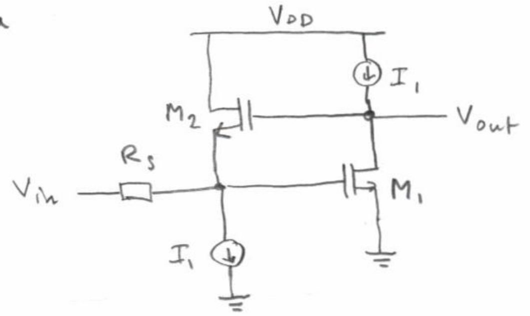
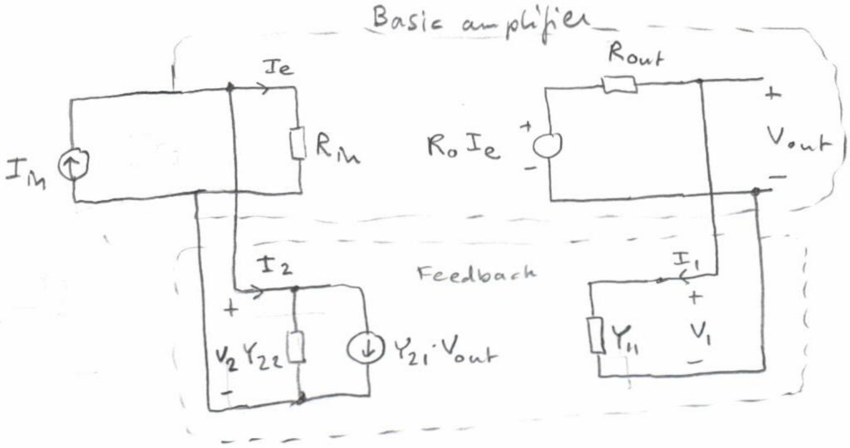
Problem 8.10 a

8.10 a

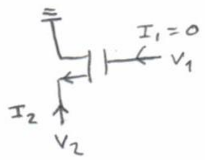


Type of feedback:
Sensing output voltage
Feed back as current to input
⇒ Voltage - current

Voltage - current feedback circuit with simplified Y-model (fig 8.46)



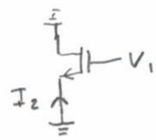
Feedback



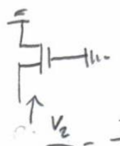
From 8.47, 8.48 and circuit ⇒

$Y_{11} = \left(\frac{I_1}{V_1}\right)_{V_2=0} = 0$ (no current into gate of M_2)

$Y_{21} = \left(\frac{I_2}{V_1}\right)_{V_2=0} = -g_{m2}$



$Y_{22} = \left(\frac{I_2}{V_2}\right)_{V_1=0} = g_{m2}$



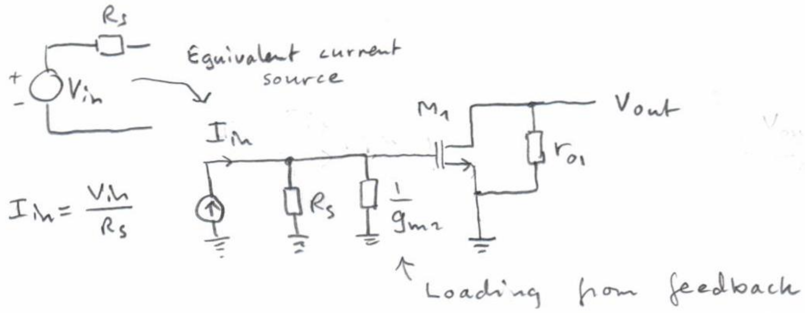
$\frac{V_2}{I_2} = \frac{1}{g_{m2}}$ ($\gamma = 0 \Rightarrow g_{mb} = 0$)

to be continued…

8.10 a continued

Open loop gain of basic amplifier including loading

Break the loop ($Y_{21}=0$), include loading Y_{11} and Y_{22} of feedback network when gain, R_{in}, R_{out} is calculated.



