March 11, 2019

Name:

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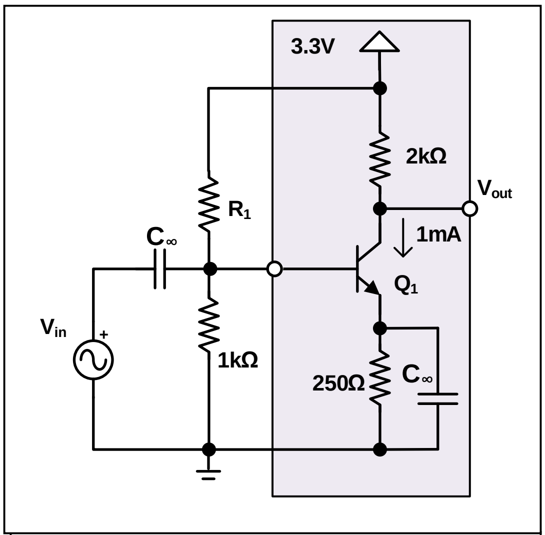
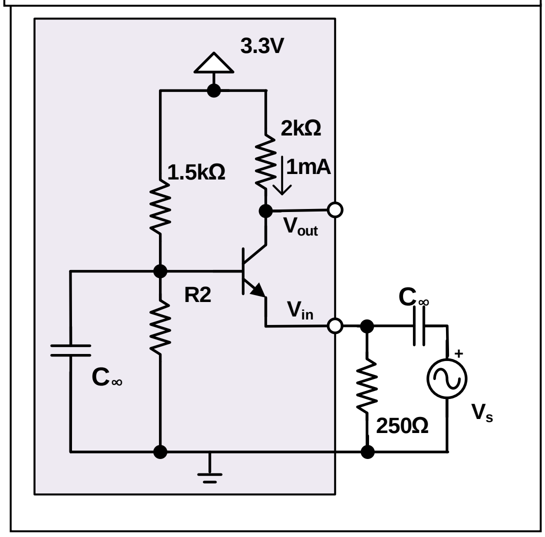
EHB 262E ELECTRONICS 2

1. β=80; V_A=50V; I_c= 1 mA; I_s = 6.91x10^{-16} A; V_T=25 mV
   a) Calculate all DC voltages and R1.
   b) Calculate Gm, Rout and unloaded voltage gain for the amplifier.
   c) Assume an RL resistor is connected to the output. Express Rin (excluding biasing resistors) as a function of RL.

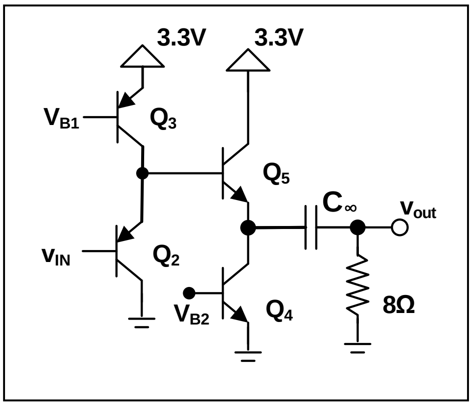


2. β =80; V_A=50V; I_c= 1 mA; I_s = 6.91x10^{-16} A; V_T=25 mV
   a) Calculate all DC voltages and R2.
   b) Calculate Gm, Rout and unloaded voltage gain for the amplifier.
   c) Assume an RL resistor is connected to the output. Express Rin as a function of RL. Hint: Treat 250Ω resistor as an external resistor connected in parallel with the amplifier input Don't include it in the Rin calculation.



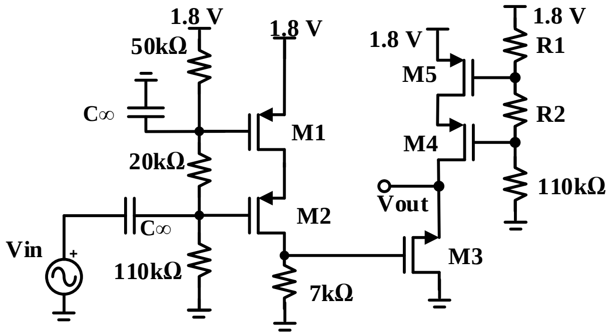
3. $\beta2=\beta3$=60; $\beta4=\beta5$=80;$V_{A2}=V_{A3}$=30V; $V_{A4}=V_{A5}$=50V; V_{B1}=2.6V; V_{B2}=0.7V; $I_{s2}=I_{s3}$=6.91x10^{-16} A; $I_{s4}=I_{s5}$=3.455x10^{-14} A;
   a) Input resistance of the voltage buffer shown in figure 3 while driving a 8Ω load resistor.
   b) Calculate the voltage gain of the buffer.

