Second SPICE Exercise

Fundamentals Of Electronics - a.a. 2018-2019 - University of Padua (Italy)

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Contents

Chapter 1

NMOS common source amplifier with bypass capacitances

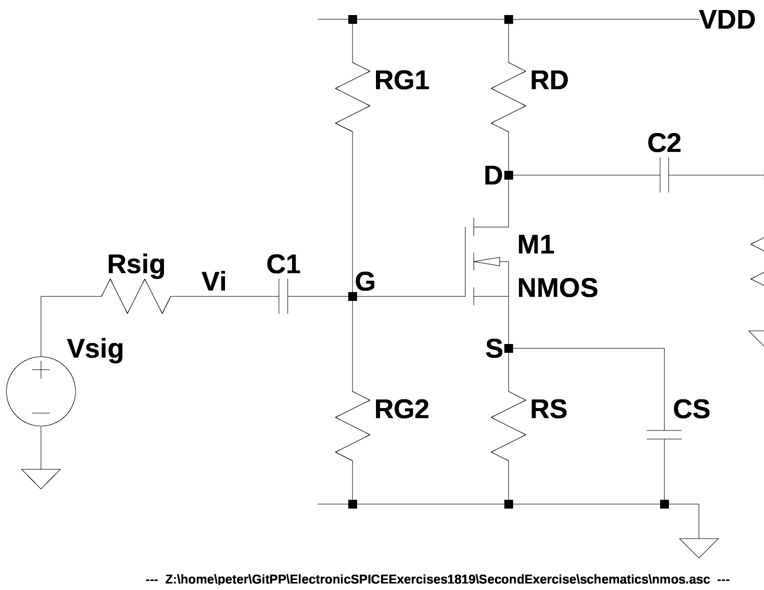

Figure 1.1: NMOS common source amplifier

Designing the common source amplifier of the figure 1.1 .
The MOSFET should have a $V_t = 1V$, a $K_n = 4mA/V$ and a $\lambda = 0$.
Other requested parameters are: $I_{DQ} = 0.5mA$, $V_S = 3.5V$, $V_D = 11V$, $V_{DD} = 15V$ and $R_{G2} = 1097752\Omega$.

1.1 Analytic solutions

1.1.1 DC analysis

On a Direct Current analysis the capacitances can be considered as open circuits, the inductances can be considered as short circuits, the signal and the load are removed and the alternate current inputs are not considered.
The figure 1.2 represents the circuit for the DC analysis.

R_D

$$V_D = V_{DD} - R_D I_D \tag{1.1}$$

$$R_D = \frac{V_{DD} - V_D}{I_D} \tag{1.2}$$

$$R_D = \frac{15V - 11V}{0.5mA} = 8k\Omega \tag{1.3}$$

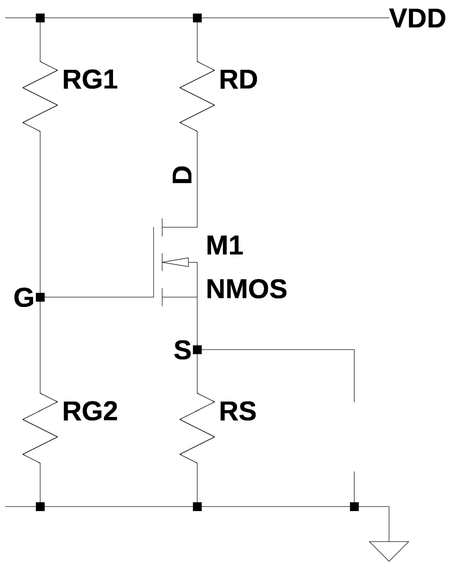

Figure 1.2: NMOS common source amplifier - DC analysis

R_S

$$V_S = R_S I_D \implies R_S = \frac{V_S}{I_D} \tag{1.4}$$

$$R_S = \frac{3.5V}{0.5mA} = 7k\Omega \tag{1.5}$$

V_{GS}

$$I_D = \frac{1}{2} K_n V_{ov}^2 \implies V_{ov} = \pm\sqrt{\frac{2I_D}{K_n}} \tag{1.6}$$

$$V_{ov} = \pm\sqrt{\frac{2 \cdot 0.5mA}{4mA/V^2}} \tag{1.7}$$

$$V_{ov} = \begin{cases} +0.5V & \text{Real value of } V_{ov}. \\ -0.5V & \text{No physical sense.} \end{cases} \tag{1.8}$$

