IMPORTANT: Besides your calculator and the sheets you use for calculations you are only allowed to have an A4 sized "copy sheet" during this exam. Notes, problems and alike are not permitted. Please submit your "copy sheet" along with your solutions. You may get your "copy sheet" back after your solutions have been graded. ***Do not forget to write down units and convert units carefully! Cell phones are not allowed and should be placed on the front desk before the exam.***

ELE222E INTRODUCTION TO ELECTRONICS (21134)

Midterm Exam #2 ✎ 16 April 2012 ⌛ 9.30-11.30

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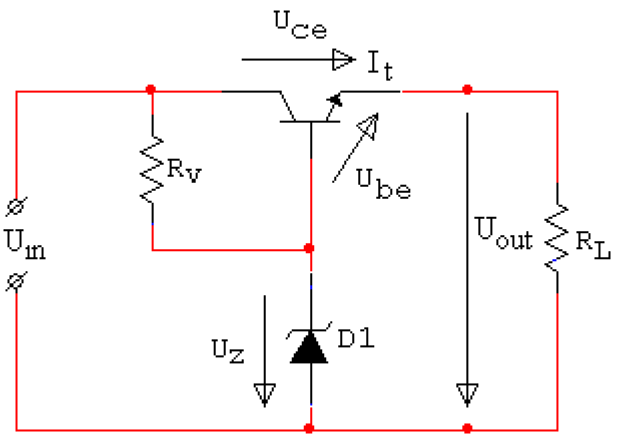
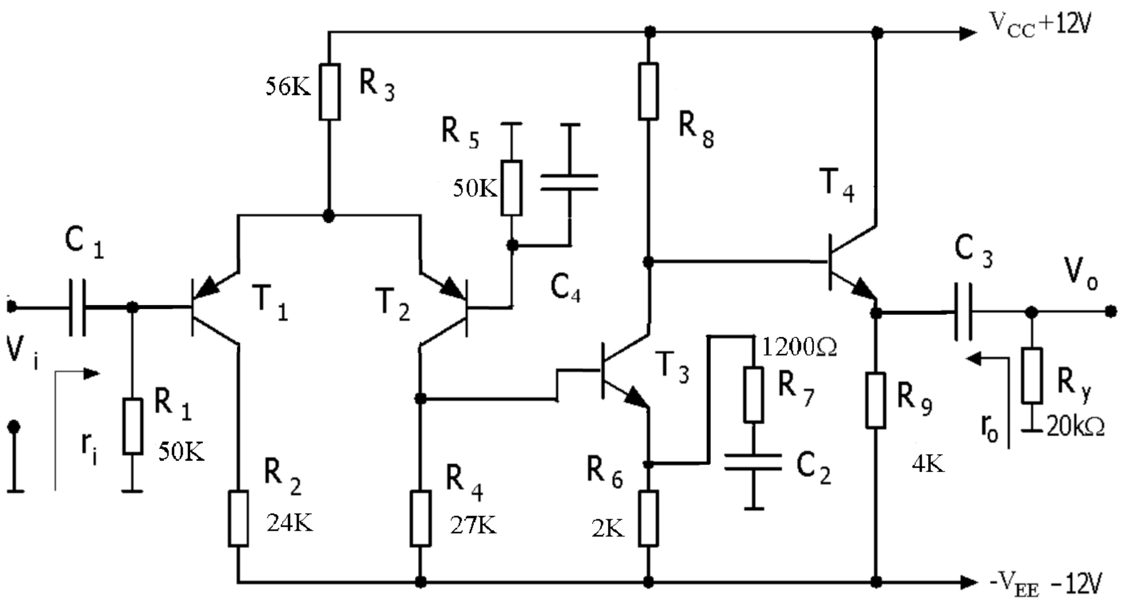


1. The figure left shows a Zener voltage regulator that uses an emitter follower stage. The load current I_t is supplied by the transistor whose base is connected to the Zener diode. Thus the transistor's base current (I_B) forms the load current for the Zener diode and is much smaller than I_t, the current through R_L. For $|V_{BE}| = 0,6$ V, $h_{FE} = 100$, $I_t = 100$ mA, and $U_Z = V_Z = 5,6$ V, $I_{Zmin} = 10$ mA to produce a stable voltage. (30 points)

    a. Find U_{out} (V_{out}) for U_{in} (V_{in}) varying between 7,8 to 9,6 V with NO load resistor R_L connected to the output.
    b. Estimate the minimum value for R_V .
    c. Check the Zener diode performance under the worst conditions and calculate power dissipation on the Zener diode.

