EE 210 Sol^n to HA # 8

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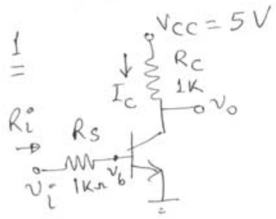

$I_C = 1\,mA \quad g_m = \frac{I_C}{V_T} = \frac{1}{26}\,℧ \quad A_v|_{max} = -g_m R_C = \underline{-38.46}$

Actual gain $A_v = -32 = -g_m(r_o \| R_C) \Rightarrow r_o \simeq \underline{5\,K\Omega}$

$r_o = \frac{V_A}{I_C} \Rightarrow V_A = \underline{5\,V} \Rightarrow$ Indicative of severe Early Effect.

With $R_S = 1\,K\Omega$, using Generic Ckt. approach, $\frac{v_o}{v_b} = \underline{-32}$,

& $\frac{v_b}{v_i} = \frac{r_\pi}{r_\pi + R_S}$ with $r_\pi \simeq \beta r_E \simeq \beta \frac{V_T}{I_C} = 2.6\,k\Omega \Rightarrow \frac{v_b}{v_i} = \frac{2.6}{3.6} = 0.\underline{72}$

$\therefore \frac{v_o}{v_i} = \frac{v_o}{v_b} \times \frac{v_b}{v_i} = -32 \times 0.72 = \underline{-23}$, & $R_i = R_S + r_\pi = \underline{3.6\,K\Omega}$

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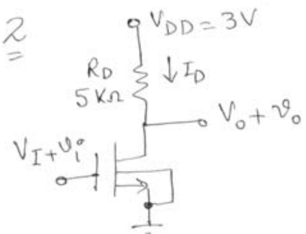

Device operates at boundary bet^n saturation & non-sat.

$\therefore V_O = V_{DS} = V_{DS,sat} = V_{GS} - V_{TN} = \Delta V$, & $V_{TN} = V_{TNO}$,

$\because$ no body effect (B & S tied together). No CLM.

$\Rightarrow I_D = \frac{K_n'}{2}\frac{W}{L}\Delta V^2$ & $\Delta V = V_{DD} - I_D R_D$.

Resulting quadratic eqn: $5\Delta V^2 + \Delta V - 3 = 0 \Rightarrow \Delta V = \underline{0.68V}$ or $\underline{-0.88V}$

$V_{DS} = -0.88V$ is absurd $\Rightarrow V_{DS} = \underline{0.68V} = V_{GS} - V_{TNO}$

$\Rightarrow V_{GS} = V_I = \underline{1.28V}$ & $I_D = \underline{462.4\,\mu A}$ & $V_o = \underline{0.68V}$

$g_m = \sqrt{2K_n I_D} = \underline{1.36\,m℧}$ (or $g_m = K_n \Delta V = 1.36\,m℧ \rightarrow$ both should give same values)

$\therefore A_v = -g_m R_D = \underline{-6.8} \Rightarrow$ This is the max. gain attainable from this ckt.

For unity gain, $|g_m R_D| = 1 \Rightarrow g_m = \frac{1}{R_D} = \underline{0.2\,m℧} = K_n(V_{GS} - V_{TNO})$

$\Rightarrow V_{GS} = V_I = \underline{0.7V}$, $I_D = \underline{10\,\mu A}$, & $V_O = V_{DS} = V_{DD} - I_D R_D = \underline{2.95V}$

$\because V_{DS} > V_{GS} - V_{TN}$, the device is indeed operating in the saturation region.

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3 $g_m = \sqrt{2K_n I_D} = \underline{282.84\,\mu℧} \Rightarrow A_v = -g_m R_D = \underline{-2.83}$, $R_i \to \underline{\infty}$, $R_o = \underline{10K\Omega} = R_D$.

Now, with $\lambda = 0.2\,V^{-1}$ & assuming $\lambda V_{DS} \ll 1$, with $I_D = 100\,\mu A$, g_m stays same. But $r_o = \frac{1}{\lambda I_D} = \underline{50\,K\Omega} \Rightarrow$ New $A_v = -g_m(r_o \| R_D) = \underline{-2.36}$ (Reduction).

$R_i \to \infty$, & $R_o = r_o \| R_D = \underline{8.33\,k\Omega}$. For the device, $\Delta V = \sqrt{\frac{2I_D}{K_n'\frac{W}{L}}} = \underline{0.707V}$

$\therefore$ Max. gain attainable from this ckt, $A_v = -\frac{2}{\lambda \times \Delta V} = \underline{-14.14}$

Transconductance to drain current ratio $g_m/I_D = \frac{2}{\Delta V} = \underline{2.83\,V^{-1}}$

$1/V_T$ at room temp $= \underline{38.46\,V^{-1}}$. $\therefore$ MOSFETS have much lower g_m/I_D.

