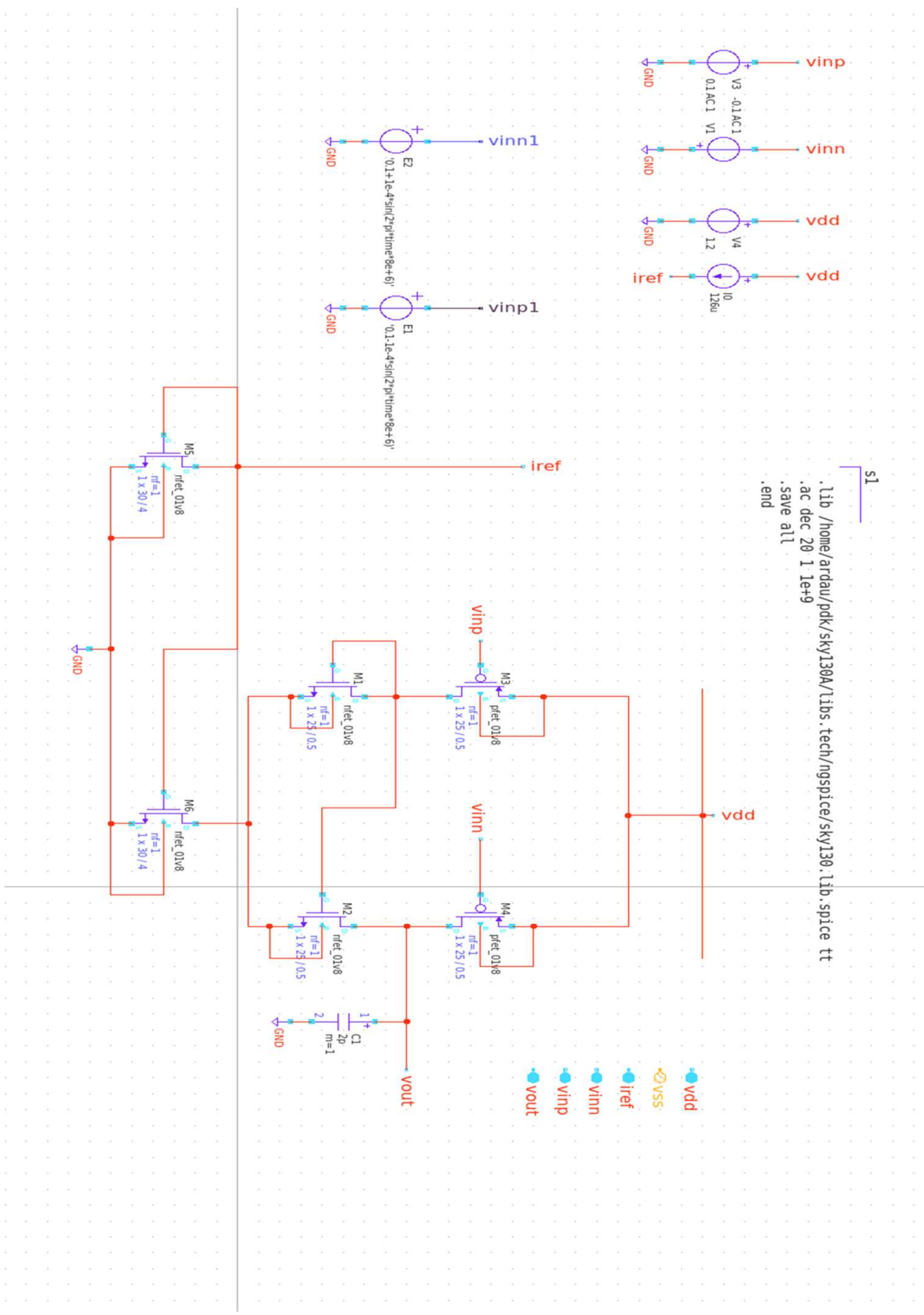
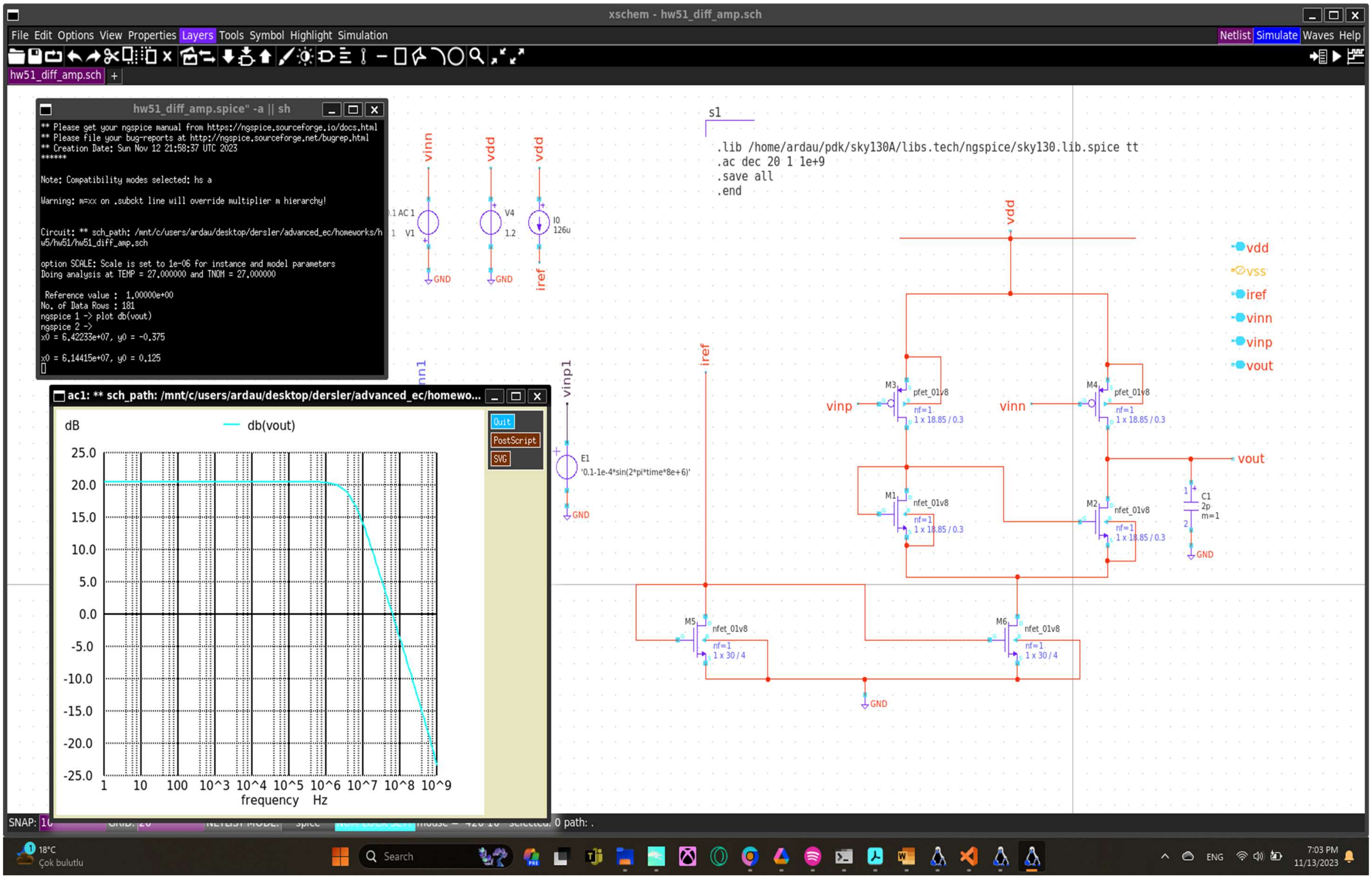
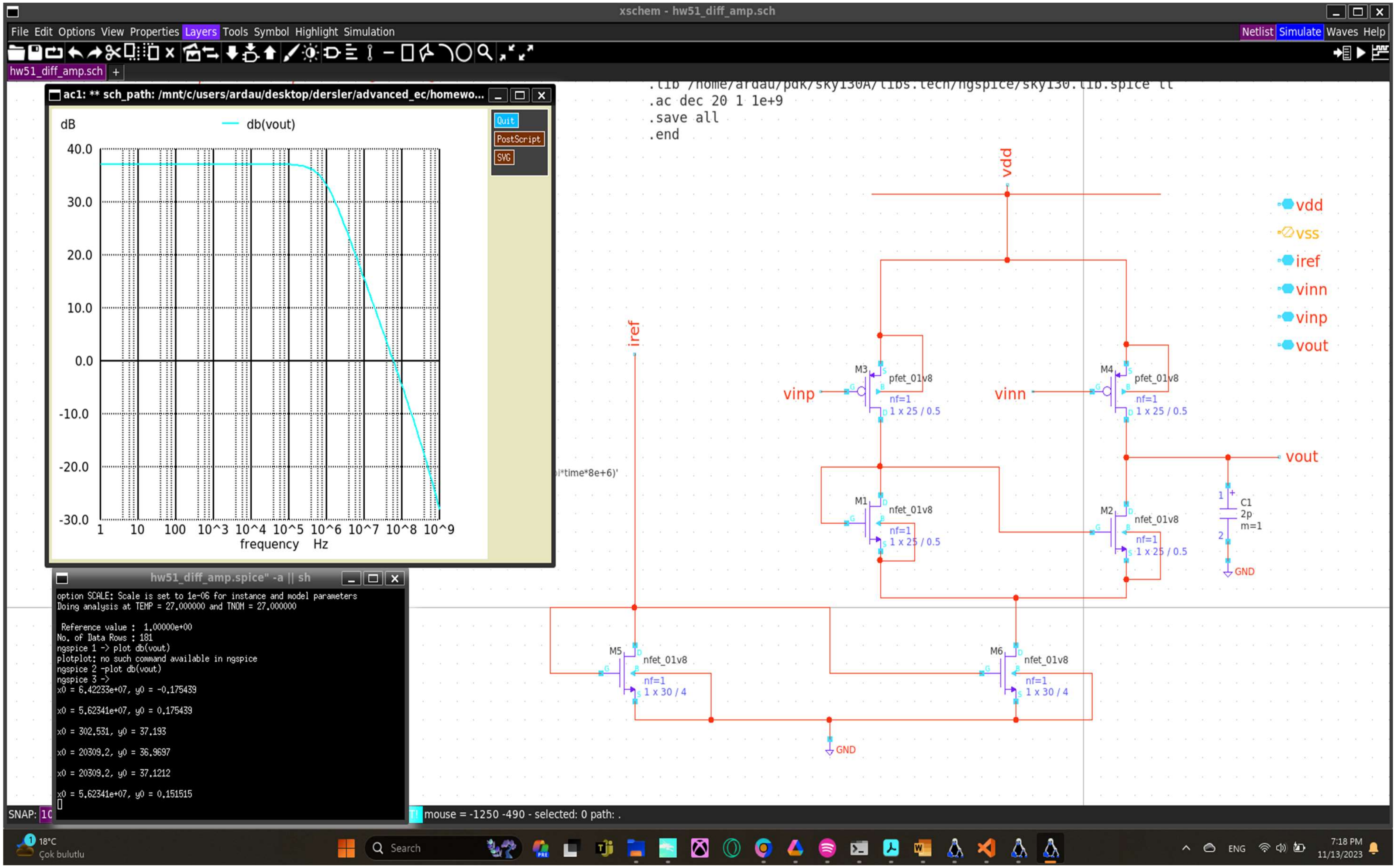
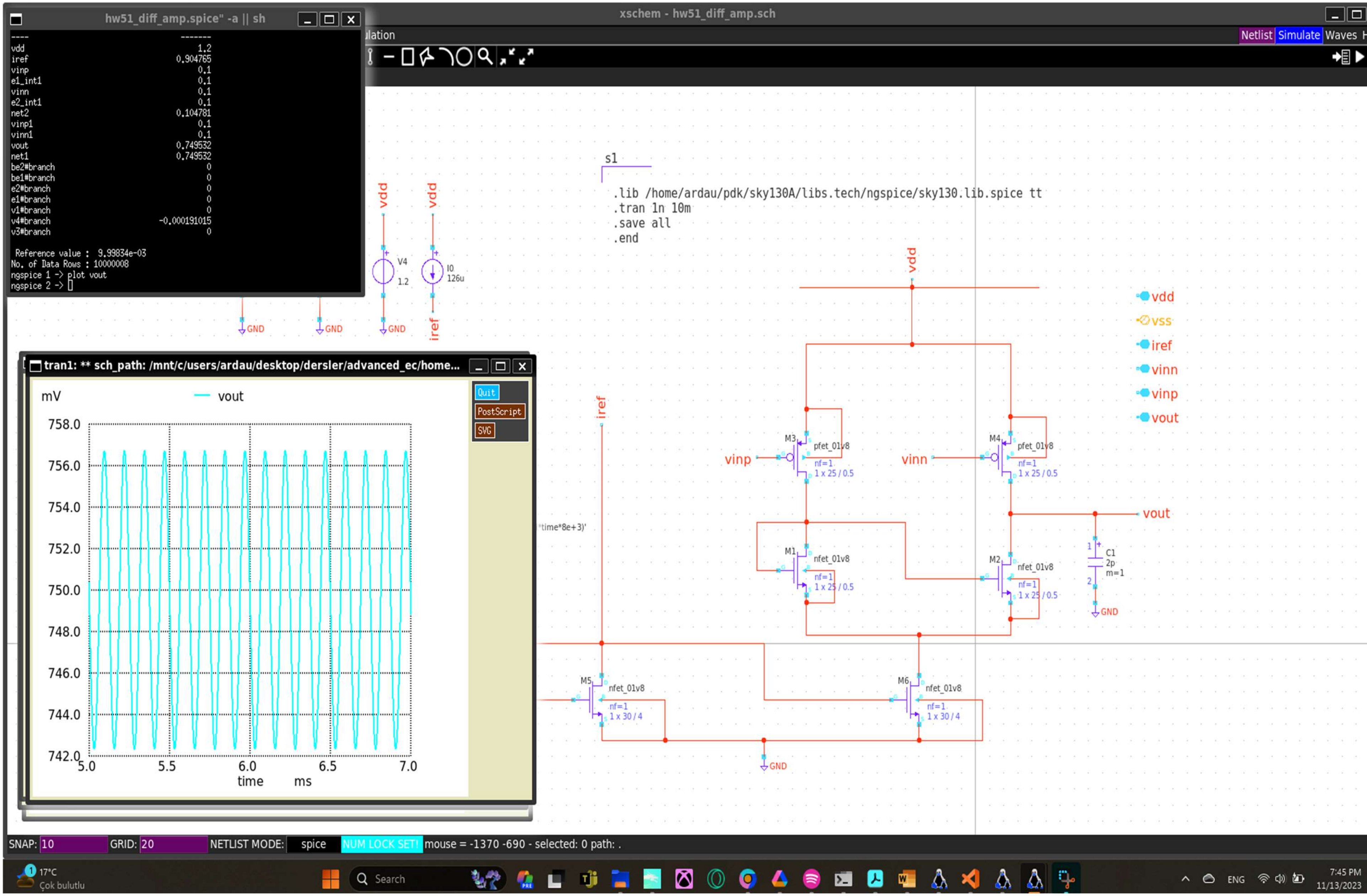
HOMEWORK 5
ARDA ÜNAL