$$I_{in} = \frac{V_{in}}{R_s}$$

<u>Open loop gain</u>

$$R_0 = \frac{V_{out}}{I_{in}} = -g_{m1} r_{o1} \cdot \left(\frac{1}{g_{m2}} \parallel R_s\right)$$

open loop

$$R_{in} = \left(\frac{1}{g_{m2}} \parallel R_s\right)$$

$$R_{out} = r_{o1}$$

Feedback factor $g_{mF} = -g_{m2}$

<u>Closed loop</u>

$$\text{Gain } R_m = \left(\frac{V_{out}}{I_n}\right)_{closed} = \frac{R_0}{1 + g_{mF} \cdot R_0} = \frac{-g_{m1} \cdot r_{o1} \cdot \left(\frac{1}{g_{m2}} \parallel R_s\right)}{1 + (-g_{m2})\left(-g_{m1} \cdot r_{o1}\left(\frac{1}{g_{m2}} \parallel R_s\right)\right)}$$

$$= -\frac{1}{\frac{1}{g_{m1} r_{o1}\left(\frac{1}{g_{m2}} \parallel R_s\right)} + g_{m2}} \rightarrow -\frac{1}{g_{m2}} \text{ when } r_{o1} \rightarrow \infty$$

Input resistance

$$R_{in\,closed} = \frac{R_{in\,open}}{1 + g_{mF} \cdot R_0} = \frac{\frac{1}{g_{m2}} \parallel R_s}{1 + g_{m1} \cdot r_{o1}} =$$

$$= \frac{\left(\frac{1}{g_{m2}} \parallel R_s\right) \cdot \frac{1}{g_{m1} r_{o1}}}{\frac{1}{g_{m1} \cdot r_{o1}} + 1} \rightarrow 0 \text{ when } r_{o1} \rightarrow \infty$$

$$R_{out\,closed} = \frac{R_{out\,open}}{1 + g_{mF} \cdot R_0} = \frac{r_{o1}}{1 + g_{m1} r_{o1} \cdot g_{m2} \cdot \left(\frac{1}{g_{m2}} \parallel R_s\right)} =$$

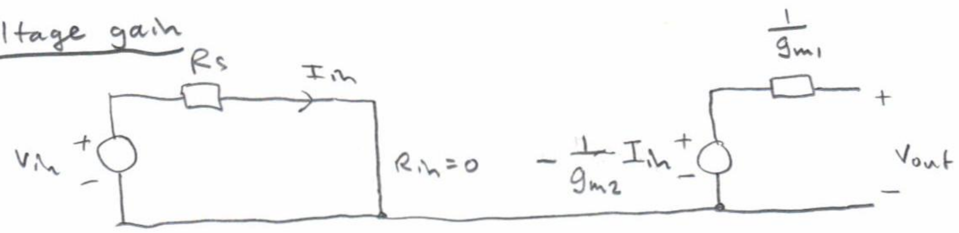
$$= \frac{1}{\frac{1}{r_{o1}} + g_{m1} \cdot g_{m2}\left(\frac{1}{g_{m2}} \parallel R_s\right)} \rightarrow \frac{1}{g_{m1} g_{m2}\left(\frac{1}{g_{m2}} \parallel R_s\right)} \text{ when } r_{o1} \rightarrow \infty$$

$$= \frac{1}{g_{m1}} + \frac{1}{g_{m1} g_{m2} R_s}$$

to be continued…

8.10 a continued

Voltage gain

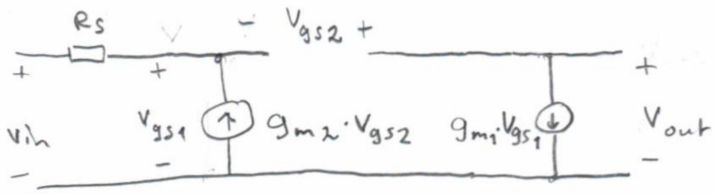


$$I_{in} = \frac{V_{in}}{R_s}$$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{I_{in}} \cdot \frac{I_{in}}{V_{in}} = -\frac{1}{g_{m2}} \cdot \frac{1}{R_s} = -\frac{1}{g_{m2} \cdot R_s}$$

Solve the same problem without using feedback concept.

Small signal model



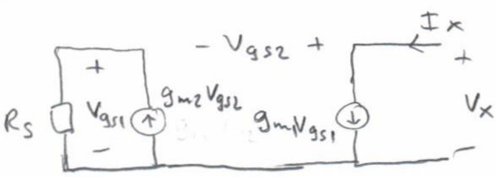
$$\begin{cases} V_{gs1} = V_{in} + g_{m2} \cdot V_{gs2} \cdot R_s \\ V_{out} = V_{gs1} + V_{gs2} \end{cases}$$

