2.1) $V_t = 2V$

$i_D = 1mA$ se $V_{GD} = V_{DS} = 3V \Rightarrow$ Saturação

$i_D = k \cdot (V_{GS} - V_t)^2 \Leftrightarrow k = 1 \times 10^{-3}$

a) $3 \geq 4-2 \Rightarrow$ Saturação

$i_D = k \cdot (V_{GS} - V_t)^2 =$

$= 4mA$

b) $0.5 < 4-2 \Rightarrow$ Triodo

$i_D = k\left[2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right]$

$\hookrightarrow i_D \approx 2k(V_{GS} - V_t)V_{DS}$

$R_{DS}^{-1} \approx 2k(V_{GS} - V_t) \Rightarrow R_{DS} = 250\Omega$

Triodo:

$V_{DS} < V_{GS} - V_t$

$i_D = k\left[2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right]$

$\hookrightarrow i_D \approx 2k(V_{GS} - V_t)V_{DS}$

Saturação

$V_D \geq V_{GS} - V_t$

$I_D = k(V_{GS} - V_t)^2$

2.2) $i_D = 2mA$: $V_{GS} = 0$, $V_{DS} = 4V$

$V_t = -2V$

$4 \geq 0 + 2 \Rightarrow$ Saturação $\Rightarrow i_D = k(V_{GS} - V_t)^2 \Leftrightarrow k = 5 \times 10^{-4}$

a) $V_{GS} = 1V$ $4 \geq 1+2 \Rightarrow$ Saturação

$V_{DS} = 4V$ Logo

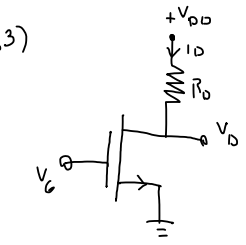
$I_D = k(V_{GS} - V_t)^2 = 4.5mA$

b) $V_{GS} = 1V$ $2 < 1+2 \Rightarrow$ Triodo

$V_{DS} = 1V$ Logo

$i_D = k\left[2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right] = 4mA$

2.3)



$V_{DD} = 5V$

$R_D = 5k\Omega$

$k = 1mA V^{-2}$

$V_t = 2V$

a)

V_G[V]	i_D[mA]	V_D [V]
0	0	5
2.5	0.25	3.75
5	0.967	0.161

$V_G = V_{GS}$

$V_D = V_{DS}$

$V_G = 0$

$V_{GS} < V_t \Rightarrow$ Corte

$V_G = 2.5V$

Assumir Saturação

$V_D \geq V_G - V_t \Leftrightarrow V_D \geq 0.5V$

$I_D = k(V_G - V_t)^2 = 0.25mA$

$V_{DD} = R_1 I_D + V_D \Leftrightarrow V_D = 3.75V$

$V_G = 5V$

Assumir triodo

$V_D < V_G - V_t \Leftrightarrow V_D < 3V$

$I_D = 2k(V_{GS} - V_t)V_{DS}$

$i_D = 6 \times 10^{-3} V_{DS} = 0.967mA$

$V_{DD} = R_1 I_D + V_{DS} \Leftrightarrow \frac{V_{DD}}{R_1 6 \times 10^{-3} + 1} = V_{DS} = 0.161V$

b) $V_D = V_G - V_t$

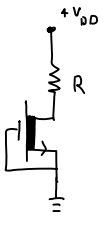
$I_D = k(V_G - V_t)^2 \Leftrightarrow i_D = k V_D^2$

$V_{DD} = R_1 I_D + V_D \Leftrightarrow R_1 k V_D^2 + V_D - V_{DD} = 0 \Leftrightarrow V_D \begin{cases} \rightarrow -1.10S \rightarrow \text{Impr.} \\ \rightarrow 0.905 // \end{cases}$

$V_G = V_D + V_t = 2.905V$

$V_{GS} \leq 2.905V$

2.4)



$K = 1mA V^{-2}$

$V_t = -2V$

$V_{DD} = 6V$

a)

R[kΩ]	i_D[mA]	V_D [V]
0	4	6
0.5	4	4
2	2.59	0.814

$R = 0$ $6 \geq 2 \Rightarrow$ Saturação $\Rightarrow I_D = k(V_{GS} - V_t)^2 \Leftrightarrow$