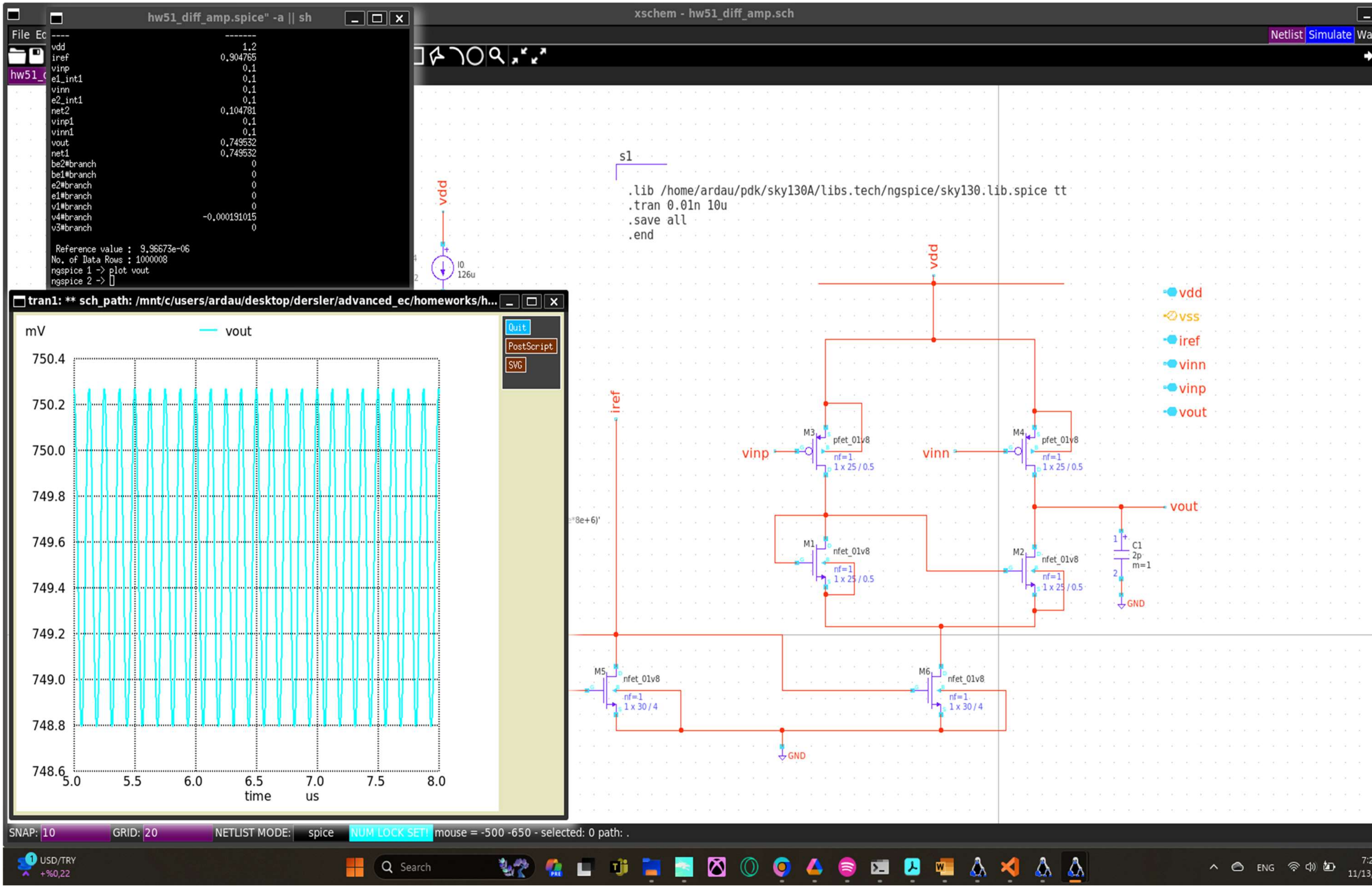
1)




xschem - hw51_diff_amp.sch
File Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves Help
hw51_diff_amp.sch
hw51_diff_amp.spice" -a || sh
** Please get your ngspice manual from https://ngspice.sourceforge.io/docs.html
** Please file your bug-reports at http://ngspice.sourceforge.net/bugrep.html
** Creation Date: Sun Nov 12 21:58:37 UTC 2023
******
Note: Compatibility modes selected: hs a
Warning: m=xx on .subckt line will override multiplier m hierarchy!
Circuit: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/hw5/hw51/hw51_diff_amp.sch
option SCALE: Scale is set to 1e-06 for instance and model parameters
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Reference value : 1.00000e+00
No. of Data Rows : 181
ngspice 1 -> plot db(vout)
ngspice 2 ->
x0 = 6.42233e+07, y0 = -0.375
x0 = 6.14415e+07, y0 = 0.125
ac1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homewo...
Quit
PostScript
SVG
dB
db(vout)
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
frequency Hz
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.ac dec 20 1 1e+9
.save all
.end
vinn
vdd
vdd
V1
AC 1
V4
1.2
I0
126u
iref
GND
vinp1
E1
'0.1-1e-4*sin(2*pi*time*8e+6)'
iref
vdd
vinp
vinn
M3
pfet_01v8
nf=1
1 x 18.85 / 0.3
M4
pfet_01v8
nf=1
1 x 18.85 / 0.3
M1
nfet_01v8
nf=1
1 x 18.85 / 0.3
M2
nfet_01v8
nf=1
1 x 18.85 / 0.3
M5
nfet_01v8
nf=1
1 x 30 / 4
M6
nfet_01v8
nf=1
1 x 30 / 4
C1
2p
m=1
vout
vdd
vss
iref
vinn
vinp
vout
SNAP:
path: .
Search
18°C
Çok bulutlu
ENG
7:03 PM
11/13/2023


xschem - hw51_diff_amp.sch
File Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves Help
hw51_diff_amp.sch
ac1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homewo...
Quit
PostScript
SVG
dB
db(vout)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
1 10 100 10^3 10^4 10^5 10^6 10^7 10^8 10^9
frequency Hz
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.ac dec 20 1 1e+9
.save all
.end
vdd
vss
iref
vinn
vinp
vout
M3
pfet_01v8
nf=1
1 x 25 / 0.5
M4
pfet_01v8
nf=1
1 x 25 / 0.5
M1
nfet_01v8
nf=1
1 x 25 / 0.5
M2
nfet_01v8
nf=1
1 x 25 / 0.5
M5
nfet_01v8
nf=1
1 x 30 / 4
M6
nfet_01v8
nf=1
1 x 30 / 4
C1
2p
m=1
GND
hw51_diff_amp.spice" -a || sh
option SCALE: Scale is set to 1e-06 for instance and model parameters
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Reference value : 1.00000e+00
No. of Data Rows : 181
ngspice 1 -> plot db(vout)
plotplot: no such command available in ngspice
ngspice 2 -plot db(vout)
ngspice 3 ->
x0 = 6.42233e+07, y0 = -0.175439
x0 = 5.62341e+07, y0 = 0.175439
x0 = 302.531, y0 = 37.193
x0 = 20309.2, y0 = 36.9697
x0 = 20309.2, y0 = 37.1212
x0 = 5.62341e+07, y0 = 0.151515
SNAP: 10
mouse = -1250 -490 - selected: 0 path: .
18°C
Çok bulutlu
Search
ENG
7:18 PM
11/13/2023


hw51_diff_amp.spice" -a || sh
vdd 1.2
iref 0.904765
vinp 0.1
e1_int1 0.1
vinn 0.1
e2_int1 0.1
net2 0.104781
vinp1 0.1
vinn1 0.1
vout 0.749532
net1 0.749532
be2#branch 0
be1#branch 0
e2#branch 0
e1#branch 0
v1#branch 0
v4#branch -0.000191015
v3#branch 0
Reference value : 9.99834e-03
No. of Data Rows : 10000008
ngspice 1 -> plot vout
ngspice 2 ->
xschem - hw51_diff_amp.sch
Netlist Simulate Waves
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.tran 1n 10m
.save all
.end
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/home...
Quit
PostScript
SVG
mV
vout
758.0
756.0
754.0
752.0
750.0
748.0
746.0
744.0
742.0
5.0
5.5
6.0
6.5
7.0
time ms
'time*8e+3)'
vdd
V4
1.2
I0
126u
iref
GND
vinp
vinn
vout
vss
M1 nfet_01v8
M2 nfet_01v8
M3 pfet_01v8
M4 pfet_01v8
M5 nfet_01v8
M6 nfet_01v8
nf=1
1 x 25 / 0.5
1 x 30 / 4
C1
2p
m=1
SNAP: 10 GRID: 20 NETLIST MODE: spice NUM LOCK SET! mouse = -1370 -690 - selected: 0 path: .
17°C
Çok bulutlu
Search
ENG
7:45 PM
11/13/2023

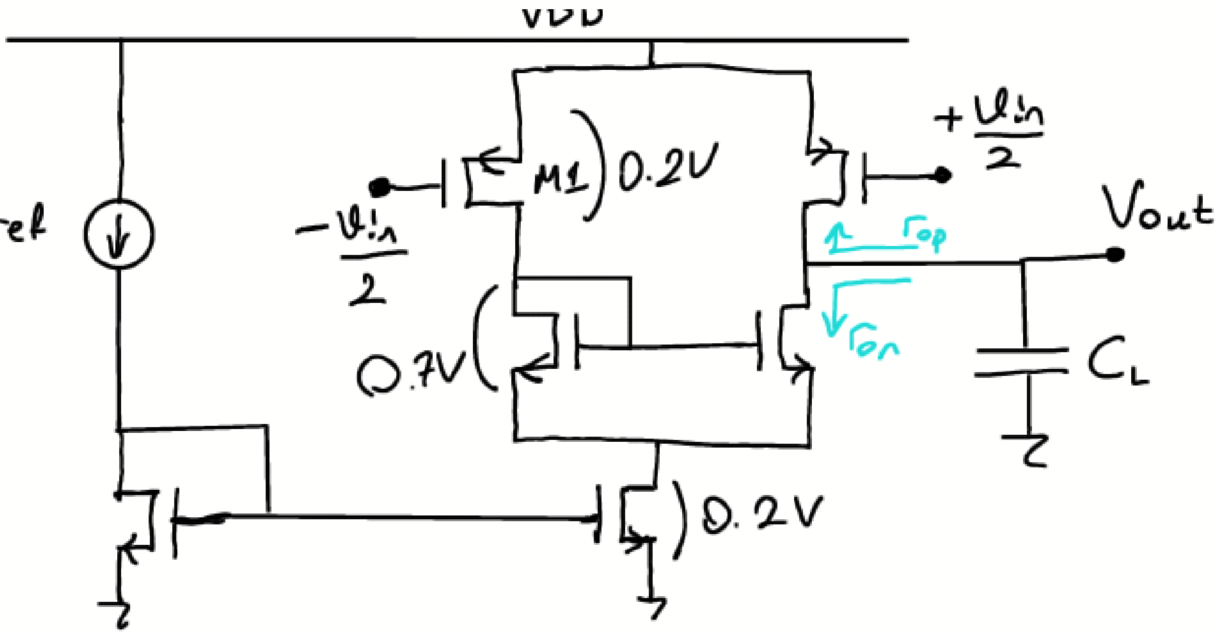


xschem - hw51_diff_amp.sch
hw51_diff_amp.spice" -a || sh
vdd 1.2
iref 0.904765
vinp 0.1
e1_int1 0.1
vinn 0.1
e2_int1 0.1
net2 0.104781
vinp1 0.1
vinn1 0.1
vout 0.749532
net1 0.749532
be2#branch 0
be1#branch 0
e2#branch 0
e1#branch 0
v1#branch 0
v4#branch -0.000191015
v3#branch 0
Reference value : 9.96673e-06
No. of Data Rows : 1000008
ngspice 1 -> plot vout
ngspice 2 ->
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/h...
mV
vout
750.4
750.2
750.0
749.8
749.6
749.4
749.2
749.0
748.8
748.6
5.0
5.5
6.0
6.5
7.0
7.5
8.0
time us
Quit
PostScript
SVG
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.tran 0.01n 10u
.save all
.end
vdd
I0
126u
iref
vinp
vinn
vout
M1
M2
M3
M4
M5
M6
pfet_01v8
nfet_01v8
nf=1
1 x 25 / 0.5
1 x 30 / 4
C1
2p
m=1
GND
vss
Netlist
Simulate
SNAP: 10
GRID: 20
NETLIST MODE: spice
NUM LOCK SET!
mouse = -500 -650 - selected: 0 path: .

hw51

Today 02:01 Uncategorized

1)



$A_v = g_{m1} R_{out}$ $\quad$ $GBW = \dfrac{g_{m1}}{2\pi C_L}$

$\Rightarrow g_{m1} = 2\pi \times 2\times 10^{-12} \times 50\times 10^{6}$

$= 6.2832 \times 10^{-4}\ S$

→From design perspective,

$g_m = \dfrac{2 I_D}{V_{GS}-V_T} \Rightarrow I_D = 62.832\,\mu A$

$\Rightarrow I_{ref} = 2\times I_D = 125.664\,\mu A$

Since $g_m = \sqrt{2k' \frac{W}{L} I_D} \Rightarrow \frac{W}{L} = 62.832$

$R_{out} = r_{on} // r_{op} \Rightarrow A_v = g_m \frac{R_{out}}{2} = 70$

$\Rightarrow R_{out} = 55.7k\Omega \Rightarrow r_{op} \approx 111k\Omega$

$\rightarrow$ Since $r_{on} > r_{op}$ for same L, we just need to decide r_{op} and we can use same L for NMOS as well.