$g_{m1} V_{gs1} = 0 \Rightarrow V_{gs1} = 0 \Rightarrow V_{out} = V_{gs2}$

$V_{in} + R_s \cdot g_{m2} \cdot V_{out} = 0$

$$A_v = \frac{V_{out}}{V_{in}} = -\frac{1}{g_{m2} \cdot R_s}$$

$$R_{in} = \frac{V_{in}}{I_{in}} = R_s$$



$$R_{out} = \frac{V_x}{I_x} = \frac{V_{gs2} + g_{m2} V_{gs2} \cdot R_s}{g_{m1} V_{gs1}} = \frac{V_{gs2}(1 + g_{m2} R_s)}{g_{m1} \cdot g_{m2} \cdot V_{gs2} \cdot R_s} =$$

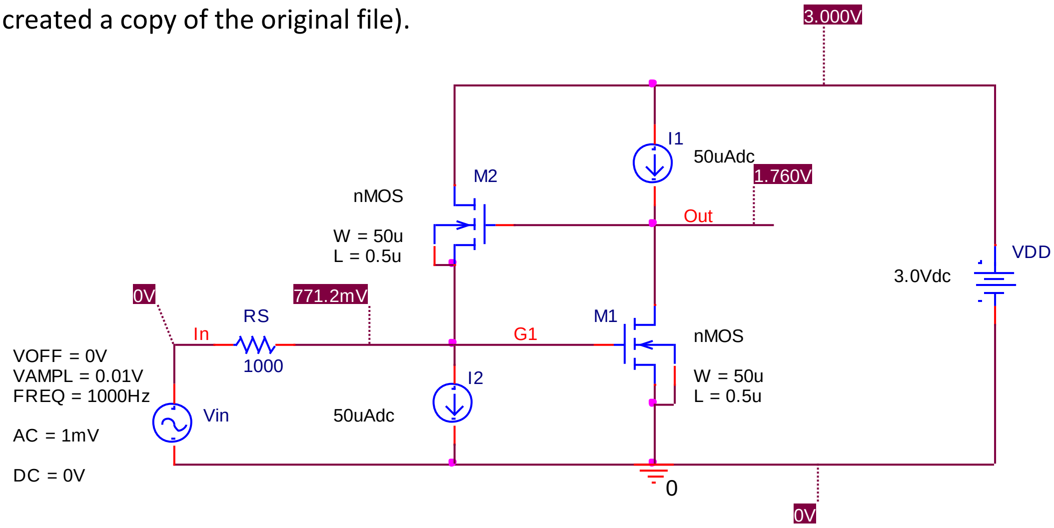
$$= \frac{1 + g_{m2} R_s}{g_{m1} g_{m2} R_s} = \frac{1}{g_{m1}} + \frac{1}{g_{m1} g_{m2} R_s}$$

Same results, ok!

Simulation to verify the result

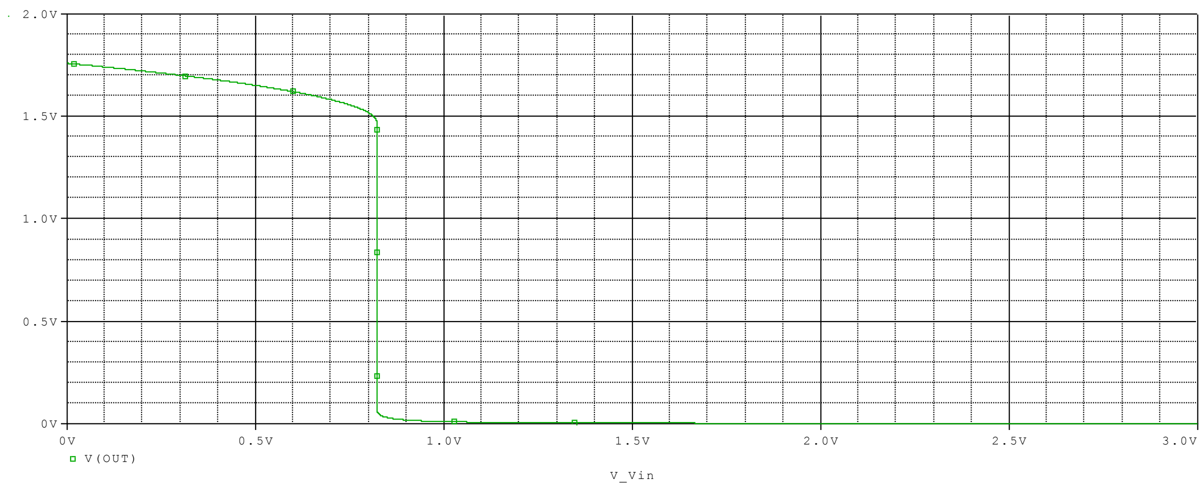
First try:

In problem is given that $\gamma=\lambda=0$. Body effect is eliminated in simulation by connecting body to source in schematic. Channel length modulation is eliminated by changing LAMBDA to zero in SPICE parameter file (I created a copy of the original file).



