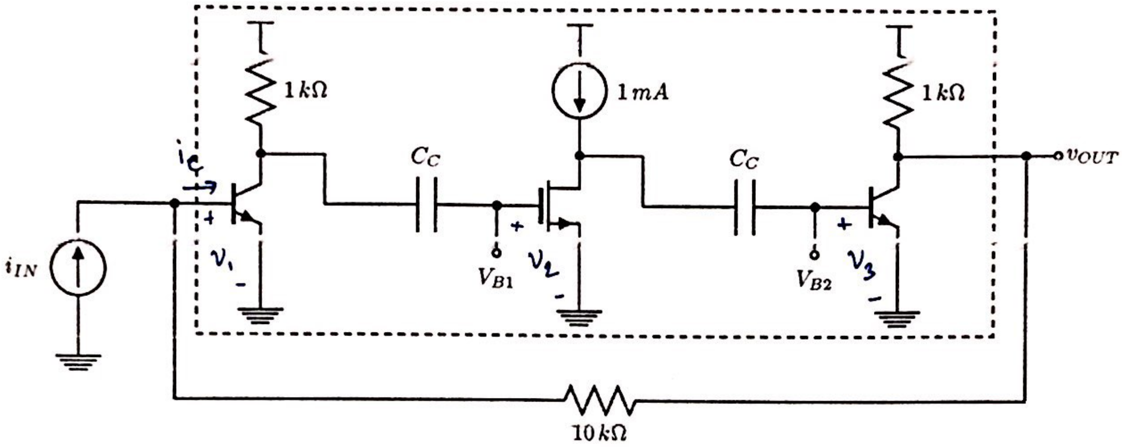
ANSWER KEY

Part I:

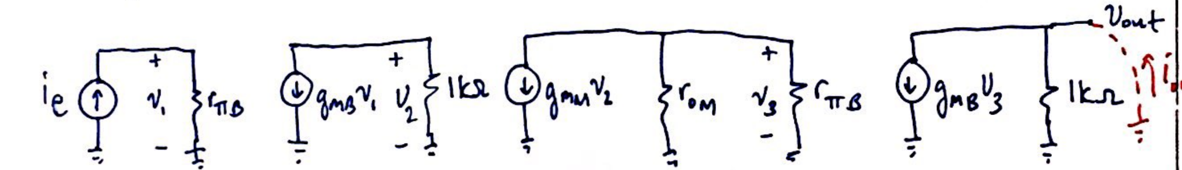
(20 points) The cascaded amplifier circuit in the figure below, shown inside the dashed box, is connected in a feedback amplifier employing **shunt-shunt** feedback. The BJT parameters are as follows: $g_m = 1\,\text{mS}$, $\beta = 200$, and $V_A \to \infty$. The MOSFET parameters are as follows: $k = 1\,\frac{\text{mA}}{V^2}$ and $\lambda = \frac{1}{50}\,V^{-1}$. Note that the coupling capacitors, C_C, are very large and that the voltages, V_{B1} and V_{B2}, are purely DC voltages.



1. Draw the **Norton** two-port network representation of the cascaded amplifier. Label all components with their calculated values. (*5 points*)

BJT: $g_{m_B} = 1\text{mS}$, $r_{\pi B} = \frac{\beta}{g_m} = 200\,k\Omega$, $r_{oB} \to \infty$ (since $V_A \to \infty$)

MOSFET: $g_{mM} = \sqrt{4KI_D} = 2\text{mS}$, $r_{oM} = \frac{1}{\lambda I_D} = 50\,k\Omega$



$R_{in} = \frac{v_1}{i_{in}}\Big|_{v_{out}=0} = r_{\pi B} = 200\,k\Omega$

$R_{out} = \frac{v_{out}}{i_{out}}\Big|_{i_e=0} = 1\,k\Omega$

$G_m = \frac{i_{out}}{v_1}\Big|_{v_{out}=0}$

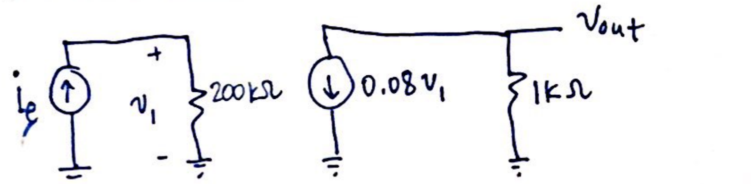
$i_{out} = g_{mB}\,v_3 = g_{mB}\left(-g_{mM}v_2\,(r_{oM}\,//\,r_{\pi B})\right)$