$r_{op} = \frac{V_{Ap}}{I_D} \Rightarrow V_{Ap} = 7$ $\rightarrow$ Thus we need to find L_p for this V_{Ap}.

$\rightarrow$ When $V_{GS} = -3V$, $V_A = 3.5$ for $L = 0.15\mu m$ PMOS and $I_D = 0.22567$ mA at $V_{DS} = 3V$

$\Rightarrow V_{T_p} = -0.8V$, so $\frac{\mu_p C_{ox}}{2} = 1.088 \times 10^{-4}$

$V_{OV_p} = 0.2V \Rightarrow \quad V_{GS} + 0.8 = 0.2V$

$\Rightarrow V_{GS} = -0.6V$, so $V_{GS} = 0.1V$ $\rightarrow$ For our circuit.

$\rightarrow$ So V_{DD} must be at least $1.1V$, thus let us choose $V_{DD} = 1.2V$.

$V_{Ap} = 7 = V_E L$ since $V_E = 23.3 \times 10^6$

$\Rightarrow L = 0.3\mu m \Rightarrow W = 18.85\mu m$

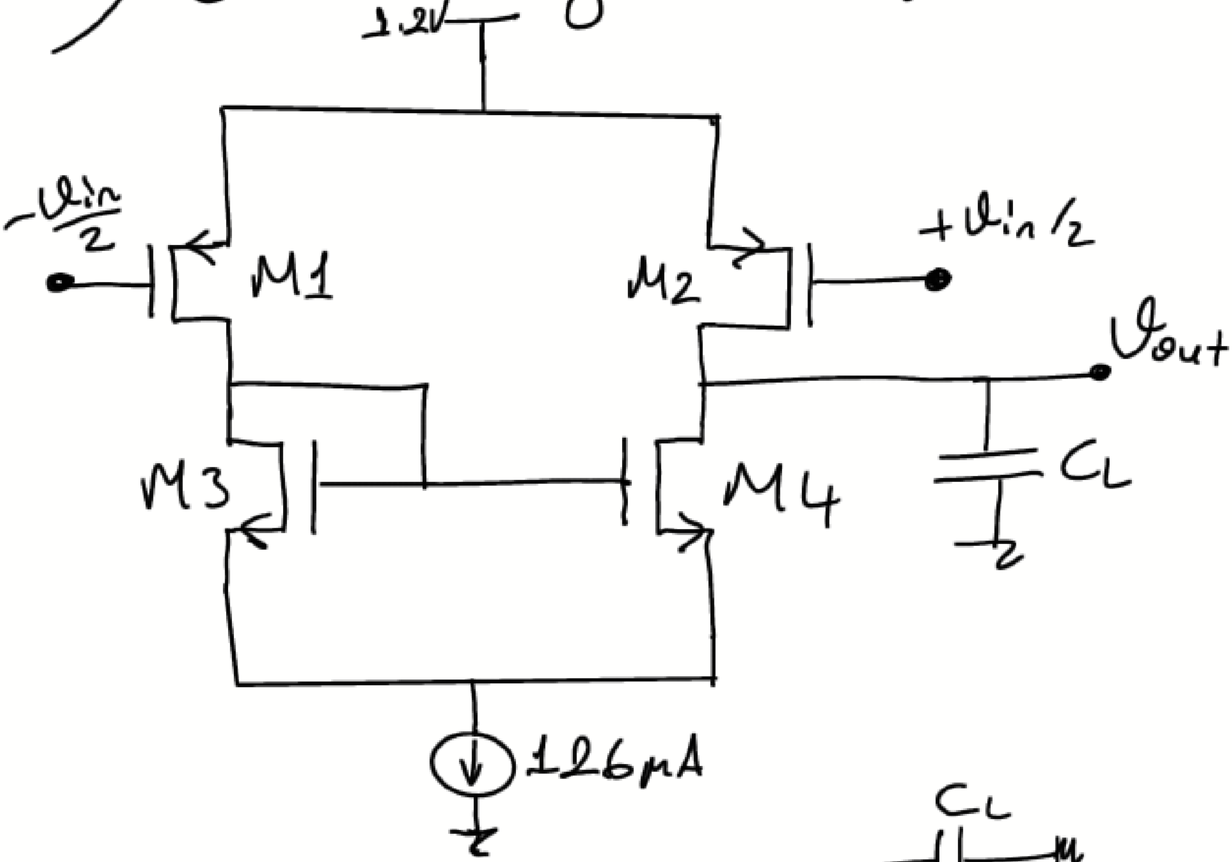
$\rightarrow$ To catch specifications, let say

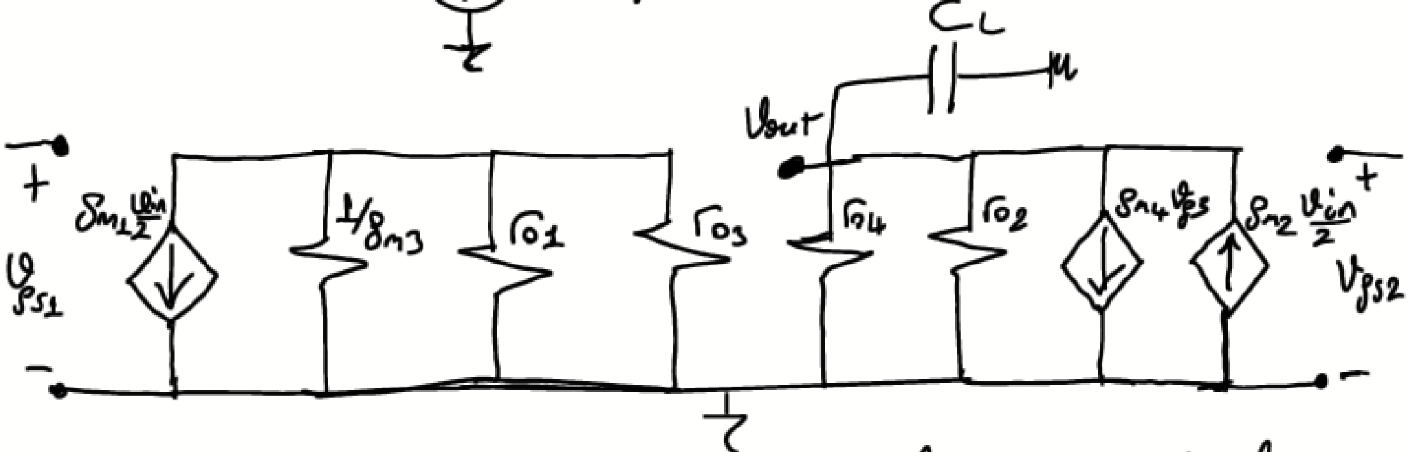
$L = 0.5\mu m$ and $W = 25\mu m$

hw52

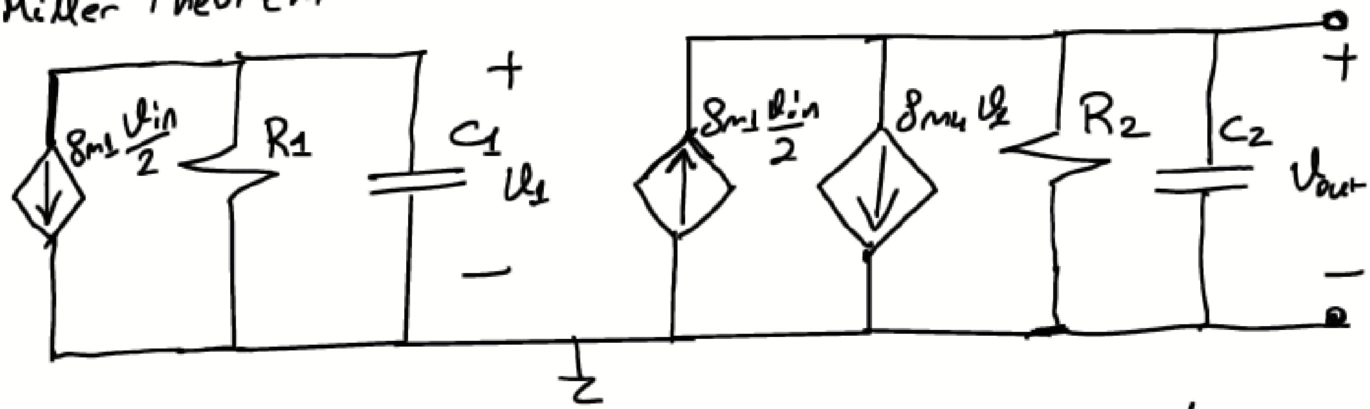
Today 02:01 Uncategorized

2) Small Signal Equivalent Circuit





→ by including capacitances, above circuit becomes
"Miller Theorem"



$R_2 = r_{o4} // r_{o2}$ $\quad R_1 = \frac{1}{g_{m3}} // r_{o1} // r_{o3} \approx \frac{1}{g_{m3}}$

$R_2 = r_{ou} // r_{o2}$, ... g_{m3} ...

$$C_1 = C_{gd1} + C_{gs3} + C_{gs4} + C_{bd1} + C_{bd3}$$

$$C_2 = C_{gd2} + C_{gd4} + C_{bd2} + C_{bd4} + C_L$$

$$C_{gs,p} = C_{gs,n} = \frac{2}{3} WLC_{ox} + WC_{ov}$$

$$C_{gd,p} = C_{gd,n} = WC_{ov}, \text{ and } C_{bd,n,p} = C_J$$

→ Since I do not know exactly how to calculate C_{ov} and C_j, I will assume that they are zero, so

$$C_{gs} = \frac{2}{3} WLC_{ox} \cong 4.1667 \times 10^{-18}\ F$$

$$\Rightarrow C_1 = 0{,}04\,pF \text{ and } C_2 = 2\,pF$$

$$v_1 = -g_{m1} \frac{v_{in}}{2} \left(\frac{1}{g_{m3} + sC_1} \right)$$

$$i_o = -g_{m4} v_1 + g_{m1} \frac{v_{in}}{2} \quad \text{and}$$

$$V_{out} = -\left(R_2 // \frac{1}{sC_2}\right) i_o$$

$$= -\left(R_2 // \frac{1}{sC_2}\right)\left(-g_{m4} v_1 + g_{m1} \frac{v_{in}}{2}\right)$$

$$= -\frac{R_2}{1 + sC_2R_2} \left[+g_{m4} g_{m1} \frac{v_{in}}{2} \left(\frac{1}{g_{m3} + sC_1} \right) + g_{m1} \frac{v_{in}}{2} \right]$$

$$\Rightarrow V_{out} = -\frac{R_2}{1 + sC_2R_2} g_{m1} \frac{v_{in}}{2} \left(\frac{g_{m4}}{g_{m3} + sC_1} + 1 \right)$$

$$\Rightarrow A_v = \frac{v_{in}}{V_{out}} = \frac{-g_{m1} R_2}{2(1 + sC_2R_2)} \left(\frac{g_{m4}}{g_{m3} + sC_1} + 1 \right)$$

→ Now let us define 2 frequency variables (poles):

$\omega_2 = \frac{1}{\ldots}$ and $\omega_1 = \frac{1}{\ldots}$

$$\omega_2 = \frac{\quad}{R_2 C_2} \quad \text{and} \quad \omega_1 = \frac{\quad}{R_1 C_1}$$

$$\Rightarrow A_V = \frac{-g_{m1} R_2 \omega_2}{2(s+\omega_2)} \left[1 + \frac{g_{m4} R_1 \omega_1}{s+\omega_1} \right]$$

