Name: Solution (please print)

Signature: ______________________________

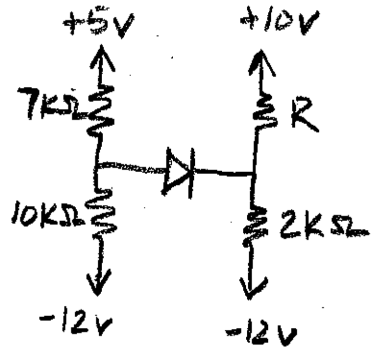
ECE3455

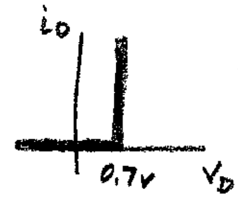
Exam 2

Keep this test closed and face up until you are told to begin

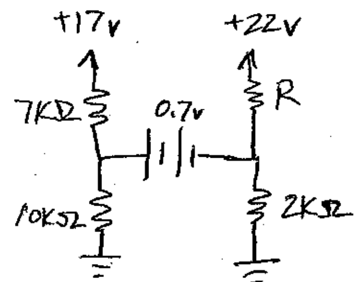
1. This exam is closed book, closed notes
2. You may use two crib sheets
3. You may use a calculator
4. Show all work on the attached pages. Show all work necessary to complete the problem. A solution without the appropriate work shown will receive no credit. A solution which is not given in a reasonable order will lose credit.
5. It is assumed that your work will begin on the same page as the problem statement. If you choose to begin your work on another page, you must indicate this on the page with the problem statement, with a clear indication of where the work can be found. If your work continues on to another page, indicate clearly where your work can be found. Failure to indicate this clearly will result in a loss of credit.
6. Do not use red ink. Do not use red pencil.
7. You will have 90 minutes to work on this exam.

1. For the circuit below, determine the range of values for R where the diode is forward biased.

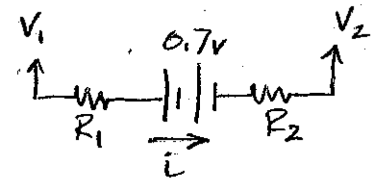




Since ground is not defined, we can redraw the circuit:



Thev. equiv. ⇒



$$V_1 = 17v \cdot \frac{10K\Omega}{10K\Omega + 7K\Omega} = 10v$$

$$V_2 = 22v \cdot \frac{2K\Omega}{R + 2K\Omega} = \frac{44\ v \cdot K\Omega}{R + 2K\Omega}$$

$$R_1 = 10K\Omega \,\|\, 7K\Omega$$

$$R_2 = \frac{2K\Omega \cdot R}{2K\Omega + R}$$

if forward biased, i > 0

$$i = \frac{V_1 - V_2 - 0.7v}{R_1 + R_2} > 0$$

$$V_1 - V_2 - 0.7v > 0$$

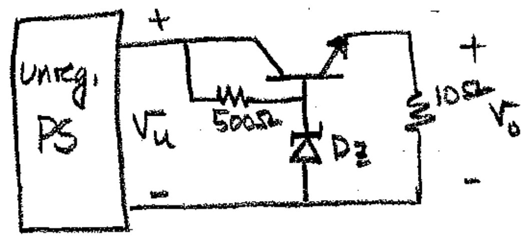
$$10v - \frac{44\ v \cdot K\Omega}{R + 2K\Omega} - 0.7v > 0$$

$$9.3v\,(R + 2K\Omega) > 44\ V \cdot K\Omega$$

$$9.3\, R > 44K\Omega - 18.6K\Omega = 25.4K\Omega$$

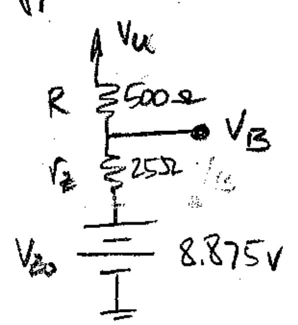
$$R > 2.73K\Omega$$

2. In the regulator circuit below, determine the value of V_o for V_u = 15[redacted] volts. Assume that $\beta = 100$ for the transistor and that the Zener diode parameters are V_z = 9 volts when I_z = 5mA and $r_z = 25\ \Omega$.



There are two ways to solve this problem. The first is to recognize that the base connection is the current load to the Zener regulator circuit we discussed in class. The second is to solve the problem directly.