2. Study the 3-stage BJT amplifier circuit below with $|V_{BE}| = 0,6$ V, $V_T = 25$mV, $h_{oe} = h_{re} = 0$, and $h_{FE} = h_{fe} = 250$ for all four transistors. (70 points)

    a. Indicate the configurations for all four stages. (i.e., common C, common E, common B, etc.)
    b. How should R_8 be chosen, such that, waveform distortion at the output V_o is minimum and symmetrical?
    c. Find input and output resistances, r_i and r_o .
    d. Find $K_v = v_o/v_i$ and and **CMRR** of the differential stage.
    e. Find which resistor determines the voltage gain K_v and adjust that resistor for **$|K_v|$ = 1000** without changing biasing conditions.



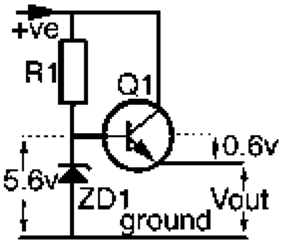
GOOD LUCK

SOLUTIONS:

1. Check out http://www.satcure-focus.com/tutor/page5.htm

One of the most commonly used circuits is that of the VOLTAGE REGULATOR.

The simplest voltage regulator uses just a resistor and a zener diode. In the circuit diagram you can see a resistor (R1) and a zener diode (ZD1) connected across a power supply. The resistor is connected to the positive (+ve) supply wire and the zener diode anode is connected to the zero volt (ground) wire. At the junction of these two components the voltage is clamped by the zener diode to its specified voltage - in this case 5.6 volts.



This method is OK for low currents but the resistor becomes too hot if larger currents are needed. To cope with this problem we can add the NPN transistor (Q1). Now the transistor passes the current required at the output.

What is the output voltage?

It is easy to calculate. The voltage at Q1 base connection is 5.6 volts.
The voltage between base and emitter of a silicon transistor is always 0.6 volts if the transistor is "on".
So the voltage at the Q1 emitter (Vout) must be 5.6 - 0.6 = 5.0 volts.

The output voltage will remain at a constant voltage of 5.0 volts provided that the input voltage from the supply is more than 6 volts (the zener voltage plus a little to compensate for that "lost" across the resistor).

In fact the input voltage can be swinging up and down between, say, 6 volts and 12 volts and the output voltage at Q1 emitter will still be a steady 5.0 volts.

The limiting factors are the amount of heat generated by R1, ZD1 and Q1 since all excess voltage must be shed as heat. The "wattage" ratings of the individual components must be calculated to suit:

1. The average input current (through R1 and ZD1) and
2. the output current (through Q1).

1. can be calculated from Ohms Law and
2. is decided by whatever the regulator is to supply voltage to.

Ohms Law **I = V/R**	V = Volts I = Amps if R = Ohms or I = mA if R = k½

Let's assume the following:

The circuit which this regulator is driving needs 5.0v at a current of 100mA.

A BC337 transistor is suitable since it can handle current up to 800mA.
Its gain at 100mA is listed as 100 (minimum) so it's easy to see that it will need at least 1mA into its base to allow 100mA to flow from collector to emitter.

For the zener diode let's choose a BZX55C5V6. This will need a minimum of 10mA of current to produce a stable voltage. So Q1 requires 1mA, ZD1 requires 10mA, making a total of 11mA through R1.

If the minimum supply voltage is, say, 7.8v then the minimum voltage across R1 is 2.2v.
Ohms law says that the resistance = V/I
= 2.2/11
= 0.2k resistance
= 200R

Suppose the maximum supply voltage might be 9.6v.
Then the maximum voltage across R1 will be 9.6 - 5.6 = 4.0v.