$\rightarrow$ Since $R_1 C_1$ is too small, the dominant freq. is $\omega_2 = \frac{1}{R_2 C_2} = \frac{1}{R_{out} C_L} = \frac{1}{55.7k \times 2p} \cong 9\,MHz$

and $\omega_1 = \frac{1}{0.04 \times 10^{-12} \times (5.8 \times 10^{-4})^{-1}}$

$\hookrightarrow$ by using $g_m = \sqrt{2k' \frac{W}{L} I_D}$

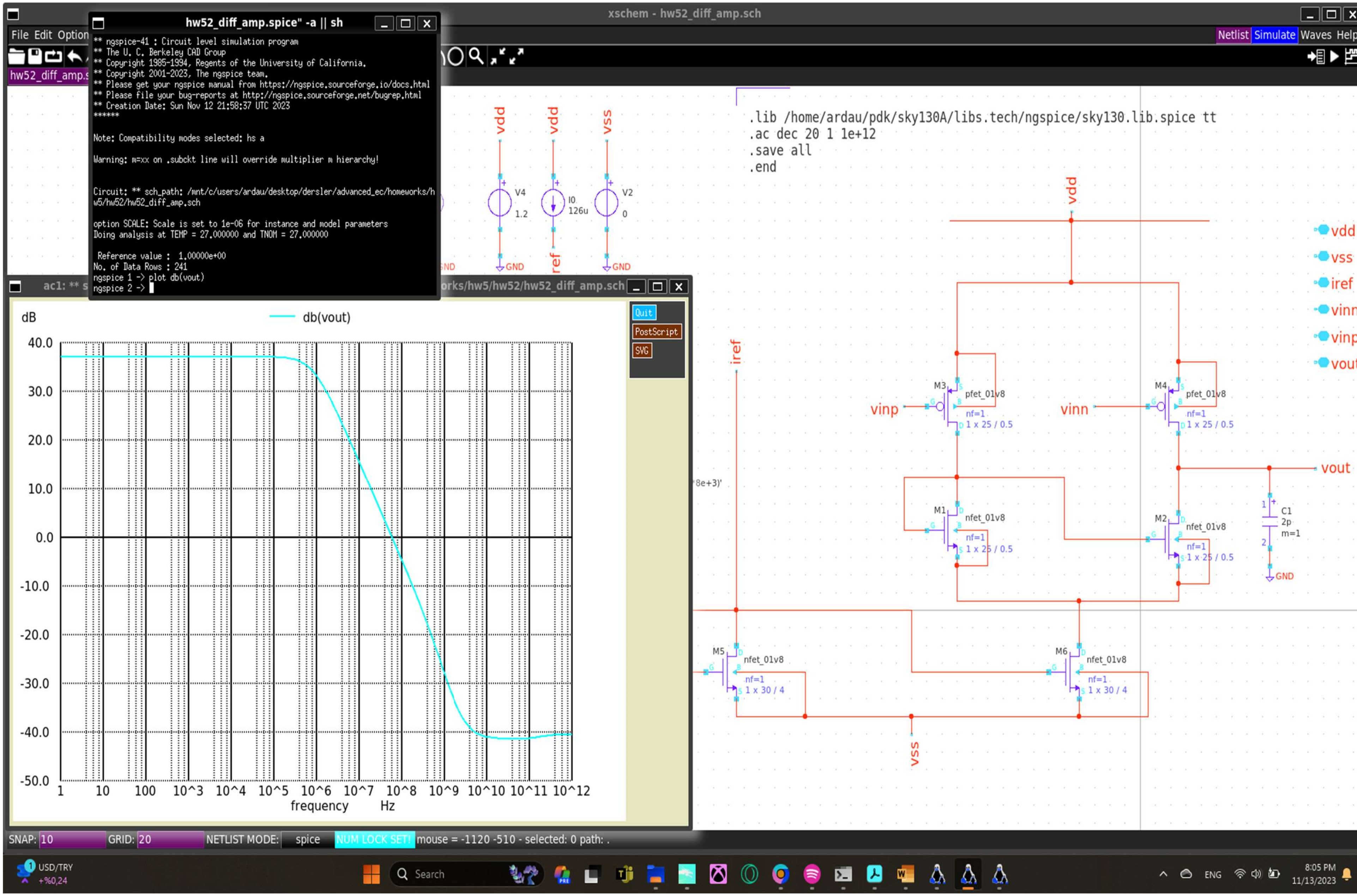
$\Rightarrow \omega_1 = 14.5\,GHz$

$$\Rightarrow A_V = \frac{-g_{m1} R_2 \omega_2}{2(s+\omega_2)} - \frac{g_{m1} g_{m4} R_1 R_2 \omega_1 \omega_2}{2(s+\omega_2)(s+\omega_1)}$$

$$\Rightarrow A_V = -\frac{g_{m1} R_2 \omega_2 (s+\omega_1) + g_{m1} g_{m4} R_1 R_2 \omega_1 \omega_2}{2(s+\omega_2)(s+\omega_1)}$$

zero: $s + \omega_1 + g_{m4} R_1 \omega_1 = 0 \Rightarrow \omega_0 \cong 2\omega_1$

$\Rightarrow \omega_0 = 29.5\,GHz$


xschem - hw52_diff_amp.sch
File Edit Option
Netlist Simulate Waves Help
hw52_diff_amp.spice" -a || sh
** ngspice-41 : Circuit level simulation program
** The U. C. Berkeley CAD Group
** Copyright 1985-1994, Regents of the University of California.
** Copyright 2001-2023, The ngspice team.
** Please get your ngspice manual from https://ngspice.sourceforge.io/docs.html
** Please file your bug-reports at http://ngspice.sourceforge.net/bugrep.html
** Creation Date: Sun Nov 12 21:58:37 UTC 2023
Note: Compatibility modes selected: hs a
Warning: m=xx on .subckt line will override multiplier m hierarchy!
Circuit: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/hw5/hw52/hw52_diff_amp.sch
option SCALE: Scale is set to 1e-06 for instance and model parameters
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Reference value : 1.00000e+00
No. of Data Rows : 241
ngspice 1 -> plot db(vout)
ngspice 2 ->
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.ac dec 20 1 1e+12
.save all
.end
dB
db(vout)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
10^12
frequency
Hz
Quit
PostScript
SVG
vdd
vss
iref
vinn
vinp
vout
V4
1.2
I0
126u
V2
0
GND
M1
M2
M3
M4
M5
M6
pfet_01v8
nfet_01v8
nf=1
1 x 25 / 0.5
1 x 30 / 4
C1
2p
m=1
SNAP: 10
GRID: 20
NETLIST MODE: spice
NUM LOCK SET!
mouse = -1120 -510 - selected: 0 path: .
USD/TRY
+%0,24
Search
ENG
8:05 PM
11/13/2023

hw53

Today 02:01 Uncategorized

3) Common mode gain can be found by using CMRR which is used in lesson slides:

Since $CMRR = \left|\frac{A_d}{A_c}\right|$, so

$A_d = g_{mp}(r_{on} // r_{op})$ and CMRR was given as

$$CMRR \cong (2 g_{m(dp)} r_{tail}) g_{m(mir)} (r_{o(dp)} // r_{o(mir)})$$

$$\Rightarrow A_c = \frac{g_{m(dp)} r_{o(dp)}}{(2 g_{m(dp)} r_{tail}) g_{m(mir)} (r_{o(dp)} // r_{o(mir)})}$$

$$\Rightarrow = r_{o(dp)} / [2 g_{m(mir)} r_{tail} (r_{o(dp)} // r_{o(mir)})]$$

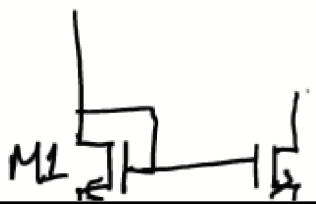
$r_{tail} = r_{on}$, $r_{o(mir)} = 1/g_{m(mir)}$, $r_{o(dp)} = R_{out}$

$$\Rightarrow A_c = \frac{R_{out}\,(R_{out} + 1/g_{m(mir)})}{2\, g_{m(mir)}\, r_{on}\, \frac{R_{out}}{g_{m(mir)}}}$$

$$\Rightarrow A_c = \frac{R_{out} + 1/g_{m(mir)}}{2\, r_{on}}$$

found via Python script

$R_{out} = 55.7k$, $r_{on} = \frac{V_E L}{I_D} \cong 115k$



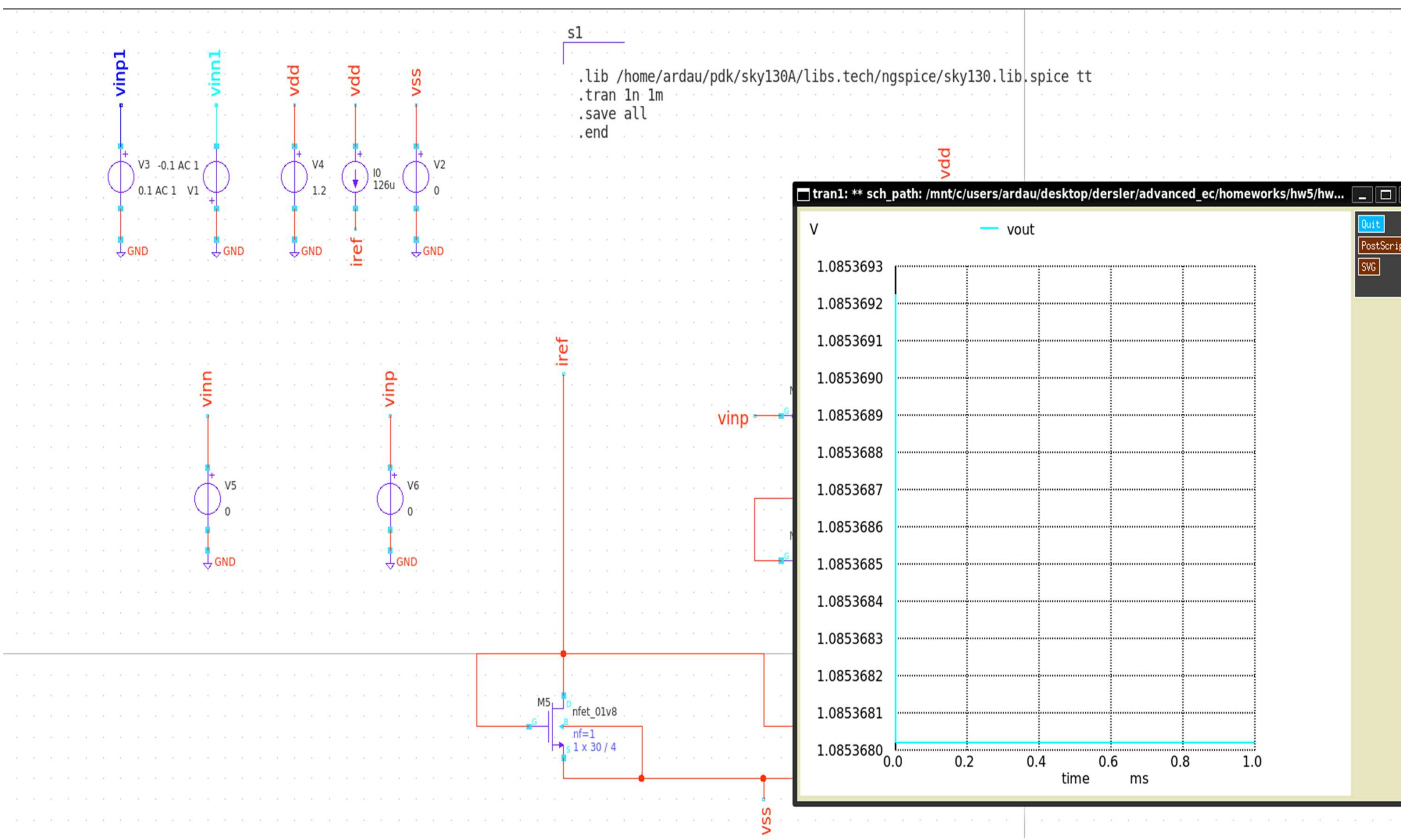
This is equal to 1 for our case.

$; g_{m(mir)} = \frac{g_{m1}}{R \ldots + 1/\ldots} \cdot \frac{(W_2/L_2)}{(W_1/L_1)}$

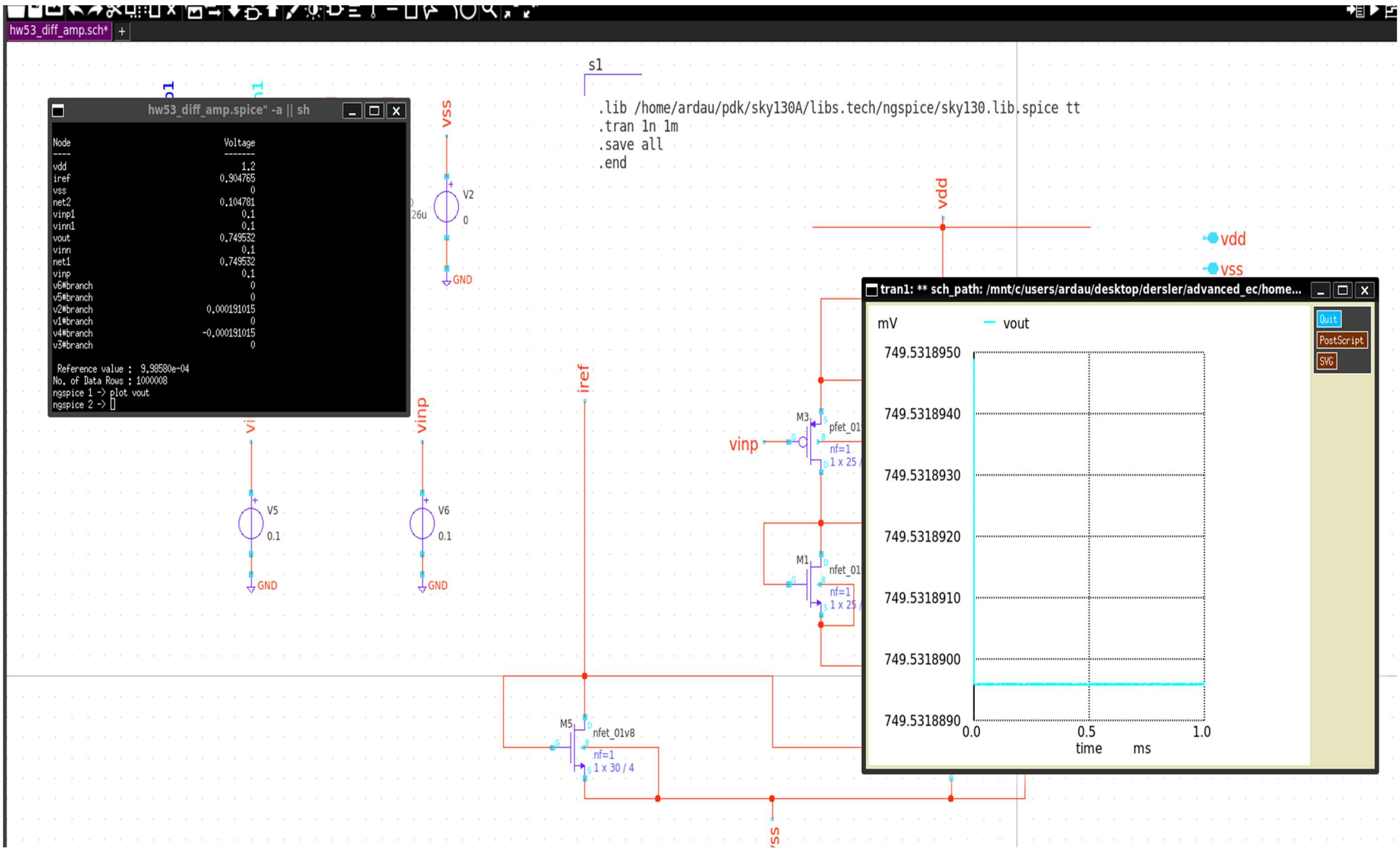
$$\Rightarrow g_{m(mir)} \cong \frac{3.165\times10^{-4}}{\underbrace{\frac{1}{80k}}_{r_{o1}} + \underbrace{3.165\times10^{-4}}_{g_m}} = 0.962$$