First approach:



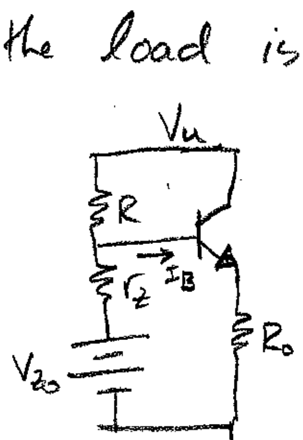
$$V_Z = V_{Z0} + I_Z r_Z$$

$$V_{Z0} = V_Z - I_Z r_Z = 9V - 5mA \cdot 25\Omega$$

$$= 8.875V$$

so: $I_Z = (V_u - V_{Z0})/(R + r_Z)$ for no load

when the load is added, some of the Zener current will flow through the base of the transistor. So the new Zener current will be



$$I_Z' = I_Z - I_B = \frac{V_u - V_{Z0}}{R + r_Z} - \frac{V_o}{R_o} \cdot \frac{1}{1+\beta} \quad (1)$$

Also:

$$V_B = I_Z' \cdot r_Z + V_{Z0} = V_o + V_{BE} \quad (2)$$

so; using equ. (1) and equ. (2)

$$(V_u - V_{Z0})\frac{r_Z}{R+r_Z} - \frac{r_Z}{R_o}\cdot\frac{V_o}{(1+\beta)} + V_{Z0} = V_o + V_{BE}$$

$$V_o\left[1 + \frac{r_Z}{R_o(1+\beta)}\right] = (V_u - V_{Z0})\frac{r_Z}{R+r_Z} + V_{Z0} - V_{BE}$$

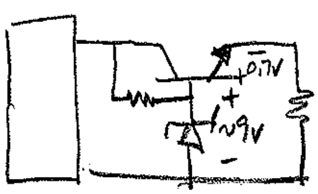
$$V_o = \frac{(V_u - V_{Z0})\frac{r_Z}{R+r_Z} + V_{Z0} - V_{BE}}{1 + \frac{r_Z}{R_o(1+\beta)}}$$

Hence:

$$V_o = \frac{(15V - 8.875V)\frac{25\Omega}{525\Omega} + 8.875V - 0.7V}{1 + \frac{25\Omega}{10\Omega \cdot 101}}$$

$$= 8.26 \text{ volts}$$

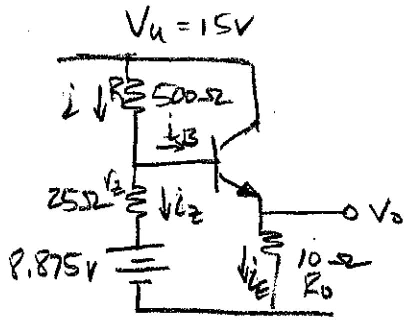
This very close to the value one would expect:



$9V - 0.7V = 8.3$ volts!

Also, since $V_c = V_u > V_B > V_E$, transistor is active

In the second approach, we solve the circuit directly



$$V_o = i_E \cdot R_o = (\beta+1) i_B \cdot R_o \quad \Rightarrow \quad i_B = \frac{V_o}{(\beta+1) R_o}$$

$$i = i_Z + i_B \Rightarrow i_B = i - i_Z \quad \Rightarrow \quad i = i_Z + \frac{V_o}{(\beta+1) R_o} \qquad (1)$$

$$-V_u + V_{Z0} + i \cdot R + i_Z \cdot r_Z = 0 \quad \Rightarrow \quad i = \frac{V_u - V_{Z0} - i_Z r_Z}{R} \qquad (2)$$

$$V_o = V_{Z0} + i_Z r_Z - V_{BE} \qquad (3)$$

Equ.(1) - Equ.(2)

$$0 = i_Z + \frac{V_o}{(\beta+1) R_o} - \left(\frac{V_u - V_{Z0} - i_Z r_Z}{R} \right)$$

$$-i_Z \left(\frac{r_Z}{R} + 1 \right) = \frac{V_o}{(\beta+1) R_o} + \frac{V_{Z0} - V_u}{R}$$

$$i_Z = \frac{V_u - V_{Z0}}{R\left(\frac{r_Z}{R} + 1\right)} - \frac{V_o}{(\beta+1) R_o \left(\frac{r_Z}{R} + 1\right)}$$

Plug into Equ. (3)

$$V_o = V_{Z0} + \left[\frac{V_u - V_{Z0}}{r_Z + R} - \frac{V_o}{(\beta+1) R_o \left(\frac{r_Z}{R}+1\right)} \right] \cdot r_Z - V_{BE}$$

$$V_o \left[1 + \frac{r_Z}{(\beta+1) R_o \left(\frac{r_Z}{R} + 1\right)} \right] = V_{Z0} + \frac{V_u - V_{Z0}}{r_Z + R} \cdot r_Z - V_{BE}$$

