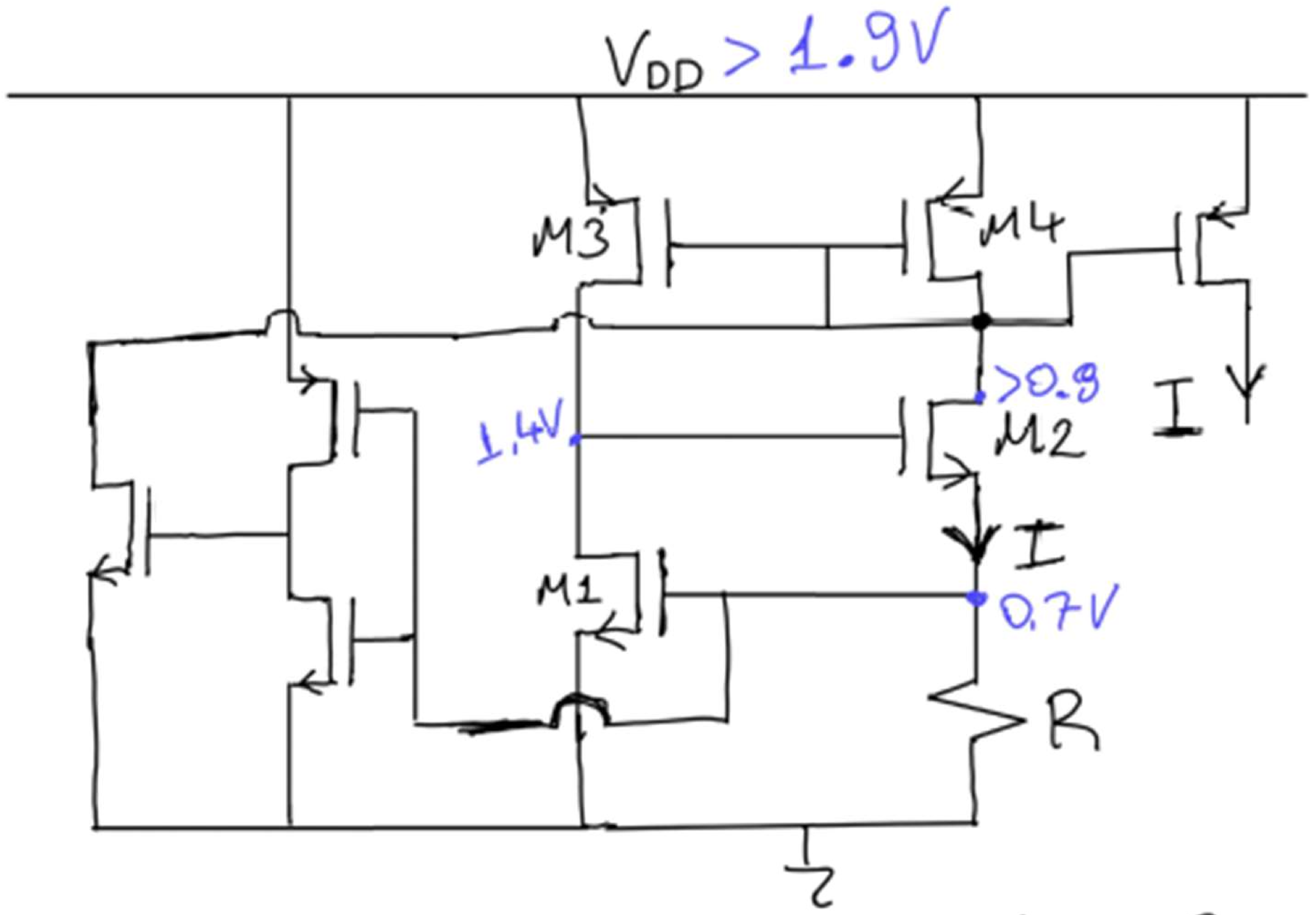
HOMEWORK 7

ARDA ÜNAL

7.1)