4. Assume you ant to drive an 8Ω speaker with a signal source with 500Ω output resistance and a peak to peak voltage of 10mV.
   a) You connect the amplifier in Q1 and the buffer in Q3 and drive the 8Ω resistor. Calculate the peak to peak voltage applied to the load resistor.
   b) You connect the amplifier in Q2 and the buffer in Q3 and drive the 8Ω resistor. Calculate the peak to peak voltage applied to the load resistor. 250Ω resistor is still connected to the input of the amplifier.
   c) Why is there such a big difference between output signals of these 2 structures?



5. μ_n= 0.05 $m^2V^{-1}s^{-1}$, μ_p= 0.02$m^2V^{-1}s^{-1}$, C_{ox}= 0.0125 F/m^2, V_{thn}=0.4V, V_{thp}= -0.4V, λ_n=0,15 V^{-1}, λ_p=0,3 V^{-1}

$W_1=W_2=40\mu m$; $W_3=W_4=W_5=100\mu m$; All L are 0.5µm



a. Determine values for R1, R2, which will keep M6 in SAT and 100mV away from edge of triode region if $I_{D4}=I_{D5}$ is 1mA.
b. Calculate DC voltages of all nodes in circuit.
c. Calculate DC currents in all branches.
d. Calculate the Voltage Gain of the circuit.

Equations:

Common Emitter Amplifier: $$R_{in}=r_\pi+\frac{(1+\beta)R_E r_o+R_E\left(R_C\|R_L\right)}{R_E+\left(R_C\|R_L\right)+r_o}$$

$$R_{out}=\left(g_m r_o\left(R_E\|r_\pi\right)+R_E\|r_\pi+r_o\right)\|R_C \qquad G_m=\frac{g_m r_o r_\pi-R_E}{\left(r_\pi+R_E\right)\left(\left(g_m r_o+1\right)\left(r_\pi\|R_E\right)+r_o\right)}$$

Common Base Amplifier: $$R_{in}=r_\pi\left\|\left(\frac{r_o+R_C\|R_L}{g_m r_o+1}\right)\right. \qquad R_{out}=r_o\|R_C \qquad G_m=-\frac{g_m r_o+1}{r_o}$$

Emitter Follower: $$R_{in}=(\beta+1)\left(r_o\|R_E\|R_L\right)+r_\pi \qquad R_{out}=\frac{1}{g_m}\|r_\pi\|R_E\|r_o \qquad G_m=-\frac{g_m r_\pi+1}{r_\pi}$$

Common Source Amplifier: $$R_{in}=\infty \qquad R_{out}=\left(g_m r_o R_S+R_S+r_o\right)\|R_D$$

$$G_m=\frac{g_m r_o}{\left(g_m r_o+1\right)R_S+r_o}$$

Common Gate Amplifier: $$R_{in}=\frac{r_o+R_D\|R_L}{g_m r_o+1} \qquad R_{out}=r_o\|R_D \qquad G_m=-\frac{g_m r_o+1}{r_o}$$

Emitter Follower: $$R_{in}=\infty \qquad R_{out}=\frac{1}{g_m}\|R_S\|r_o \qquad G_m=-g_m$$

Gain: $$A_V=-G_m\left(R_{out}\|R_L\right)$$

$$I_C=I_S\exp\left(\frac{|V_{BE}|}{V_T}\right) \qquad I_D=\frac{1}{2}\mu C_{ox}\frac{W}{L}\left(|V_{GS}|-|V_{TH}|\right)^2$$

