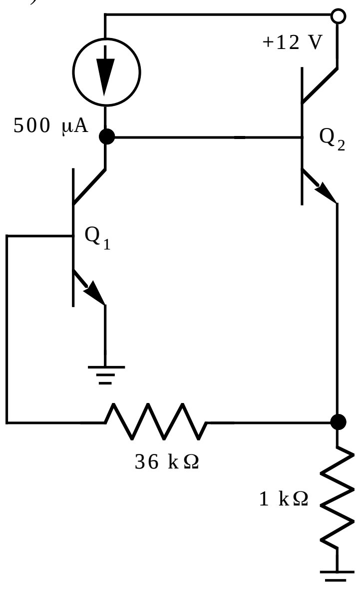
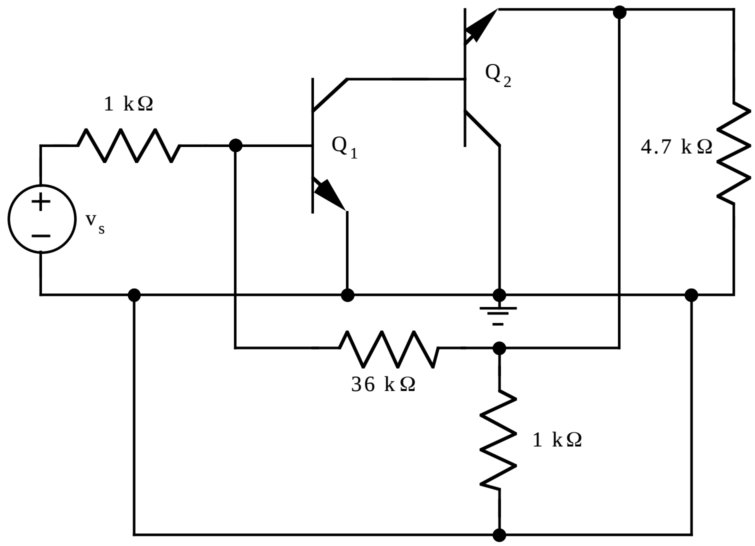
Homework Assignment No. 12 - Solutions

1.) Problem 18.16 of the text.

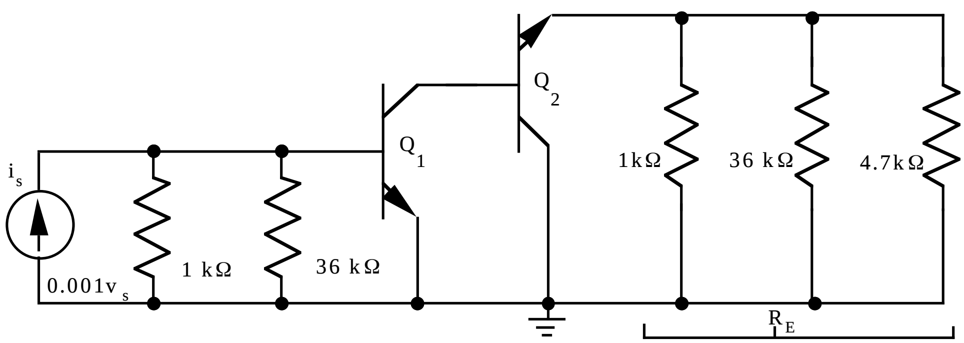




$$I_{C1} = 500\mu A - I_{B2} \quad I_{E2} = I_{B1} + \frac{36000 I_{B1} + 0.7}{1000} = 37 I_{B1} + 700\mu A \quad I_{B2} = \frac{I_{E2}}{101}$$

$$I_{C1} = 500\mu A - \frac{37 I_{B1} + 700\mu A}{101} = 493\mu A - 0.366 I_{B1} \rightarrow I_{C1} = 491.2\mu A$$

$$I_{E2} = 37\frac{I_{C1}}{100} + 700\mu A = 881.7\mu A \quad I_{C2} = \frac{100}{101} I_{E2} = 873\mu A$$