$V_{GS1} = RI \quad V_{TN} = 0.5V$ and $V_{TP} = 0.8V$

$\Rightarrow V_{GS1} = 0.7V$ and $I = 10^{-4} A \Rightarrow R = 7k\Omega$

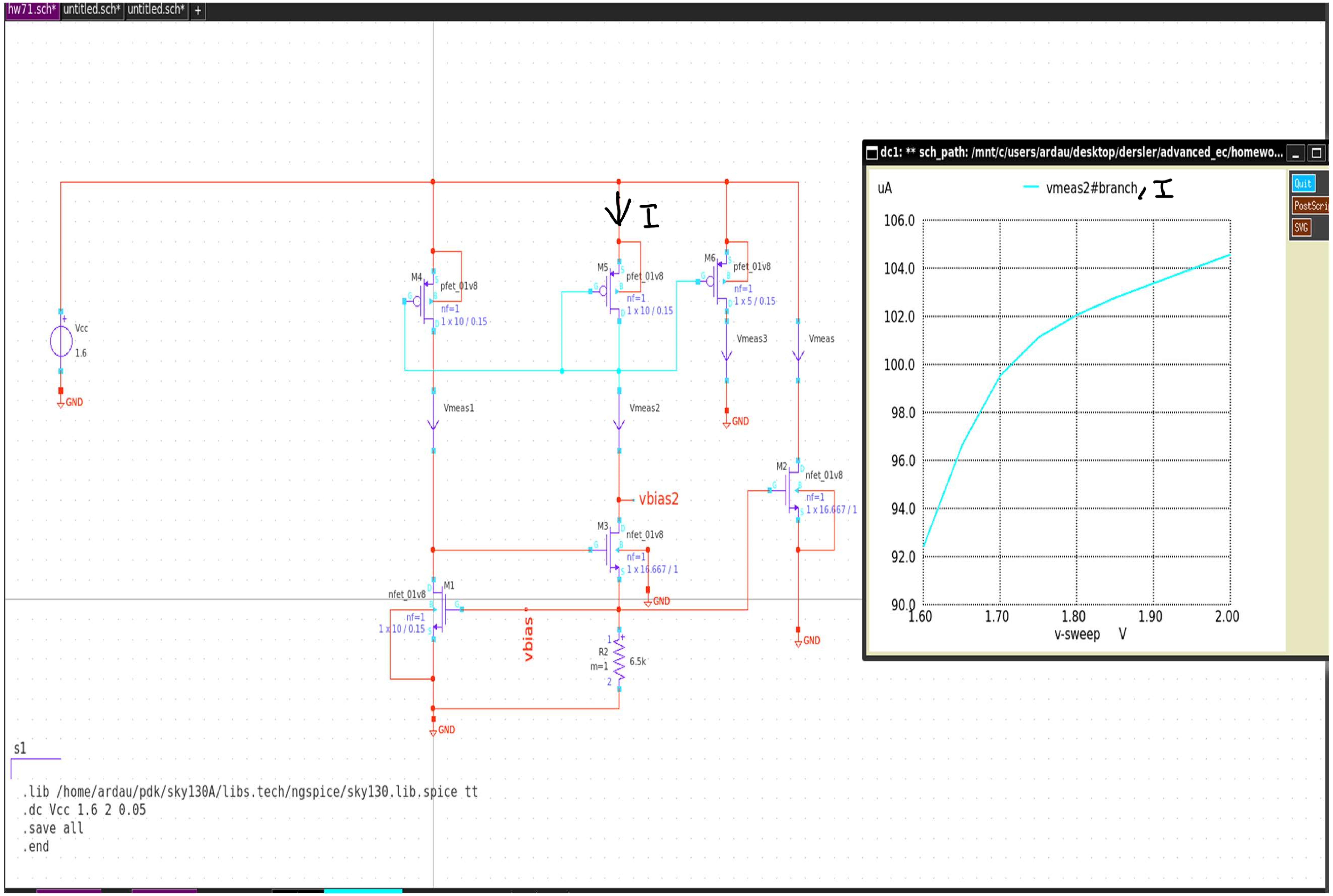
$V_{GS1} = V_{TN} + \sqrt{\frac{2IL_1}{\mu_n C_{ox} W_1}} \Rightarrow \left(\frac{W}{L}\right)_1 = 16.667$