Soln

1) a) $I_B = \frac{I_C}{\beta} = \frac{10^{-3}}{80} = 12.5\mu A$

$V_C = V_{CC} - I_C R_C = 3.3 - 2000\left(10^{-3}\right) = 1.3V$

$V_E = I_E R_E = 250\left(1.0125\times 10^{-3}\right) = 253.125mV$

$V_{BE} = V_T \ln\left(\frac{I_C}{I_S} + 1\right) = 700.016mV$

$V_B = V_E + V_{BE} = 953.141mV$

$R_1 = \frac{V_{CC} - V_B}{I_B + \frac{V_B}{1k\Omega}} = 2430.36\Omega$

b) G_m=g_{m1} for common source amplifier

$G_m = g_{m1} = \frac{I_C}{V_T} = 40mS$

$r_{o1} = \frac{V_A}{I_C} = 50k\Omega$

$R_{out} = r_o \| R_C = 50k\Omega \| 2k\Omega = 1923.08\Omega$

$A_V = -G_m R_{out} = -76.92V/V$

c) $R_{in} = r_\pi + R_E \frac{(\beta+1)r_o + \left(R_C \| R_L\right)}{r_o + \left(R_C \| R_L\right) + R_E}$

Re is shorted to ground in this amplifier, so this equation simplifies to

$R_{in} = r_{\pi 1} = 2k\Omega$

2) a) $I_B = \frac{I_C}{\beta} = \frac{10^{-3}}{80} = 12.5\mu A$

$V_C = V_{CC} - I_C R_C = 3.3 - 2000\left(10^{-3}\right) = 1.3V$

$V_E = I_E R_E = 250\left(1.0125\times 10^{-3}\right) = 253.125mV$

$V_{BE} = V_T \ln\left(\frac{I_C}{I_S} + 1\right) = 700.016mV$

$V_B = V_E + V_{BE} = 953.141mV$

$R_2 = \frac{V_B}{\frac{V_{CC} - V_B}{1.5k\Omega} - I_B} = 614.11\Omega$

b) $g_{m1} = \frac{I_C}{V_T} = 40mS$

$$r_{o1} = \frac{V_A}{I_C} = 50k\Omega$$

$$G_m = -g_{m1} - \frac{1}{r_{o1}} = -40.02mS$$

$$R_{out} = r_o \| R_C = 50k\Omega \| 2k\Omega = 1923.08\Omega$$

$$A_V = -G_m R_{out} = 76.96V/V$$

c) $R_{in} = r_\pi \left\| \frac{r_{o1} + \left(R_C \| R_L\right)}{g_{m1} r_{o1} + 1} \right.$

$$R_{in} = 2000 \left\| \frac{50k\Omega + \left(2000 \| R_L\right)}{2001} \right.$$

RL in parallel with 2kΩ will be less than 2kΩ. This will be small compared to 50kΩ. Therefore, Rin will be relatively independent of RL.

3) a) First determine collector currents of all 4 transistors

$$I_{C4} = I_{s4}\left(\exp\left(\frac{V_{BE4}}{V_T}\right) - 1\right) = 49.968mA$$

$$I_{C5} = \frac{\beta_5}{\beta_5 + 1} I_{E5} = \frac{\beta_5}{\beta_5 + 1} I_{C4} = 49.351mA$$

$$I_{B5} = \frac{I_{E5}}{\beta_5 + 1} = 617\mu A$$

$$I_{C3} = I_{s3}\left(\exp\left(\frac{|V_{BE3}|}{V_T}\right) - 1\right) = 999.36\mu A$$

$$I_{E2} = I_{C3} - I_{B5} = 382.4\mu A$$

$$I_{C2} = \frac{\beta_2}{\beta_2 + 1} I_{E2} = 376.20\mu A$$

$$g_{m5} = \frac{I_{C5}}{V_T} = 1.9741S \qquad r_{o5} = \frac{V_{A5}}{I_{C5}} = 1013.15\Omega \qquad r_{\pi 5} = \frac{V_T}{I_{B5}} = 40.526\Omega$$

$$g_{m4} = \frac{I_{C4}}{V_T} = 1.9987S \qquad r_{o4} = \frac{V_{A4}}{I_{C4}} = 1000.64\Omega \qquad r_{\pi 4} = \frac{V_T}{I_{B4}} = 40.025\Omega$$

$$g_{m3} = \frac{I_{C3}}{V_T} = 39.975mS \qquad r_{o3} = \frac{V_{A3}}{I_{C3}} = 30019.1\Omega \qquad r_{\pi 3} = \frac{V_T}{I_{B3}} = 1500.96\Omega$$

$$g_{m2} = \frac{I_{C2}}{V_T} = 1.5048mS \qquad r_{o2} = \frac{V_{A2}}{I_{C2}} = 79744.3\Omega \qquad r_{\pi 2} = \frac{V_T}{I_{B2}} = 3987.2\Omega$$

