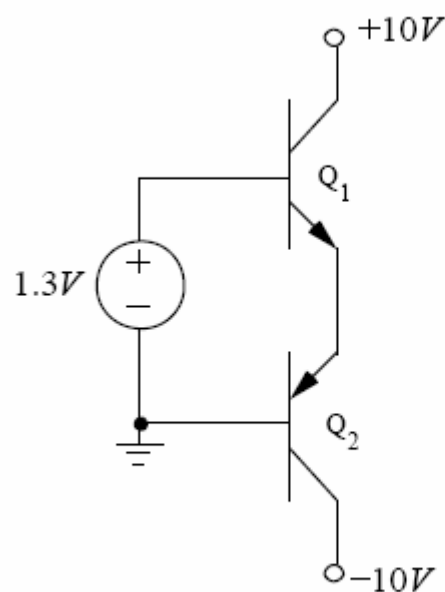


15.130



$$I_{C1} = I_{S1} e^{\left(\frac{V_{BE1}}{V_T} \right)} \quad I_{C2} = I_{S2} e^{\left(\frac{V_{EB2}}{V_T} \right)}$$

$$1.3 = V_{BE1} + V_{EB2} = V_T \ln \frac{I_{C1}}{I_{S1}} + V_T \ln \frac{I_{C2}}{I_{S2}}$$

$$1.3 = V_T \ln \frac{I_C^2}{I_{S1} I_{S2}}$$

$$I_C = \sqrt{(5 \times 10^{-15})(10^{-15}) \exp \frac{1.3}{0.025}} = 438 \mu A$$

$$I_{E1} = \frac{I_{S1}}{\alpha_{F1}} e^{\left(\frac{V_{BE1}}{V_T} \right)} \quad I_{E2} = \frac{I_{S2}}{\alpha_{F2}} e^{\left(\frac{V_{EB2}}{V_T} \right)}$$

$$I_{E1} = I_{E2}$$

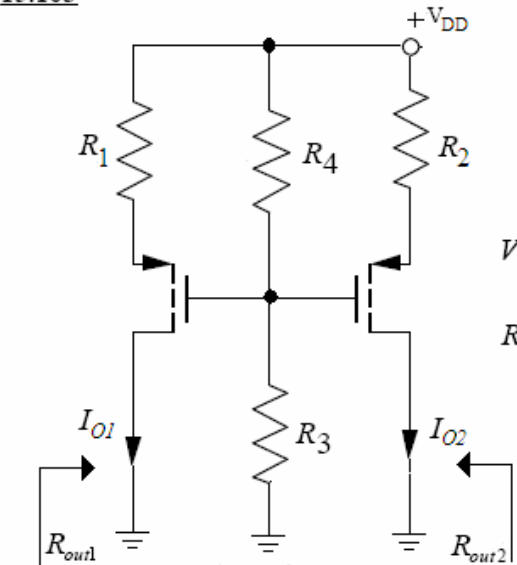
$$\frac{I_{S1}}{\alpha_{F1}} e^{\left(\frac{V_{BE1}}{V_T} \right)} = \frac{I_{S2}}{\alpha_{F2}} e^{\left(\frac{V_{EB2}}{V_T} \right)}$$

$$I_{S1} e^{\left(\frac{V_{BE1}}{V_T} \right)} = \frac{\alpha_{F1}}{\alpha_{F2}} I_{S2} e^{\left(\frac{V_{EB2}}{V_T} \right)}$$