Let all $V_{ov} = 0.2$, then

$\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 4.167, \ \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_1$

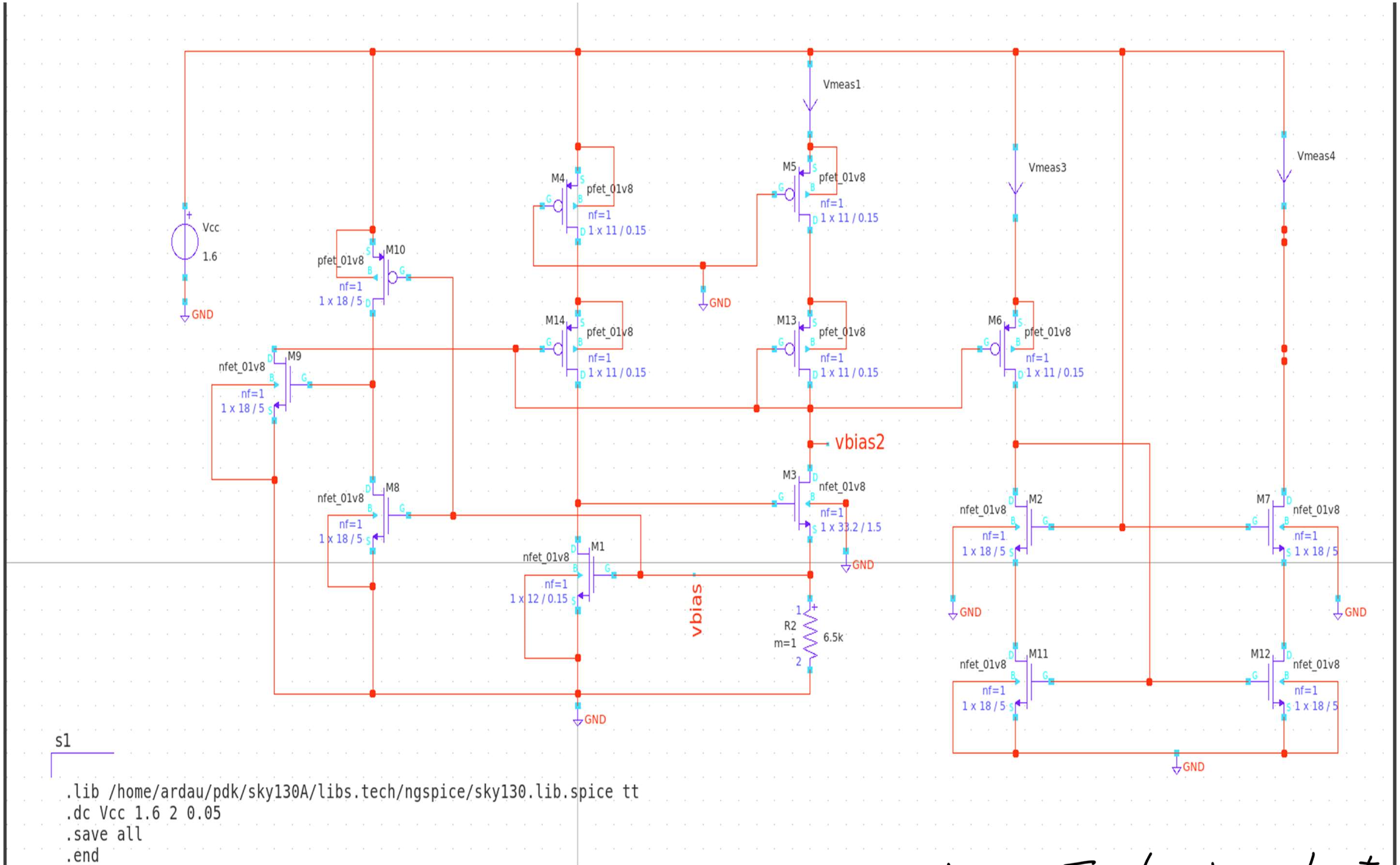
→ To achieve an acceptable result, I played with

$\left(\frac{W}{L}\right)_1, \left(\frac{W}{L}\right)_{3and4}$ and R.

