Data Provided: None

The University Of Sheffield.

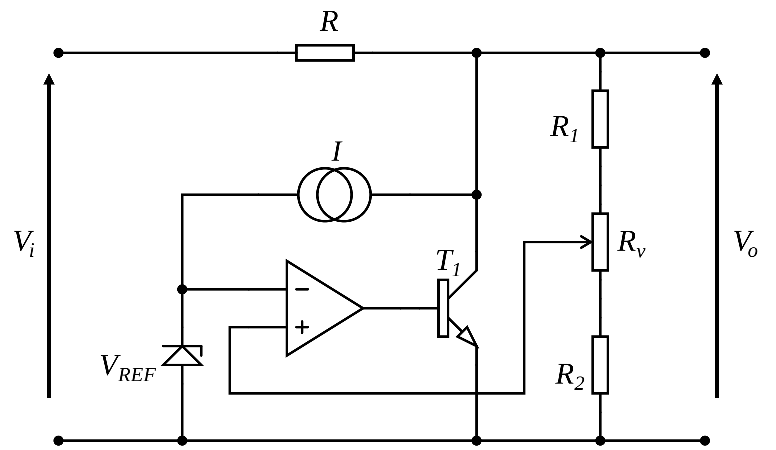
DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2010-2011 (2 hours)

EEE340 Analogue and Switching Circuits 3

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth 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.**

1. The circuit shown in Figure 1 is an adjustable linear shunt regulator. It is to be used to supply a load current which may vary between 0 and 40mA. For the circuit to maintain correct operation the current through T_1 must be always greater than 10mA. You may neglect the power dissipated in the voltage divider network, T_1, I, V_{REF} and the operational amplifier. The component values for the circuit are given in Table I.



V_i	18V to 25V
V_{REF}	3.3V
R_1	10kΩ
R_v	4.7kΩ
R_2	4.7kΩ

Table I

Figure 1

a. What range of output voltage, V_o, is available by adjusting R_v? **(4)**

b. What is the maximum value of R that will ensure correct operation of the circuit over the full range of output voltage, load current and supply voltage conditions? **(3)**

c. What power is dissipated by R under the worst case normal operating condition and with a prolonged short circuit across the output? **(4)**

d. What maximum power must T_1 be capable of dissipating? **(4)**

e. What is the efficiency of the shunt regulator if the input voltage is set to 20V, output voltage is set to 10V and applied to a 500Ω load resistor? You may neglect the power dissipated in the voltage divider network, T_1, I, V_{REF} and the operational amplifier. **(5)**

2. **a.** Explain why hysteresis is usually necessary in comparator circuits. Provide an example where hysteresis might be used. **(2)**

b. Sketch the transfer characteristic, V_O against V_I, of the Schmitt trigger circuit shown in Figure 2a, highlighting the area of hysteresis.

Determine the two input voltage values required at V_I to achieve Low-High and High-Low switching transitions. You may assume that the voltage across the zener diode clamp is either V_{OH} or V_{OL} where V_{OH}=-V_{OL}. Determine the circuit's hysteresis in terms of V_{OH}, V_{OL}, R_1 and R_2.

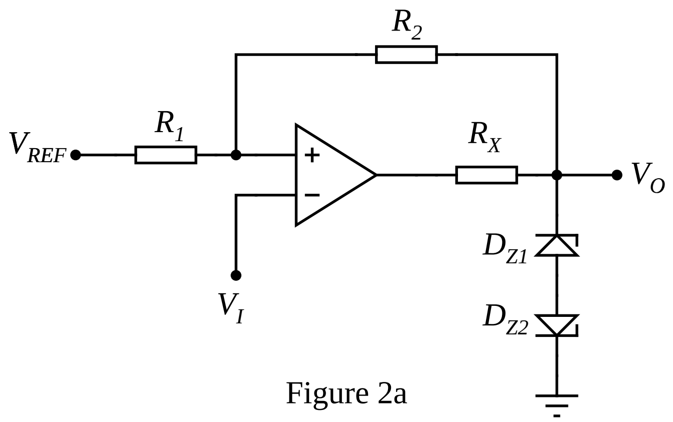


Figure 2a **(5)**

The circuit presented in Figure 2a is now modified to form a triangle/square waveform oscillator as shown in Figure 2b.