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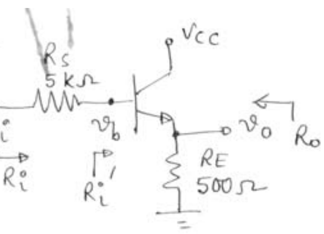

$r_E \approx \frac{V_T}{I_c} = \underline{26\Omega}$ $\quad r_\pi = \beta r_E = \underline{2.6\ k\Omega}$ (2)

$R_i = R_S + r_\pi + (\beta+1)R_E = 5K + 2.6K + 101 \times 500\Omega = \underline{58.1K}$

$R_o = R_E \parallel \left(r_E + \frac{R_S}{\beta+1}\right) = 500 \parallel \left(26 + \frac{5K}{101}\right) = \underline{65.6\Omega}$

$\frac{v_o}{v_b} = \frac{R_E}{r_E + R_E} = \frac{500}{500+26} = \underline{0.9506}$ $\quad R_i' = r_\pi + (\beta+1)R_E = \underline{53.1K}$

$\Rightarrow \frac{v_b}{v_i} = \frac{R_i'}{R_i' + R_s} = \frac{53.1K}{58.1K} = \underline{0.9139}$ $\Rightarrow A_v = \frac{v_o}{v_b} \times \frac{v_b}{v_i} = 0.8688 \simeq \underline{0.87}$

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5 i) Ignoring body effect & with $R \to \infty$, $I_D = \underline{200\mu A}$, $V_{TN} = V_{TNO} = \underline{0.7V}$

$I_D = \frac{K_n'}{2}\frac{W}{L}(V_{GS} - V_{TNO})^2 = 200\mu A \Rightarrow V_{GS} - V_{TNO} = \underline{1\ V} \Rightarrow V_{GS} = \underline{1.7V}$, $V_o = 3 - V_{GS}$ $= \underline{1.3V}$, & $V_{DS} = 5 - V_o = \underline{3.7V}$. $V_{DS} > (V_{GS} - V_T) \to$ Saturated.

$A_v = \frac{g_m R_S}{1 + (g_m + g_{mb})R_S}$ with $R_S \to \infty$, g_{mb} does not exist $\Rightarrow \boxed{A_v \to 1}$

ii) $V_{BS} = -V_o$ $\quad V_{TN} = V_{TNO} + \gamma\left(\sqrt{2\Phi_F + V_o} - \sqrt{2\Phi_F}\right)$ & $I_D = 200\mu A$.

Easiest way is to iterate these simultaneous eqns, with initial guess $V_o = 1.3V$, which is the answer for part i). After a few iterations, it converges to $V_o = \underline{1.09V}$, $V_{TN} = \underline{0.91V}$, $V_{GS} = \underline{1.91V}$, $V_{DS} = \underline{3.91V}$. (Saturated)

$\chi = \frac{\gamma}{2\sqrt{2\Phi_F + V_o}} = \underline{0.154}$ $\quad A_v = \frac{g_m R_S}{1 + (g_m + g_{mb})R_S} \simeq \frac{g_m}{g_m + g_{mb}} = \frac{1}{1+\chi} = \underline{0.867}$ (Reduction)

$V_{GS} - V_{TN} = \sqrt{\frac{2 I_D}{K_n'\left(\frac{W}{L}\right)}}$

6 i) R is finite (100 kΩ) $\Rightarrow I_D = 200\mu A + \frac{V_o}{100K}$

$V_o = 3 - V_{GS}$ $\quad V_{TN} = V_{TNO} + \gamma\left(\sqrt{2\Phi_F + V_o} - \sqrt{2\Phi_F}\right)$.

This set of eqns. need to be iterated with initial guess $V_o = 1.09V$ (P.5, p. ii). After a few iterations, converges to $V_o = \underline{1.067V}$, $I_D = \underline{210.67\mu A}$, $V_{GS} = \underline{1.933V}$, $V_{TN} = \underline{0.907V}$, & $V_{DS} = \underline{3.933\ V}$ (Saturated). $\chi = \underline{0.155}$

$A_v = \frac{g_m R_S}{1 + (g_m + g_{mb})R_S} = \frac{g_m R}{1 + (1+\chi) g_m R} = \underline{0.866}$ $\quad \left(g_m = \sqrt{2 K_n I_D} = \underline{4.1 \times 10^{-4}\ ℧}\right)$

ii) For this case, $R = 10\,k\Omega$, which changes I_D to $I_D = 200\mu A + \frac{V_o}{10K}$. Rest of the eqns. remain same. A few iterations give $V_o = \underline{0.911V}$, $I_D = \underline{291.1\mu A}$, $V_{GS} = \underline{2.089V}$, $V_{TN} = \underline{0.882V}$, $V_{DS} = \underline{4.089V}$ (Saturated). $\chi = \underline{0.163}$

$g_m = \underline{4.826 \times 10^{-4}\ ℧}$ $\Rightarrow A_v = \frac{g_m R}{1 + (1+\chi) g_m R} = \underline{0.73}$

(Note the drastic reduction in A_v as R is reduced).
