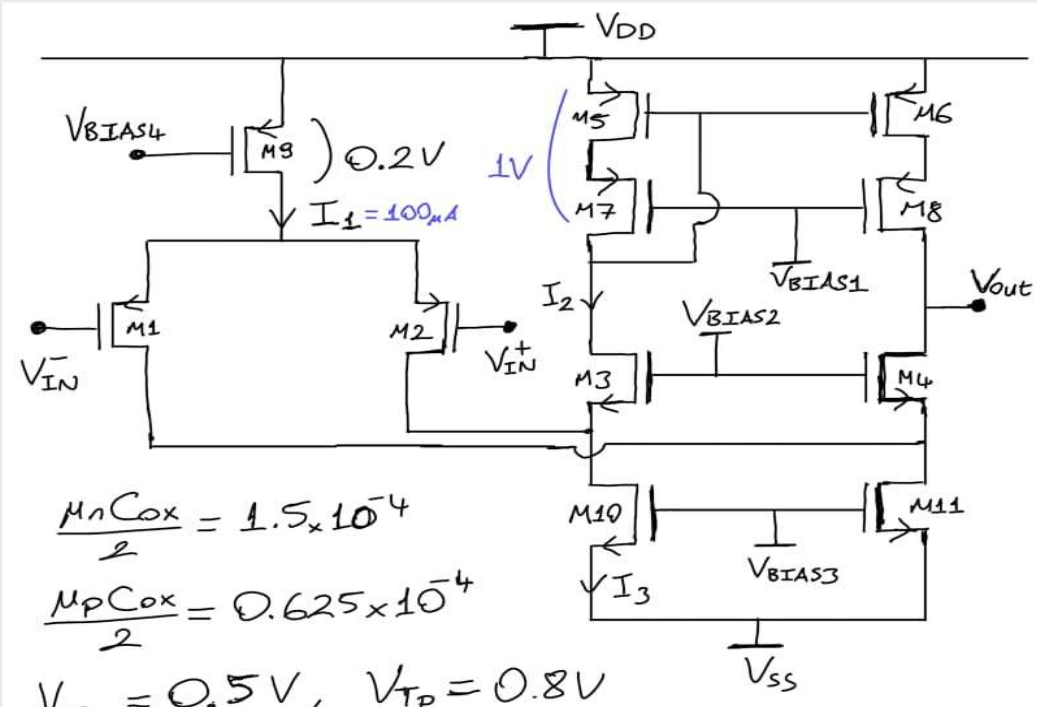
# HOMEWORK 9

## ARDA ÜNAL




$\frac{\mu_n C_{ox}}{2} = 1.5 \times 10^{-4}$

$\frac{\mu_p C_{ox}}{2} = 0.625 \times 10^{-4}$

$V_{TN} = 0.5V, \quad V_{TP} = 0.8V$

→ Bias current through M9 is 100μA, so

$\left(\frac{W}{L}\right)_9 = 40$ assuming $V_{ov}^{min} = 0.2V$

$\Rightarrow V_{BIAS4}^{min} = V_{DD} - 1V$

→ Since M1 and M2 will carry 50μA, then

$\left(\frac{W}{L}\right)_{1,2} = 20$, again assuming $V_{ov}^{min} = 0.2V$

$\Rightarrow V_{BIAS+,-} = V_{DD} - 0.2V - 1V = V_{DD} - 1.2V$

→ $V_{ov\,10-11} = 0.5V$ and they will carry 100μA each, thus

$\left(\frac{W}{L}\right)_{10-11} = 2.667$ and $V_{BIAS3} = 0.5 + 0.5 + V_{SS} = 1V + V_{SS}$

→ For M3 and M4, $V_{ov} = 0.2\,V$, so

$V_{source,3,4}^{min} = 0.5\,V$, $V_{source,3,4}^{max} = V_{DD} - 0.4\,V$

→ Thus to be in pinch-off region

$V_{BIAS2} = 0.5 + 0.7 = 1.2\,V$

$\left(\frac{W}{L}\right)_{3,4} = 8.334$

→ For M5 to be in pinch-off region,

$V_{DS}^{M5} + V_{DS}^{M7} \geq 1\,V$, thus if we assume that $V_{ov}^{M5} = 0.2\,V$, then $V_{ov}^{M7} = 0.8\,V$

$\Rightarrow \left(\frac{W}{L}\right)_{5,6}^{max} = 20$ and $\left(\frac{W}{L}\right)_{7,8}^{min} = 1.25$

and $V_{BIAS1}^{min} = V_{DD} - 1\,V$

→ To extend working range of circuit, we can choose middle of the operating range for bias voltages:

$V_{out}^{max} = V_{DD} - 1$, $V_{out}^{min} = V_{SS} + 0.7\,V$

→ Let $V_{DD} = 3.3\,V$ and $V_{SS} = 0\,V$, then

$V_{out}^{max} = 2.3\,V$ and $V_{out}^{min} = 0.7\,V$

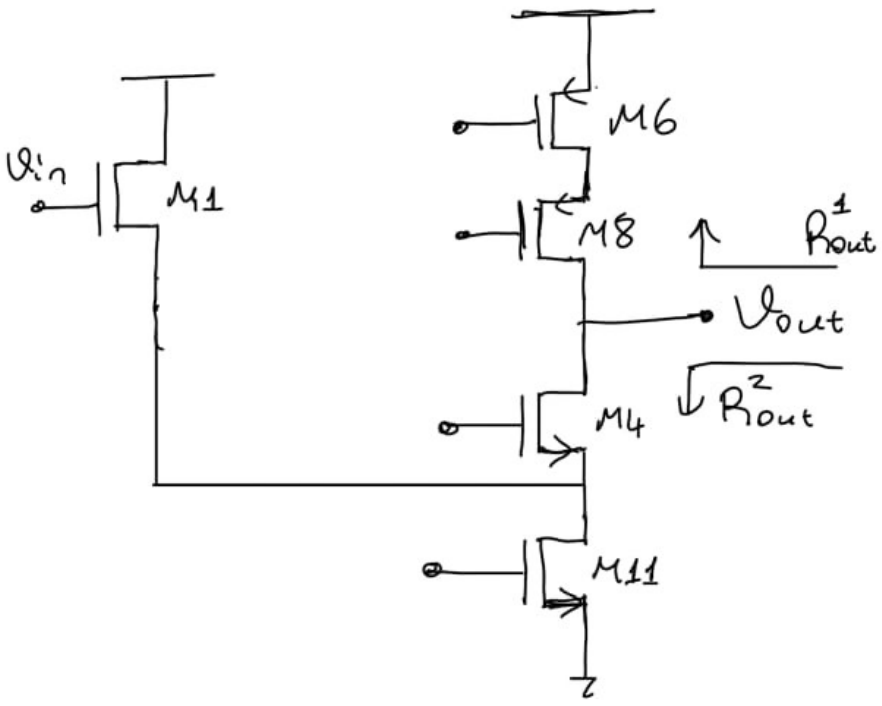
$\rightarrow V_{BIAS+,-} = \frac{V_{DD} - 0.2 - 0.5}{2} = 1.3\,V$

$\rightarrow V_{BIAS1} = 1.65\,V$ and $V_{BIAS2} = 1.2\,V$

$GBW = \frac{g_{m1}}{2\pi C_L} \Rightarrow g_{m1} = 7.746 \times 10^{-4}\,S$

$\Rightarrow GBW = 61.6\,MHz$

→ To calculate the gain, we should find Rout.




$\Rightarrow R_{out} = R_{out}^1 \,//\, R_{out}^2$

$\Rightarrow R_{out}^1 = g_{m8} r_{o8} r_{o6}$ , $R_{out}^2 = g_{m4} r_{o4} (r_{o11} // r_{o1})$

$\Rightarrow A_V = -g_{m1} \left[ g_{m8} r_{o8} r_{o6} // g_{m4} r_{o4} (r_{o11} // r_{o1}) \right]$

$r_o = \frac{V_A}{I_D} = \frac{V_{EL}}{I_D}$ and $g_m = \sqrt{2k' \frac{W}{L} I_D}$

→ VE values for NMOS and PMOS for $V_{GS}$'s are

→ $V_{GS}^P = 1.6 \Rightarrow V_E^P = 29700260$

→ $V_{GS}^P = 1.8 \Rightarrow V_E^P = 31642515$

→ $V_{GS}^N = 1 \Rightarrow V_E^N = 8302985$

→ $V_{GS}^N = 0.7 \Rightarrow V_E^N = 36505350$

$\Rightarrow r_{o11} = 124.5 k\Omega$ , $r_{o1} = 316.4 k\Omega$

$\Rightarrow r_{o4} = 109.5 k\Omega$ , $r_{o8,6} = 297 k\Omega$

$\Rightarrow g_{m_4} = 5\times10^{-4}S$, $g_{m6} = 1.25\times10^{-4}S$

and $g_{m1} = 5\times10^{-4}S$

$\Rightarrow R^1_{out} = 11\,M\Omega$, $r_{o11}//r_{o1} = 89.3k\Omega$

$\Rightarrow R^2_{out} = 4.89\,M\Omega$

$\Rightarrow A_v = -1692.5$

→ Bandwidth can be calculated via

$$BW = \frac{GBW}{A_V} = \frac{61.6\,MHz}{1692.5} \cong 36.4kHz$$

→ I have changed the bias voltages to find an appropriate DC operating point and I played with the $(\frac{W}{L})$ value of $M_{10,11}$ for the same reason. I increased $(\frac{W}{L})$ ratio of $M_{1,2}$ to increase $g_m$ means that I increased GBW.