Both transistors seem to be in saturation.

Checking DC transfer function.

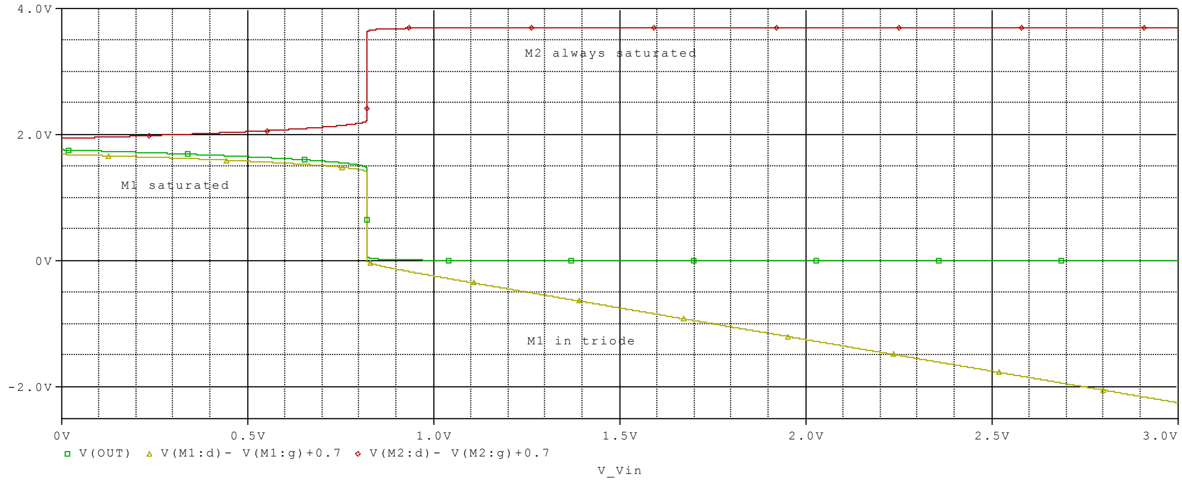


Seem to be very low gain for input voltages below approximately 0.72 V.

Checking when transistors are saturated.

$$V_{DS} > V_{GS} - V_{TH}, \quad V_{DS} - V_{GS} + V_{TH} > 0, \quad V_D - V_S - (V_G - V_S) + V_{TH} > 0, \quad V_D - V_G + V_{TH} > 0$$

Check when $V_D - V_G + 0.7 > 0$ ($V_{TH} = 0.7$ V)



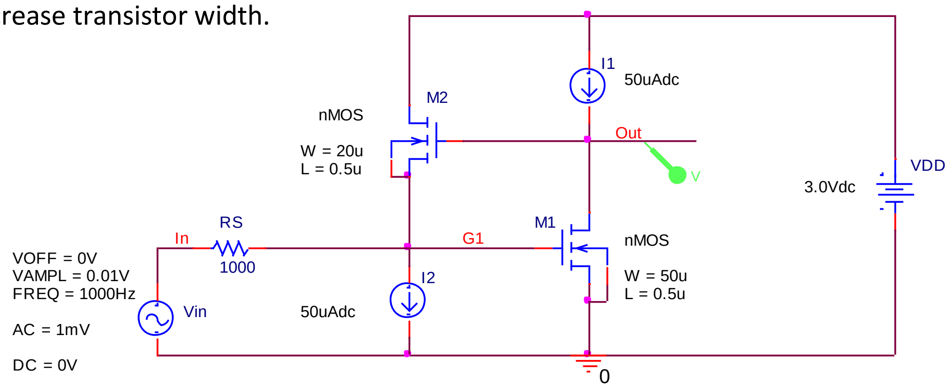
Transistor M2 is always saturated, but M1 goes out of saturation when input voltage is about 0.72 V.