From Ohms Law, the current through R1 will now be V/R
= 4.0/200
= 0.02A
= 20mA

Watts = Volts x Amps	milliWatts = Volts x milliAmps

Watts = Volts x Amps so the minimum Wattage of R1 must be
4.0 x 0.02 = 0.08W - not a lot!
A standard 0.25 Watt resistor will be more than adequate for R1.

Let's check the zener diode rating under the worst conditions:

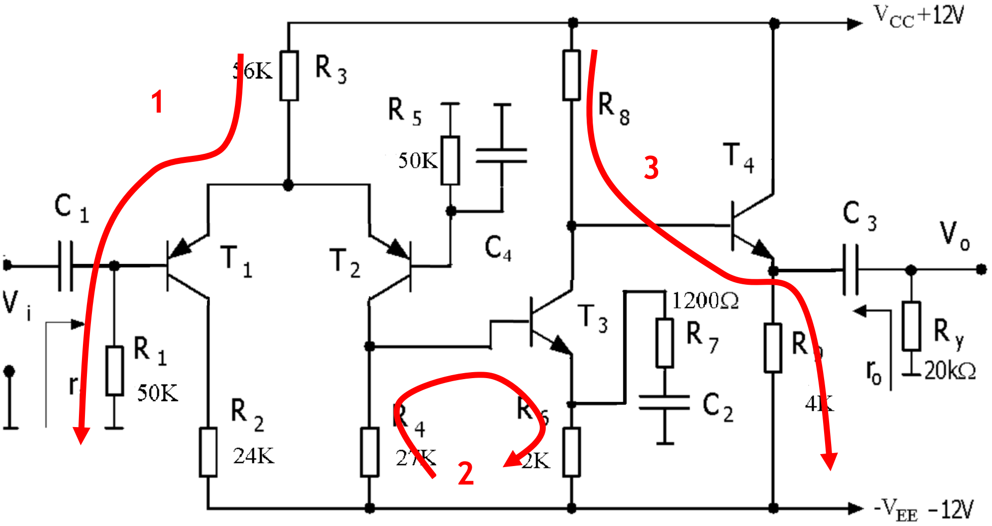
The voltage across ZD1 will still be 5.6v
The current in the worst case will be 20mA, assuming none goes through Q1.
So the Wattage of ZD1 must be at least 5.6 x 0.02 = 0.112W
= 112mW
A BZX zener diode will dissipate up to 500mW so the circuit is safe.

2. Check solution to Problem 3 in http://web.itu.edu.tr/cilesiz/courses/ELE222/ELE222-2008-YYSS-cozumlu.pdf

   a. T1: Common C; T2: common B; T3: common E and T4 Common C.

   b. **From loop 1** $I_E = I_{E1} + I_{E2}$ and $V_{CC} = I_E R_E + V_{EB} + I_{B1} R_1$ and $I_{B1} = I_{B2} \cong \dfrac{2I_E}{h_{fe}}$ you can find

$$I_E = \underline{\underline{200\mu A}} \text{ and } r_{e1} = r_{e2} = r_e \cong \frac{V_T}{I_{E1}} = \underline{\underline{250\Omega}}.$$



From loop 2 assuming $I_{C2} \cong I_{E2}$ we can write $(I_{B3} - I_{C2})R_4 + V_{BE3} + I_{E3} R_6 = 0$ and find

$$I_{E3} = \frac{I_{C2} R_4 - V_{BE3}}{R_4 / h_{fe} + R_6} \cong \underline{\underline{1mA}} \text{ and } r_{e3} = \underline{\underline{25\Omega}}$$

Since $V_{E4} = 0V$ thus $V_{B4} = 0,6V$ and $I_{E4} = \dfrac{0-(-V_{EE})}{R_4} = \underline{\underline{3mA}}$ and $r_{e4} = \underline{\underline{8,33\Omega}}$