→ According to simulation results,

$A_v = 59.1\,dB = 901.5$

$GBW = 54\,MHz$

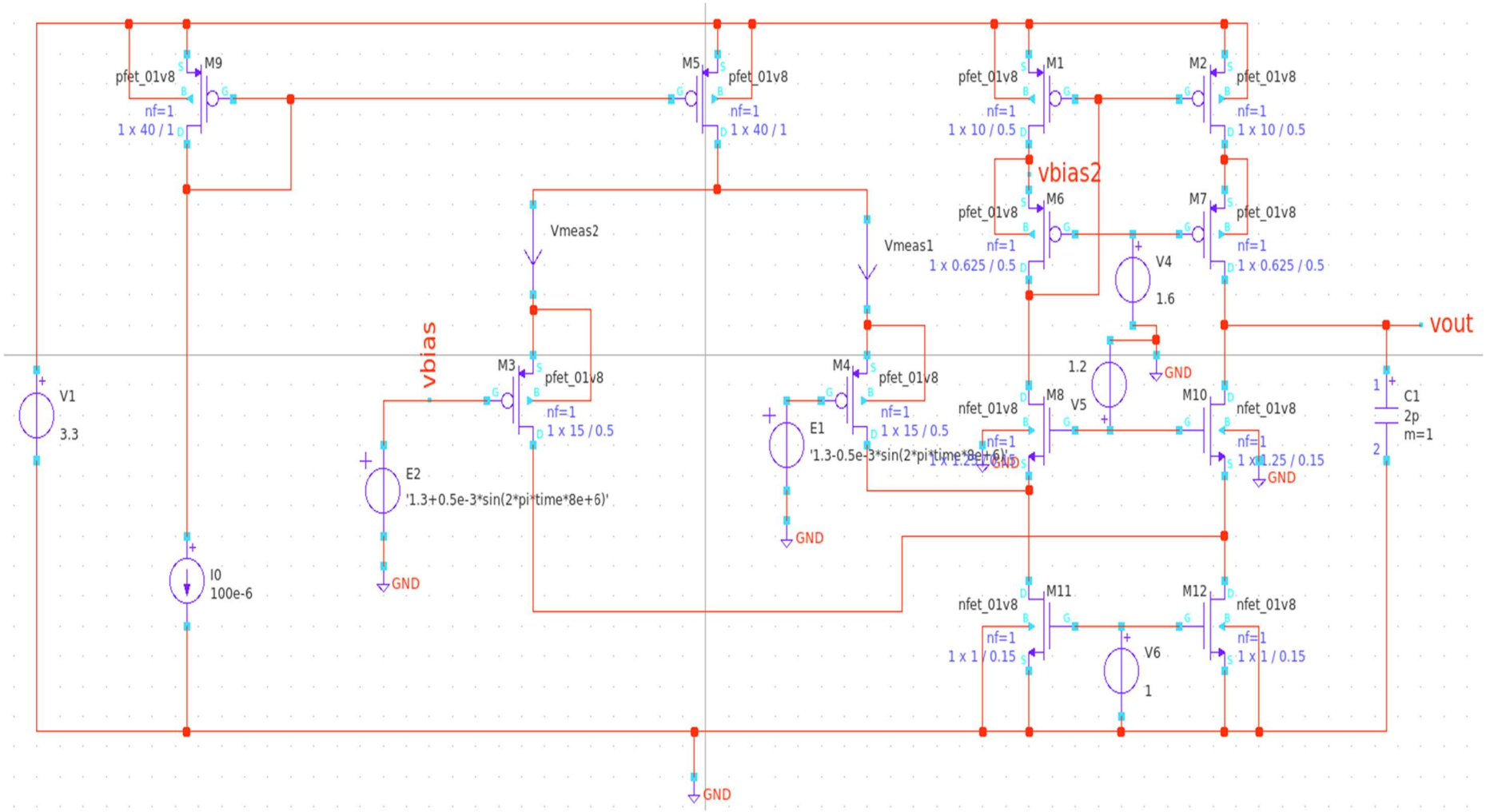
$BW \cong 54\,kHz$ (-3dB)

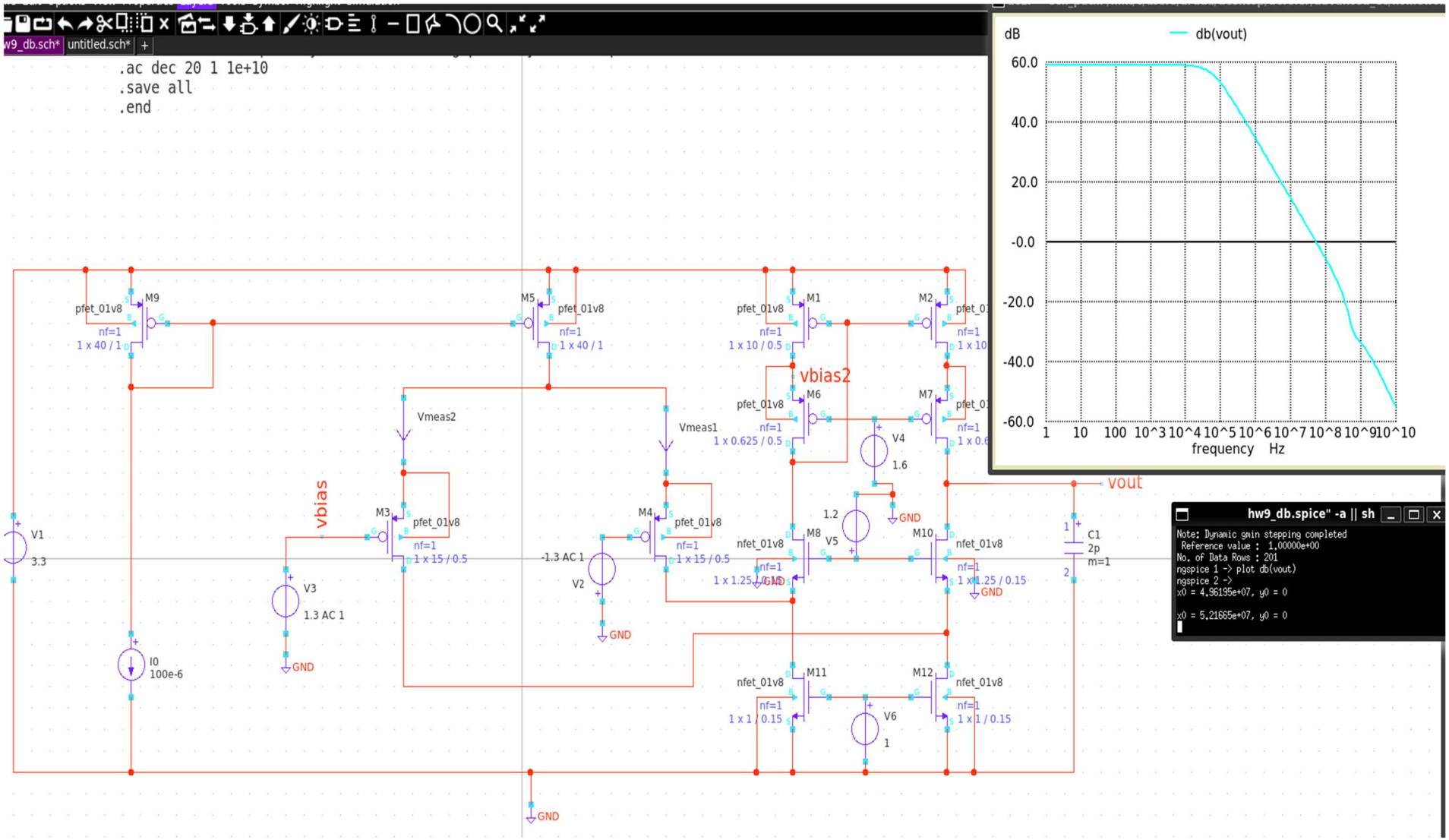
FOM for hand calculation:

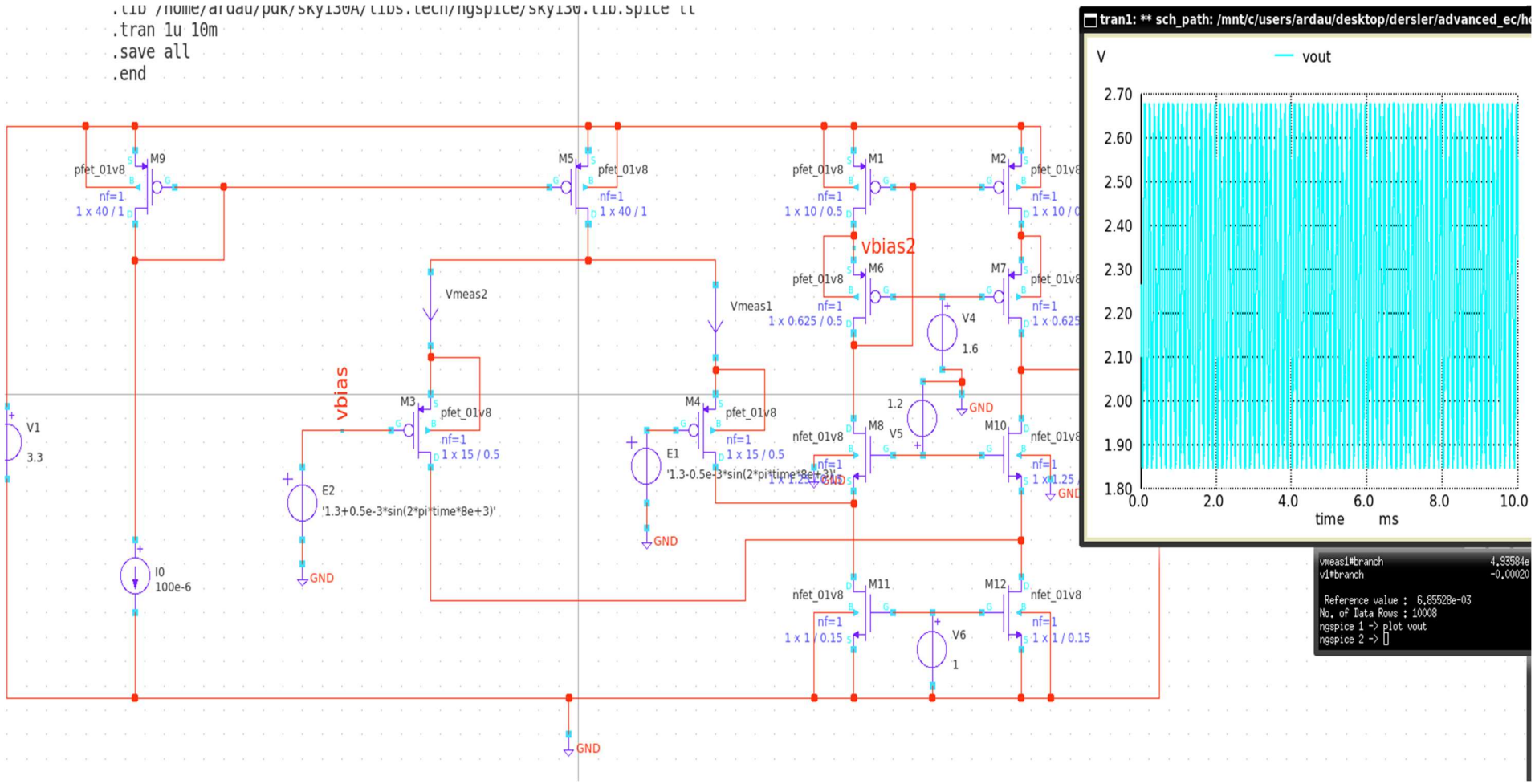
$$FOM = \frac{GBW \times C_L}{I_{BIAS}} = 1232$$