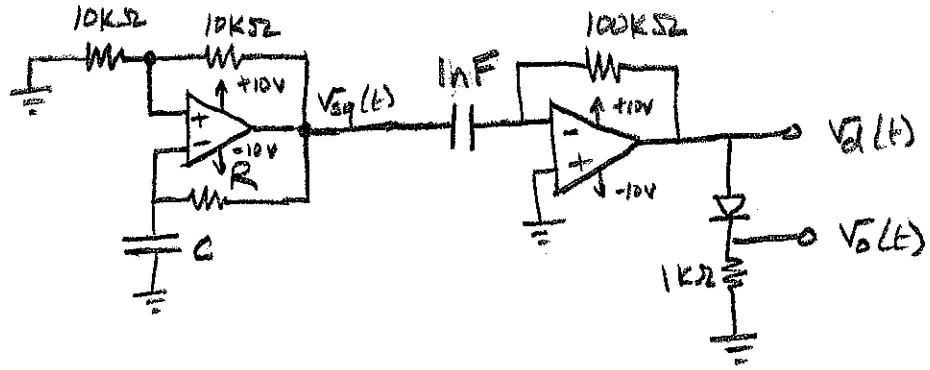
so:

$$V_o = \frac{V_{Z0} + \frac{r_Z}{R + r_Z}(V_{i} - V_{Z0}) - V_{BE}}{1 + \frac{r_Z}{(\beta+1) R_O \left(\frac{r_Z}{R} + 1\right)}}$$

If we note that $\frac{r_Z}{R} \ll 1$, then this answer is identical to the previous solution!