$$I_{C1} = \frac{\alpha_{F1}}{\alpha_{F2}} I_{C2}$$

$$I_{C1} \cong I_{C2} = I_C$$

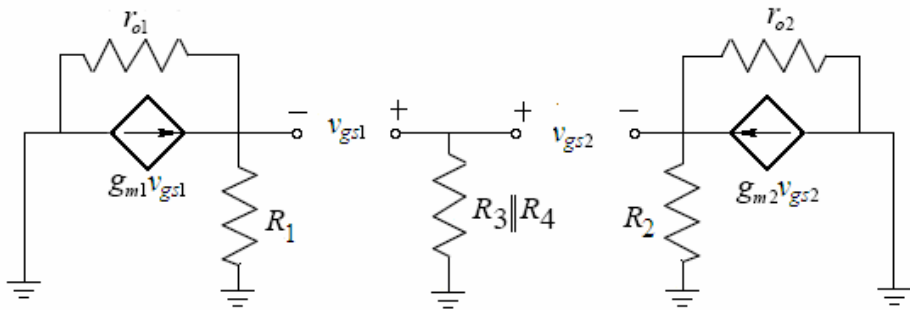
15.163



$$I_{G1} = I_{G2} = 0$$

$$V_{EQ} = 12V \frac{2M\Omega}{2M\Omega + 2M\Omega} = 6.00V$$

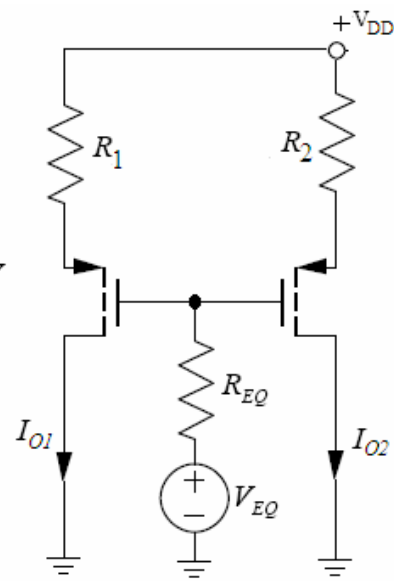
$$R_{EQ} = 2M\Omega \parallel 2M\Omega = 1.00M\Omega$$



R_{out2} is found by following the same steps in deriving R_{out1}

$$R_{out2} = r_{o2}(1 + g_{m2}R_2) = \frac{1}{\lambda} \frac{1 + |V_{DS2}|}{I_{D2}} \left(1 + \sqrt{2K_n I_{D2} (1 + \lambda |V_{DS2}|)} R_2 \right)$$

$$R_{out2} = \frac{50V + 7.28V}{10.0\mu A} \left(1 + 470k\Omega \sqrt{2(250\mu A)(10.0\mu A)[1 + 0.02(7.28)]} \right) = 210M\Omega$$



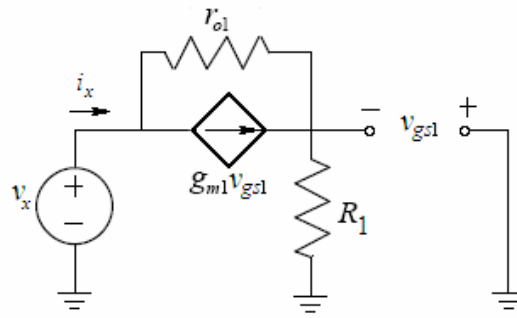
Assume saturation :

$$12 - 10^5 I_{D1} + V_{GS1} = 6 \quad | \quad V_{GS1} = -1 - \sqrt{\frac{2I_{D1}}{2.5 \times 10^{-4}}}$$

$$I_{O1} = I_{D1} = 44.1\mu A \quad | \quad V_{GS1} = -1.59V \quad | \quad V_{DS1} = -(6 - V_{GS1}) = -7.59V$$

$$12 - 4.7 \times 10^5 I_{D2} + V_{GS2} = 6 \quad | \quad V_{GS2} = -1 - \sqrt{\frac{2I_{D2}}{2.5 \times 10^{-4}}}$$

$$I_{O2} = I_{D2} = 10.0\mu A \quad | \quad V_{GS2} = -1.28V \quad | \quad V_{DS2} = -(6 - V_{GS2}) = -7.28V$$