$$y_{11}^F = \left.\frac{\mathbf{i_1}}{\mathbf{v_1}}\right|_{\mathbf{v_2}=0} = \frac{1}{36k\Omega} \quad | \quad y_{22}^F = \left.\frac{\mathbf{i_2}}{\mathbf{v_2}}\right|_{\mathbf{v_1}=0} = \frac{1}{36k\Omega \| 1k\Omega} \quad | \quad y_{12}^F = \left.\frac{\mathbf{i_1}}{\mathbf{v_2}}\right|_{\mathbf{v_1}=0} = -\frac{1}{36k\Omega}$$

$$r_{\pi 1} = \frac{100(0.025)}{491\mu A} = 5.09k\Omega \;|\; r_{\pi 2} = \frac{100(0.025)}{873\mu A} = 2.86k\Omega \;|\; r_{o1} = \frac{50 + 1.6}{493x10^{-6}} = 105k\Omega$$

$$R_E = \left(1k\Omega \| 36k\Omega \| 4.7k\Omega\right) = 807\Omega$$

$$A = \frac{\mathbf{v_o}}{\mathbf{i_s}} = \left(1k\Omega \| 36k\Omega \| r_{\pi 1}\right) g_{m1}\left[r_{o1} \| \left(r_{\pi 2} + (\beta_o + 1)R_E\right)\right] \frac{r_{\pi 2} + (\beta_o + 1)R_E}{r_{o1} + r_{\pi 2} + (\beta_o + 1)R_E}$$

Problem 18.16 - Continued

$$A = \frac{\mathbf{v_o}}{\mathbf{i_s}} = -\left(1k\Omega \| 36k\Omega \| 5.09k\Omega\right) g_{m1}\left[r_{o1} \| \left(r_{\pi 2} + (\beta_o + 1)R_E\right)\right] \frac{r_{\pi 2} + (\beta_o + 1)R_E}{r_{o1} + r_{\pi 2} + (\beta_o + 1)R_E}$$

$$\left(1k\Omega \| 36k\Omega \| r_{\pi 1}\right) = \left(1k\Omega \| 36k\Omega \| 5.09k\Omega\right) = 817\Omega \quad | \quad g_m = 40(491\mu A) = 19.6mS$$

$$\left[r_{o1} \| \left(r_{\pi 2} + (\beta_o + 1)R_E\right)\right] = \left[105k\Omega \| \left(2.86k\Omega + (101)806\Omega\right)\right] = 46.8k\Omega$$

$$\frac{r_{\pi 2} + (\beta_o + 1)R_E}{r_{o1} + r_{\pi 2} + (\beta_o + 1)R_E} = \frac{2.86k\Omega + (101)806\Omega}{105k\Omega + 2.86k\Omega + (101)806\Omega} = 0.430$$

$$A = -(817\Omega)(19.6mS)(46.8k\Omega)(0.430) = -322\ k\Omega$$

$$A_{TR} = \frac{A}{1 + A\beta} = \frac{-322k\Omega}{1 + (-322k\Omega)\left(-\frac{1}{36k\Omega}\right)} = -\frac{322k\Omega}{9.94} = -32.4\ k\Omega$$

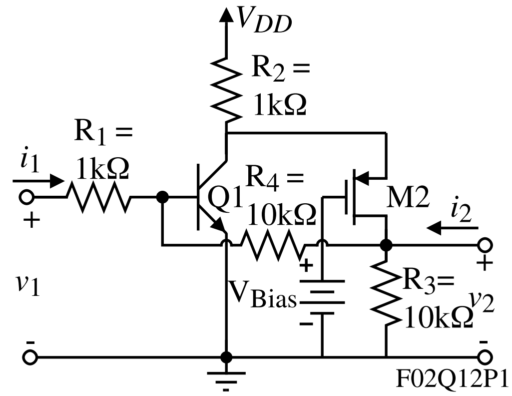
$$R_{IN} = \frac{\left(1k\Omega \| 36k\Omega \| 5.09k\Omega\right)}{1 + A\beta} = \frac{817\Omega}{9.94} = 82.2\ \Omega$$