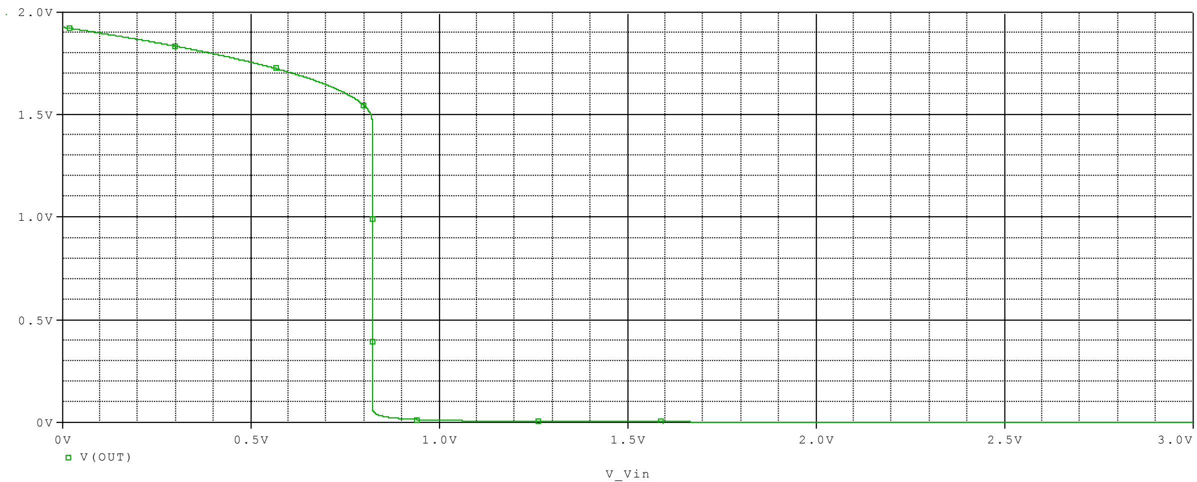
The active region with voltage gain is for input DC voltage below 0.72 V. The gain is very low, so let's see how it can be increased.

From hand calculation I derived $A_v = -\frac{1}{g_{m2} R_S}$

We can increase the gain if g_{m2} or R_S is decreased. For given DC current in transistor the only option to decrease g_m is to decrease transistor width.

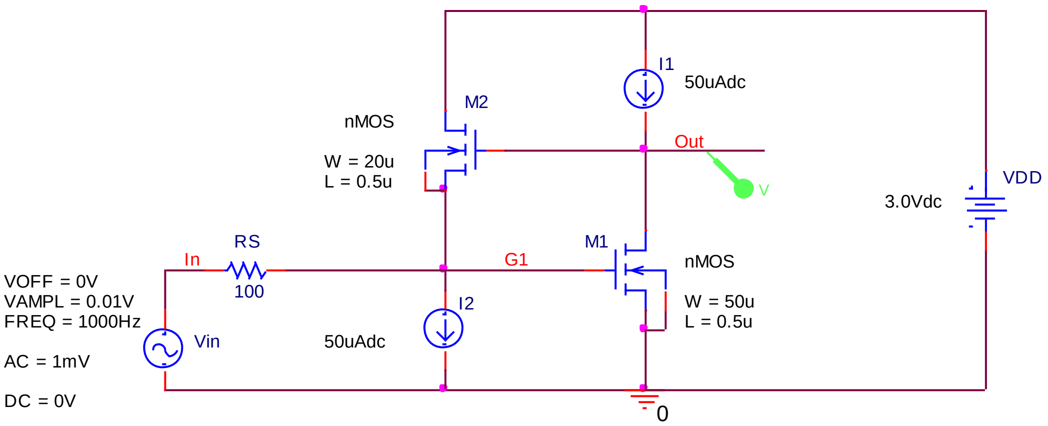
Decreasing width:

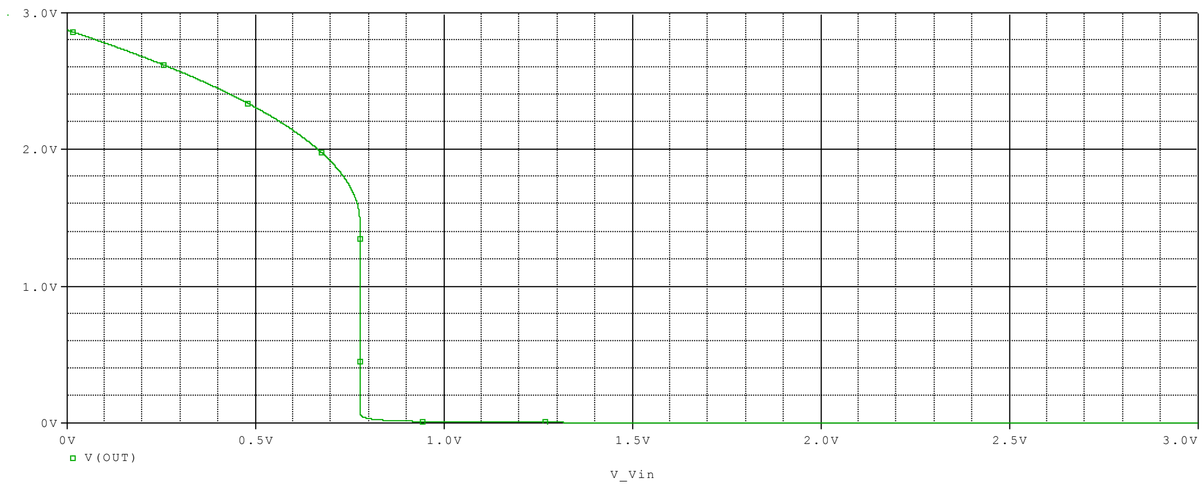




The gain is increased when width is decreased!

Decreasing R_S:

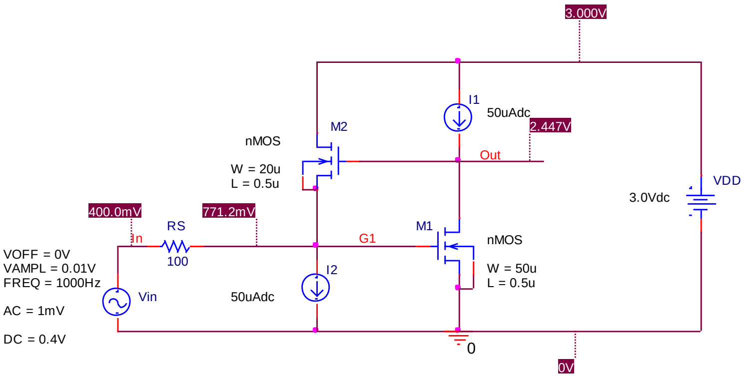




I am choosing to investigate gain, input resistance and output resistance for input DC bias 0.4 V.

From output file: DC bias point and small signal parameters for input DC bias 0.4 V.

NAME	M_M1	M_M2
MODEL	nMOS	nMOS
ID	5.00E-05	3.76E-03
VGS	7.71E-01	1.68E+00
VDS	2.45E+00	2.23E+00
VBS	0.00E+00	0.00E+00
VTH	7.00E-01	7.00E-01
VDSAT	7.12E-02	9.76E-01
GM	1.41E-03	7.71E-03
GDS	0.00E+00	0.00E+00
GMB	3.33E-04	1.83E-03



Calculated values from derived expressions but with small signal parameters based on simulated small signal model and chosen input bias 0.4 V.

From output file with DC input bias = 0.4 V

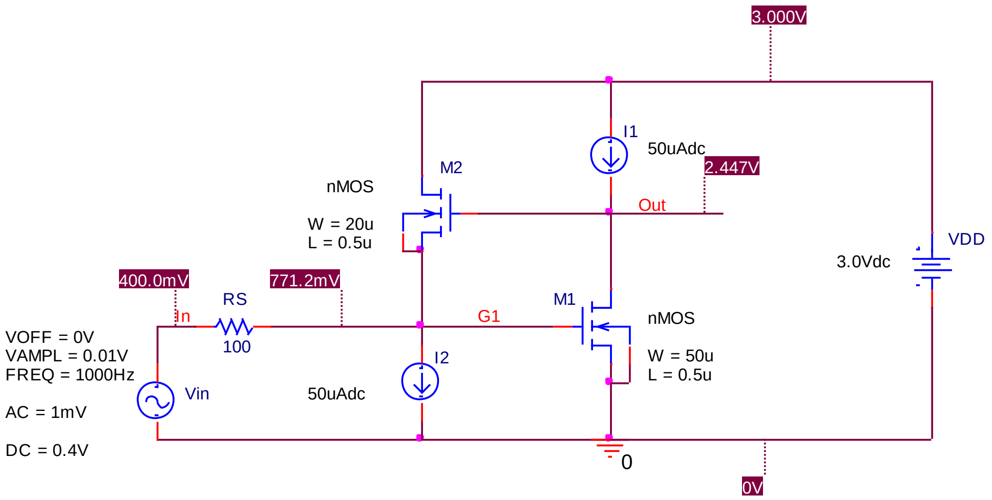
$g_{m1} = 1{,}41 \text{ mA/V} \qquad g_{m2} = 7{,}71 \text{ mA/V} \qquad R_S = 100$