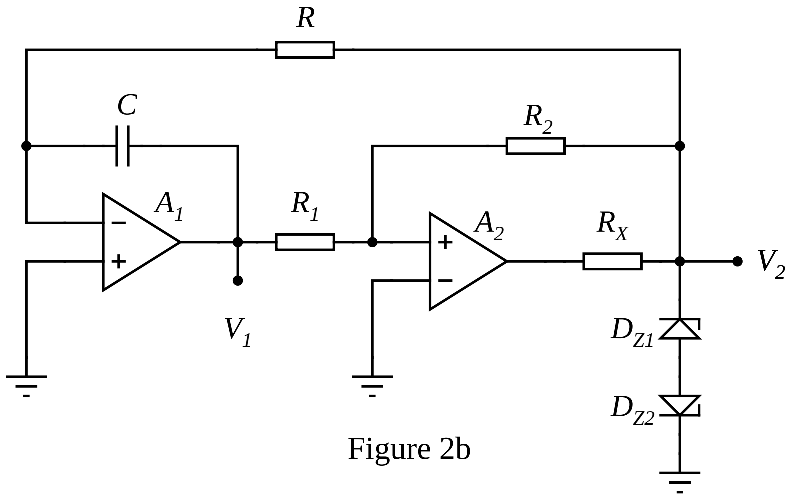


Figure 2b

c. Sketch the waveforms one would expect to observe at the inverting integrator output (V_1) and the Schmitt trigger output (V_2). Label the key points on your sketch including the triangle waveform gradient. **(6)**

d. Derive an expression for the period of oscillation in terms of R, C, R_1 and R_2. You may assume that the voltage across the zener diode clamp is either V_{OH} or V_{OL} where $V_{OH} = -V_{OL}$.

If R_1=R_2=4.7kΩ calculate the RC product required to produce an oscillation frequency of 4kHz. **(5)**

e. What is the purpose of R_x in figure 2a? **(2)**

3. **a.** Sketch a diagram of the V_{DS}-I_D output characteristic for a typical N channel MOSFET showing the influence of V_{GS} on the characteristic. On your diagram label the idealised and the practical ‘on’ and ‘off’ state operating points and illustrate the linear and saturation operating regions. **(5)**

b. Sketch the switching waveforms of V_{DS}, I_D and V_{GS} as a function of time for the circuit shown in Figure 3a. Assume that v_{in} is a pulse that is long in duration in comparison with the time constants of the MOSFET, and large enough in amplitude to ensure proper on-state operation. On your diagram label the following events, turn-on and turn-off delay times, the turn-on and turn-off switching times and the on-time.

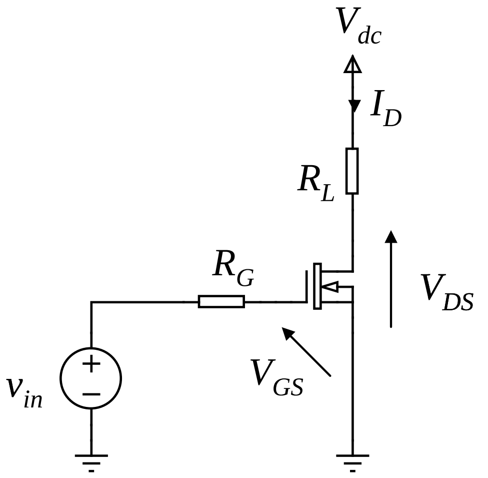


Figure 3a

V_{dc}	60V
R_L	5Ω
R_G	180Ω
C_{DG}	33pF
C_{GS}	100pF
r_{DSON}	0.2Ω
V_{TH}	4V
v_{in}	0□9V

Table III

(6)

c. For the circuit shown in Figure 3a and using the parameters shown in table III, determine the turn-on delay time and the turn-on switching time. **(5)**

d. To accelerate the turn-off process, the circuit in Figure 3a is modified by connecting a series diode-resistor network in parallel with R_G as illustrated in Figure 3b. Assuming the diode has ideal characteristics (i.e. negligible forward voltage drop while conducting), what is the turn-off delay time and the turn-off switching time.