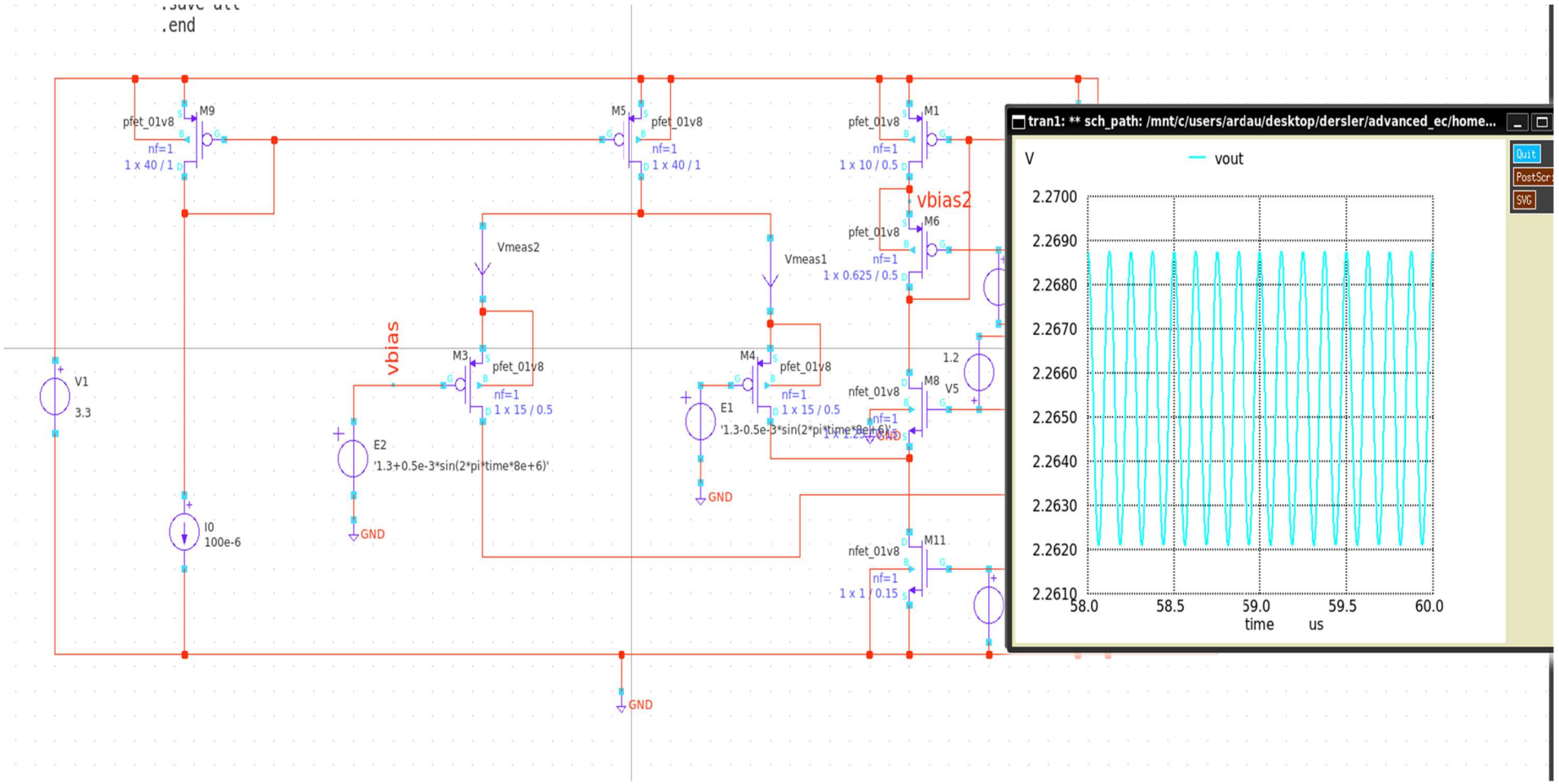
→ For simulation: FOM = 1040

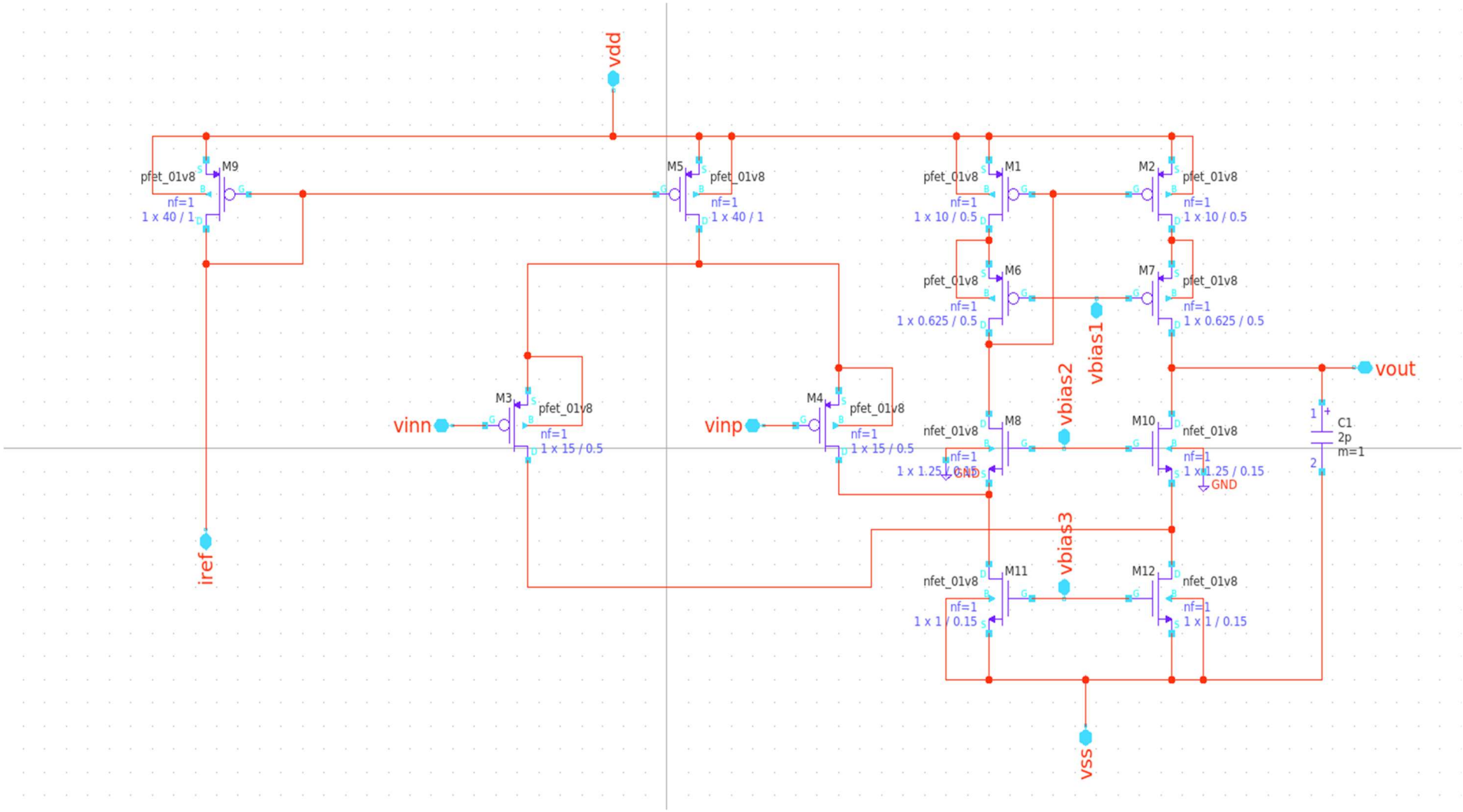
→ For layout post-sim: FOM =


M9
pfet_01v8
nf=1
1 x 40 / 1
M5
pfet_01v8
nf=1
1 x 40 / 1
M1
pfet_01v8
nf=1
1 x 10 / 0.5
M2
pfet_01v8
nf=1
1 x 10 / 0.5
vbias2
M6
pfet_01v8
nf=1
1 x 0.625 / 0.5
M7
pfet_01v8
nf=1
1 x 0.625 / 0.5
V4
1.6
vout
Vmeas2
Vmeas1
vbias
M3
pfet_01v8
nf=1
1 x 15 / 0.5
M4
pfet_01v8
nf=1
1 x 15 / 0.5
1.2
V5
M8
nfet_01v8
nf=1
1 x 1.25 / 0.15
M10
nfet_01v8
nf=1
1 x 1.25 / 0.15
C1
2p
m=1
V1
3.3
E2
'1.3+0.5e-3*sin(2*pi*time*8e+6)'
E1
'1.3-0.5e-3*sin(2*pi*time*8e+6)'
I0
100e-6
M11
nfet_01v8
nf=1
1 x 1 / 0.15
M12
nfet_01v8
nf=1
1 x 1 / 0.15
V6
1
GND


w9_db.sch*
untitled.sch*
.ac dec 20 1 1e+10
.save all
.end
M9
pfet_01v8
nf=1
1 x 40 / 1
M5
1 x 40 / 1
M1
1 x 10 / 0.5
M2
vbias2
M6
M7
1 x 0.625 / 0.5
Vmeas2
Vmeas1
V4
1.6
vout
vbias
M3
1 x 15 / 0.5
M4
V1
3.3
-1.3 AC 1
V2
1.2
V5
M8
nfet_01v8
M10
1 x 1.25 / 0.15
C1
2p
m=1
V3
1.3 AC 1
I0
100e-6
GND
M11
1 x 1 / 0.15
M12
V6
1
dB
db(vout)
60.0
40.0
20.0
-0.0
-20.0
-40.0
-60.0
1
10
100
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
frequency Hz
hw9_db.spice" -a || sh
Note: Dynamic gmin stepping completed
Reference value : 1.00000e+00
No. of Data Rows : 201
ngspice 1 -> plot db(vout)
ngspice 2 ->
x0 = 4.96195e+07, y0 = 0
x0 = 5.21665e+07, y0 = 0