$= g_{mB}\left[-g_{mM}(-g_{mB}v_1)(1k\Omega)(r_{oM}\,//\,r_{\pi B})\right]$

$G_m = g_{mB}^2\,g_{mM}\,(1k\Omega)(r_{oM}\,//\,r_{\pi B})$

$= 80\,\text{mS}$

Equivalent 2-Port Circuit:



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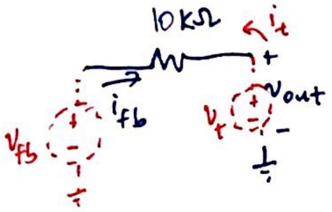
2. Draw the **Norton** two-port network representation of the feedback network. Label all components with their calculated values. (*3 points*)

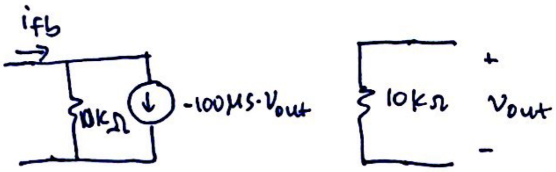


$$R_{if} = \frac{v_t}{i_t}\Big|_{v_{fb}=0} = 10k\Omega$$

$$R_{of} = \frac{v_{fb}}{i_{fb}}\Big|_{v_t=0} = 10k\Omega$$

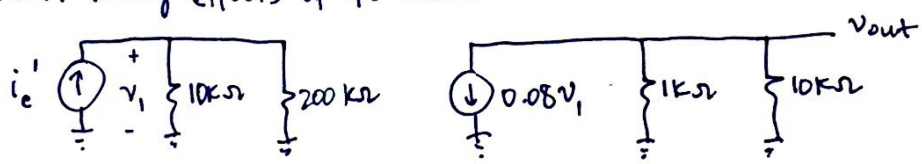
$$f = \frac{i_{fb}}{v_{out}}\Big|_{v_{fb}=0} = \frac{-1}{10k\Omega} = -100\mu S$$

Equivalent 2-Port Circuit:



3. Calculate the open-loop gain of the cascaded amplifier with loading of the feedback network. (*4 points*)

from #1 + loading effects of fb circuit:



$$a_R = \frac{v_{out}}{i_e'}\Big|_{i_{out}=0} \quad : \quad v_{out} = -0.08\,v_1\,(1k\Omega \,//\, 10k\Omega)$$

$$= -0.08\,(i_e')\,(10k\Omega \,//\, 200k\Omega)\,(1k\Omega \,//\, 10k\Omega)$$

$$\frac{v_{out}}{i_e'} = -692.64\ k\Omega$$

loaded open-loop amplifier gain = $-692.64\ k\Omega$

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4. Calculate the closed-loop gain of the feedback amplifier. (*2 points*)

$T = a_R \cdot f = 69.264$

$A_R = \dfrac{v_{out}}{i_{in}} = \dfrac{a_R}{1+T} = -9858\,\Omega$

closed-loop amplifier gain = $-9858\,\Omega$

5. Calculate the closed-loop output resistance of the amplifier, $R_{o,CL}$. (*2 points*)

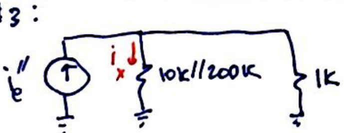
from #3, R_o with loading $= 1\text{k}\Omega \,//\, 10\text{k}\Omega = 909\,\Omega$

Since topology is shunt-shunt, $R_{o,CL} = \dfrac{R_{o,\text{loaded}}}{1+T} = 12.94\,\Omega$

$R_{o,CL} =$ $12.94\,\Omega$

6. If the input current source has a source resistance of $1\,\text{k}\Omega$ in parallel with to it, what would be the new closed-loop output resistance of the circuit? (*4 points*)

from #3:



$a_R^{OLD} = \dfrac{v_o}{i_x} = -692.64\,\text{k}\Omega$

$a_R^{NEW} = \dfrac{v_o}{i_x} \cdot \dfrac{i_x}{i_e''}$

from current division, $i_x = \dfrac{1K}{1K + (10K//200K)}\, i_e''$

$\dfrac{i_x}{i_e''} = 0.095$

$\therefore\ a_R^{NEW} = -65.82\,\text{k}\Omega$

$T^{NEW} = a_R^{NEW} \cdot f = 6.582$

$R_{o,CL}(\text{new}) = \dfrac{R_{o,\text{loaded}}}{1+T^{NEW}} = 119.91\,\Omega$

$R_{o,CL}(\text{new}) \approx$ $120\,\Omega$

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