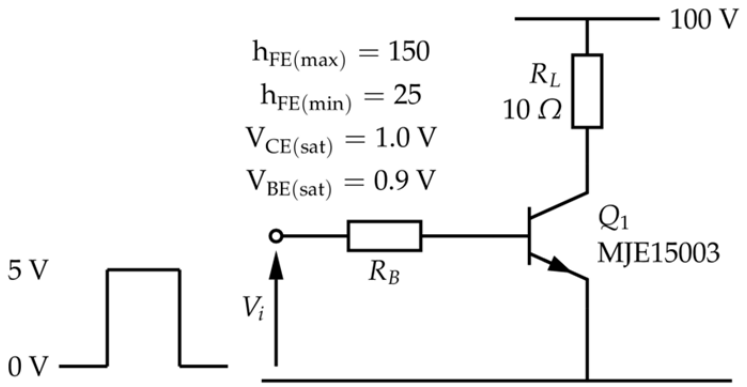


Figure 3a

b. The load resistance, R_L, in Figure 3a is replaced by an electro-mechanical relay. The relay can be modelled by a series combination of inductance and resistance, where R = 10 Ω and L = 120 mH.

i) Sketch a circuit diagram showing the new switching circuit. **(1)**

ii) Calculate the inductor current just after the switch opens. **(1)**

iii) Calculate the energy stored in the inductor assuming the transistor has been switched on of a long time. **(1)**

iv) Add to your diagram any components required to prevent damage to the transistor. **(2)**

c. The circuit of Figure 3b shows a small signal amplifier.

i) Show that the algebraic expression for the quiescent collector may be given by:

$$I_C = \frac{V_{CC} - \dfrac{0.7 \cdot (R_L + R_1 + R_2)}{R_2}}{R_L + \dfrac{R_E \cdot (R_L + R_1 + R_2)}{R_2}}$$

(4)

ii) Hence or otherwise compute the value of the quiescent collector voltage. **(3)**

d. **i)** Draw a small signal model for the amplifier in Figure 3b. **(3)**

ii) Develop an algebraic expression for the mid-band small signal gain of the amplifier and calculate its numerical value. Assume β = 100 and R_S = 1 kΩ. **(4)**

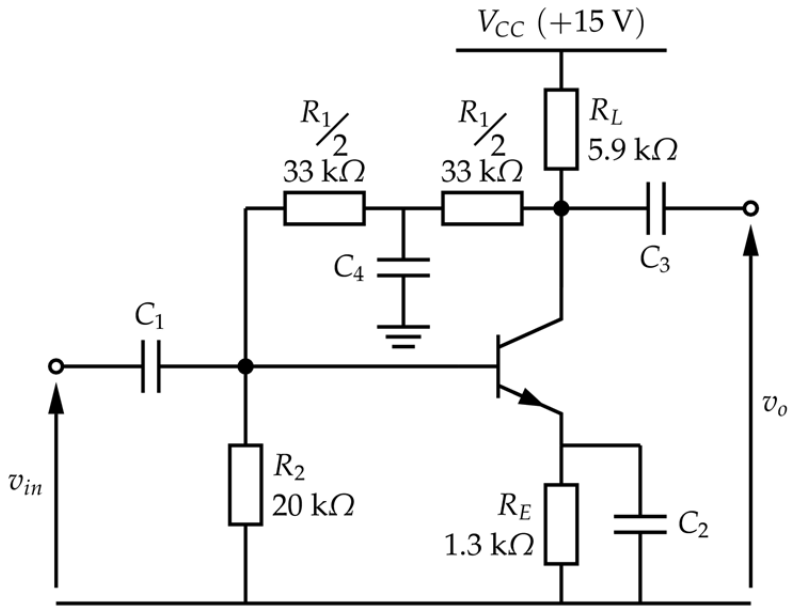

V_{CC} (+15 V)
$R_1/2$
33 kΩ
$R_1/2$
33 kΩ
R_L
5.9 kΩ
C_4
C_3
C_1
v_o
v_{in}
R_2
20 kΩ
R_E
1.3 kΩ
C_2

Figure 3b

4. This question is about field effect transistors.

a. Explain the operation of a planar junction field effect transistor (as used in integrated circuits) using sketches but without derivation. Your explanations should include diagrams showing the effect of gate voltage, and drain current versus drain voltage curves. Explain in detail the effect of increasing the gate voltage.. **(12)**

b. Using the expression for the depletion depth dependence in reverse bias of a "one-sided" (i.e. $p^+ >> n$) abrupt junction given at the beginning of this paper, calculate the pinch-off voltage for a Si junction field effect transistor with a channel thickness of 1 μm and donor density of 1×10^{22} m^{-3}. Assume the built-in potential for the junction is 0.7 V. Would this design be suitable for a digital circuit with a supply voltage of 5 V? **(6)**

c. Calculate the channel resistance (resistance between the source and the drain) for this device for a source-drain spacing of 5 μm and gate width (long dimension) of 50 μm. Ignore the thickness of the p-gate region in your calculation. **(4)**

d. Calculate the gate capacitance of this device with an applied gate voltage greater than the pinch-off value, assuming a gate length of 1 μm. **(3)**