$$v_x = (i_x - g_{m1}v_{gs1})r_{o1} + i_x R_1$$

$$v_x = (i_x - g_{m1}(-i_x R_1))r_{o1} + i_x R_1$$

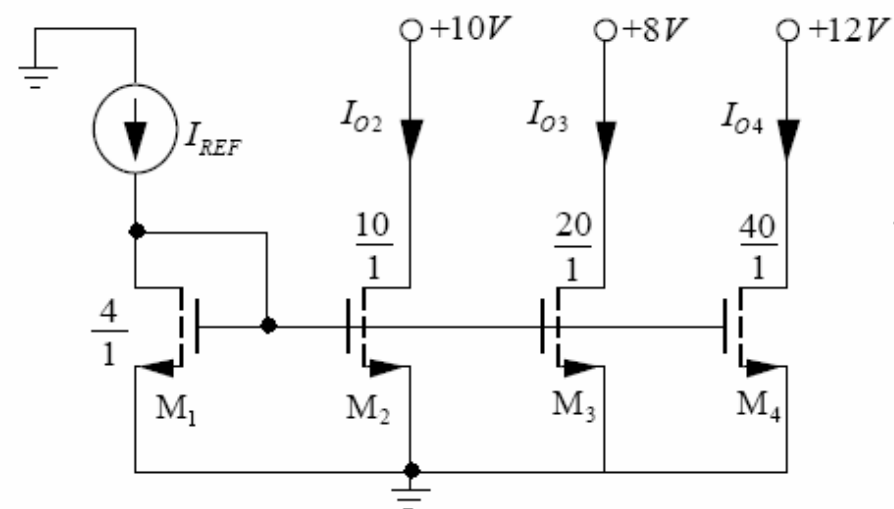
$$v_x = i_x(r_{o1}(1 + g_{m1}R_1) + R_1) \quad (r_{o1}(1 + g_{m1}R_1) \gg R_1)$$

$$R_{out1} = \frac{v_x}{i_x} = r_{o1}(1 + g_{m1}R_1)$$

$$R_{out1} = r_{o1}(1 + g_{m1}R_1) = \frac{1}{\lambda} \frac{1 + |V_{DS1}|}{I_{D1}} \left(1 + \sqrt{2K_n I_{D1} (1 + \lambda |V_{DS1}|)} R_1 \right)$$

$$R_{out1} = \frac{50V + 7.59V}{44.1\mu A} \left(1 + 100k\Omega \sqrt{2(250\mu A)(44.1\mu A)[1 + 0.02(7.69)]} \right) = 22.2M\Omega$$

16.8



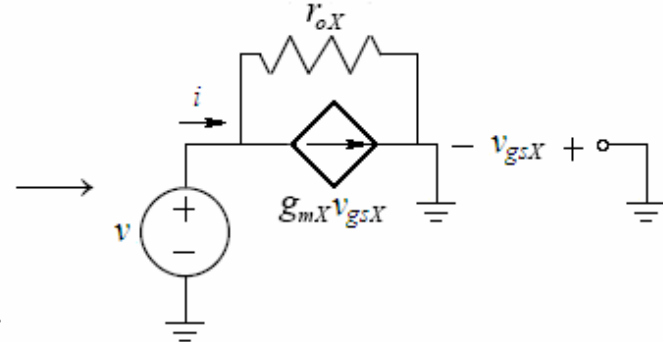
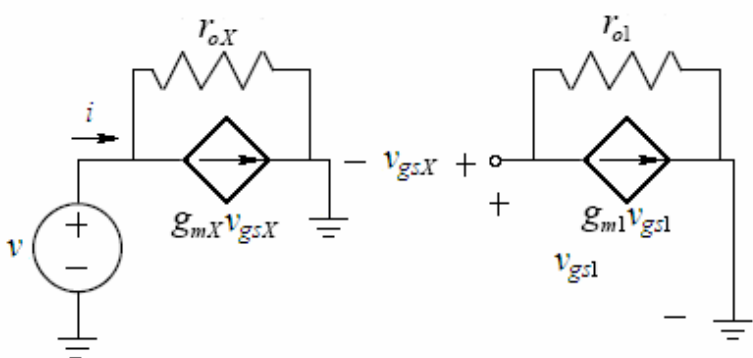
(a) $I_{REF} = I_{D1} = 30 \mu A$

$$V_{DS1} = V_{GS1} = V_{TN} + \sqrt{\frac{2I_{D1}}{K_n}} = 0.75 + \sqrt{\frac{2(30 \times 10^{-6})}{4(25 \times 10^{-6})}} = 1.52V$$

$$I_{OX} = K_n' \left(\frac{W}{L} \right)_X (V_{GSX} - V_{TN})^2 (1 + \lambda V_{DSX}) \quad \Bigg| \quad I_{REF} = I_{D1} = K_n' \left(\frac{W}{L} \right)_1 (V_{GS1} - V_{TN})^2 (1 + \lambda V_{DS1})$$

$$V_{GS1} = V_{GSX} \rightarrow (V_{GSX} - V_{TN})^2 = (V_{GS1} - V_{TN})^2$$

$$I_{OX} = \left(\frac{W}{L} \right)_X \frac{I_{REF}}{\left(\frac{W}{L} \right)_1} \frac{1 + \lambda V_{DSX}}{1 + \lambda V_{DS1}}$$