$$R_{OUT} = \frac{\left(1k\Omega \| 36k\Omega \| 4.7k\Omega \| \frac{r_{\pi 2} + r_{o1}}{101}\right)}{1 + A\beta} = \frac{\left(806\Omega \| \frac{2.86k\Omega + 105k\Omega}{101}\right)}{9.94} = 46.2\ \Omega$$

$$\mathbf{i_s} = 10^{-3}\mathbf{v_s} \rightarrow A_V = \frac{\mathbf{v_o}}{\mathbf{v_s}} = \frac{\mathbf{v_o}}{1000\mathbf{i_s}} = -32.4$$

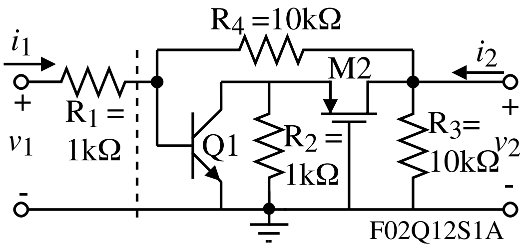
Note that this amplifier can be analyzed as a shunt-shunt feedback amplifier. This is good for student practice - See Problem 18.25.

2.) A shunt-shunt feedback amplifier is shown. Use the methods of feedback analysis to find the numerical values of v_2/v_1, v_1/i_1, and v_2/i_2. For Q1, assume that $h_{fe} = 100$, $g_m = 50$mS and $r_o = \infty$. For M2, assume that $g_m = 1$mS and $r_{ds} = \infty$.



Solution

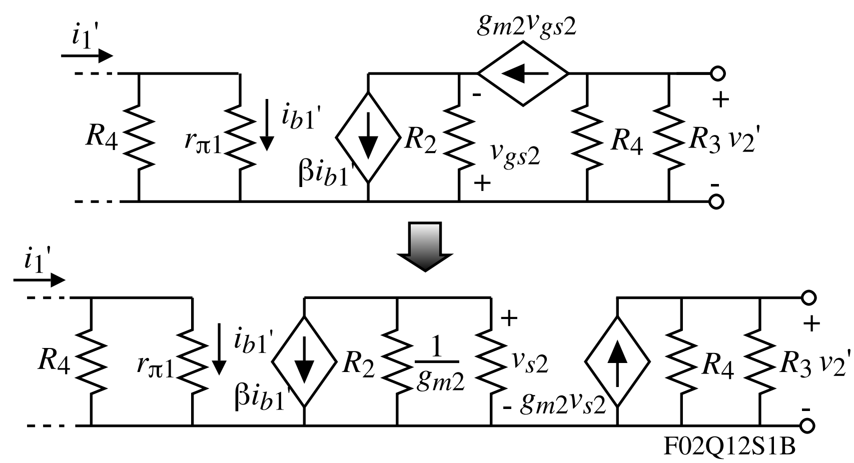
Quasi-ac model of this circuit.



The feedback β is given as

$$\beta = g_{12F} = \frac{i_{1F}}{v_{2F}}\bigg|_{v_{2F}=0} = \frac{-1}{R_4} = \frac{-1}{10K}$$

The open-loop circuit to calculate A is given as,



$$A = \frac{v_{2'}}{i_{1'}} = \left(\frac{v_{2'}}{v_{s2'}}\right)\left(\frac{v_{s2'}}{i_{b1'}}\right)\left(\frac{i_{b1'}}{i_{1'}}\right) = (g_{m2}\cdot R_3||R_4)[-\beta_1\cdot R_2||(1/g_{m2})]\left(\frac{R_4}{R_4 + r_{\pi 1}}\right)$$

$$= (5)(-50K)(10/12) = -208.33k\Omega \qquad \left(r_{\pi 1} = \frac{100}{50mS} = 2k\Omega\right)$$

$$A_F = \frac{v_2}{i_1} = \frac{A}{1+A\beta} = \frac{-208.33K}{1+(-208.33K/-10K)} = \frac{-208.33K}{1+20.833} = \frac{-208.33K}{21.833} = -9.542k\Omega$$

