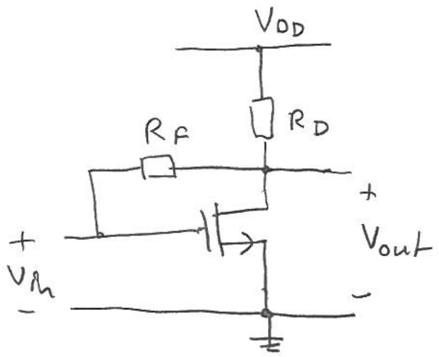
2010-01-19 / Bengt M.

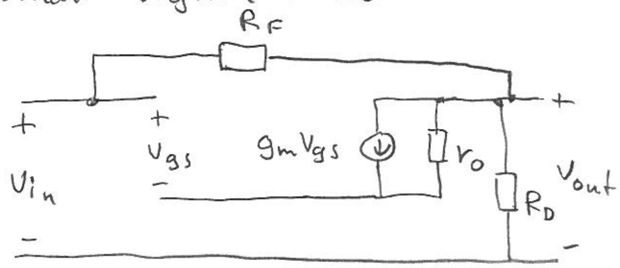
3.20 a



Assume transistor in saturation

$V_{DS} > V_{GS} - V_{TH}$

Small signal model



$$\begin{cases} V_{gs} = V_{in} \\ \dfrac{V_{out} - V_{in}}{R_F} + \dfrac{V_{out}}{r_o} + \dfrac{V_{out}}{R_D} + g_m V_{gs} = 0 \end{cases}$$

$$V_{out}\left(\frac{1}{R_F} + \frac{1}{r_o} + \frac{1}{R_D}\right) = V_{in}\left(\frac{1}{R_F} - g_m\right)$$

$$A_v = \frac{V_{out}}{V_{in}} = -\frac{g_m - \frac{1}{R_F}}{\frac{1}{R_F} + \frac{1}{r_o} + \frac{1}{R_D}}$$

Check with values, use model in Table 2.1

Assume: Bias at input $V_{in} = 1{,}0$ V DC

$$\frac{W}{L_{drawn}} = \frac{50}{0{,}5} \Rightarrow L_{eff} = L_{drawn} - 2L_D = 0{,}5 - 2 \cdot 0{,}08 = 0{,}34\mu$$

$V_{TH} = 0{,}7$ V

$$I_D = \frac{1}{2}\mu_n C_{ox} \cdot \frac{W}{L}\left(V_{GS} - V_{TH}\right)^2$$

$$\frac{cm^2}{Vs} \cdot \frac{F}{cm^2} = \frac{F}{Vs} = \frac{As/V}{Vs} = \frac{A}{V^2}$$

$$\mu_n = U_0 = 350 \ \frac{cm^2}{Vs}$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{8{,}85 \cdot 10^{-14} \cdot 3{,}9 \ F/cm}{9 \cdot 10^{-7} \ cm} = 3{,}84 \ F/cm^2$$

$$\mu_n C_{ox} = 350 \cdot 3{,}84 = 134 \ \mu A/V^2$$

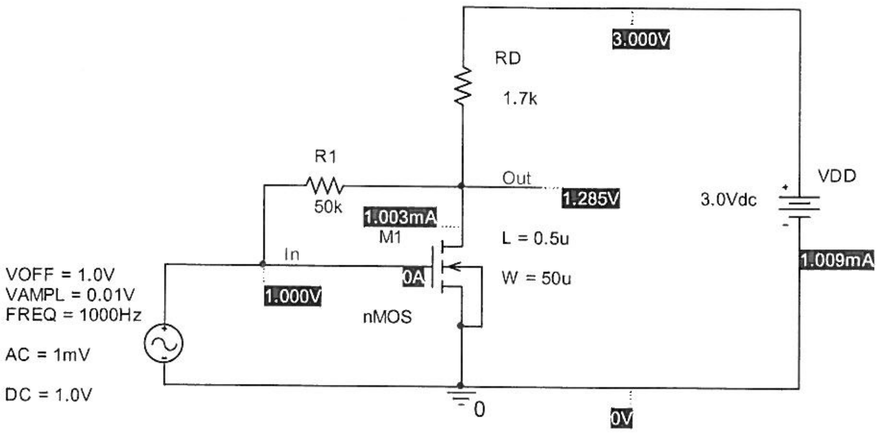
$$I_D = \frac{1}{2} \cdot 134\mu \cdot \frac{50\mu}{0{,}34\mu}\left(1 - 0{,}7\right)^2 = 0{,}88 \ mA$$

Design V_{out} DC-level $\simeq 1{,}5$ V and $V_{DD} = 3$ V

$$R_D = \frac{V_{DD} - V_{DS}}{I_D} = \frac{3 - 1{,}5}{0{,}88m} = \frac{1{,}5}{0{,}88m} = 1{,}7 \ k\Omega$$

$R_F = 50$ k

Problem 3.2 a



From output file

NAME	M_M1
MODEL	nMOS
ID	1.00E-03
VGS	1.00E+00
VDS	1.29E+00
VBS	0.00E+00
VTH	7.00E-01
VDSAT	3.00E-01
GM	6.69E-03
GDS	8.89E-05