$$R_{outX} = \frac{v}{i} = r_{oX} = \frac{1}{\lambda} + \frac{V_{DSX}}{I_{OX}}$$

$V_{DS2} = 10V \quad | \quad V_{DS3} = 8V \quad | \quad V_{DS4} = 12V$

$$I_{O2} = \frac{10}{4} (30 \mu A) \frac{1 + 0.015(10)}{1 + 0.015(1.52)} = 84.3 \mu A \quad | \quad R_{out2} = \frac{\frac{1}{0.015} + 10}{84.3 \mu A} = 909 k\Omega$$

$$I_{O3} = \frac{20}{4} (30 \mu A) \frac{1 + 0.015(8)}{1 + 0.015(1.52)} = 164 \mu A \quad | \quad R_{out3} = \frac{\frac{1}{0.015} + 8}{164 \mu A} = 455 k\Omega$$

$$I_{O4} = \frac{40}{4} (30 \mu A) \frac{1 + 0.015(12)}{1 + 0.015(1.52)} = 346 \mu A \quad | \quad R_{out4} = \frac{\frac{1}{0.015} + 12}{346 \mu A} = 227 k\Omega$$

(b) $\lambda = 0.015$

$$V_{DS1} = V_{GS1} = V_{TN} + \sqrt{\frac{2I_{D1}}{K_n}} = 0.75 + \sqrt{\frac{2(50 \times 10^{-6})}{4(25 \times 10^{-6})}} = 1.75V$$

$$I_{OX} = \left(\frac{W}{L}\right)_X I_{REF} \frac{1 + \lambda V_{DSX}}{1 + \lambda V_{DS1}} \quad | \quad R_{outX} = \frac{\frac{1}{\lambda} + V_{DSX}}{I_{OX}}$$

$$I_{O2} = \frac{10}{4}(50\mu A) \frac{1 + 0.015(10)}{1 + 0.015(1.75)} = 140\mu A \quad | \quad R_{out2} = \frac{\frac{1}{0.015} + 10}{140\mu A} = 548k\Omega$$

$$I_{O3} = \frac{20}{4}(50\mu A) \frac{1 + 0.015(8)}{1 + 0.015(1.75)} = 273\mu A \quad | \quad R_{out3} = \frac{\frac{1}{0.015} + 8}{273\mu A} = 274k\Omega$$

$$I_{O4} = \frac{40}{4}(50\mu A) \frac{1 + 0.015(12)}{1 + 0.015(1.75)} = 575\mu A \quad | \quad R_{out4} = \frac{\frac{1}{0.015} + 12}{575\mu A} = 137k\Omega$$

