

Problem 1

a. *****10 points*****

Since there is no current in gate terminal, current flowing through R_S is also I_D .

By KVL,

$$R_L I_D + R_S I_D + V_{DS} - 9 = 0 \quad (1)$$

$\Rightarrow V_{DS} = 5V$, which is independent of λ .

b. *****10 points*****

When $\lambda = 0$,

$$I_D = k(V_{GS} - V_{TO})^2 \quad (2)$$

Where $I_D = 1mA$, $k = 10^{-3}$, $V_{GS} = 5V$, $V_{TO} = 1V$

$\Rightarrow V_{GS} = 2V$

Again, there is no current in gate terminal. Therefore,

$$I_{Ra} = I_{Rb} \quad (3)$$

Where

$$I_{Ra} = \frac{V_{DD} - V_G}{R_a} = \frac{V_{DD} - (V_{GS} + I_D R_S)}{R_a} \quad (4)$$

$$I_{Rb} = \frac{V_G}{R_b} = \frac{V_{GS} + I_D R_S}{R_b} \quad (5)$$

$\Rightarrow R_b = 5Meg$

c. *****10 points*****

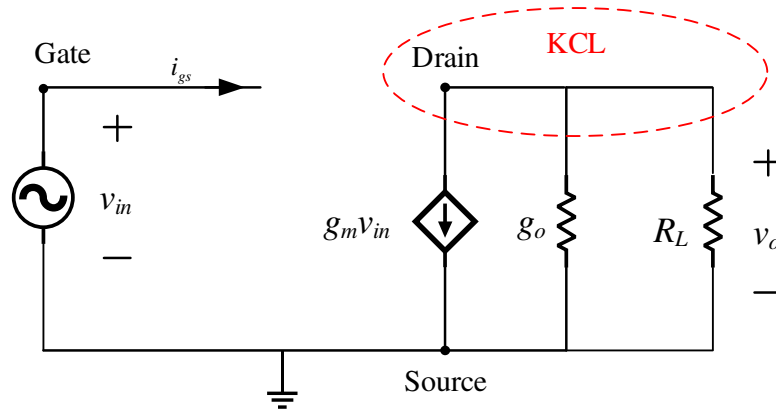


Fig. 1 Small signal equivalent circuit for this problem 1

By KCL

$$g_m v_{in} + g_o v_o + \frac{v_o}{R_L} = 0 \quad (6)$$

$$\Rightarrow \text{gain} = \frac{v_o}{v_{in}} = -\frac{g_m}{g_o + 1/R_L} \quad (7)$$

When $\lambda = 0$,

$$\text{gain} = \frac{v_o}{v_{in}} = -\frac{g_m}{g_o + 1/R_L} = -\frac{g_m}{0 + 1/R_L} = -g_m R_L \quad (8)$$

Where

$$g_m = \frac{2I_D}{V_{GS} - V_{TO}} \quad (9)$$

$$\Rightarrow \text{gain} = -6$$

d. *****10 points*****

When $\lambda = 0.2$,

$$I_D = k(V_{GS} - V_{TO})^2 (1 + \lambda V_{DS}) \quad (10)$$

Where $I_D = 1\text{mA}$, $k = 10^{-3}$, $V_{GS} = 5\text{V}$, $V_{TO} = 1\text{V}$, $V_{DS} = 5\text{V}$

$$\Rightarrow V_{GS} = 1.7\text{V}$$

According to (3)-(5)

$$\Rightarrow R_b = 4.3\text{Meg}$$

e. *****10 points*****

According to (7),

$$\Rightarrow \text{gain} = -5.3$$

Problem 2

*****45 points for voltage gain expression*****

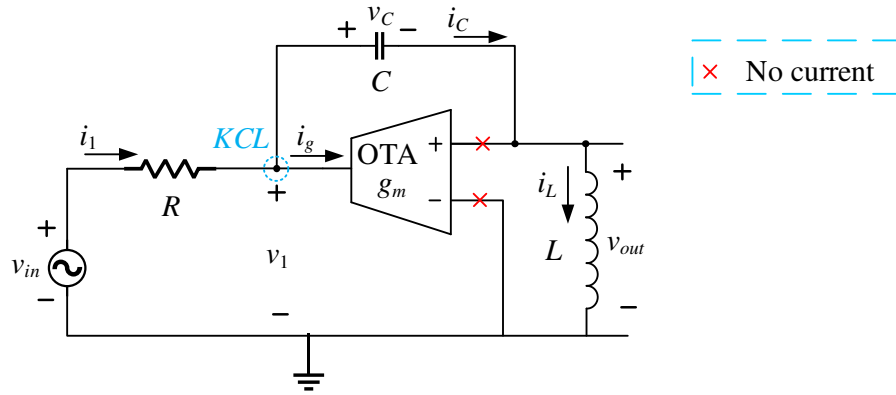


Fig. 2 Small signal OTA circuit

$$i_L = \frac{v_{out}}{sL} \quad (11)$$

$$i_c = i_L \quad (12)$$

$$v_c = i_c \frac{1}{sC} \quad (13)$$

Therefore, v_1 can be calculated as:

$$v_1 = \frac{v_{out}}{sL} \left(sL + \frac{1}{sC} \right) \quad (14)$$

By KCL

$$i_1 - i_c - i_g = 0 \quad (15)$$

Where

$$i_1 = \frac{v_{in} - v_1}{R} \quad (16)$$

$$i_g = g_m v_{out} \quad (17)$$

By (11) - (17), the voltage gain is

$$\frac{v_{out}}{v_{in}} = \frac{s^2 LC}{(g_m R + 1)s^2 LC + RCs + 1} \quad (18)$$

*****5 points for discussion on forming an oscillator*****

When there is no damping, the circuit will form an oscillator. That is $R=0$.

Problem 3

a.

*****10

points*****

Substitute $v_d = 5$ into (19)

$$i_d = 0.1v_d(v_d^2 - 10.5v_d + 30) \quad (19)$$

$$\Rightarrow i_d = 1.25$$

Another point in the graph is ($v_d=10, i_d=-0.3$) (you can also choose other points in graph)

$$\Rightarrow m = -0.31, Y_O = 2.8$$

b. *****20 points*****

Solve equations (20)

$$\begin{cases} i_d = 0.1v_d(v_d^2 - 10.5v_d + 30) \\ i_d = -0.31v_d + 2.8 \end{cases} \Rightarrow 0.1v_d^3 - 1.05v_d^2 + 3.31v_d - 2.8 = 0 \quad (20)$$

$$\Rightarrow \begin{cases} v_d = 5 \\ i_d = 1.25 \end{cases} \quad \begin{cases} v_d = 4.15 \\ i_d = 1.51 \end{cases} \quad \begin{cases} v_d = 1.35 \\ i_d = 2.38 \end{cases}$$

c.

*****20

points*****

$$g = \frac{di_d}{dv_d} = 0.3(v_d - 2)(v_d - 5) \quad (21)$$

$$\Rightarrow \begin{cases} v_d = 5 \\ g = 0 \end{cases} \quad \begin{cases} v_d = 4.15 \\ g = -0.55 \end{cases} \quad \begin{cases} v_d = 1.35 \\ g = 0.71 \end{cases}$$