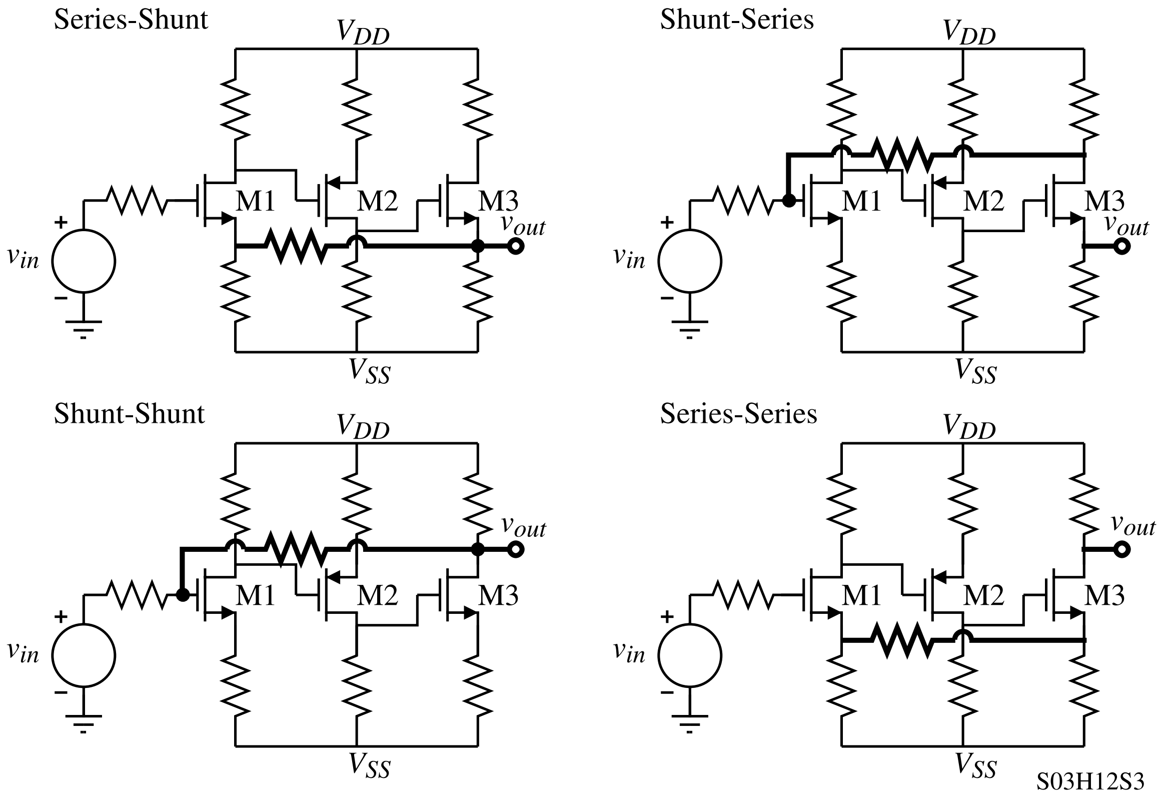
$$R_{in} = R_4||r_{\pi 1} = 2k||10K = 1.67K \qquad \rightarrow R_{inF} = \frac{1.67k}{21.833} = 76.34\Omega$$

$$\therefore\ \frac{v_1}{i_1} = 1k\Omega + 76.34\Omega = \underline{\underline{1.076k\Omega}} \qquad \frac{v_2}{v_1} = \left(\frac{v_2}{i_1}\right)\left(\frac{i_1}{v_1}\right) = \frac{-9.542k\Omega}{1.076k\Omega} = \underline{\underline{-8.652\text{ V/V}}}$$