$$A_v = -\frac{1}{g_{m2} R_S} = -\frac{1}{7{,}71 \cdot 10^{-3} \cdot 100} = -1{,}3$$

$$R_{in} = R_S = 100\ \Omega$$

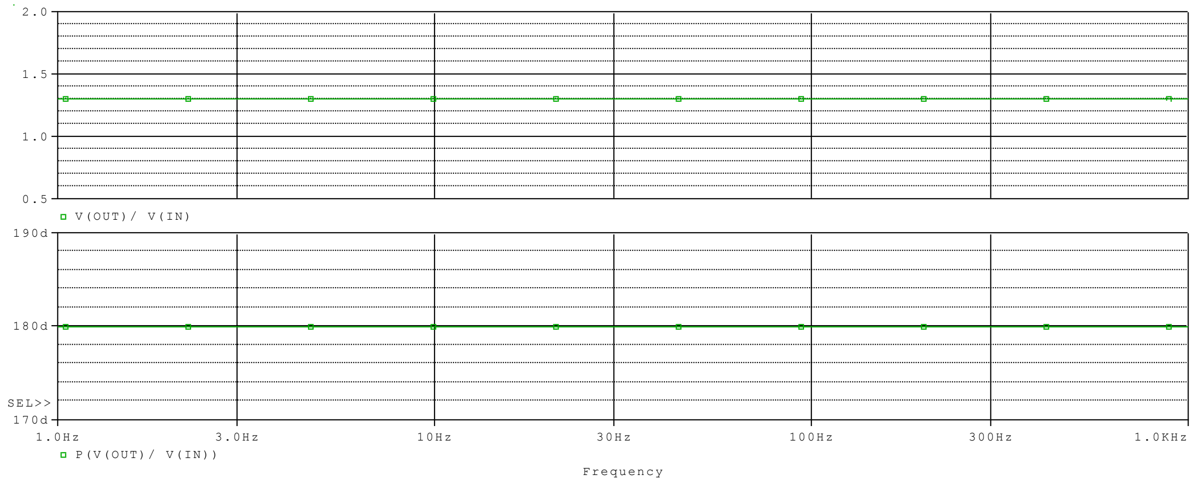
$$R_{out} = \frac{1}{g_{m1}} + \frac{1}{g_{m1} g_{m2} R_S} = \frac{1}{1{,}41m} + \frac{1}{1{,}41m \cdot 7{,}71m \cdot 0{,}1k} =$$