$V_{DD} = V_{DS} = 6$

$\Leftrightarrow i_D = 4mA$

$R = 0.5\ k\Omega$ Assumir Saturação

$V_{DD} = R i_D + V_{DS}$ $V_{DS} \geq 2$

$V_{DS} = 4V$ $\hookrightarrow I_D = 4mA$

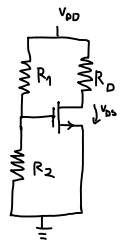
Saturação ignorada

$R = 2\ k\Omega$ Assumir Triodo

$V_{DS} < V_{GS} - V_t \Leftrightarrow V_{DS} < 2V$

$\begin{cases} i_D = k\left(2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right) \\ V_{DD} = R I_D + V_{DS} \end{cases} \Leftrightarrow \begin{cases} I_D = 10^{-3}(4V_{DS} - V_{DS}^2) \\ 6 = 2000 i_D + V_{DS} \end{cases} \Leftrightarrow \begin{cases} 6 - V_{DS} = 2(4V_{DS} - V_{DS}^2) \\ \frac{6 - V_{DS}}{2000} = I_D = 2.59mA \end{cases} \begin{cases} V_{DS} = 0.814V \\ V_{DS} = 3.69V \rightarrow \text{Impr.} \end{cases}$

2.5)



$K = 1 \times 10^{-3} A V^{-2}$

$V_t = 2V$

$I_D = I_S = 1mA$

$V_{DS} = 2V$

$R_1 = 1M\Omega$

$V_{DD} = 6V$

$R_D = 4k\Omega$

$R_2 = 1M\Omega$

$i_D' = 0.25mA \Rightarrow \frac{\Delta i_D}{i_D} = -75\%$

$V_{DD} = R_D I_D + V_{DS} \Leftrightarrow \frac{V_{DD} - V_{DS}}{I_D} = R_D = 4k\Omega$

Saturação?

$2 \geq V_{GS} - 2 \Rightarrow 4 \geq V_{GS}$

$I_D = k(V_{GS} - V_t)^2 \Leftrightarrow V_{GS} = 3V$

Confirma-se

$I_{R_1} = I_{R_2}$

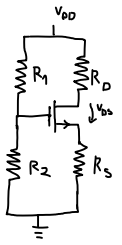
$I_{R_1} R_1 + i_{R_2} R_2 = V_{DD} \Leftrightarrow i_{R_1}(R_1 + R_2) = V_{DD}$

$R_2 I_{R_1} = V_{GS} \Leftrightarrow I_{R_1} = \frac{V_{GS}}{R_2}$

Logo

$\frac{V_{GS}}{R_2}(R_1 + R_2) = V_{DD} \Leftrightarrow \frac{V_{GS}}{R_2} R_1 + V_{GS} = V_{DD} \Leftrightarrow$

$\frac{V_{GS} R_1}{(V_{DD} - V_{GS})} = R_2 = 1M\Omega$



$K = 1 \times 10^{-3} A V^{-2}$

$V_t = 2V$

$I_D = I_S = 1mA$

$V_{DS} = 2V$

$R_1 = 1M\Omega$

$R_S = 2k\Omega$

$V_{DD} = 6V$

$i_D = i_S$

$R_D i_D + V_{DS} + R_S i_S = V_{DD} \Leftrightarrow$

$R_D = \frac{V_{DD} - V_{DS} - R_S i_S}{i_S} = 2k\Omega$

Saturação?

$V_{DS} \geq V_{GS} - V_t \Leftrightarrow 4 \geq V_{GS}$

$i_D = K(V_{GS} - V_t)^2 \Rightarrow V_{GS} = 3V$ - Prova-se

$R_2 I_2 = V_{GS} + R_S i_S \Leftrightarrow i_2 = \frac{V_{GS} + R_S i_S}{R_2}$

$i_1 = i_2$ e $R_1 i_1 + R_2 I_2 = V_{DD}$ logo $i_2(R_1 + R_2) = V_{DD}$

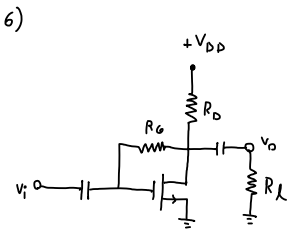
$R_2 = \frac{(V_{GS} + R_S i_S) R_1}{V_{DD} - (V_{GS} + R_S I_S)} = 5M\Omega$

$V_G = 5V$

$\begin{cases} V_G - V_G' = V_S = I_D' R_S \\ i_D' = K(V_{GS}' - V_t)^2 \end{cases} \Leftrightarrow V_{GS}' = \begin{cases} 3.4V \\ 1.1V \rightarrow \text{Impr.} \end{cases}$

$I_D' = 0.8mA$ logo $\frac{\Delta i}{i} = -20\%$

2.6)



$V_t = 1.5\,V$
$k = 0.5\,mA\,V^{-2}$
$\lambda^{-1} = 50\,V$
$V_{DD} = 12\,V$
$R_D = 5\,k\Omega$
$R_G = 10\,M\Omega$
$R_L = 10\,k\Omega$

Corte:
$V_{GS} < V_t$

Triodo:
$V_{DS} < V_{GS} - V_t$
$i_D = k[2(V_{GS}-V_t)V_{DS} - V_{DS}^2]$
$\hookrightarrow i_D \approx 2k(V_{GS}-V_t)V_{DS}$