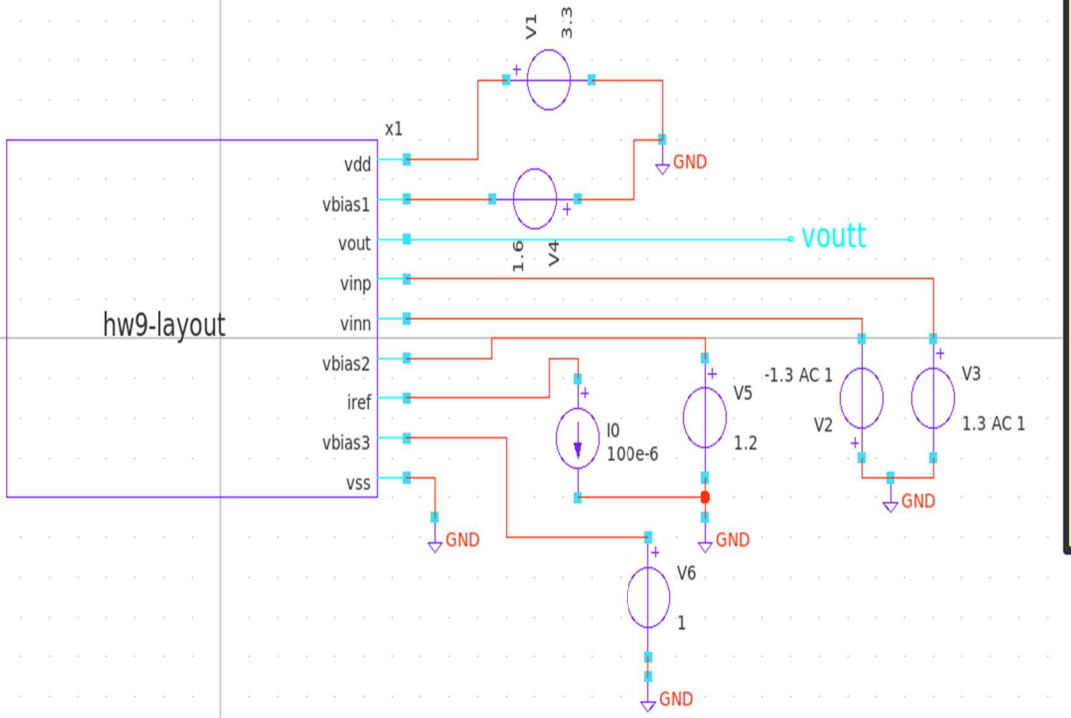

.lib "/home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice" tt
.tran 1u 10m
.save all
.end
M9
pfet_01v8
nf=1
1 x 40 / 1
M5
pfet_01v8
nf=1
1 x 40 / 1
M1
pfet_01v8
nf=1
1 x 10 / 0.5
M2
pfet_01v8
nf=1
1 x 10 / 0
vbias2
M6
pfet_01v8
nf=1
1 x 0.625 / 0.5
M7
pfet_01v8
nf=1
1 x 0.625
V4
1.6
Vmeas2
Vmeas1
vbias
M3
pfet_01v8
nf=1
1 x 15 / 0.5
M4
pfet_01v8
nf=1
1 x 15 / 0.5
1.2
GND
V1
3.3
E2
'1.3+0.5e-3*sin(2*pi*time*8e+3)'
E1
'1.3-0.5e-3*sin(2*pi*time*8e+3)'
M8
nfet_01v8
nf=1
1 x 1.25 / 0.5
V5
M10
nfet_01v8
nf=1
1 x 1.25
I0
100e-6
M11
nfet_01v8
nf=1
1 x 1 / 0.15
M12
nfet_01v8
nf=1
1 x 1 / 0.15
V6
1
GND
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/h
V
vout
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
0.0
2.0
4.0
6.0
8.0
10.0
time
ms
vmeas1#branch 4.93584e
v1#branch -0.00020
Reference value : 6.85528e-03
No. of Data Rows : 10008
ngspice 1 -> plot vout
ngspice 2 ->

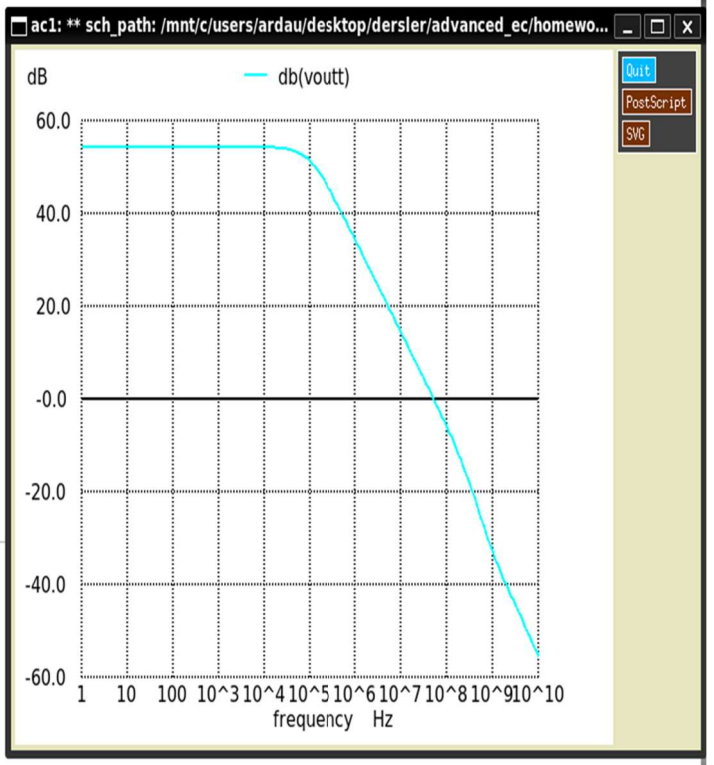

.end
M9
pfet_01v8
nf=1
1 x 40 / 1
M5
pfet_01v8
nf=1
1 x 40 / 1
M1
pfet_01v8
nf=1
1 x 10 / 0.5
vbias2
M6
pfet_01v8
nf=1
1 x 0.625 / 0.5
Vmeas2
Vmeas1
vbias
M3
pfet_01v8
nf=1
1 x 15 / 0.5
M4
pfet_01v8
nf=1
1 x 15 / 0.5
1.2
M8
nfet_01v8
nf=1
V5
V1
3.3
E2
'1.3+0.5e-3*sin(2*pi*time*8e+6)'
E1
'1.3-0.5e-3*sin(2*pi*time*8e+6)'
GND
I0
100e-6
M11
nfet_01v8
nf=1
1 x 1 / 0.15
tran1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/home...
V
vout
Quit
PostScr
SVG
2.2700
2.2690
2.2680
2.2670
2.2660
2.2650
2.2640
2.2630
2.2620
2.2610
58.0
58.5
59.0
59.5
60.0
time
us