Rin2 is resistance seen looking into base of Q5.

$$R_{in2} = r_{\pi 5} + \left(\beta_5 + 1\right)\left(r_{o4} \| r_{o5} \| R_L\right) = 678.39\Omega$$

$$R_{in} = r_{\pi 2} + \left(\beta_2 + 1\right)\left(r_{o2} \| r_{o3} \| R_{in2}\right) = 44120.6\Omega$$

b)We have 2 Emitter Follower stages cascaded.

$$G_{m1} = -\left(g_{m2} + \frac{1}{r_{\pi 2}}\right) = -15.30mS$$

$$R_{out1} = \frac{1}{g_{m2}} \| r_{o2} \| r_{\pi 2} \| r_{o3} = 65.17\Omega$$

$$G_{m2} = -\left(g_{m5} + \frac{1}{r_{\pi 5}} \right) = -1.9987S$$

$$R_{out2} = \frac{1}{g_{m5}} \| r_{o5} \| r_{\pi 5} \| r_{o4} = 0.4998\Omega$$

$$A_{v1} = -G_{m1}\left(R_{out1} \| R_{in2}\right) = 0.90963 V/V$$

$$A_{v2} = -G_{m2}\left(R_{out2} \| R_L\right) = 0.94026 V/V$$

$$A_v = A_{v1}A_{v2} = 0.8553 V/V$$

4) a) $R_{in,Q1B} = r_{\pi 1} = 2k\Omega$ Resistance seen looking into base of Q1 in Question 1

$$R_{in,CE} = R_{in,Q1B} \| R_1 \| R_2 = 2k\Omega \| 2.43k\Omega \| 1k\Omega = 523.16\Omega$$

Input voltage of the CE amplifier is determined by voltage division with Rsc and Rin,CE

$$\left|v_{in,CE}\right| = \frac{R_{in,CE}}{R_{in,CE} + R_{sc}} \left|v_{sc}\right| = 5.11mV$$

$$A_{V,CE} = \frac{v_{o,CE}}{v_{in,CE}} = -G_{m,CE}\left(R_{out,CE} \| R_{in,buf}\right) = -0.04\left(1923.08\Omega \| 2k\Omega\right) = -73.71 V/V$$

$$A_{V,buf} = 0.8553 V/V$$

$$\left|v_{out}\right| = A_{v,CE}A_{v,buf}\left|v_{in,CE}\right| = 322.35mV$$

b) $$R_{in,Q1E} = 2000 \| \frac{50k\Omega + \left(2000 \| R_{in,buf}\right)}{2001} = 25.611\Omega$$

$R_{in,Q1E} = 25.611\Omega$ Resistance seen looking into emitter of Q1 in Question 2

If ro is much larger than Rc and RL, you may use the following equation:

$$R_{in,Q1E} = r_{\pi 1} \| \frac{r_{o1}}{g_{m1}r_{o1} + 1} = 24.68\Omega$$

Notice that load resistance has a much larger effect on Rin compared to CE Amplifier.
Input of the CE amplifier is determined by voltage division with Rsc and Rin,CE
Don't ignore effects of Rc and RL in CB amplifier.

$$R_{in,CB} = R_{in,Q1E} \| R_E = 25.611\Omega \| 250\Omega = 23.23\Omega$$

$$\left|v_{in,CB}\right| = \frac{R_{in,CB}}{R_{in,CB} + R_{sc}} \left|v_{sc}\right| = 444\mu V$$

$$A_{V,CB} = \frac{v_{o,CB}}{v_{in,CB}} = -G_{m,CB}\left(R_{out,CB} \| R_{in,buf}\right) = -0.04002\left(1923.08\Omega \| 44.12k\Omega\right) = 73.75 V/V$$

$$A_{V,buf} = 0.8553 V/V$$

$$\left|v_{out}\right| = A_{v,CE}A_{v,buf}\left|v_{in,CE}\right| = 28.00mV$$

c) Input signal applied to the CB amplifier is much weaker than input voltage of the CE amplifier. This is because of small input resistance of the CB amplifier. Voltage divider is ratio is very small in CB case.

5)