Saturação
$V_{DS} \geq V_{GS} - V_t$
$I_D = k(V_{GS}-V_t)^2$

a) PFR: Saturação $V_{DS} = 3.36V$ $I_D = 1.73\,mA$

$$\begin{cases} V_{DD} = R_D I_D + V_{DS} \\ I_D = k(V_{GS}-V_t)^2 \\ V_{GS} = V_{DS} \end{cases} \Leftrightarrow \frac{V_{DD}-V_{DS}}{R_D} = k(V_{DS}-V_t)^2 \Leftrightarrow \begin{cases} V_{DS} = 3.36V \\ V_{DS} = -0.76\,V \rightarrow \text{Impl} \end{cases}$$

Incremental

$i_d = g_m v_{gs}$

$g_m = 2k(V_{GS}-V_t) = 2\sqrt{kI_D} = \frac{V_{GS}-V_t}{2I_D}$

Caso haja Early:

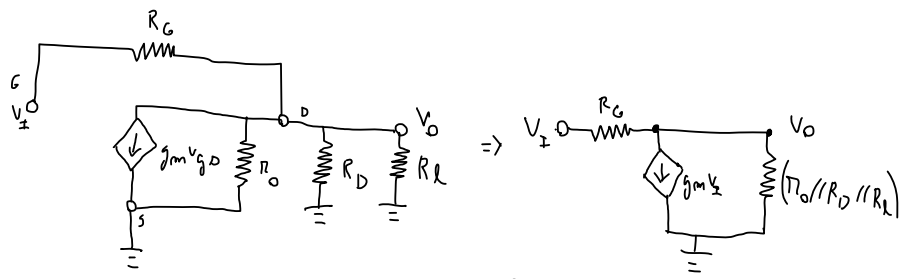
$r_O = \frac{1+\lambda V_{DS}}{\lambda I_D} \approx \frac{1}{\lambda I_D} = \frac{V_A}{I_D}$

b)

$g_m = 2\sqrt{kI_D} = 1.86\,mS$

$r_O = \frac{1+\lambda V_{DS}}{\lambda I_D} = 30.8\,k\Omega$

c)



Ri

$$\begin{cases} V_I = R_G i_g + (r_O // R_D // R_L) i_R \\ i_g = g_m V_I + i_R \end{cases} \Leftrightarrow R_i = \frac{v_i}{i_i} = \frac{R_G + (r_O // R_D // R_L)}{1 + g_m (r_O // R_D // R_L)} = 1.52\,M\Omega$$

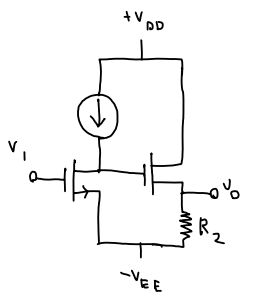
A

$v_i = i_g R_G + v_O \Leftrightarrow v_O = v_i\left(1 - \frac{R_G}{R_i}\right) \Rightarrow A_V = \frac{v_O}{v_i} = -5.6$

$i_g = \frac{v_i}{R_i}$

$R_O = R_G // r_O // R_D \approx 4.26\,k\Omega$

2.7)



$+V_{DD} = 6V$
$-V_{EE} = -3V$
$k = 10\,\mu A\,V^{-2}$
$V_t = 1V$
$\lambda^{-1} = 60V$

a) PFR:

$V_I = V_O = 0 \Rightarrow I_{D2} = 40\,\mu A$

Para Q_1 $\Rightarrow$ Saturação

$V_{GS} = 3V$ $V_{DS} \geq V_{GS} - V_t \Leftrightarrow V_{DS} \geq 2V$

$V_t = 1V$

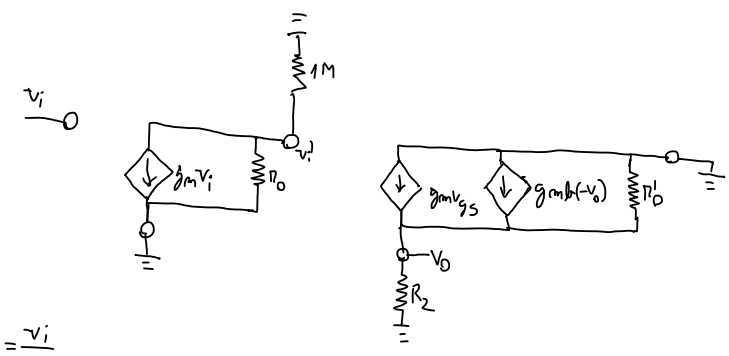
$I_D = k(-V_{GG} - V_t)^2 = 40\,\mu A$

Logo $I_1 = 40\,\mu A$

Para Q_2

$I_D = i_S = \frac{V_{R2}}{R_2} = \frac{V_O - (-V_{EE})}{R_2} \Rightarrow R_2 = 75\,k\Omega$

b)