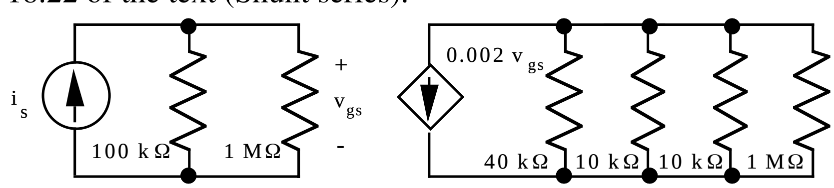
$$R_{out} = R_3||R_4 = 5k\Omega \quad \rightarrow \quad \frac{v_2}{i_2} = \frac{5k\Omega}{21.833} = \underline{\underline{229\Omega}}$$

3.) For each of the MOSFET amplifiers shown below, show how to connect a single resistor from the output to the input that achieves a series-shunt, series-series, shunt-shunt and shunt-series negative feedback amplifier. For each of the four configurations, identify on the schematic the correct variables (voltage or current) for x_s, x_f, x_i, and x_o. The outputs should be at the drain or source of M3.

<u>*Solution*</u>



4.) Problem 18.22 of the text (Shunt series).



$$y_{11}^F = \left.\frac{\mathbf{i_1}}{\mathbf{v_1}}\right|_{\mathbf{v_2=0}} = 10^{-6}\,\mathrm{S} \quad | \quad y_{22}^F = \left.\frac{\mathbf{i_2}}{\mathbf{v_2}}\right|_{\mathbf{v_1=0}} = 10^{-6}\,\mathrm{S} \quad | \quad y_{12}^F = \left.\frac{\mathbf{i_1}}{\mathbf{v_2}}\right|_{\mathbf{v_1=0}} = -10^{-6}\,\mathrm{S}$$

$$\mathbf{v_{gs}} = \mathbf{i_s}(100\,\mathrm{k\Omega}\|1\mathrm{M\Omega}) = (90.9\,\mathrm{k\Omega})\mathbf{i_s} \quad | \quad \mathbf{v_o} = -(2\mathrm{x}10^{-3})\mathbf{v_{gs}}(40\,\mathrm{k\Omega}\|10\,\mathrm{k\Omega}\|10\,\mathrm{k\Omega}\|1\mathrm{M\Omega})$$

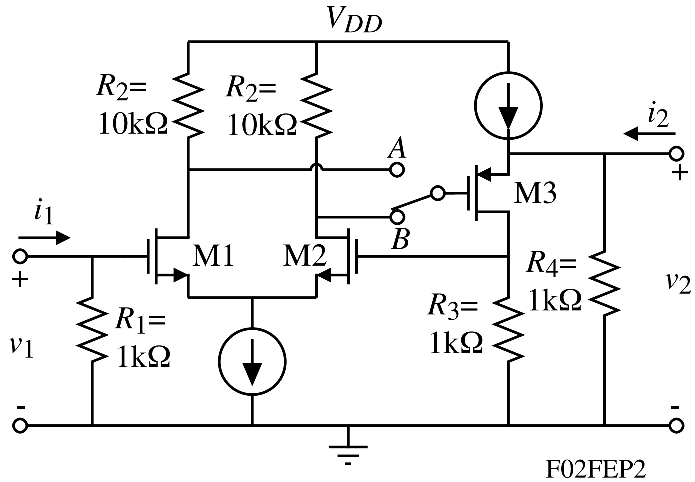
$$A = \frac{\mathbf{v_o}}{\mathbf{i_s}} = -(2\,\mathrm{mS})(4.44\,\mathrm{k\Omega})(90.9\,\mathrm{k\Omega}) = -8.08\mathrm{x}10^5$$