$$\Rightarrow A_c \approx 0.242$$

Simulation Result $= 3.355$



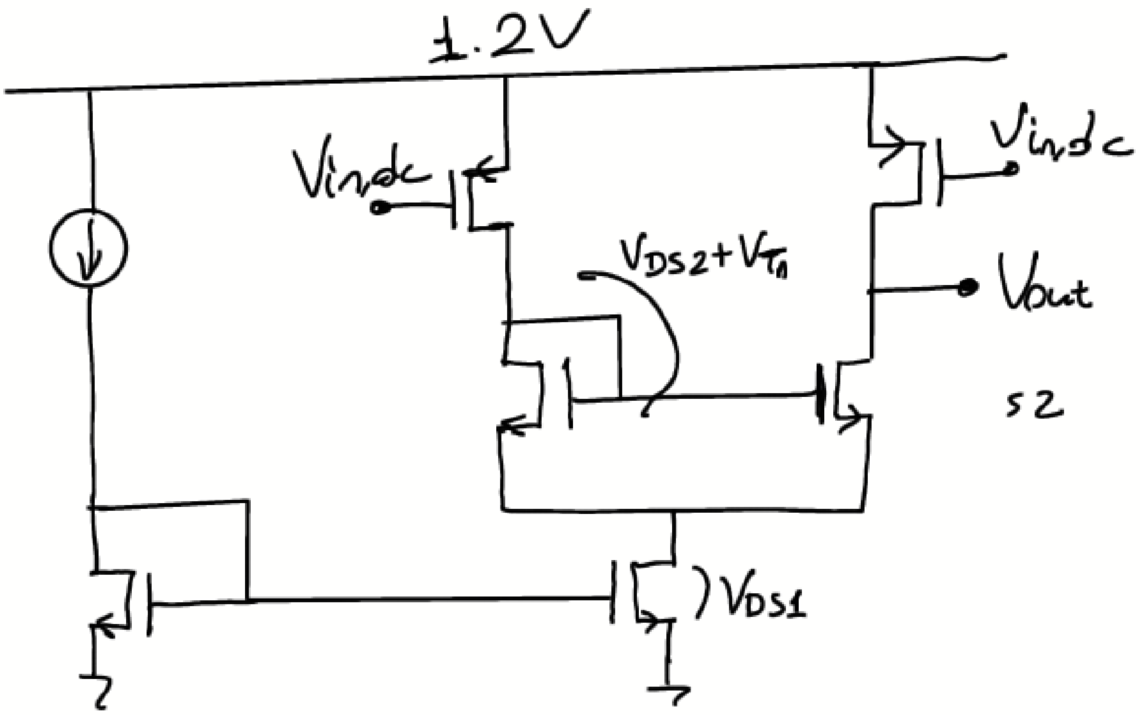
vinp1
vinn1
vdd
vdd
vss
V3 -0.1 AC 1
0.1 AC 1 V1
V4
1.2
I0
126u
V2
0
GND
iref
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.tran 1n 1m
.save all
.end
vinn
vinp
V5
0
V6
0
iref
vinp
M5
nfet_01v8
nf=1
1 x 30 / 4
vss
vdd
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/hw5/hw...
V
vout
1.0853693
1.0853692
1.0853691
1.0853690
1.0853689
1.0853688
1.0853687
1.0853686
1.0853685
1.0853684
1.0853683
1.0853682
1.0853681
1.0853680
0.0
0.2
0.4
0.6
0.8
1.0
time ms
Quit
SVG

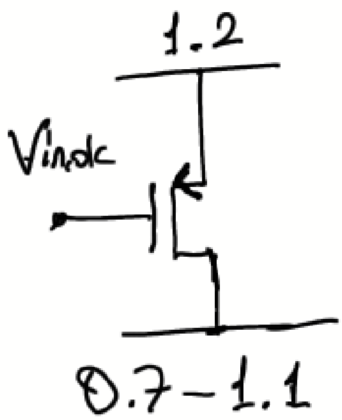

hw53_diff_amp.sch*
hw53_diff_amp.spice" -a || sh
Node Voltage
vdd 1.2
iref 0.904765
vss 0
net2 0.104781
vinp1 0.1
vinn1 0.1
vout 0.749532
vinn 0.1
net1 0.749532
vinp 0.1
v6#branch 0
v5#branch 0
v2#branch 0.000191015
v1#branch 0
v4#branch -0.000191015
v3#branch 0
Reference value : 9.98580e-04
No. of Data Rows : 1000008
ngspice 1 -> plot vout
ngspice 2 ->
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.tran 1n 1m
.save all
.end
vss
V2
0
GND
vdd
iref
vinp
V5
0.1
V6
0.1
M3
pfet_01
nf=1
M1
nfet_01
M5
nfet_01v8
nf=1
1 x 30 / 4
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/home...
mV
vout
749.5318950
749.5318940
749.5318930
749.5318920
749.5318910
749.5318900
749.5318890
0.0
0.5
1.0
time ms
Quit
PostScript
SVG

hw54

Today 02:01 Uncategorized

4)