$A = \frac{v_i}{v_o}$

$v_i' = -(r_O // 1M) g_m v_i$

$v_i' = v_{gs} + v_O \Leftrightarrow v_{gs} = v_i' - v_O$

$v_O = g_{m_2}(v_i' - v_O)(r_{O_2} // R_2) - g_{mb_2} v_O (r_{O_2} // R_2) \Leftrightarrow$

$\Leftrightarrow v_O + v_O\, g_{m_2}(r_{O_2} // R_2) + g_{mb_2} v_O (r_{O_2} // R_2) = g_{m_2} v_i' (r_{O_2} // R_2)$

$v_O = \left(g_{m_2} v_{gs} + g_{mb_2}(-v_O)\right)(r_{O_2} // R_2) \Leftrightarrow \frac{v_O}{v_i} = -g_m (r_O // 1M) \cdot \frac{g_{m_2}(r_{O_2} // R_2)}{1 + g_{m_2}(r_{O_2} // R_2) + g_{mb_2}(r_{O_2} // R_2)} = -15.5$

$= g_{m_2} v_{gs}(r_{O_2} // R_2) - g_{mb_2} v_O (r_{O_2} // R_2)$

$g_m = g_{m_2} = 2\sqrt{kI_D}$

$r_O \approx r_{O_2} \approx \frac{\lambda^{-1}}{I_D}$

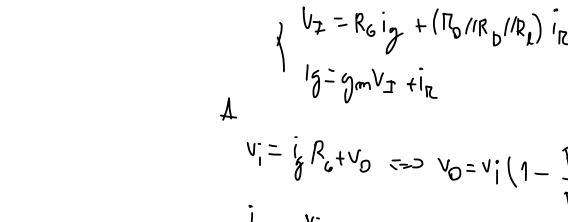
$R_O = \frac{v_O}{i_O} = r_O // g_{m_2}^{-1} // g_{mb_2}^{-1} // R_2 = 16\,k\Omega$

Se $g_{mb_2} = 0$ $\rightarrow A = -17.8$
$\rightarrow R_O = 18.5\,k\Omega$

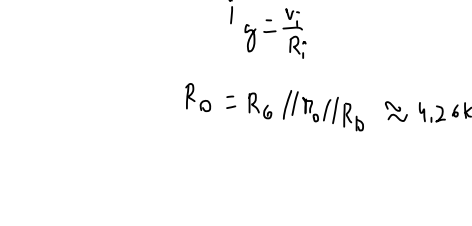
2.8)

$k = 10\,\mu A\,V^{-2}$
$V_t = 1V$
$\lambda^{-1} = 50V$
$I_1 = 20\,\mu A$
$R_1 = 100\,M\Omega$

a)



$G_m = \left.\frac{i_O}{v_i}\right|_{v_o=0} = g_{m1} = 2\sqrt{kI_1} = 28.28\,\mu S$



$V_O = r_{O_2}\left(i_X - (g_{m_2} + g_{mb_2}) V_{gs2}\right) - V_{gs2}$

$V_{gs2} = -r_{O_1} i_X$

$R_O' = r_{O_1} + r_{O_2}\left[1 + (g_{m_2} + g_{mb_2}) r_{O_1}\right]$

$R_O = R_1 // R_O' \approx R_1 // (r_{O_1} \cdot r_{O_2} \cdot g_{m_2}) = 63.9\,M\Omega$

$A = G_m R_O = 1810$

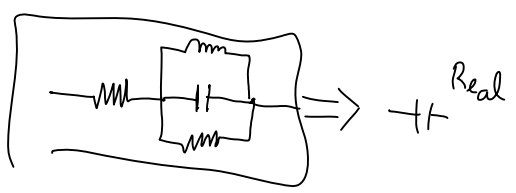
b) $I_1 = I_{D_1} = I_{D_2} = I_{S_1} = I_{S_2}$

$I_D = k(V_{GS} - V_t)^2 \Rightarrow V_{GS_1} = V_{GS_2} = V_{im}$

$V_{DS_1} = V_{GS_1} - V_t \Rightarrow V_{DS_1} = V_{DS_2} = V_{im} - V_t$

$V_B = V_{GS_2} + V_{DS_1} \Rightarrow 5 = V_{im} + V_{im} - V_t \Rightarrow V_{im} = 3V$

$V_O = V_{DS_1} + V_{DS_2} = 2(3-1) = 4V$



$A_{11} = \frac{v_{cc}}{}$

$$A_V = \frac{v_{ce}}{v_b} =$$