label axes

3. For the circuit below, sketch the functions for $v_d(t)$ and $v_o(t)$ given the waveform $v_{sq}(t)$. [redacted]



$$V_d(t) = -RC\frac{dv_{sq}(t)}{dt}$$

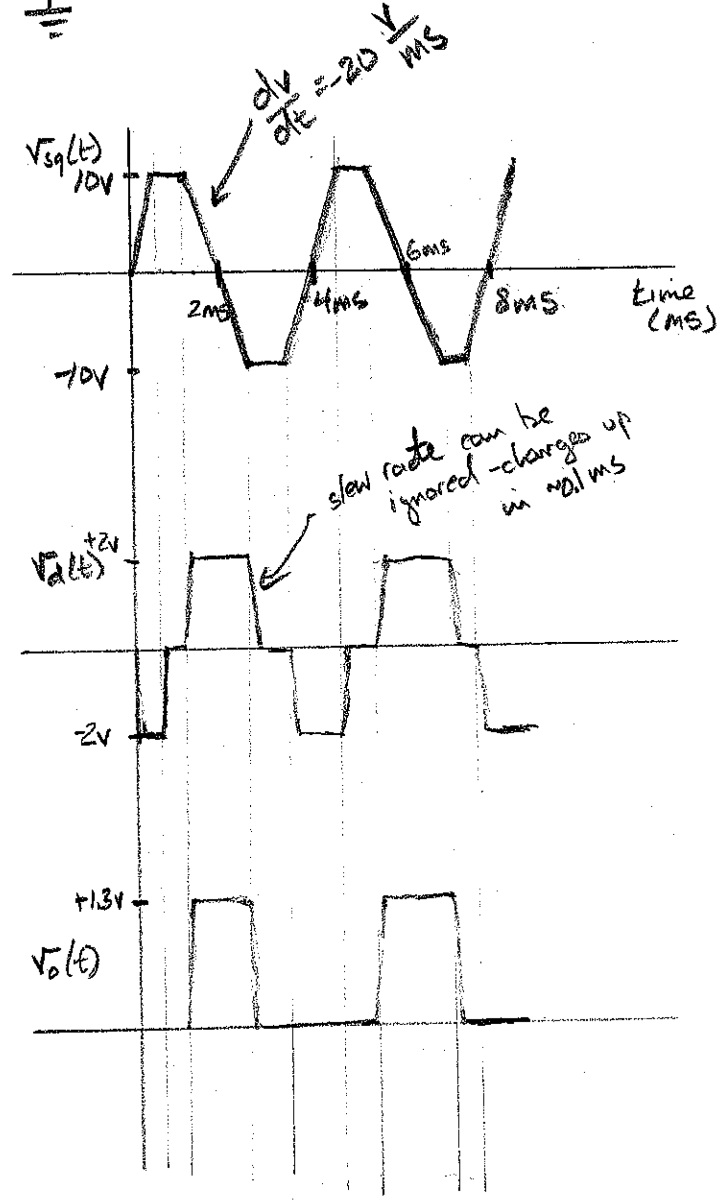
$$RC = 1nF \cdot 100K\Omega$$

$$= 1\times10^{-9}F \cdot 1\times10^{5}\Omega$$

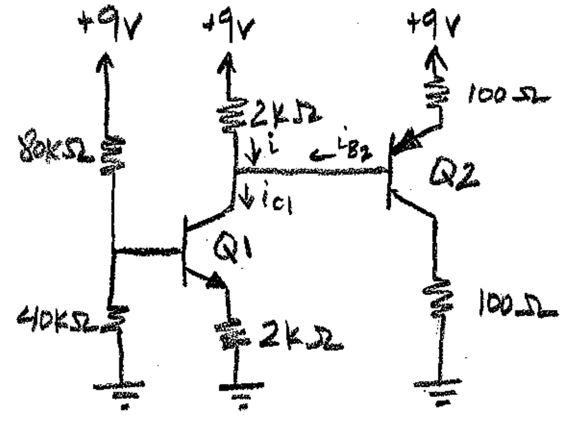
$$= 0.1\,ms$$

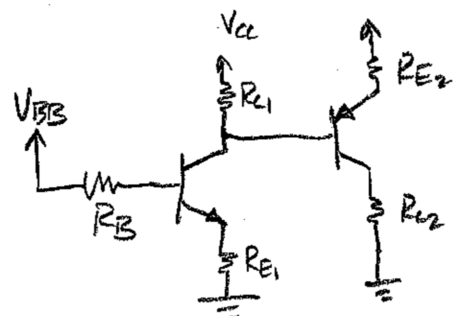
$$V_d(t) = \begin{cases} 0 & \text{for } \frac{dv_{sq}}{dt} = 0 \\ -2V & \text{for } \frac{dv_{sq}}{dt} = 20\frac{V}{ms} \\ +2V & \text{for } \frac{dv_{sq}}{dt} = -20\frac{V}{ms} \end{cases}$$

$$V_o(t) = \begin{cases} V_d - 0.7v & \text{for } V_d \geq 0.7 \\ 0 & \text{for } V_d < 0.7 \end{cases}$$



4. Determine the following currents and voltages for the circuit given below given that β = 100 for both transistors: i_{B1}, i_{E1}, i_{C1}, i_{B2}, i_{E2}, i_{C2}, v_{B2}, and v_{C2}. The numeral in the subscript identifies the transistor (either Q1 or Q2) and the letter identifies the transistor terminal.





$$V_{BB} = \frac{40K\Omega}{120K\Omega} \cdot 9V = 3V$$

$$R_B = 80K\Omega \| 40K\Omega = \frac{40 \cdot 80}{120}$$

$$R_B = 26.7K\Omega$$

$$V_{BB} = i_{B1} R_B + V_{BE1} + i_{E1} R_{E1}$$

$$i_{E1} = \frac{V_{BB} - V_{BE1}}{R_{E1} + R_B/(1+\beta)} = \frac{3V - 0.7V}{2K\Omega + 26.7K\Omega/101} = 1.02mA$$

$$i_{C1} = i + i_{B2} \Rightarrow i = i_{C1} - i_{B2}$$

$$i_{E2} \cdot R_{E2} + V_{EB2} = i\, R_{C1}$$

$$i_{E2} \cdot R_{E2} + V_{EB2} = (i_{C1} - i_{B2}) R_{C1} = (\alpha i_{E1} - i_{E2}/(1+\beta)) R_{C1}$$

$$i_{E2}\left(R_{E2} + \frac{R_{C1}}{1+\beta}\right) = \alpha i_{E1} R_{C1} - V_{EB2}$$

$$i_{E2} = \frac{\alpha i_{E1} R_{C1} - V_{EB2}}{R_{E2} + \frac{R_{C1}}{1+\beta}} = \frac{\left(\frac{100}{101}\right)(1.02mA)(2K\Omega) - 0.7V}{100\Omega + 2K\Omega/101}$$

$$i_{E2} = 10.9mA$$

Once we know i_{E1} & i_{E2}, we know the rest:

$$i_{B1} = \frac{i_{E1}}{1+\beta} = 10.1\,\mu A$$

$$i_{C1} = \frac{\beta}{1+\beta} \cdot i_{E1} = 1.01\,mA$$

$$i_{B2} = \frac{i_{E2}}{1+\beta} = 108\,\mu A$$

$$i_{C2} = \frac{\beta}{\beta+1} \cdot i_{E2} = 10.8\,mA$$

$$V_{B2} = 9V - (i_{C1} - i_{B2}) \cdot 2K\Omega = 7.2\,V$$

$$V_{C2} = i_{C2} \cdot 100\Omega = 1.08\,V$$

Also note:

$$V_{E1} = 1.02\,mA \cdot 2K\Omega = 2.04\,V$$

$$V_{B1} = 3V - i_{B1} R_B = 3 - 0.01 \cdot 26.7 = 2.73\,V$$

$$V_{C1} = V_{B2} = 7.2\,V$$

so, Q1 is active ✓

$$V_{E2} = 9V - 100\Omega \cdot i_{E2} = 9V - 100\Omega \cdot 10.9\,mA$$

$$= 9V - 1.09V = 7.91\,V$$

so, Q2 is also active

✓