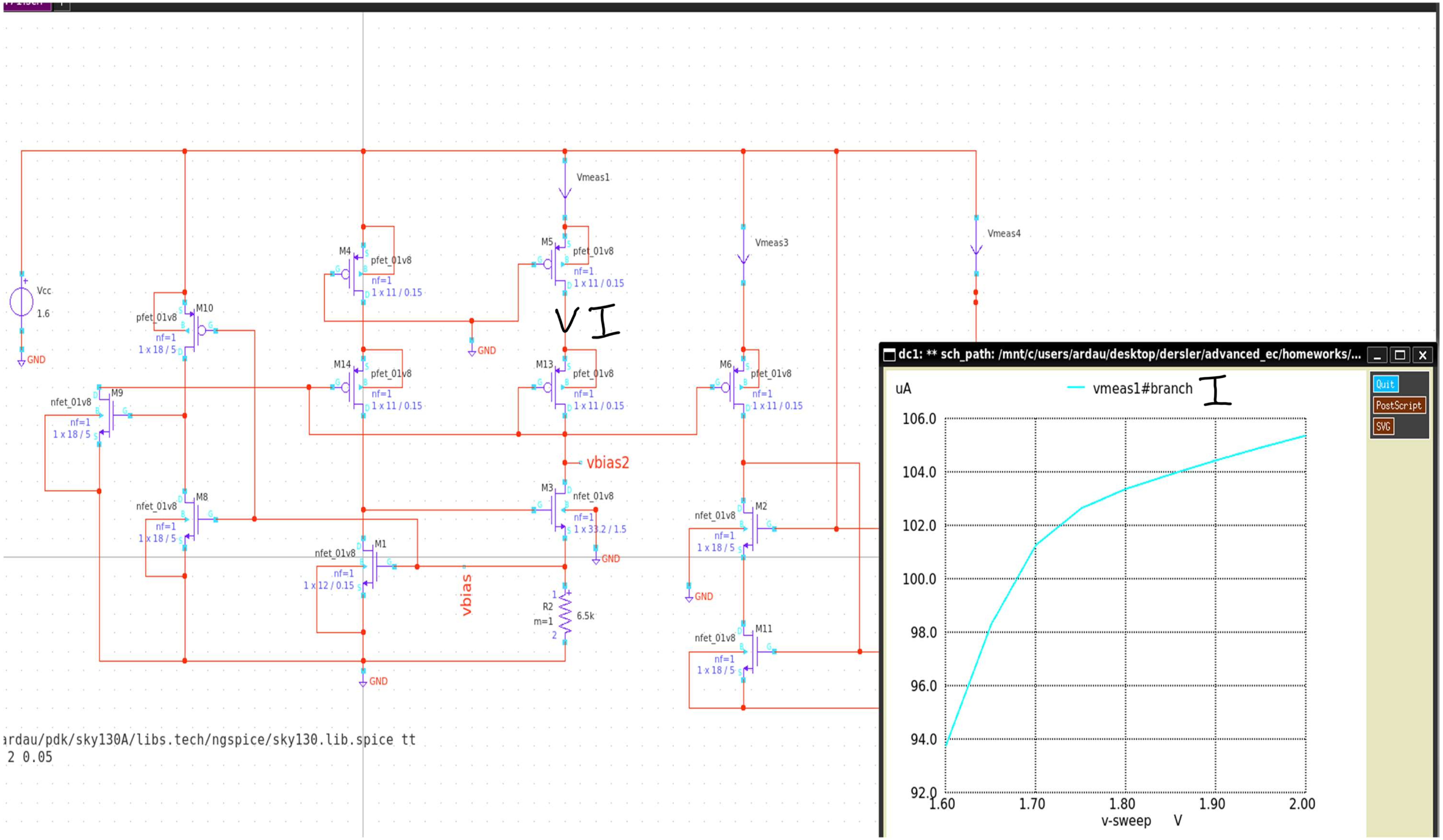


hw71.sch*
untitled.sch*
untitled.sch*
Vcc
1.6
GND
M4
pfet_01v8
nf=1
1 x 10 / 0.15
M5
pfet_01v8
nf=1
1 x 10 / 0.15
M6
pfet_01v8
nf=1
1 x 5 / 0.15
I
Vmeas1
Vmeas2
Vmeas3
Vmeas
vbias2
M3
nfet_01v8
nf=1
1 x 16.667 / 1
M2
nfet_01v8
nf=1
1 x 16.667 / 1
M1
nfet_01v8
nf=1
1 x 10 / 0.15
vbias
R2
m=1
6.5k
s1