$$A_{TR} = \frac{A}{1 + A\beta} = \frac{-8.08\mathrm{x}10^5}{1 + (-8.08\mathrm{x}10^5)(-10^{-6})} = \frac{-8.08\mathrm{x}10^5}{1.81} = -446\ \mathrm{k\Omega}$$

$$R_{IN} = \frac{(100\,\mathrm{k\Omega}\|1\mathrm{M\Omega})}{(1 + A\beta)} = \frac{90.9\,\mathrm{k\Omega}}{1.81} = 50.2\ \mathrm{k\Omega}$$

$$R_{OUT} = \frac{(40\,\mathrm{k\Omega}\|10\,\mathrm{k\Omega}\|10\,\mathrm{k\Omega}\|1\mathrm{M\Omega})}{(1 + A\beta)} = \frac{4.44\,\mathrm{k\Omega}}{1.81} = 2.45\,\mathrm{k\Omega}$$

5.) The simplified schematic of a feedback amplifier is shown. Assume that all transistors are matched and g_m = 1mA/V and r_{ds} = ∞. (a.) Where should the switch be connected for negative feedback? (b.) Use the method of feedback analysis to find v_2/v_1, $R_{in} = v_1/i_1$, and $R_{out} = v_2/i_2$.



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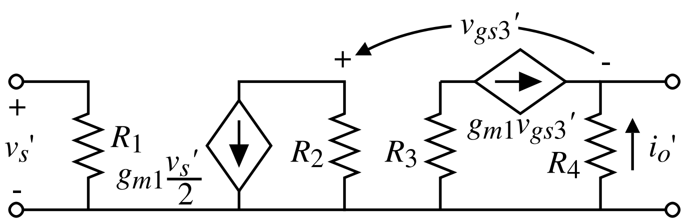
Solution

(a.) A quick check of the ac voltage changes around the loop show that the switch should be connected to A.

(b.) This feedback circuit is series-series. The units of A are A/V and the units of β are V/A.

$$\beta = z_{12f} = \frac{v_{1f}}{i_{2f}}\Big|_{i_{1f}=0} = R_3 = 1\text{k}\Omega$$

The circuit for calculating the small-signal open-loop gain is,



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$$A = \frac{i_o'}{v_s'} = \left(\frac{i_o'}{v_{gs3}'}\right)\left(\frac{v_{gs3}'}{v_{g3}'}\right)\left(\frac{v_{id}'}{v_s'}\right) = (-g_{m3})\left(\frac{1}{1+g_{m3}R_4}\right)\left(\frac{-g_{m1}R_2}{2}\right)$$

$$A = \frac{i_o'}{v_s'} = (1\text{mS})(0.5)(5) = 2.5\text{mS} \rightarrow A_F = \frac{i_o}{v_s} = \frac{A}{1+A\beta} = \frac{2.5\text{mS}}{1+2.5\cdot 1} = 0.714 \text{ mS}$$

$$\frac{v_2}{v_1} = \frac{v_2}{v_s} = \left(\frac{v_2}{i_o}\right)\left(\frac{i_o}{v_s}\right) = -R_4(0.714\text{mS}) = -0.714 \text{ V/V}$$

$$\boxed{\frac{v_2}{v_s} = -0.714 \text{ V/V}}$$

R_1 is not influenced by feedback so $\boxed{\frac{v_1}{i_1} = R_1 = 1\text{k}\Omega}$

$$R_o = R_4 + (1/g_{m3}) = 1\text{k}\Omega + 1\text{k}\Omega = 2\text{k}\Omega \rightarrow \quad R_{oF} = 2\text{k}\Omega(1+2.5) = 7\text{k}\Omega$$

$$R_{out} = \frac{v_2}{i_2} = (R_{oF} - R_4)||R_4 = 7\text{k}\Omega||1\text{k}\Omega = 875\Omega$$

$$\boxed{\frac{v_2}{i_2} = 875\Omega}$$