$$V_{ov} = V_{GS} - V_t \implies V_{GS} = V_{ov} + V_t \tag{1.9}$$

$$V_{GS} = 0.5V + 1V = 1.5V \tag{1.10}$$

R_{G1}

$$V_{GS} = V_G - V_S \implies V_G = V_{GS} + V_S \tag{1.11}$$

$$V_G = 1.5V + 3.5V = 5V \tag{1.12}$$

$$I_G R_{G2} - V_{GS} - I_D R_S = 0 \implies I_G = \frac{V_{GS} + I_D R_S}{R_{G2}} \tag{1.13}$$

$$I_G = \frac{1.5V + 0.5mA \cdot 7k\Omega}{1097.752k\Omega} = 4.5547628\mu A \simeq 4.55\mu A \tag{1.14}$$

$$R_{G1} = \frac{V_{DD} - V_G}{I_G} \tag{1.15}$$

$$= \frac{15V - 5V}{4.5547628\mu A} \tag{1.16}$$

$$= 2.19550M\Omega \simeq 2.20M\Omega \tag{1.17}$$

g_m

$$g_m = K_n V_{ov} = 4mA/V^2 \cdot 0.5V = 2mA/V \tag{1.18}$$

r_0

$$r_0 = \frac{1}{\lambda I_D} \xrightarrow{\lambda=0} r_0 = \infty \quad r_0 \text{ is considered as an open circuit.} \tag{1.19}$$

1.1.2 AC analysis

On an Alternate Current analysis the capacitances can be considered as short circuits, the inductances can be considered as open circuits and the direct current inputs are not considered.
The figure 1.3 represents the circuit for the AC analysis.
Other requested parameters are: $R_{sig} = 200k\Omega$ and $R_L = 8k\Omega$.

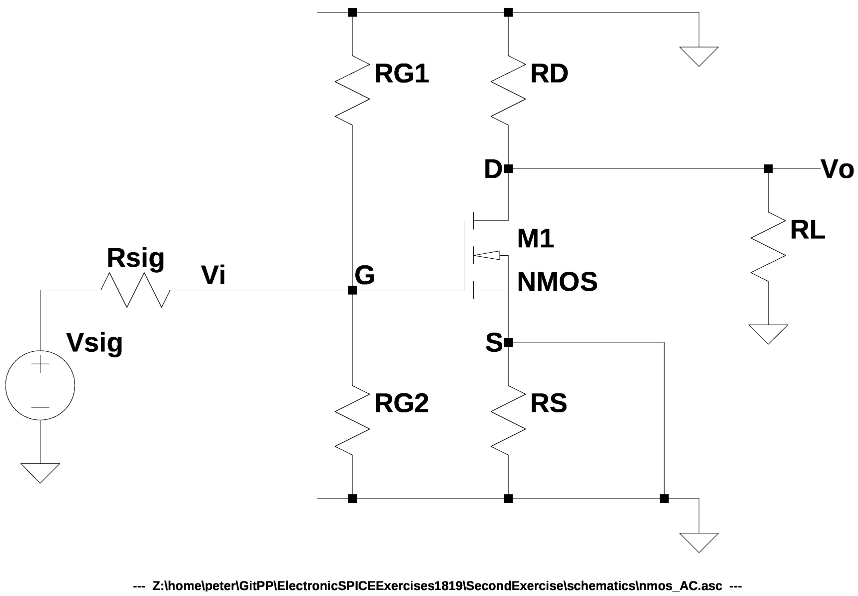

Figure 1.3: NMOS common source amplifier - AC analysis

Hybrid π model

For a small signal analysis it can be used an equivalent model to represent the behaviour of the transistor.
In this case it is used the hybrid π model (figure 1.4).

R_{IN} from G

Removing the signal, the load and applying a test voltage source as in figure 1.5 it is possible to calculate the input's resistance R_{IN}.

$$R_{IN} = \frac{V_x}{I_x} \tag{1.20}$$

$$\tag{1.21}$$

$$I_x = \frac{V_x}{R_{G1} \parallel R_{G2}} \implies R_{G1} \parallel R_{G2} = \frac{V_x}{I_x} \implies R_{IN} = R_{G1} \parallel R_{G2} \tag{1.22}$$

$$\begin{aligned} R_{IN} &= \frac{R_{G1} R_{G2}}{R_{G1} + R_{G2}} && (1.23)\\ &= \frac{2.19550M\Omega \cdot 1097752\Omega}{2.19550M\Omega + 1097752\Omega} && (1.24)\\ &= 733.16756k\Omega \simeq 733.2k\Omega && (1.25) \end{aligned}$$