.lib /home/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.dc Vcc 1.6 2 0.05
.save all
.end
dc1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homewo...
Quit
PostScri
SVG
uA
vmeas2#branch, I
106.0
104.0
102.0
100.0
98.0
96.0
94.0
92.0
90.0
1.60
1.70
1.80
1.90
2.00
v-sweep V

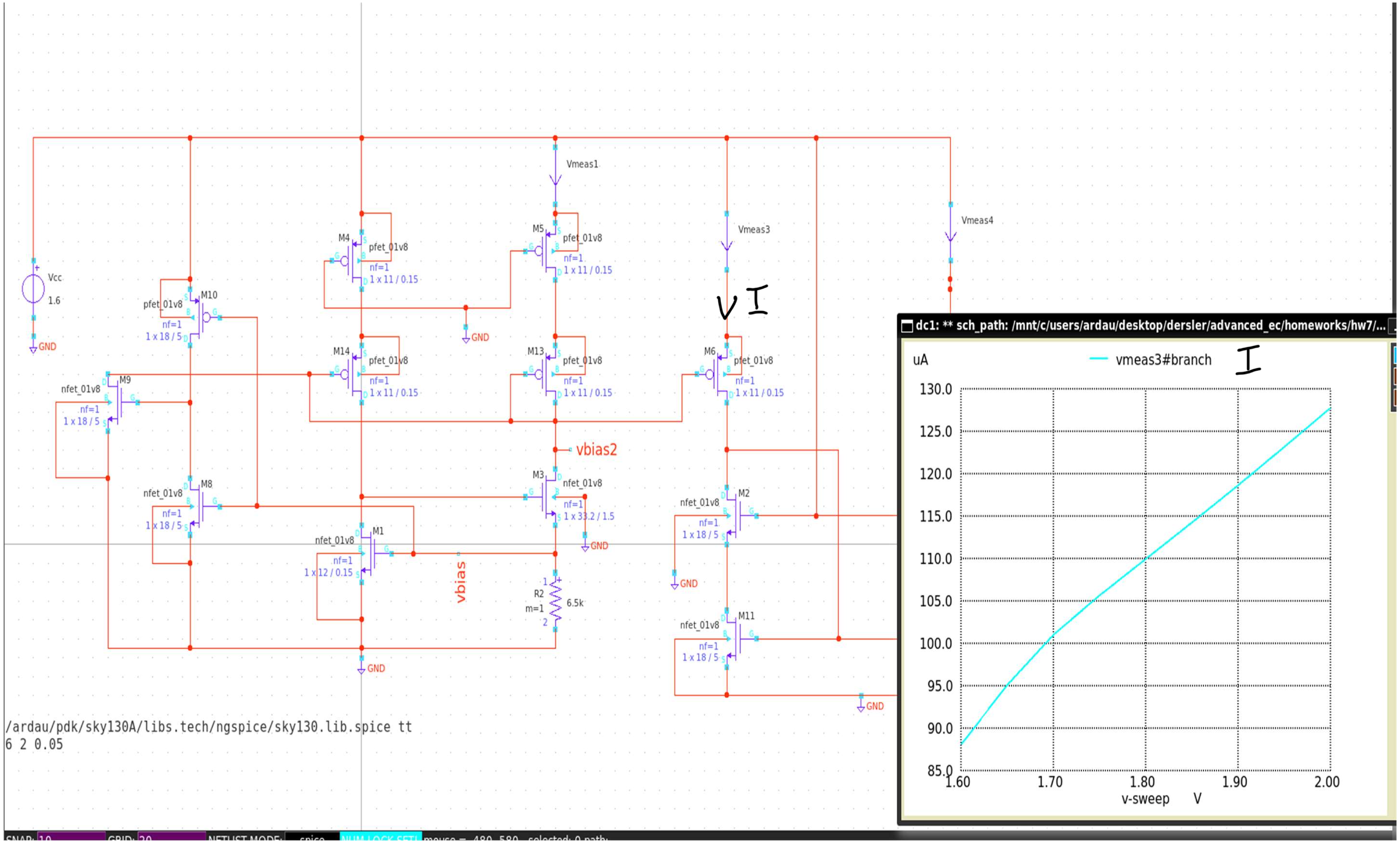
Cascoded current mirrors combined with startup circuit



