Union College
ECE 363
QUIZ 3 Fall 2017

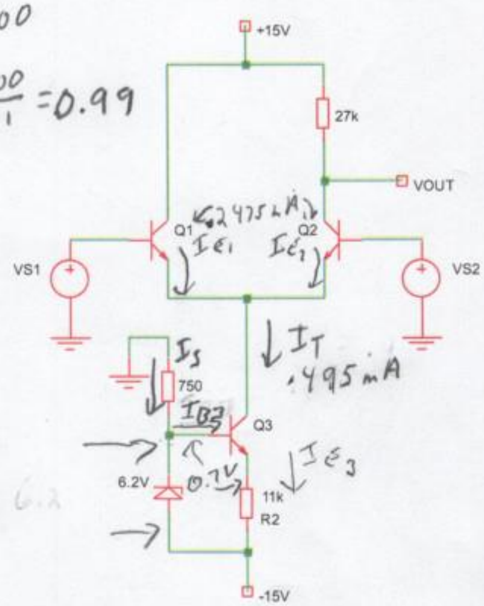
NAME: Solution

Problem #1: Differential amplifier analysis (15 pts)

Consider the differential amplifier shown to the right. The power supplies are +/-15V, and the current source uses a 6.2V zener. Assume β = 100 and V_{BE} = 0.7V for all transistors. Assume Q3 has V_A = 120V. The inputs are V_{S1} = 2.01V and V_{S2} = 2.05V.

$\beta = 100$

$\alpha = \frac{100}{101} = 0.99$



a) Compute the tail current I_T.

b) Compute the differential gain A_d.

c) Compute the common mode gain A_{CM}.

Hint #1: $R_{OUT} = r_o\left[1 + \beta \frac{R2}{R2+(\beta+1)r_e'}\right]$

Hint #2: $A_{CM} = \alpha R_C/2R_{OUT}$.

d) Compute the CMRR of your amplifier.

e) Compute the output voltage V_{OUT} of your amplifier.

f) Suppose you want to use capacitive coupling to connect V_{OUT} to another amplifier that has an input impedance of 2kΩ. What value capacitor would you use if you would like the low frequency cut-off to be 100 Hz?

a) Assume $I_Z > 10$ mA

$$I_{E3} = \frac{6.2 - 0.7}{11k} = \boxed{.5 mA}$$

Now check zener $I_Z = I_S - I_B = \frac{15-6.2}{750\Omega} - \frac{.5mA}{101} = 11.73mA$ OK

b) $A_d = \frac{\alpha R_C}{2r_e'}$; $r_{e1}' = r_{e2}' = \frac{.026}{\frac{1}{2}I_T} = \frac{.026}{\frac{1}{2}(.495mA)} = 105\Omega$

$$A_d = \frac{(0.99)(27k)}{(2)(105\Omega)} = \boxed{127.3}$$

(extra sheet for work)

for Q_3

c) $A_{CM} = \frac{\alpha R_C}{2 R_{out}} \Rightarrow$ need $R_{out} = r_o\left[1+\beta \frac{R_2}{R_2+(\beta+1)r_e'}\right]$

~~need R_{out}~~

~~first need~~ $r_o = \frac{V_A}{I_{C3}} = \frac{120V}{.495mA} = 242.4k$

$r_e' = \frac{0.26}{I_{E3}} = \frac{.026}{.5mA} = 52\,\Omega$

$R_{out} = (242.4k)\left[1 + 100\frac{11k}{11k+(101)(52)}\right] = 166494k$

$A_{CM} = \frac{(0.99)(27k)}{(2)(166494k)} = \boxed{8\times10^{-4}}$

d) $CMRR = 20\log_{10}\frac{A_d}{A_{CM}} = 20\log_{10}\left(\frac{127.3}{8\times10^{-4}}\right) = \boxed{104dB}$

e) $V_{out} = V_{CQ} + \Delta V_{out} = \Delta V_{out} = \Delta V_{in} A_d + V_{CM} A_{CM}$

$\Delta V_{in} = 2.01 - 2.05 = -0.04V$; $V_{CM} = \frac{2.01+2.05}{2} = 2.03V$

$\Delta V_{out} = (127.3)(-0.04V) + (8\times10^{-4})(2.03V) = -5.09V$

$V_{CQ} = 15 - (0.99)(\frac{1}{2})(.495mA)(27k = 8.384V$

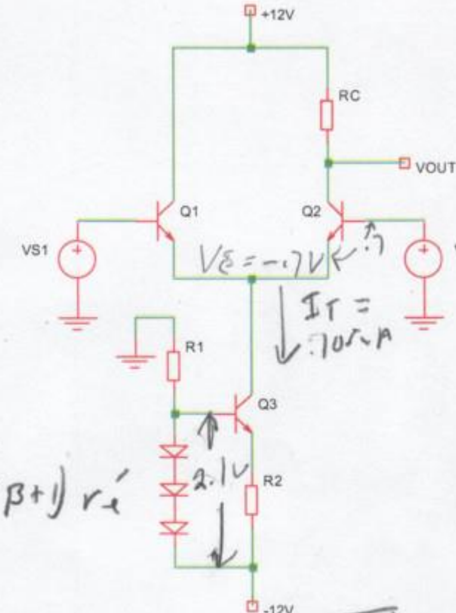
$V_{out} = 8.384 - 5.090 = \boxed{3.294V}$

f) $f_c = \frac{1}{2\pi R_L C_{out}} \Rightarrow C_{out} = \frac{1}{(2\pi)(2000)(100)}$