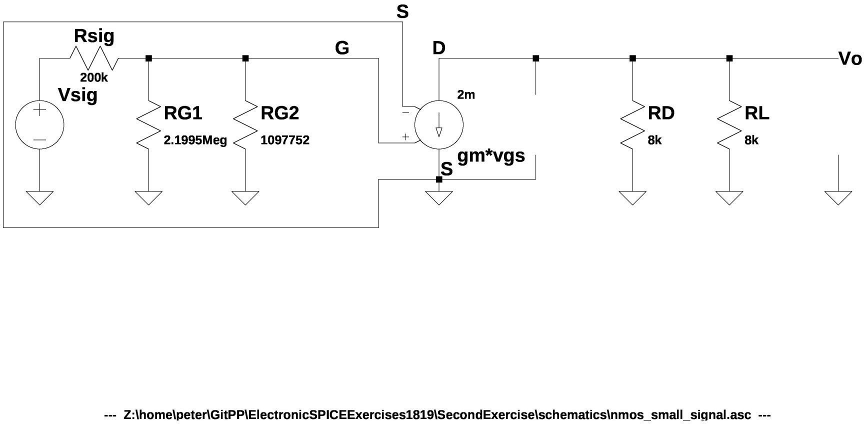

Figure 1.4: NMOS common source amplifier - Hybrid π model

R_{OUT} from D

Removing the signal, the load and applying a test voltage source as in figure 1.6 it is possible to calculate the output's resistance R_{OUT}.

$$R_{OUT} = \frac{V_x}{I_x} \tag{1.26}$$

$$\tag{1.27}$$

$$I_x = \frac{V_x}{R_D} \implies R_D = \frac{V_x}{I_x} \implies R_{OUT} = R_D \tag{1.28}$$

$$R_{OUT} = 8k\Omega \tag{1.29}$$

Voltage Gain - without R_{sig} and R_L

Calculating the gain of the amplifier represented in the figure 1.7.

$$v_{in} = v_{gs} \tag{1.30}$$

$$v_o = -g_m v_{gs} R_D \tag{1.31}$$

$$A_v = \frac{v_o}{v_{in}} = \frac{-g_m v_{gs} R_D}{v_{gs}} = -g_m R_D = 2mA/V \cdot 8k\Omega = -16 \quad V/V \tag{1.32}$$

$$A_v|_{dB} = 20log_{10}|A_v| = 20log_{10}|-16| = 24.08240dB \simeq 24.1dB \tag{1.33}$$

Voltage Gain - with R_{sig} and R_L

Calculating the gain of the amplifier represented in the figure 1.8.

$$I_{sig} = \frac{v_{sig}}{R_{sig} + (R_{G1} \parallel R_{G2})} \tag{1.34}$$

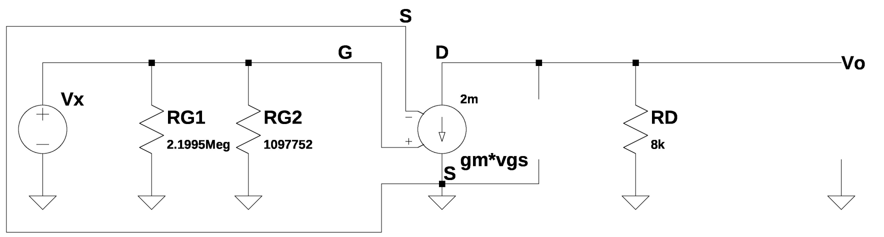

Figure 1.5: NMOS common source amplifier - Calculating R_{IN}

$$
\begin{aligned}
v_{in} = v_{gs} &= v_{sig} - R_{sig} I_{sig} && (1.35)\\
&= v_{sig} - R_{sig} \frac{v_{sig}}{R_{sig} + (R_{G1} \parallel R_{G2})} && (1.36)\\
&= v_{sig} \left(1 - R_{sig} \frac{1}{R_{sig} + (R_{G1} \parallel R_{G2})}\right) && (1.37)
\end{aligned}
$$

$$
\begin{aligned}
G_v = \frac{v_o}{v_{sig}} &= \frac{-g_m v_{sig} \left(1 - R_{sig} \frac{1}{R_{sig} + (R_{G1} \parallel R_{G2})}\right) (R_D \parallel R_L)}{v_{sig}} && (1.38)\\
&= -g_m \left(1 - R_{sig} \frac{1}{R_{sig} + (R_{G1} \parallel R_{G2})}\right) (R_D \parallel R_L) && (1.39)\\
&= -g_m \left(1 - R_{sig} \frac{1}{R_{sig} + \left(\frac{R_{G1} R_{G2}}{R_{G1} + R_{G2}}\right)}\right) \left(\frac{R_D R_L}{R_D + R_L}\right) && (1.40)\\
&= -2mA/V \left(1 - 200k\Omega \frac{1}{200k\Omega + \left(\frac{2.19550M\Omega \cdot 1097752\Omega}{2.19550M\Omega + 1097752\Omega}\right)}\right) \left(\frac{8k\Omega \cdot 8k\Omega}{8k\Omega + 8k\Omega}\right) && (1.41)\\
&= -6.28296 \quad V/V \simeq -6.3 \quad V/V && (1.42)
\end{aligned}
$$

$$
G_v|_{dB} = 20 log_{10} |G_v| = 20 log_{10} |-6.28296| = 15.96329 dB \simeq 16 dB \qquad (1.43)
$$