$$= 1{,}63\ k\Omega$$



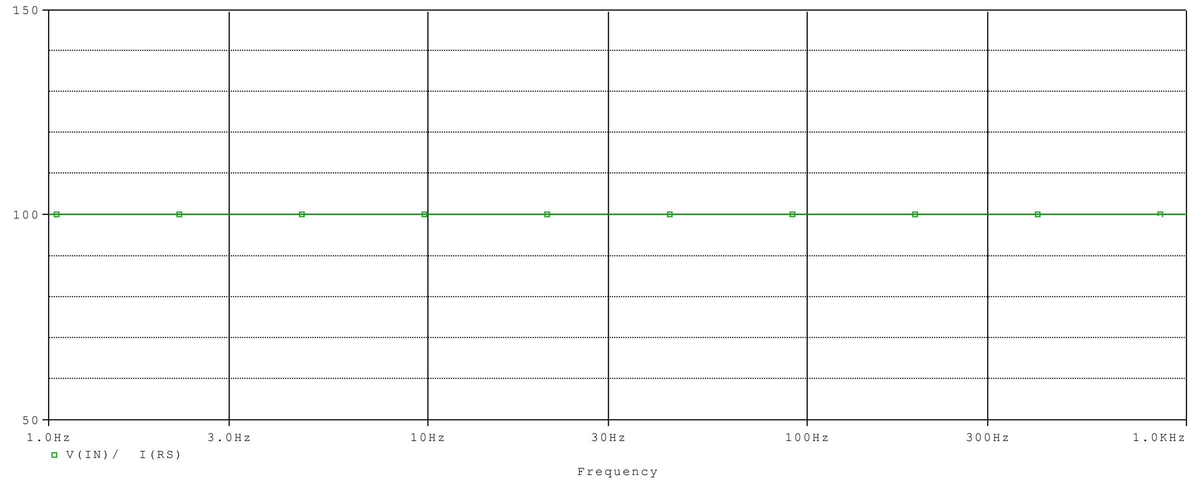
AC analysis use small signal model

Gain



Voltage gain = 1.3 V with phase 180 degrees, i.e. $A_v = -1.3$

Input resistance

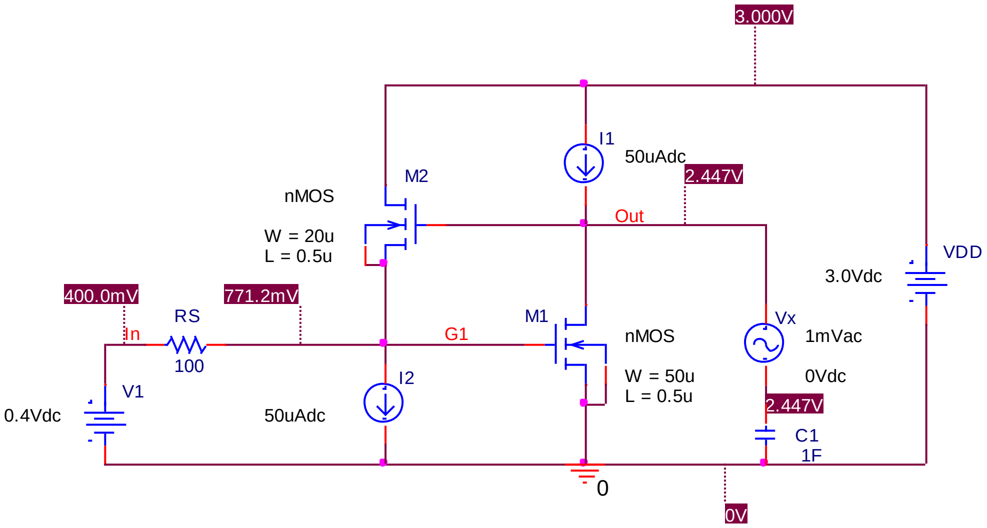


Input resistance 100 Ω, $R_{in} = R_S$

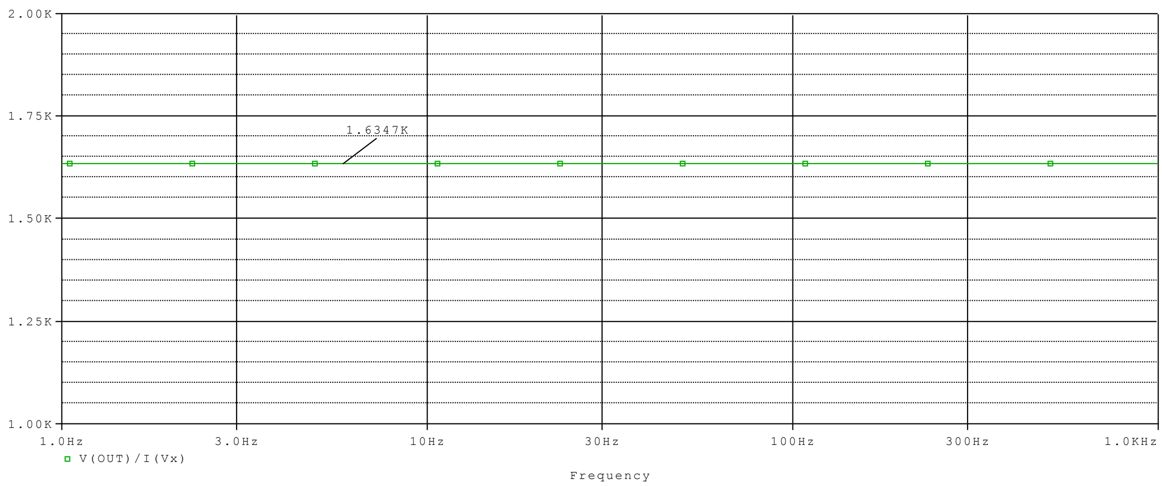
Simulating output resistance

Method:

1. Zero input small signal sources, i.e. AC ground at input, DC bias 0.4 V
2. Apply small signal test voltage at output. Avoid killing DC output level by either applying DC voltage that is equal to bias DC voltage level (2.447V) in series or connect a large capacitor in series to charge to that voltage.



AC analysis use small signal model



Output resistance R_{out} = 1.63 kΩ

Conclusion

All results are in full agreement with hand calculations. Hand calculated solution confirmed!

Comment: Strange circuit; to increase voltage gain the input resistance has to be decreased. Input resistance is well defined by Rs.