$C_{out} = 7.96\times10^{-7}F = .796\mu F$ $\boxed{\text{Choose } .82\mu F}$

Problem #2: Differential amplifier design (15 pts)

Design a differential amplifier with current source biasing. The input impedance should be $R_{IN} \geq 100$ kohm nd a differential gain $A_d \geq 120$. Use three forward-biased diodes for the current source. Assume $\beta = 100$ and $V_{BE} = 0.7V$ for all transistors. Assume Q3 has $V_A = 120V$. Use standard 5% resistor values (see chart on page 5).



a) Compute the maximum allowed tail current I_T.

b) Choose the proper R_2 and compute your actual tail current.

c) Choose the proper R_1 to bias the three diodes.

d) Choose the proper R_C and compute your actual gain A_d.

e) What is the maximum peak-to-peak output voltage swing without clipping?

a) $R_{in} \geq 100k$ and $R_{in} = 2(\beta+1) r_e'$

$$r_e' \geq \frac{100k}{(2)(101)} = 495\Omega$$

$$\frac{0.026}{\frac{1}{2}I_T} \geq .495k \implies I_T \leq \boxed{0.105mA}$$

b) Assume $I_Z \geq 10mA$

$$I_{E3} = \frac{2.1-0.7}{R_2} \implies I_T = \alpha I_3$$

and $0.99\frac{1.4V}{R_2} \leq .105mA$

$\boxed{R_2 \geq 13.2k}$ $\boxed{\text{Choose } 15k}$

Calculate actual $I_T = 0.99\frac{1.4}{15k} = \boxed{0.0924mA}$

c) Calculate R_2

need $I_D = I_s - I_B \gtrsim 1mA$

(extra sheet for work)

Then I_D

$$\frac{12-2.1}{R_1} \geq 1\,mA + \frac{I_C}{\beta} = 1\,mA + \frac{.0924\,mA}{100} = 1.001\,mA$$

and $R_1 \leq \frac{9.9V}{1.001\,mA} = 9.89k$ choose $\boxed{R_1 = 9.1k \text{ or } 10k}$

d) Find a value for R_c to give $A_d \geq 120$

$$A_d = \frac{\alpha R_c}{2r_e'} \quad \text{need } r_e' = \frac{0.026}{\frac{1}{2}I_T}$$

$$r_e' = \frac{0.026V}{(.5)(.0924\,mA)} = 563\,\Omega$$

$$= \frac{\alpha R_c}{2r_e'} \geq 120 \Rightarrow R_c = \frac{(120)(2)(563)}{.99} = \boxed{136.5k}$$

$\boxed{\text{choose } 150k}$

check actual $A_d = \frac{(.99)(150k)}{(2)(563)} = \boxed{131.9}$ OK

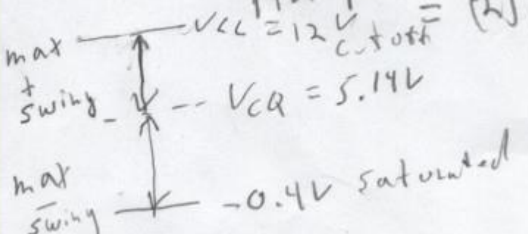
e) Find maximum, undistorted, output pk-pk output "swings" above and below V_{CQ}

$V_{CQ} = 12 - (.99)(.5)(.0924\,mA)(150k) = \boxed{5.14V}$

Max positive swing $= 12 - 5.14 = \boxed{6.86V}$

Max Neg swing $= 5.14 - (\underbrace{-0.7 + 0.3V}_{V_E}) = \boxed{5.54V}$

Max peak-to-peak output swing $= (2)(5.54) = \boxed{11.08\,V_{pk\text{-}pk}}$



* assume $V_{CE,sat} = 0.3$

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Standard Capacitor Values (±10%)						
10pF	100pF	1000pF	.010μF	.10μF	1.0μF	10μF
12pF	120pF	1200pF	.012μF	.12μF	1.2μF	
15pF	150pF	1500pF	.015μF	.15μF	1.5μF	
18pF	180pF	1800pF	.018μF	.18μF	1.8μF	
22pF	220pF	2200pF	.022μF	.22μF	2.2μF	22μF
27pF	270pF	2700pF	.027μF	.27μF	2.7μF	
33pF	330pF	3300pF	.033μF	.33μF	3.3μF	33μF
39pF	390pF	3900pF	.039μF	.39μF	3.9μF	
47pF	470pF	4700pF	.047μF	.47μF	4.7μF	47uF
56pF	560pF	5600pF	.056μF	.56μF	5.6μF	
68pF	680pF	6800pF	.068μF	.68μF	6.8μF	
82pF	820pF	8200pF	.082μF	.82μF	8.2μF	