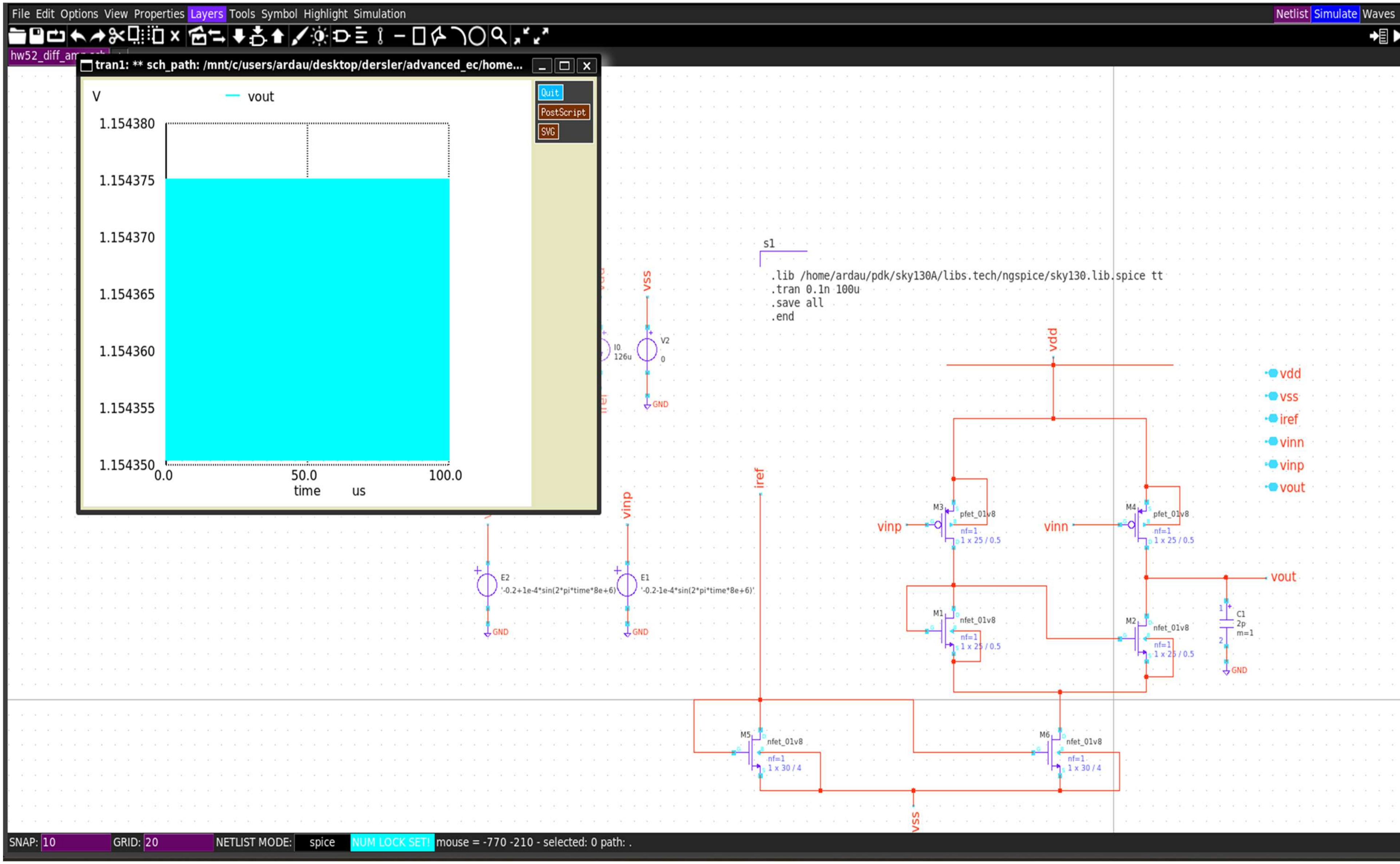


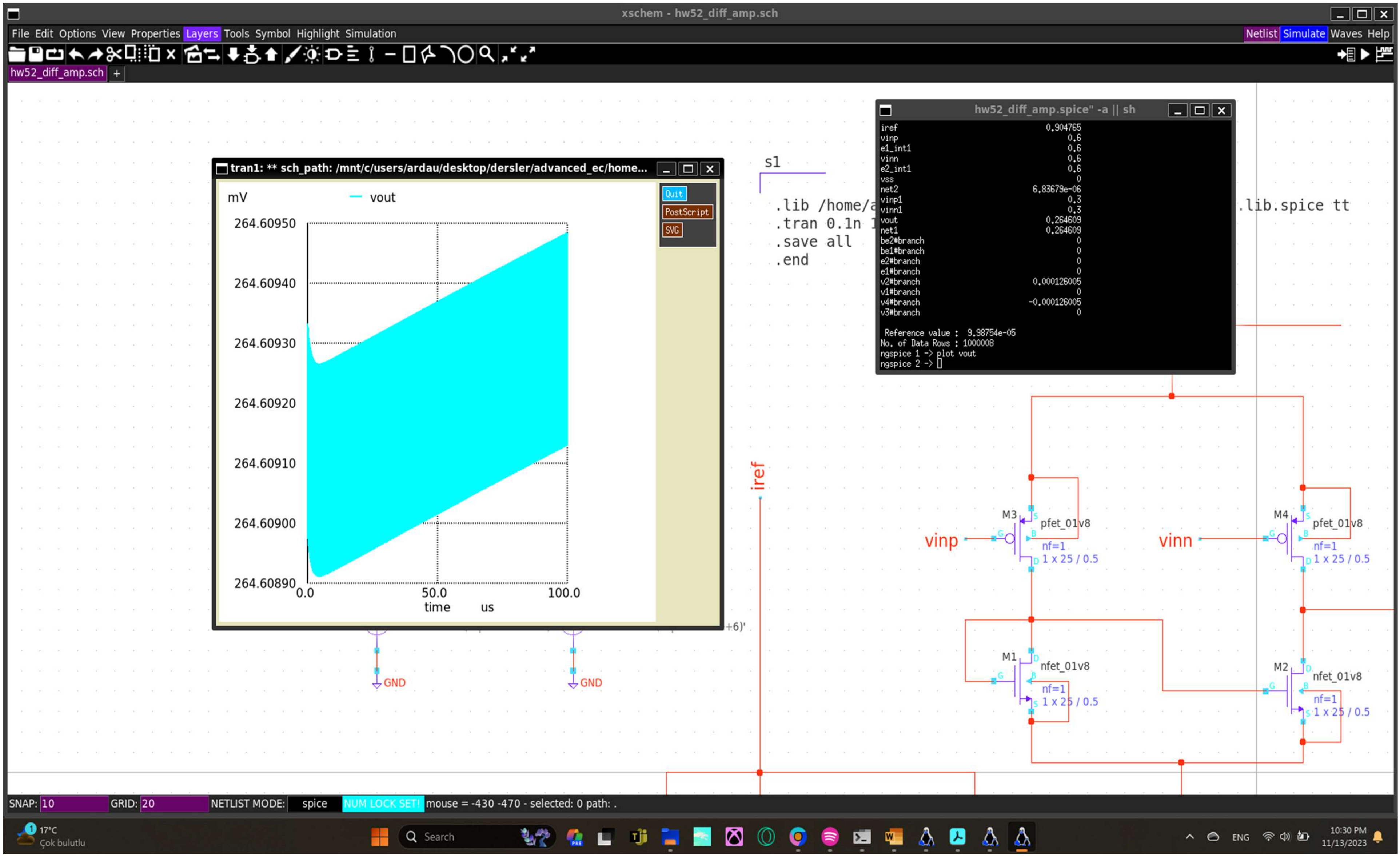
$V_{T,P} = -0.8V$

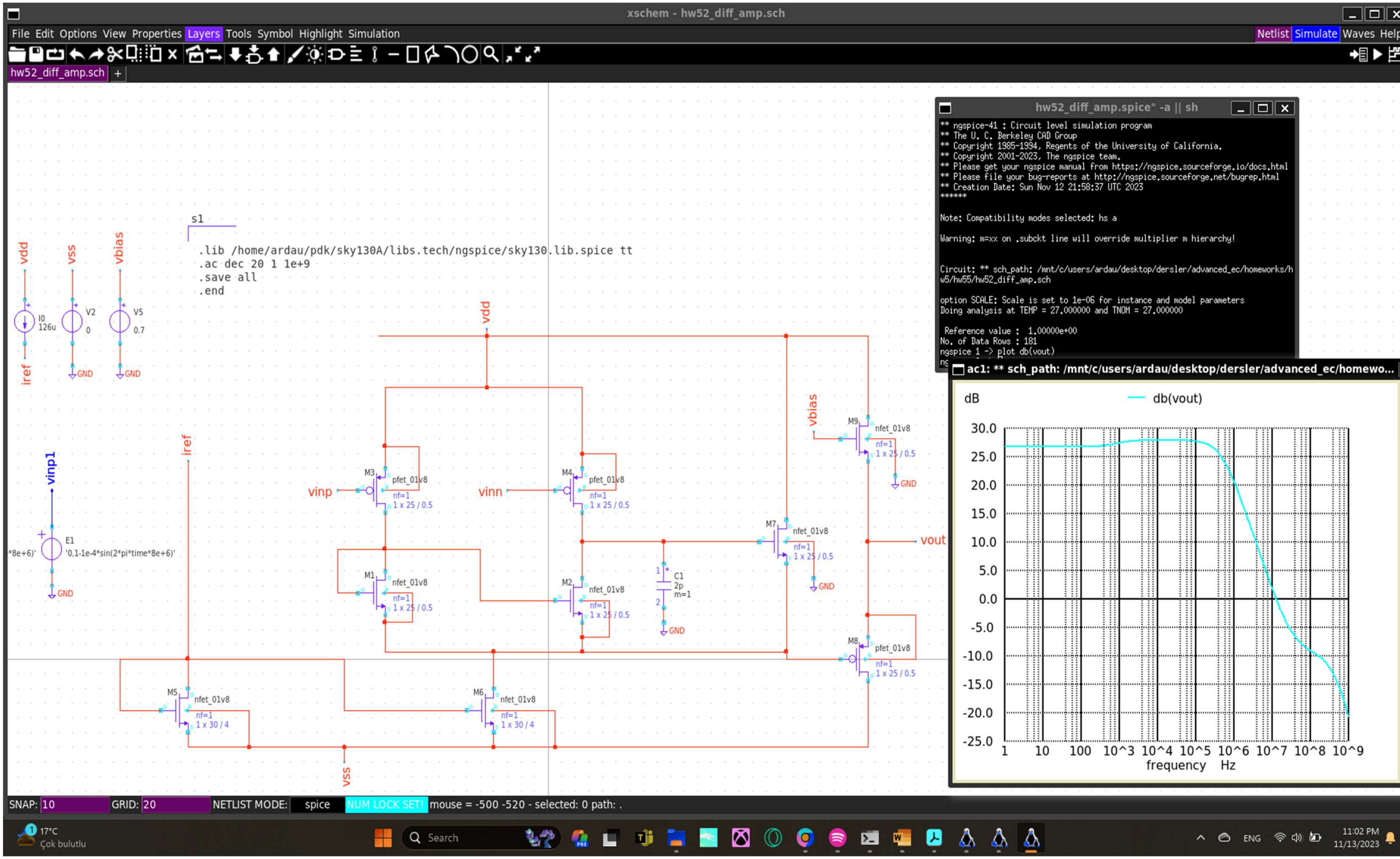
$V_{DS1} = V_{DS2} = 0.1\,V$, $V_{T,N} = 0.5V$

$V_{in,max} = 0.3V$, $V_{in,min} = -0.1V$

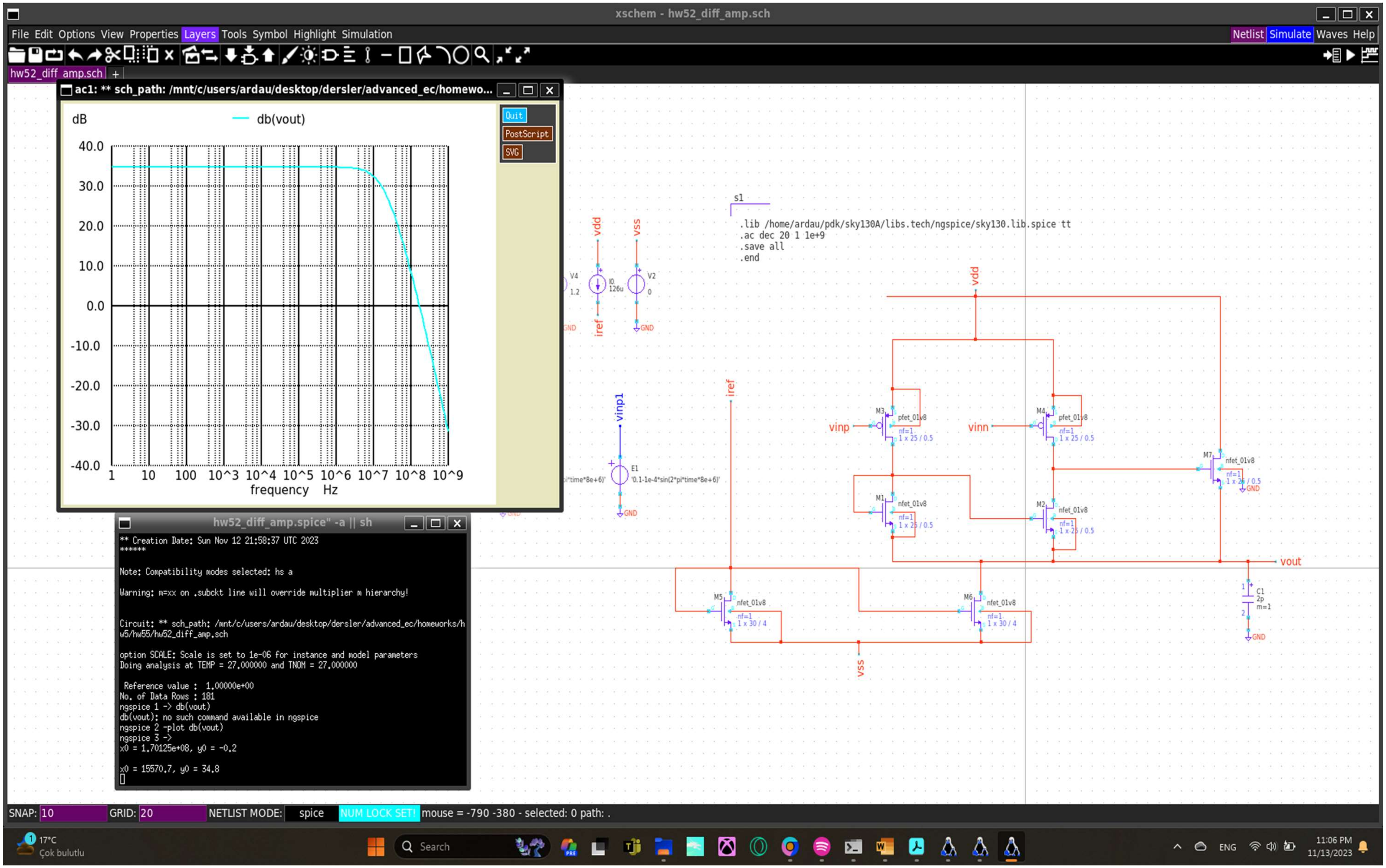
→ I found $V_{T,P} = -0.8V$ from my analysis but it seems that it is $-0.5V$ for this circuit, s $V_{in,max} = 0.55V$, $V_{in,min} = -0.2V$


File Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/home...
Quit
PostScript
SVG
V
vout
1.154380
1.154375
1.154370
1.154365
1.154360
1.154355
1.154350
0.0
50.0
100.0
time us
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.tran 0.1n 100u
.save all
.end
vdd
vss
iref
vinn
vinp
vout
V2
I0 126u
E2 '-0.2+1e-4*sin(2*pi*time*8e+6)'
E1 '-0.2-1e-4*sin(2*pi*time*8e+6)'
GND
M3 pfet_01v8 nf=1 1 x 25 / 0.5
M4 pfet_01v8 nf=1 1 x 25 / 0.5
M1 nfet_01v8 nf=1 1 x 25 / 0.5
M2 nfet_01v8 nf=1 1 x 25 / 0.5
M5 nfet_01v8 nf=1 1 x 30 / 4
M6 nfet_01v8 nf=1 1 x 30 / 4
C1 2p m=1
SNAP: 10 GRID: 20 NETLIST MODE: spice NUM LOCK SET! mouse = -770 -210 - selected: 0 path: .


xschem - hw52_diff_amp.sch
File Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves Help
hw52_diff_amp.sch
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/home...
Quit
PostScript
SVG
mV
vout
264.60950
264.60940
264.60930
264.60920
264.60910
264.60900
264.60890
0.0
50.0
100.0
time us
s1
.lib /home/a
.tran 0.1n 1
.save all
.end
.lib.spice tt
hw52_diff_amp.spice" -a || sh
iref 0.904765
vinp 0.6
e1_int1 0.6
vinn 0.6
e2_int1 0.6
vss 0
net2 6.83679e-06
vinp1 0.3
vinn1 0.3
vout 0.264609
net1 0.264609
be2#branch 0
be1#branch 0
e2#branch 0
e1#branch 0
v2#branch 0.000126005
v1#branch 0
v4#branch -0.000126005
v3#branch 0
Reference value : 9.98754e-05
No. of Data Rows : 1000008
ngspice 1 -> plot vout
ngspice 2 ->
iref
vinp
vinn
M3
pfet_01v8
nf=1
1 x 25 / 0.5
M4
pfet_01v8
nf=1
1 x 25 / 0.5
M1
nfet_01v8
nf=1
1 x 25 / 0.5
M2
nfet_01v8
nf=1
1 x 25 / 0.5
GND
GND
SNAP: 10
GRID: 20
NETLIST MODE: spice
NUM LOCK SET!
mouse = -430 -470 - selected: 0 path: .
17°C
Çok bulutlu
Search
ENG
10:30 PM
11/13/2023



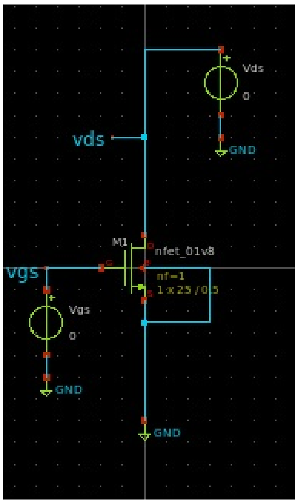
xschem - hw52_diff_amp.sch
File Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves Help
hw52_diff_amp.sch
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.ac dec 20 1 1e+9
.save all
.end
vdd
vss
vbias
iref
I0
126u
V2
0
V5
0.7
GND
vinp1
E1
'0.1-1e-4*sin(2*pi*time*8e+6)'
vinp
vinn
vout
M1
M2
M3
M4
M5
M6
M7
M8
M9
nfet_01v8
pfet_01v8
nf=1
1 x 25 / 0.5
1 x 30 / 4
C1
2p
m=1
hw52_diff_amp.spice" -a || sh
** ngspice-41 : Circuit level simulation program
** The U. C. Berkeley CAD Group
** Copyright 1985-1994, Regents of the University of California.
** Copyright 2001-2023, The ngspice team.
** Please get your ngspice manual from https://ngspice.sourceforge.io/docs.html
** Please file your bug-reports at http://ngspice.sourceforge.net/bugrep.html
** Creation Date: Sun Nov 12 21:58:37 UTC 2023
******
Note: Compatibility modes selected: hs a
Warning: m=xx on .subckt line will override multiplier m hierarchy!
Circuit: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/hw5/hw55/hw52_diff_amp.sch
option SCALE: Scale is set to 1e-06 for instance and model parameters
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Reference value : 1.00000e+00
No. of Data Rows : 181
ngspice 1 -> plot db(vout)
ac1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homewo...
dB
db(vout)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
frequency Hz
SNAP: 10 GRID: 20 NETLIST MODE: spice NUM LOCK SET! mouse = -500 -520 - selected: 0 path: .
17°C
Çok bulutlu
Search
ENG
11:02 PM
11/13/2023


xschem - hw52_diff_amp.sch
File Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves Help
ac1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homewo...
dB
db(vout)
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
1 10 100 10^3 10^4 10^5 10^6 10^7 10^8 10^9
frequency Hz
Quit
PostScript
SVG
hw52_diff_amp.spice" -a || sh
** Creation Date: Sun Nov 12 21:58:37 UTC 2023
Note: Compatibility modes selected: hs a
Warning: m=xx on .subckt line will override multiplier m hierarchy!
Circuit: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/hw5/hw55/hw52_diff_amp.sch
option SCALE: Scale is set to 1e-06 for instance and model parameters
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Reference value : 1.00000e+00
No. of Data Rows : 181
ngspice 1 -> db(vout)
db(vout): no such command available in ngspice
ngspice 2 -plot db(vout)
ngspice 3 ->
x0 = 1.70125e+08, y0 = -0.2
x0 = 15570.7, y0 = 34.8
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.ac dec 20 1 1e+9
.save all
.end
vdd
vss
iref
vinp1
vinp
vinn
vout
SNAP: 10 GRID: 20 NETLIST MODE: spice NUM LOCK SET! mouse = -790 -380 - selected: 0 path: .