(c) $\lambda = 0$

$$I_{O2} = \frac{10}{4}(30\mu A) = 75\mu A \quad | \quad R_{out2} = \infty$$

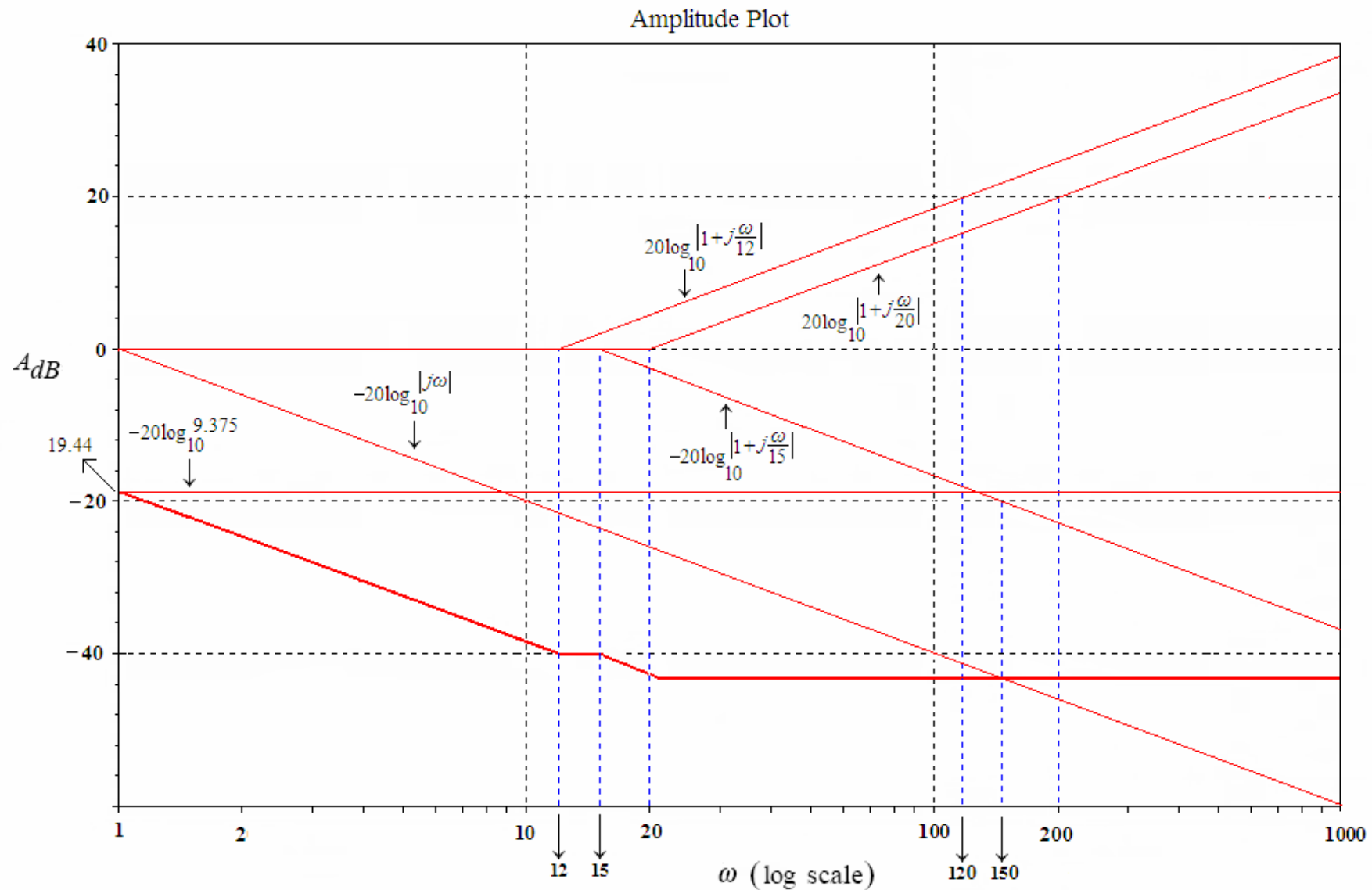
$$I_{O3} = \frac{20}{4}(30\mu A) = 150\mu A \quad | \quad R_{out3} = \infty$$

$$I_{O4} = \frac{40}{4}(30\mu A) = 300\mu A \quad | \quad R_{out4} = \infty$$

4.
$$A_v(s) = -\frac{150s(s+15)}{(s+12)(s+20)} \rightarrow A_v(s) = -\frac{(150 \times 15)s(\frac{s}{15}+1)}{(20 \times 12)(\frac{s}{12}+1)(\frac{s}{20}+1)} = -\frac{9.375s(\frac{s}{15}+1)}{(\frac{s}{12}+1)(\frac{s}{20}+1)} \rightarrow (s=j\omega) \rightarrow A_v(j\omega) = -\frac{9.375j\omega(1+j\frac{\omega}{15})}{(1+j\frac{\omega}{12})(1+j\frac{\omega}{20})}$$

The amplitude of $A_v(j\omega)$ in decibels is a

$$A_{dB} = 20\log_{10} |A_v(j\omega)| = -20\log_{10} 9.375 - 20\log_{10} |(0+j\omega)| - 20\log_{10} |(1+j\frac{\omega}{15})| + 20\log_{10} |(1+j\frac{\omega}{12})| + 20\log_{10} |(1+j\frac{\omega}{20})|$$



$$A_v(j\omega) = -\frac{9.375j\omega(1+j\frac{\omega}{15})}{(1+j\frac{\omega}{12})(1+j\frac{\omega}{20})} = -\frac{9.375|j\omega| \left|1+j\frac{\omega}{15}\right|}{\left|1+j\frac{\omega}{12}\right| \left|1+j\frac{\omega}{20}\right|} \angle \left[-0^\circ - 90^\circ - \tan^{-1}\left(\frac{\omega}{15}\right) + \tan^{-1}\left(\frac{\omega}{12}\right) + \tan^{-1}\left(\frac{\omega}{20}\right)\right]$$

Phase Plot