5. This question is about energy band structure in semiconducting crystals.

a. Explain the concepts of the conduction band, valence band and band gap in a semiconductor and indicate how they arise from atomic energy levels of the atoms making up the semiconductor. **(7)**

b. Explain the concept of a phonon in a semiconductor. **(3)**

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

d. Explain why the hole in a semiconductor may not have the same effective mass as the electron. **(3)**

e. Explain the difference between an intrinsic and extrinsic semiconductor and define the concepts of a donor and acceptor. **(4)**

f. GaAs has a band gap of 1.42eV and is considered to be a typical semiconductor with an intrinsic carrier concentration of $2.1 \times 10^{6} cm^{-3}$. Show using formulae and data given at the start of this paper why Aluminium Oxide (Al_2O_3) with a band gap of 8.4eV is considered an insulator. **(3)**

g. At what temperature might Al_2O_3 become a semiconductor, and suggest why this is not a realistic possibility. *Note: you may ignore the $T^{3/2}$ in the formula for carrier concentration for this part of the question*. **(3)**

6. This question is about operational amplifiers and circuits made using opamps.

a.

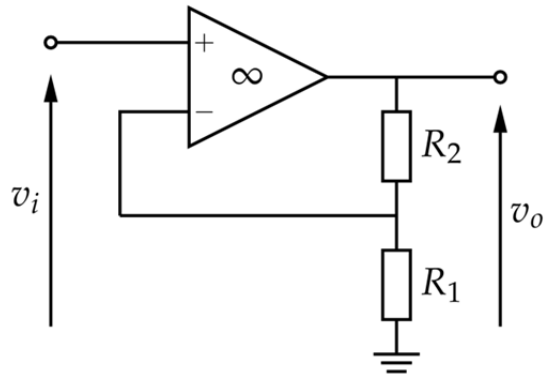


Figure 6a

i) State the opamp equation and define the terms **(3)**

ii) Show that the gain of the amplifier in Figure 6a is given by,

$$\frac{v_o}{v_i} = \frac{R_1 + R_2}{R_1}$$ **(3)**

iii) Calculate physically sensible values for R_1 and R_2 to yield a gain of approximatley 500 for the circuit in Figure 6a. **(2)**

iv) Assuming the open loop gain is not infinite show that the gain of Figure 6a including the finite open loop gain defect is,

$$\frac{v_o}{v_i} = \frac{1}{\frac{1}{A_v} + \frac{R_1}{R_1 + R_2}}$$ **(4)**

v) The open loop gain of the opamp is 120 dB. Calculate the defect in the closed loop gain due to the finite open loop gain. **(1)**

b.

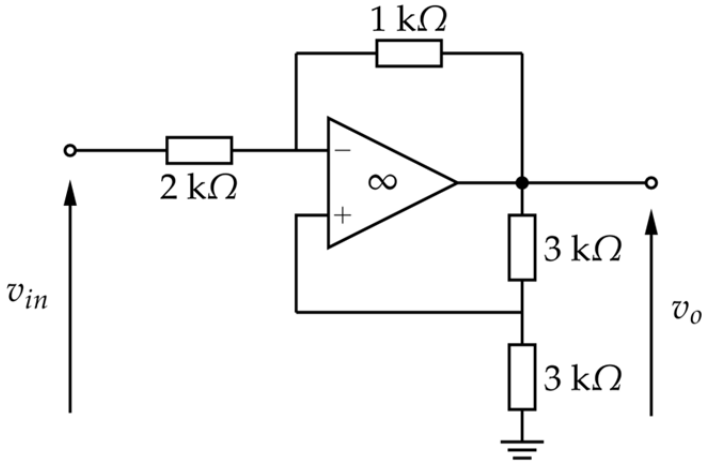


Figure 6b

i) Find the gain of the circuit shown in Figure 6b. **(4)**

ii) Suggest a simpler opamp circuit using only two resistors which would achieve the same gain. **(2)**

c. The voltage output from the circuit in Figure 6c will be of the form,

$$V_o = a + b\sin(\omega t)\ \text{V}$$

find *a* and *b*.

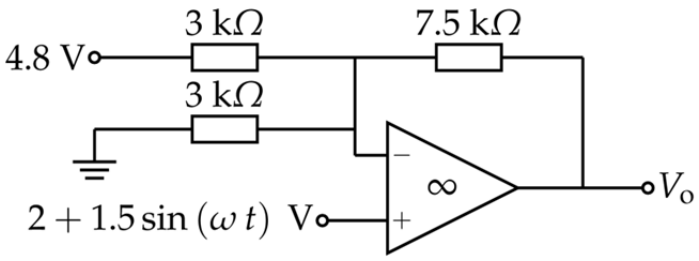


Figure 6c **(6)**

JH/JEG/MMDS