In [1]:
```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import warnings
warnings.filterwarnings("ignore")
sns.set_theme()
```

In [2]:
```python
from IPython import display
display.Image("hw53_nmos.png")
```

Out[2]:



In [3]:
```python
data = pd.read_csv("hw53_nmos.txt", delimiter=",")
data.head()
```

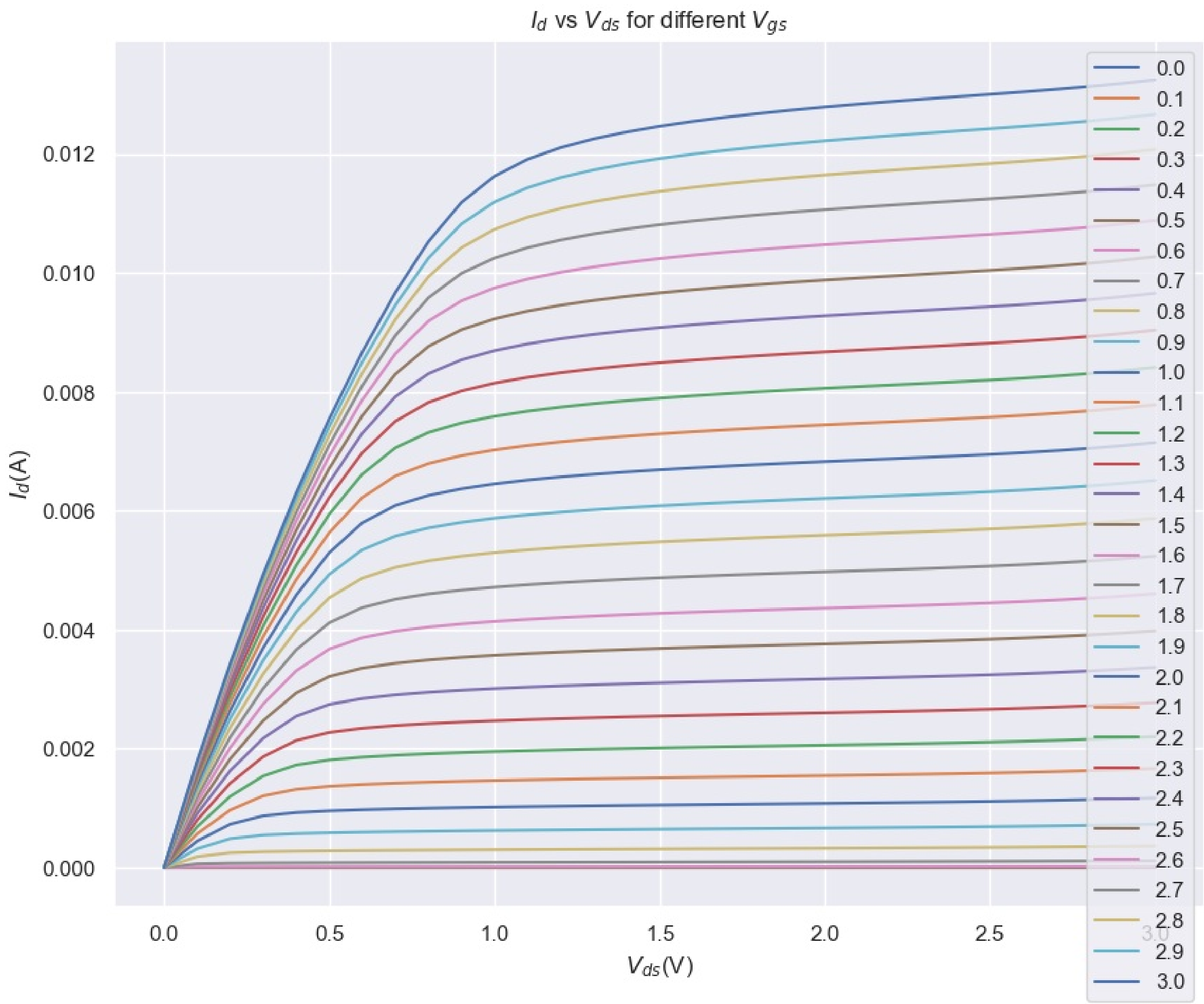
Out[3]:

	undefined	v-sweep	v(vds)	v(vgs)	i(vds)	undefined2
0	NaN	0.0	0.0	0.0	-5.948255e-40	NaN
1	NaN	0.1	0.1	0.0	-2.007283e-12	NaN
2	NaN	0.2	0.2	0.0	-2.245315e-12	NaN
3	NaN	0.3	0.3	0.0	-2.437162e-12	NaN
4	NaN	0.4	0.4	0.0	-2.607692e-12	NaN

In [4]:
```python
data["v(vgs)"] = [float(i) for i in data["v(vgs)"]]
data["v(vds)"] = [float(i) for i in data["v(vds)"]]
data["i(vds)"] = [-1*float(i) for i in data["i(vds)"]]
```

In [5]:
```python
Id_list = []
Vds_list = []
vgs_vals = data["v(vgs)"].unique()
for val in vgs_vals:
    df = data[data["v(vgs)"] == val]
    Id_list.append(list(df["i(vds)"]))
    Vds_list.append(list(df["v(vds)"]))
```

In [6]:
```python
plt.figure(figsize = (10, 8))
for count in range(len(vgs_vals)):
    plt.plot(Vds_list[count], Id_list[count], '-', label = str(vgs_vals[count]))
    plt.title("$I_d$ vs $V_{ds}$ for different $V_{gs}$")
    plt.ylabel("$I_d$(A)")
    plt.xlabel("$V_{ds}$(V)")
    plt.legend()
    plt.grid("on")
```



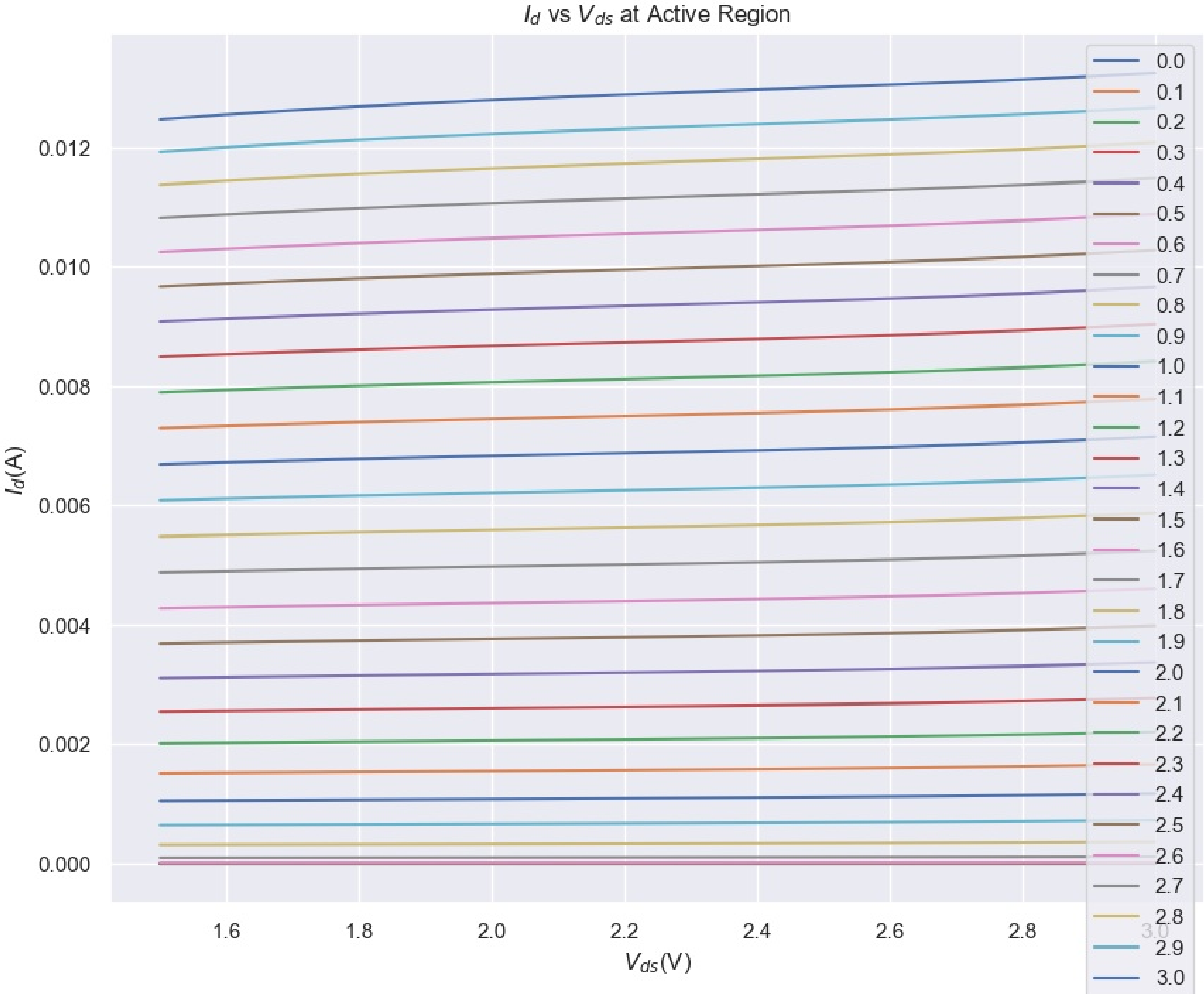
In [7]:

```
from sklearn.linear_model import LinearRegression
linear_regression = LinearRegression()

plt.figure(figsize = (10, 8))

for val in vgs_vals:
    df = data[data["v(vgs)"] == val]
    df = df[(df["v(vds)"] >= 1.5)]
    Id_list2 = df["i(vds)"]
    vds_list2 = df["v(vds)"]
    x = vds_list2.values.reshape(-1, 1)
    y = Id_list2.values.reshape(-1, 1)
    linear_regression.fit(x, y)
    b0 = linear_regression.intercept_
    b1 = linear_regression.coef_
    # y = b1*x + b0, so x = -b0/b1 at y = 0
    Va = -float(b0)/float(b1)
    Ve = Va/(0.15e-6)
    plt.plot(x, y, '-', label = str(val))
    plt.title("$I_d$ vs $V_{ds}$ at Active Region")
    plt.ylabel("$I_d$(A)")
    plt.xlabel("$V_{ds}$(V)")
    plt.legend()
    plt.grid("on")
    print("Va = {} and Ve = {} at Vgs = {}".format(Va, Ve, val))
```

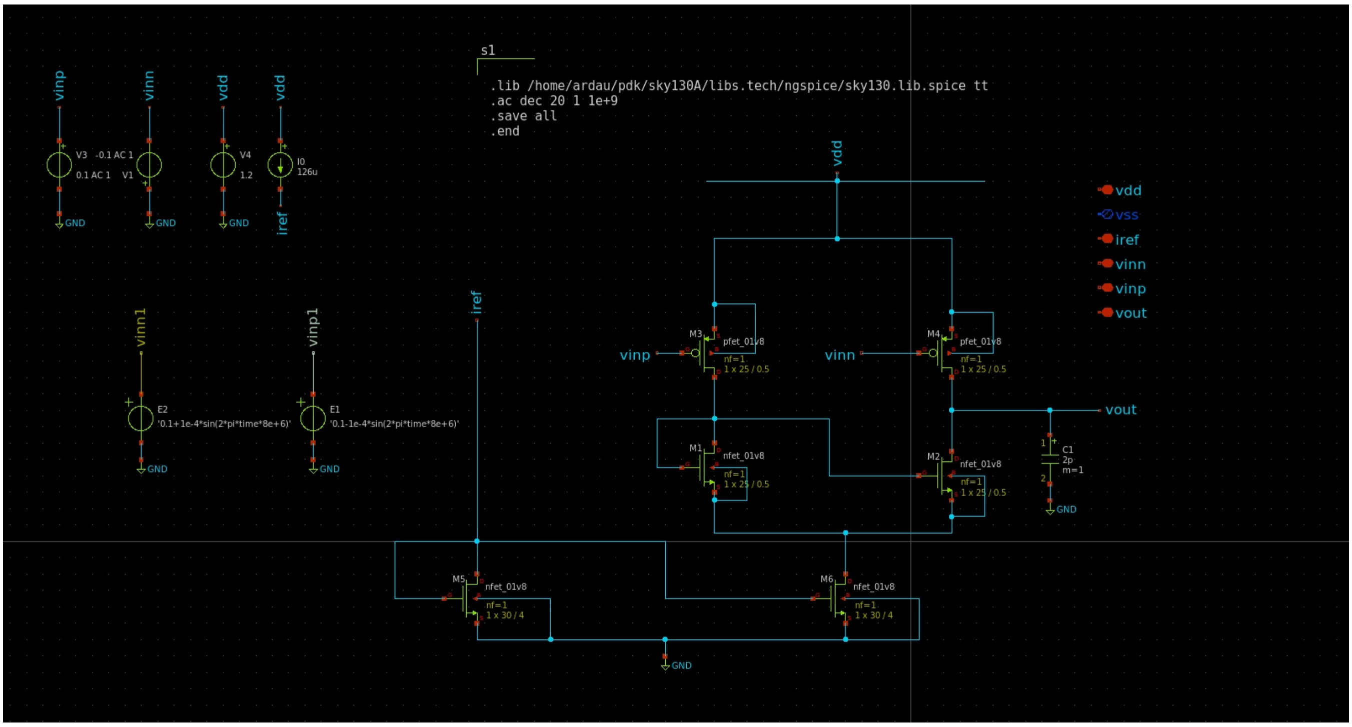
```
Va = -0.9666269368762943 and Ve = -6444179.579175295 at Vgs = 0.0
Va = -1.9942064586468284 and Ve = -13294709.72431219 at Vgs = 0.1
Va = -2.1711597787096477 and Ve = -14474398.524730986 at Vgs = 0.2
Va = -2.197746894502127 and Ve = -14651645.963347513 at Vgs = 0.3
Va = -2.237384633907754 and Ve = -14915897.559385026 at Vgs = 0.4
Va = -2.411923453567197 and Ve = -16079489.69044798 at Vgs = 0.5
Va = -3.2673549641982 and Ve = -21782366.427988 at Vgs = 0.6
Va = -5.475802508137886 and Ve = -36505350.05425258 at Vgs = 0.7
Va = -8.204654192871953 and Ve = -54697694.619146354 at Vgs = 0.8
Va = -10.557391641259205 and Ve = -70382610.94172804 at Vgs = 0.9
Va = -12.454477524869494 and Ve = -83029850.16579664 at Vgs = 1.0
Va = -14.0312889854532 and Ve = -93541926.569688 at Vgs = 1.1
Va = -15.387040126893304 and Ve = -102580267.51262203 at Vgs = 1.2
Va = -16.578600341327792 and Ve = -110524002.27551863 at Vgs = 1.3
Va = -17.64063812423988 and Ve = -117604254.16159922 at Vgs = 1.4
Va = -18.59651566090382 and Ve = -123976771.07269213 at Vgs = 1.5
Va = -19.462877014122366 and Ve = -129752513.42748244 at Vgs = 1.6
Va = -20.251643384690805 and Ve = -135010955.8979387 at Vgs = 1.7
Va = -20.971044669674086 and Ve = -139806964.4644939 at Vgs = 1.8
Va = -21.626283637138332 and Ve = -144175224.2475889 at Vgs = 1.9
Va = -22.220028493308988 and Ve = -148133523.2887266 at Vgs = 2.0
Va = -22.752824407429678 and Ve = -151685496.0495312 at Vgs = 2.1
Va = -23.223454392571043 and Ve = -154823029.28380695 at Vgs = 2.2
Va = -23.629275780947825 and Ve = -157528505.20631886 at Vgs = 2.3
Va = -23.966548914338958 and Ve = -159776992.76225972 at Vgs = 2.4
Va = -24.230760561264187 and Ve = -161538403.74176127 at Vgs = 2.5
Va = -24.41695301055837 and Ve = -162779686.7370558 at Vgs = 2.6
Va = -24.52005521393628 and Ve = -163467034.75957522 at Vgs = 2.7
Va = -24.535195484225124 and Ve = -163567969.89483416 at Vgs = 2.8
Va = -24.45802269699003 and Ve = -163053484.64660022 at Vgs = 2.9
Va = -24.28494402729102 and Ve = -161899626.8486068 at Vgs = 3.0
```