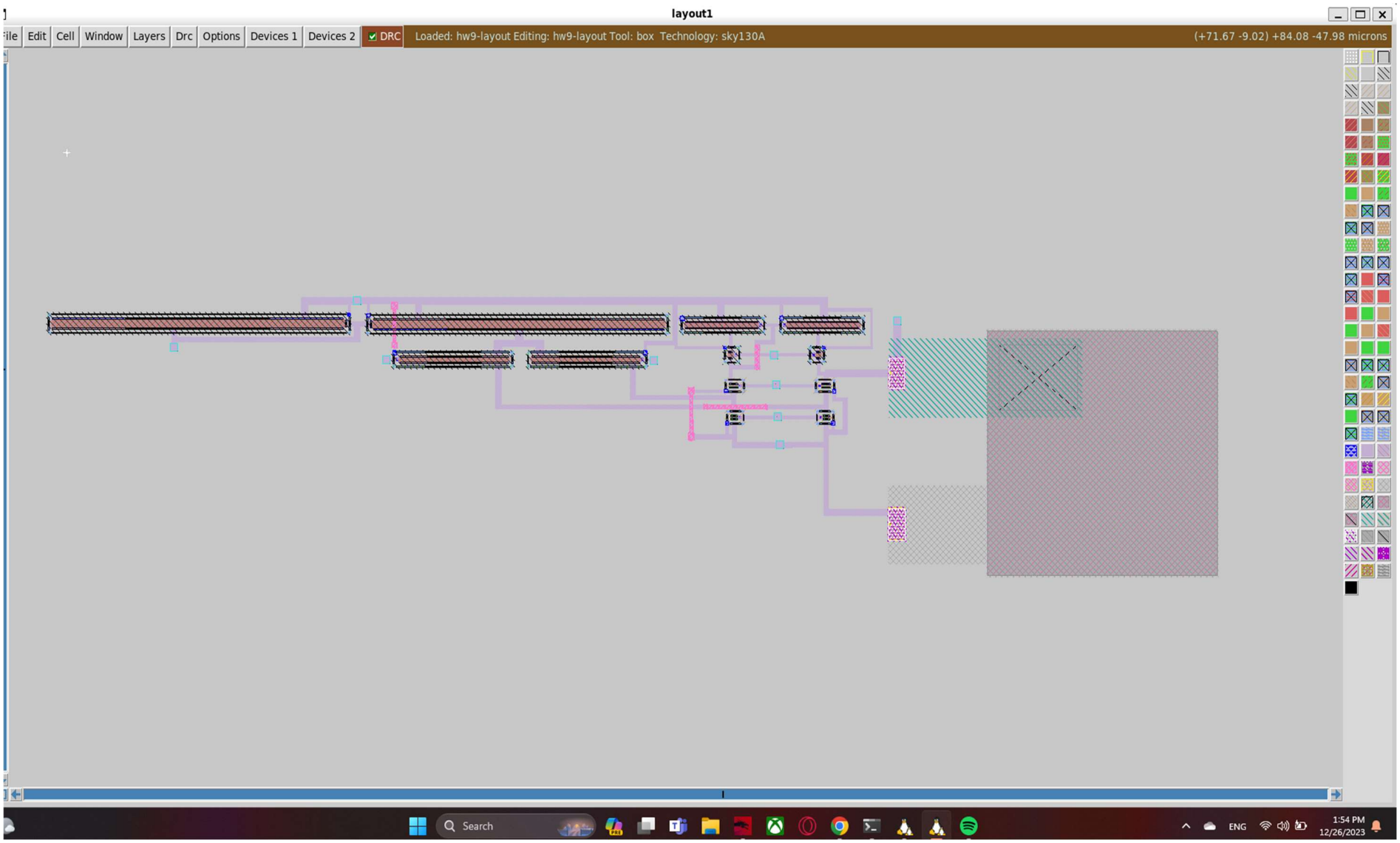

vdd
M9
pfet_01v8
nf=1
1 x 40 / 1
M5
pfet_01v8
nf=1
1 x 40 / 1
M1
pfet_01v8
nf=1
1 x 10 / 0.5
M2
pfet_01v8
nf=1
1 x 10 / 0.5
M6
pfet_01v8
nf=1
1 x 0.625 / 0.5
M7
pfet_01v8
nf=1
1 x 0.625 / 0.5
vbias1
vout
M3
pfet_01v8
nf=1
1 x 15 / 0.5
vinn
M4
pfet_01v8
nf=1
1 x 15 / 0.5
vinp
vbias2
M8
nfet_01v8
nf=1
1 x 1.25 / 0.15
GND
M10
nfet_01v8
nf=1
1 x 1.25 / 0.15
GND
C1
2p
m=1
iref
vbias3
M11
nfet_01v8
nf=1
1 x 1 / 0.15
M12
nfet_01v8
nf=1
1 x 1 / 0.15
vss

2

```
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.ac dec 20 1 1e+10
.save all
.end
```




layout1
File
Edit
Cell
Window
Layers
Drc
Options
Devices 1
Devices 2
DRC
Loaded: hw9-layout Editing: hw9-layout Tool: box Technology: sky130A
(+71.67 -9.02) +84.08 -47.98 microns
Search
ENG
1:54 PM
12/26/2023