1.2 SPICE simulations

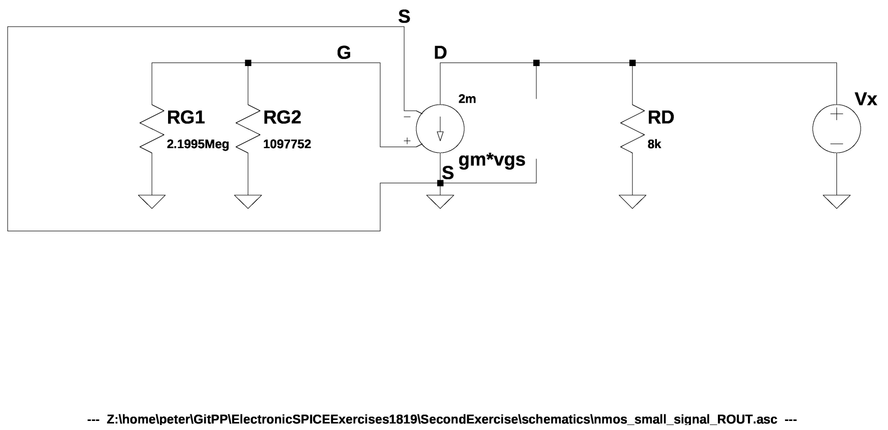

Figure 1.6: NMOS common source amplifier - Calculating R_{OUT}

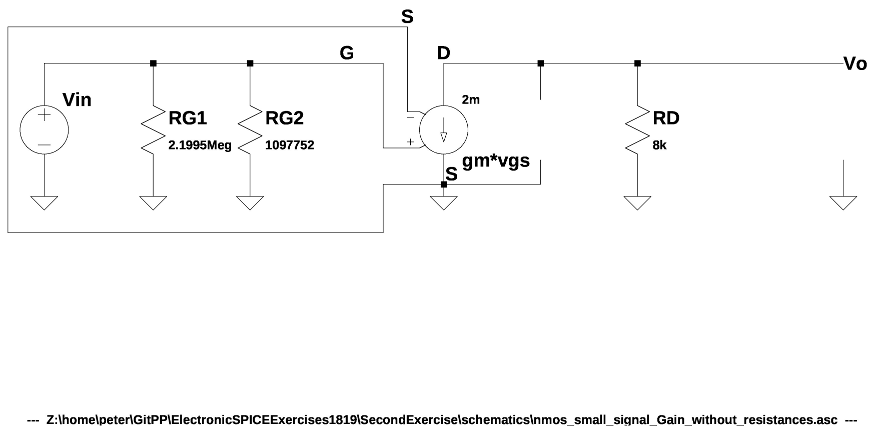

Figure 1.7: NMOS common source amplifier - Calculating the voltage gain without R_{sig} and R_L

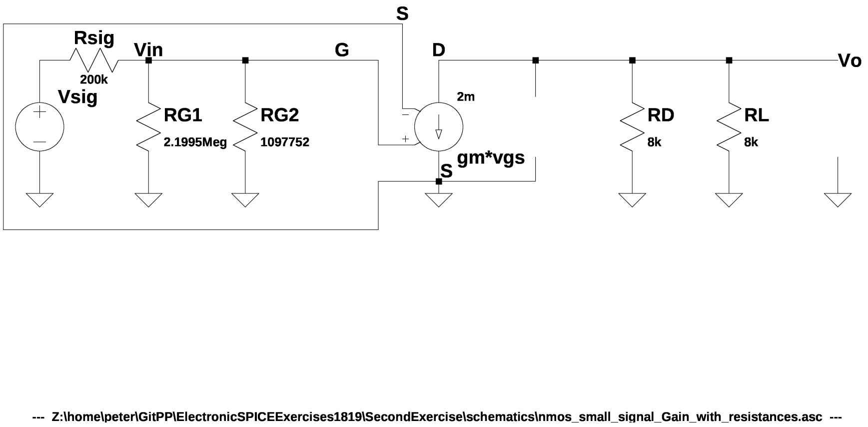

Figure 1.8: NMOS common source amplifier - Calculating the voltage gain with R_{sig} and R_L