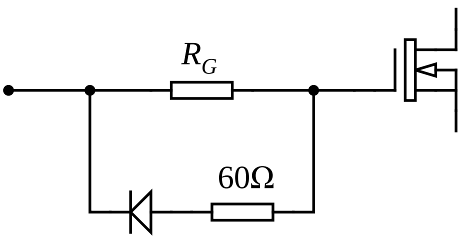


Figure 3b **(4)**

4. The circuit shown in Figure 4 is a speed controller for a permanent magnet brushed DC motor. Its operating characteristics are very similar to a "buck" step-down converter in that transistor T_1 is turned-on at a fixed interval (i.e. turned-on with constant switching frequency) and the speed of the motor ω is controlled by varying the on-time of T_1. The back-emf of the motor E is proportional to speed ($E=\psi\omega$) and the average current I drawn by the motor is proportional to the motor shaft torque ($T_m=\psi I$). The inductor L represents the motor armature inductance. It is assumed that current continuously flows into the motor.

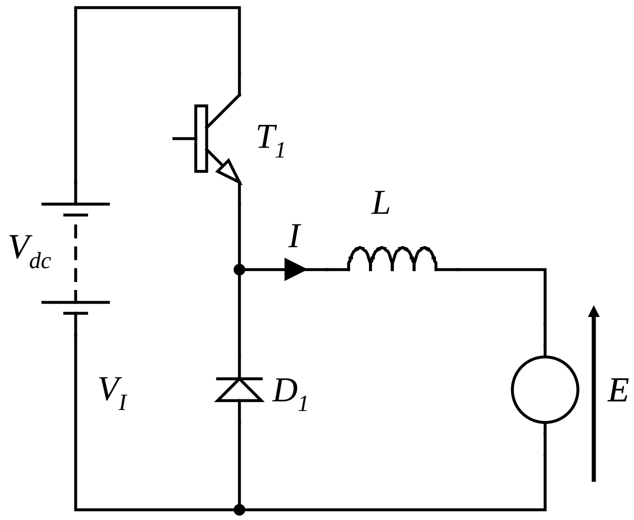


Figure 4

V_{dc}	40V
L	3.4mH
ψ	0.071Nm/A
T_1 on-state voltage drop = 0.5V	
D_1 on-state voltage drop = 1V	

Table IV

To convert RPM to rads^{-1} use

$$\omega = \frac{2\pi}{60} \times RPM$$

a. Draw the sub-circuits that represent the circuit behaviour when T_1 is turned "on" and when T_1 is turned "off" using voltage sources to represent the on-state voltage drop of the semiconductor devices. Indicate the path of current flow on your diagrams. **(5)**

b. Using the values specified in Table IV and assuming the transistor T_1 is turned "on" every 0.5ms, determine the required "on" time if the motor is to operate at 2000rpm.

Sketch the voltage across D_1, V_{D1}, that you would expect to observe if this circuit is operated for the conditions listed in Table IV. Label peak values of the voltage levels and the time durations for the various parts of the waveform. Your waveform should show at least one complete switching period. **(8)**

c. A torque of 0.15Nm is applied to the motor shaft. Determine the average current required by the motor and the maximum and minimum current that occur due to the repetitive switching nature of the circuit for the conditions used in part b. **(4)**

d. If the motor is to be operated at a minimum speed of 1000rpm, what is the minimum operating frequency that may be used that will limit the motor ripple current to 0.5A? You may neglect all transistor and diode forward voltage drops. **(3)**

MPF