In [1]:
```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import warnings
warnings.filterwarnings("ignore")
sns.set_theme()
```

In [2]:
```python
from IPython import display
display.Image("hw51_circuit.png")
```

Out[2]:



In [3]:
```python
data = pd.read_csv("hw51_pmos.txt", delimiter=",")
data.head()
```

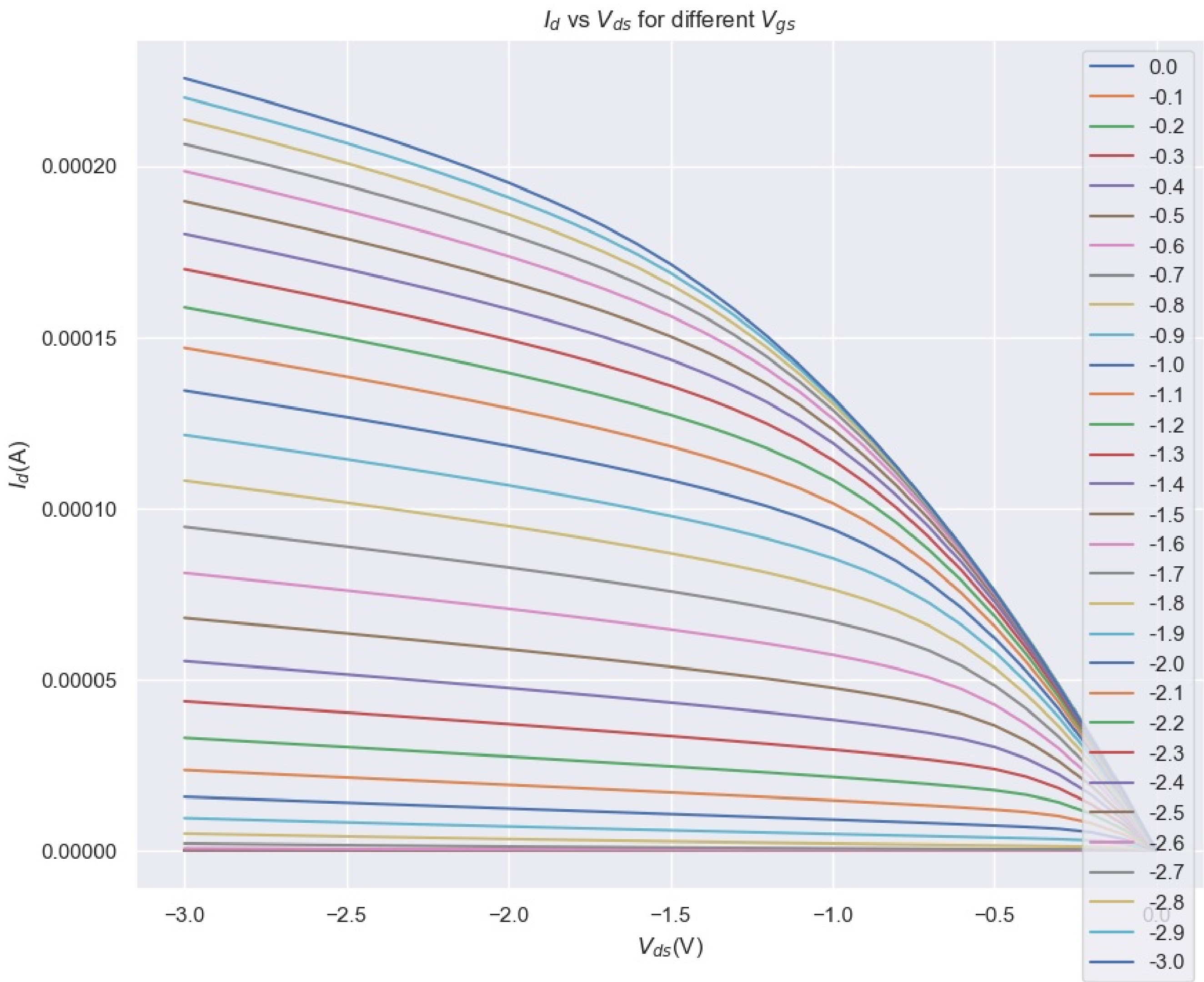
Out[3]:

	undefined2	v-sweep	v(vds)	v(vgs)	i(vds)	undefined2.1
0	NaN	0.0	0.0	0.0	6.098593e-38	NaN
1	NaN	0.1	-0.1	0.0	-2.419759e-12	NaN
2	NaN	0.2	-0.2	0.0	-2.962852e-12	NaN
3	NaN	0.3	-0.3	0.0	-3.522738e-12	NaN
4	NaN	0.4	-0.4	0.0	-4.133915e-12	NaN

In [4]:
```python
data["v(vgs)"] = [float(i) for i in data["v(vgs)"]]
data["v(vds)"] = [float(i) for i in data["v(vds)"]]
data["i(vds)"] = [-1*float(i) for i in data["i(vds)"]]
```

In [5]:
```python
Id_list = []
Vds_list = []
vgs_vals = data["v(vgs)"].unique()
for val in vgs_vals:
    df = data[data["v(vgs)"] == val]
    Id_list.append(list(df["i(vds)"]))
    Vds_list.append(list(df["v(vds)"]))
```

In [6]:
```python
plt.figure(figsize = (10, 8))
for count in range(len(vgs_vals)):
    plt.plot(Vds_list[count], Id_list[count], '-', label = str(vgs_vals[count]))
    plt.title("$I_d$ vs $V_{ds}$ for different $V_{gs}$")
    plt.ylabel("$I_d$(A)")
    plt.xlabel("$V_{ds}$(V)")
    plt.legend()
    plt.grid("on")
```



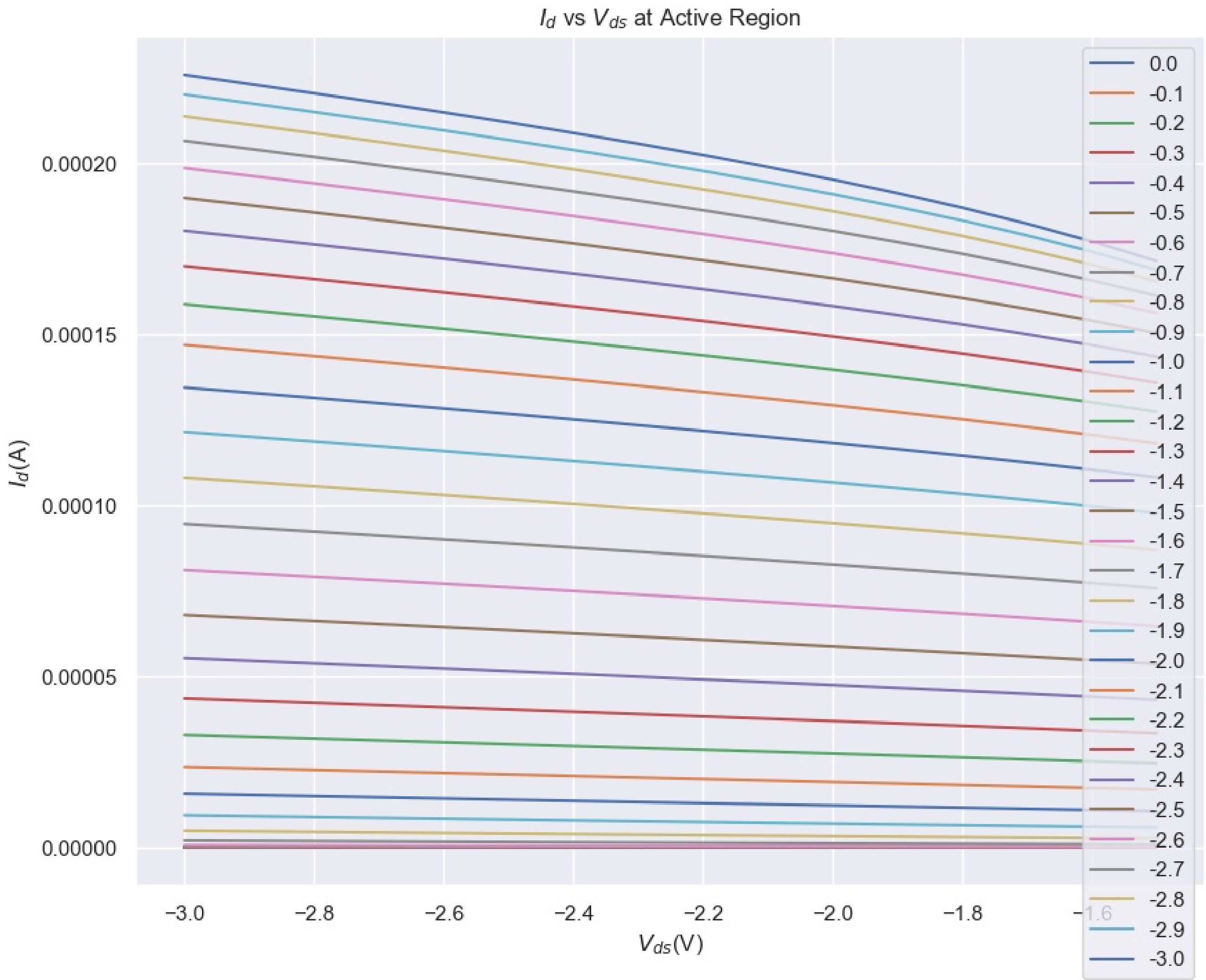
In [7]:

```
from sklearn.linear_model import LinearRegression
linear_regression = LinearRegression()

plt.figure(figsize = (10, 8))

for val in vgs_vals:
    df = data[data["v(vgs)"] == val]
    df = df[(df["v(vds)"] <= -1.5)]
    Id_list2 = df["i(vds)"]
    vds_list2 = df["v(vds)"]
    x = vds_list2.values.reshape(-1, 1)
    y = Id_list2.values.reshape(-1, 1)
    linear_regression.fit(x, y)
    b0 = linear_regression.intercept_
    b1 = linear_regression.coef_
    # y = b1*x + b0, so x = -b0/b1 at y = 0
    Va = -float(b0)/float(b1)
    Ve = Va/(0.15e-6)
    plt.plot(x, y, '-', label = str(val))
    plt.title("$I_d$ vs $V_{ds}$ at Active Region")
    plt.ylabel("$I_d$(A)")
    plt.xlabel("$V_{ds}$(V)")
    plt.legend()
    plt.grid("on")
    print("Va = {} and Ve = {} at Vgs = {}".format(Va, Ve, val))
```

```
Va = -1.6733889059687133 and Ve = -11155926.039791422 at Vgs = 0.0
Va = -1.3052078354556458 and Ve = -8701385.569704305 at Vgs = -0.1
Va = -1.018310297240141 and Ve = -6788735.314934273 at Vgs = -0.2
Va = -0.8872011916105759 and Ve = -5914674.610737173 at Vgs = -0.3
Va = -0.8465933448359222 and Ve = -5643955.632239481 at Vgs = -0.4
Va = -0.8289125836662976 and Ve = -5526083.891108651 at Vgs = -0.5
Va = -0.7345569281852217 and Ve = -4897046.187901478 at Vgs = -0.6
Va = -0.407958017164422 and Ve = -2719720.11442948 at Vgs = -0.7
Va = 0.18263460624847927 and Ve = 1217564.0416565286 at Vgs = -0.8
Va = 0.9144204281477727 and Ve = 6096136.187651819 at Vgs = -0.9
Va = 1.6605566579722564 and Ve = 11070377.719815044 at Vgs = -1.0
Va = 2.3505677769729085 and Ve = 15670451.846486058 at Vgs = -1.1
Va = 2.954863513736966 and Ve = 19699090.091579773 at Vgs = -1.2
Va = 3.4644157581953796 and Ve = 23096105.054635864 at Vgs = -1.3
Va = 3.880048486852222 and Ve = 25866989.912348147 at Vgs = -1.4
Va = 4.207527965412073 and Ve = 28050186.436080486 at Vgs = -1.5
Va = 4.455038889866701 and Ve = 29700259.26577801 at Vgs = -1.6
Va = 4.631656562728734 and Ve = 30877710.418191563 at Vgs = -1.7
Va = 4.746377398055929 and Ve = 31642515.987039533 at Vgs = -1.8
Va = 4.807552663315228 and Ve = 32050351.088768188 at Vgs = -1.9
Va = 4.8226192291816865 and Ve = 32150794.861211244 at Vgs = -2.0
Va = 4.798031648869598 and Ve = 31986877.659130655 at Vgs = -2.1
Va = 4.739311335018513 and Ve = 31595408.90012342 at Vgs = -2.2
Va = 4.651155391598578 and Ve = 31007702.610657185 at Vgs = -2.3
Va = 4.537572788804766 and Ve = 30250485.258698445 at Vgs = -2.4
Va = 4.4020312699445014 and Ve = 29346875.132963344 at Vgs = -2.5
Va = 4.247620387175554 and Ve = 28317469.24783703 at Vgs = -2.6
Va = 4.077239182509167 and Ve = 27181594.550061118 at Vgs = -2.7
Va = 3.893816458816539 and Ve = 25958776.392110262 at Vgs = -2.8
Va = 3.7005224312228107 and Ve = 24670149.541485406 at Vgs = -2.9
Va = 3.5008484128258734 and Ve = 23338989.418839157 at Vgs = -3.0
```



Loading [MathJax]/jax/output/CommonHTML/fonts/TeX/fontdata.js