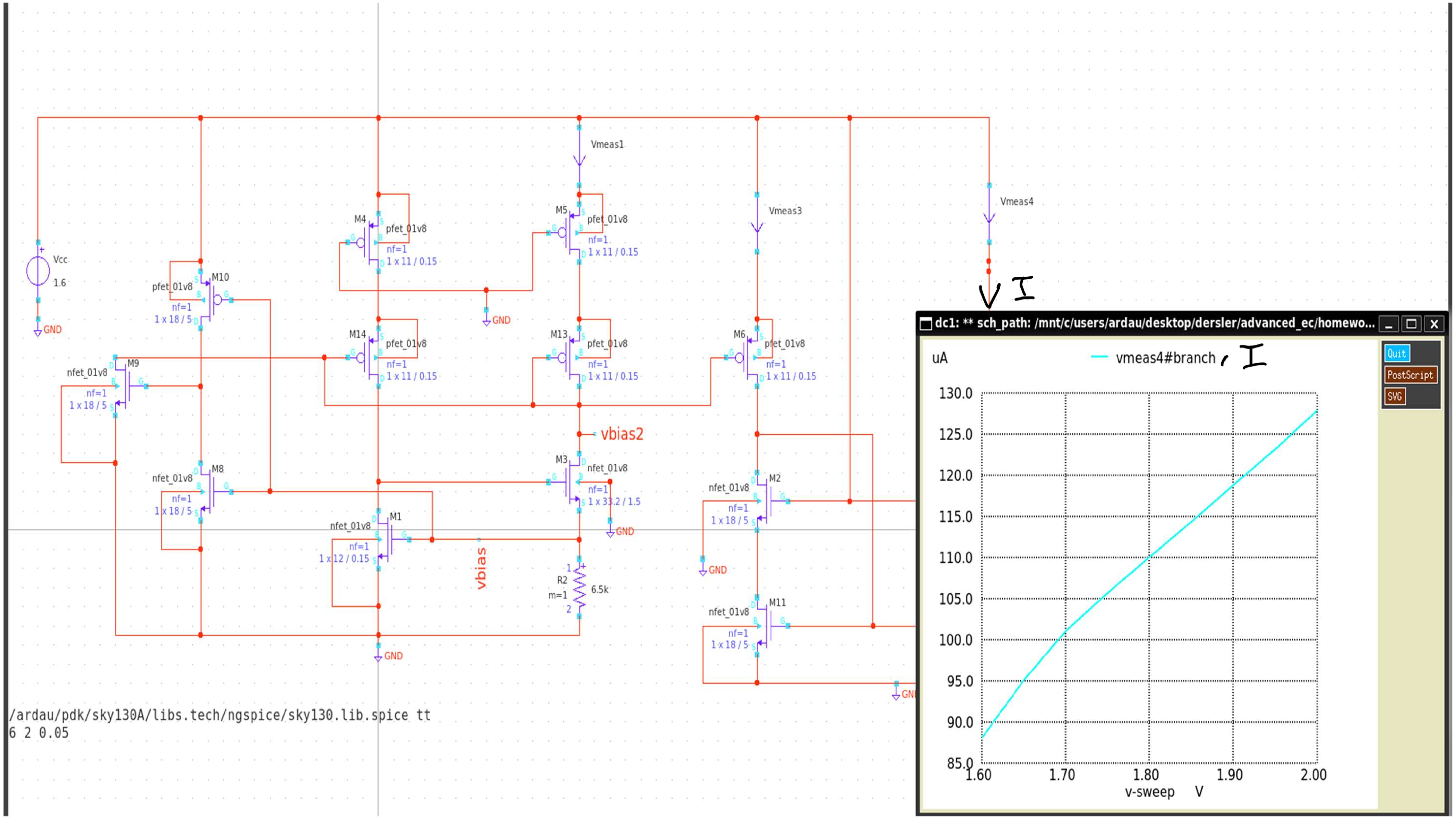
I have used NMOS current mirros that I designed at HW4 where the reference current was 100µA.