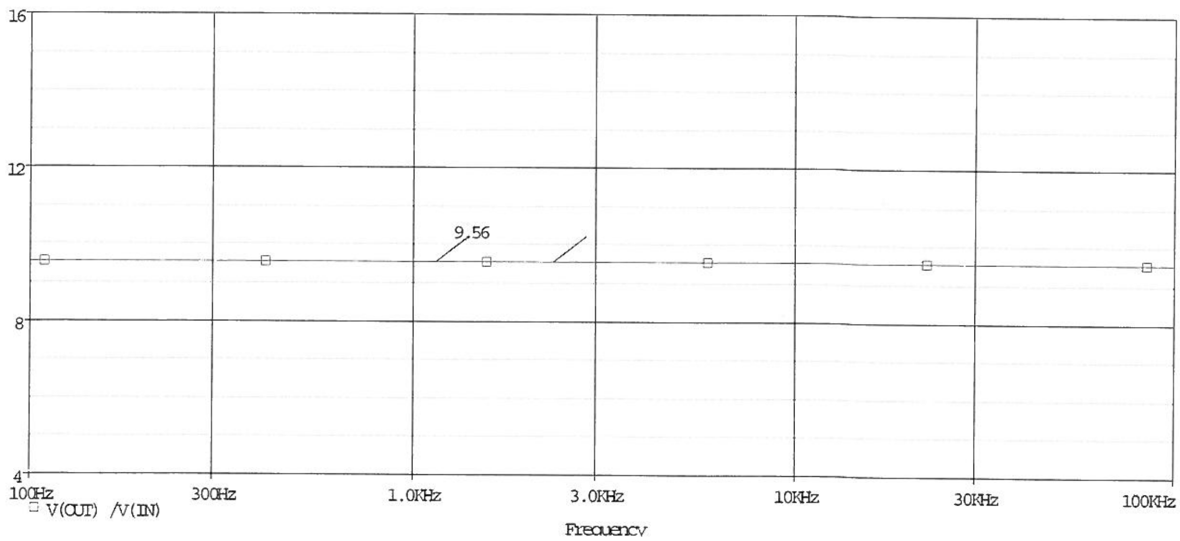
(ID through VDSAT: DC - values)

VDSAT — $V_{GS} - V_{TH} = V_{OV}$

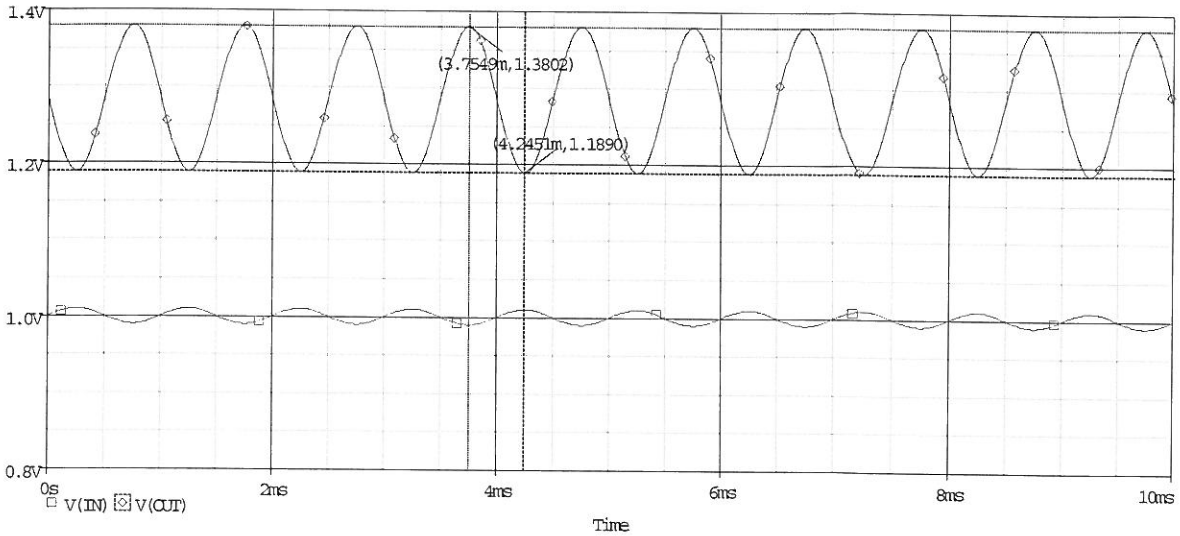
$g_m = 6{,}69 \text{ mA/V}$

$r_o = \frac{1}{GDS} = \frac{1}{8{,}89 \cdot 10^{-5}} = 11{,}2 \text{ k}\Omega$

AC-analysis gain = 9.56



Transient analysis 10 mV peak value input, output peak value 191.2/2= 95.6 mV gain = 9.56 OK!



Conclusion

Simulated DC values is higher because I have not considered channel length modulation.

$$I_D = 0{,}88m \cdot (1 + \lambda \cdot V_{DS}) = 0{,}88(1 + 0{,}1 \cdot 1{,}285) = 1{,}01 \text{ mA} \quad \text{ok!}$$

Checking gain formula:

$$g_m = \frac{2I_D}{V_{GS} - V_{TH}} = \frac{2 \cdot 1{,}0}{0{,}3} = 6{,}67 \text{ mA/V} \quad 6.69 \text{ mA/V in simulation ok!}$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{0{,}1 \cdot 1{,}0} = 10 \text{ k}\Omega \quad 11.2 \text{ k}\Omega \text{ from simulation}$$

$$R_F = 50 \text{ k}\Omega \quad R_D = 1{,}7 \text{ k}\Omega$$

$$A_V = -\frac{g_m - \frac{1}{R_F}}{\frac{1}{R_F} + \frac{1}{r_o} + \frac{1}{R_D}} = -\frac{6{,}69m - \frac{1}{50k}}{\frac{1}{50k} + \frac{1}{11.2k} + \frac{1}{1.7k}} = -9.56$$

This is exactly the same result as in simulation.

The gain formula seem to be correct!