From loop 3: $\dfrac{V_{CC}-V_{B4}}{R_8} = I_{C3} + {}^{I_{E4}}\!/_{h_{fe}}$ thus assuming $I_{C3} \cong I_{E3} = \underline{\underline{1mA}}$ we find $R_8 = \underline{\underline{11k265}}$

c. $r_i' = \beta_f(r_{e1} + r_{e2} \parallel R_3)$ and $r_i = r_i' \parallel R_1 = \underline{\underline{38k6}}$

$r_o = R_9 \parallel ({}^{R_8}\!/_{h_{fe}} + r_{e4}) = \underline{\underline{44,5\Omega}}$

d. $r_{i3} = h_{fe}(r_{e3} + R_6 \parallel R_7) = \underline{\underline{193k}}$

$r_{i4} = h_{fe}(r_{e4} + R_9 \parallel R_y) = \underline{\underline{835k}}$

$$K_v = \frac{v_o}{v_i} = \frac{v_o}{v_{c3}} \cdot \frac{v_{c3}}{v_{c2}} \cdot \frac{v_{c2}}{v_{e1,2}} \cdot \frac{v_{e1,2}}{v_i} = \frac{R_9 \parallel R_y}{r_{e4} + R_9 \parallel R_y} \cdot \frac{-R_8 \parallel r_{i4}}{r_{e3} + R_6 \parallel R_7} \cdot \frac{R_4 \parallel r_{i3}}{r_{e2}} \cdot \frac{R_3 \parallel r_{e2}}{r_e + R_3 \parallel r_{e2}}$$

$$K_v = \frac{v_o}{v_i} = \underline{\underline{-687}}$$

We can also find it this way: $K_v = \dfrac{v_o}{v_i} = \dfrac{v_o}{v_{c3}} \cdot \dfrac{v_{c3}}{v_{c2}} \cdot \dfrac{v_{c2}}{v_i} = \dfrac{R_9 \parallel R_y}{r_{e4} + R_9 \parallel R_y} \cdot \dfrac{-R_8 \parallel r_{i4}}{r_{e3} + R_6 \parallel R_7} \cdot \dfrac{R_4 \parallel r_{i3}}{2r_e}$

$$CMRR = 20\log\left|\frac{2R_E + r_e}{r_e}\right| = \underline{\underline{53dB}}$$

3. Without changing baising conditions (at DC C_2 and C_3 capacitors are used for isolation) R_7 and R_y resistors directly affect the voltage gain. However, even for $R_y \to \infty$ last stage voltage gain will not exceed 1; thus the resistor R_7 directly affects the voltage gain.

Since $K_v = \dfrac{v_o}{v_i} = \dfrac{v_o}{v_{c3}} \cdot \dfrac{v_{c3}}{v_{c2}} \cdot \dfrac{v_{c2}}{v_i} = \dfrac{R_9 \parallel R_y}{r_{e4} + R_9 \parallel R_y} \cdot \dfrac{-R_8 \parallel r_{i4}}{r_{e3} + R_6 \parallel R_7} \cdot \dfrac{R_4 \parallel h_{fe}(r_{e3} + R_6 \parallel R_7)}{2r_e}$

$$K_v = \frac{v_o}{v_i} = 0,998 \cdot \frac{-11k115}{25\Omega + R_6 \parallel R_7} \cdot \frac{27k \parallel 250(25\Omega + R_6 \parallel R_7)}{250\Omega}$$

In the extereme, for $R_7 \to 0$ that is $R_6 \parallel R_7 = 0$ then $K_v = 0,998 \cdot \dfrac{-11k115}{25\Omega} \cdot \dfrac{27k \parallel 250(25\Omega)}{250\Omega} = -9003$

Therefore the value to satisfy $K_v = -1000 = 0,998 \cdot \dfrac{-11k115}{25\Omega + 2k \parallel R_7} \cdot \dfrac{27k \parallel 250(25\Omega + 2k \parallel R_7)}{250\Omega}$ is found as

$R_7 = \underline{\underline{640\Omega}}$