Vcc
1.6
GND
pfet_01v8
M10
nf=1
1 x 18 / 5
nfet_01v8
M9
nf=1
1 x 18 / 5
nfet_01v8
M8
nf=1
1 x 18 / 5
M4
pfet_01v8
nf=1
1 x 11 / 0.15
M14
pfet_01v8
nf=1
1 x 11 / 0.15
nfet_01v8
M1
nf=1
1 x 12 / 0.15
vbias
Vmeas1
M5
pfet_01v8
nf=1
1 x 11 / 0.15
V I
M13
pfet_01v8
nf=1
1 x 11 / 0.15
vbias2
M3
nfet_01v8
nf=1
1 x 33.2 / 1.5
R2
m=1
6.5k
Vmeas3
M6
pfet_01v8
nf=1
1 x 11 / 0.15
nfet_01v8
M2
nf=1
1 x 18 / 5
nfet_01v8
M11
nf=1
1 x 18 / 5
Vmeas4
ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
2 0.05
dc1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/...
Quit
PostScript
SVG
uA
vmeas1#branch
I
106.0
104.0
102.0
100.0
98.0
96.0
94.0
92.0
1.60
1.70
1.80
1.90
2.00
v-sweep V



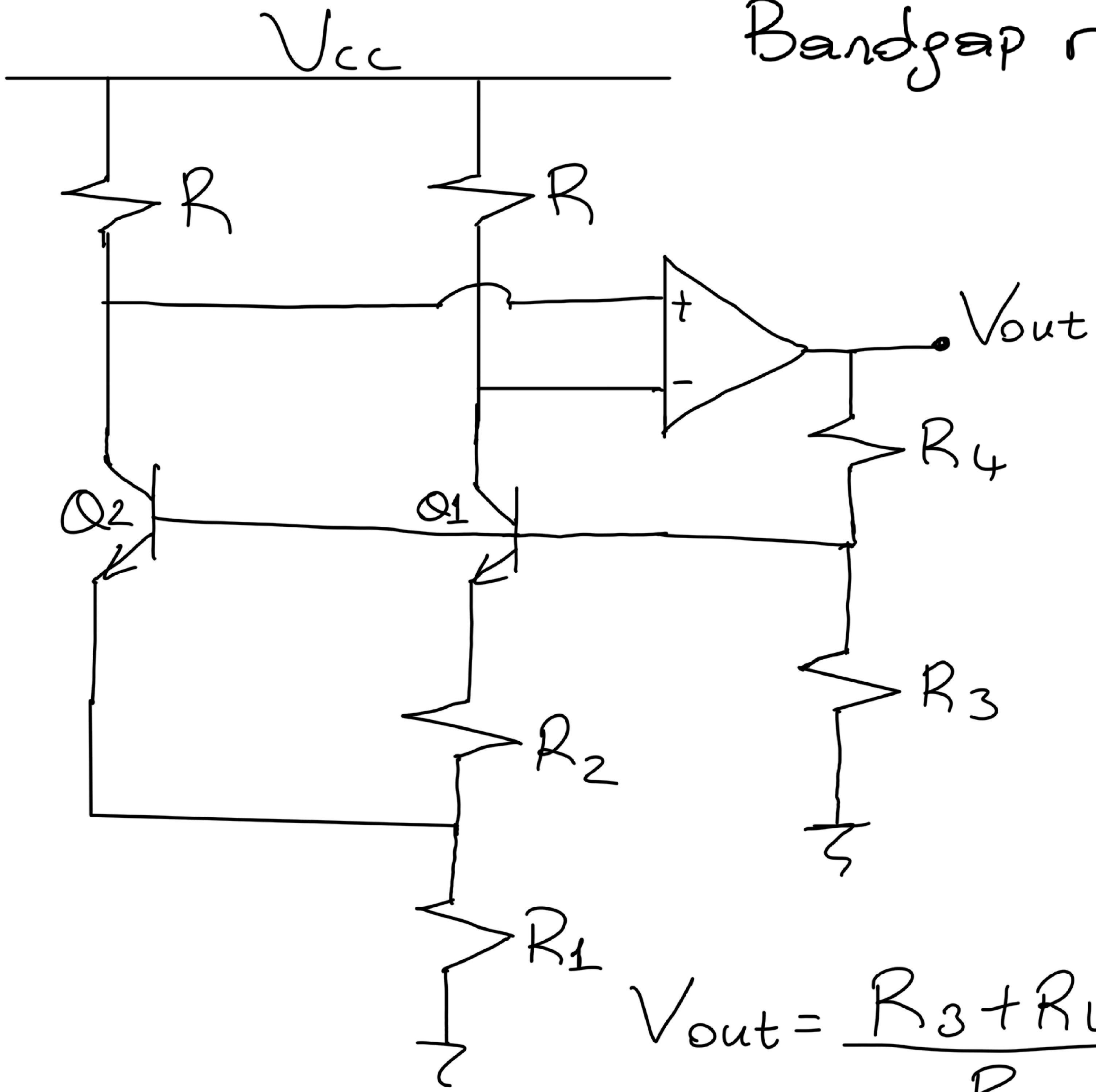
Vcc
1.6
GND
M4
pfet_01v8
nf=1
1 x 11 / 0.15
M5
Vmeas1
Vmeas3
Vmeas4
M10
M9
nfet_01v8
1 x 18 / 5
M14
M13
M6
V I
M8
M1
1 x 12 / 0.15
M3
1 x 33.2 / 1.5
vbias2
vbias
R2
m=1
6.5k
M2
M11
/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
6 2 0.05
dc1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homeworks/hw7/...
uA
vmeas3#branch
I
130.0
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
1.60
1.70
1.80
1.90
2.00
v-sweep V



Vcc
1.6
GND
M9
nfet_01v8
nf=1
1 x 18 / 5
M10
pfet_01v8
nf=1
1 x 18 / 5
M8
nfet_01v8
nf=1
1 x 18 / 5
M4
pfet_01v8
nf=1
1 x 11 / 0.15
M14
pfet_01v8
nf=1
1 x 11 / 0.15
M1
nfet_01v8
nf=1
1 x 12 / 0.15
vbias
Vmeas1
M5
pfet_01v8
nf=1
1 x 11 / 0.15
M13
pfet_01v8
nf=1
1 x 11 / 0.15
vbias2
M3
nfet_01v8
nf=1
1 x 33.2 / 1.5
R2
m=1
6.5k
Vmeas3
M6
pfet_01v8
nf=1
1 x 11 / 0.15
M2
nfet_01v8
nf=1
1 x 18 / 5
M11
nfet_01v8
nf=1
1 x 18 / 5
Vmeas4
/ardau/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
6 2 0.05
V I
dc1: ** sch_path: /mnt/c/users/ardau/desktop/dersler/advanced_ec/homewo...
Quit
PostScript
SVG
uA
vmeas4#branch , I
130.0
125.0
120.0
115.0
110.0
105.0
100.0
95.0
90.0
85.0
1.60
1.70
1.80
1.90
2.00
v-sweep V

2>

→ I designed Brokaw Bandgap reference.



$$V_{out} = \frac{R_3 + R_4}{R_3} V_{ref}$$

$$V_{ref} = V_{BE} + V_{R1} = V_{BE} + 2\frac{R_1}{R_2} V_{R_2}$$

$$\Rightarrow V_{ref} = \underbrace{V_{BE}}_{CTAT} + 2\frac{R_1}{R_2}\underbrace{\frac{kT}{q}\ln 8}_{PTAT}$$

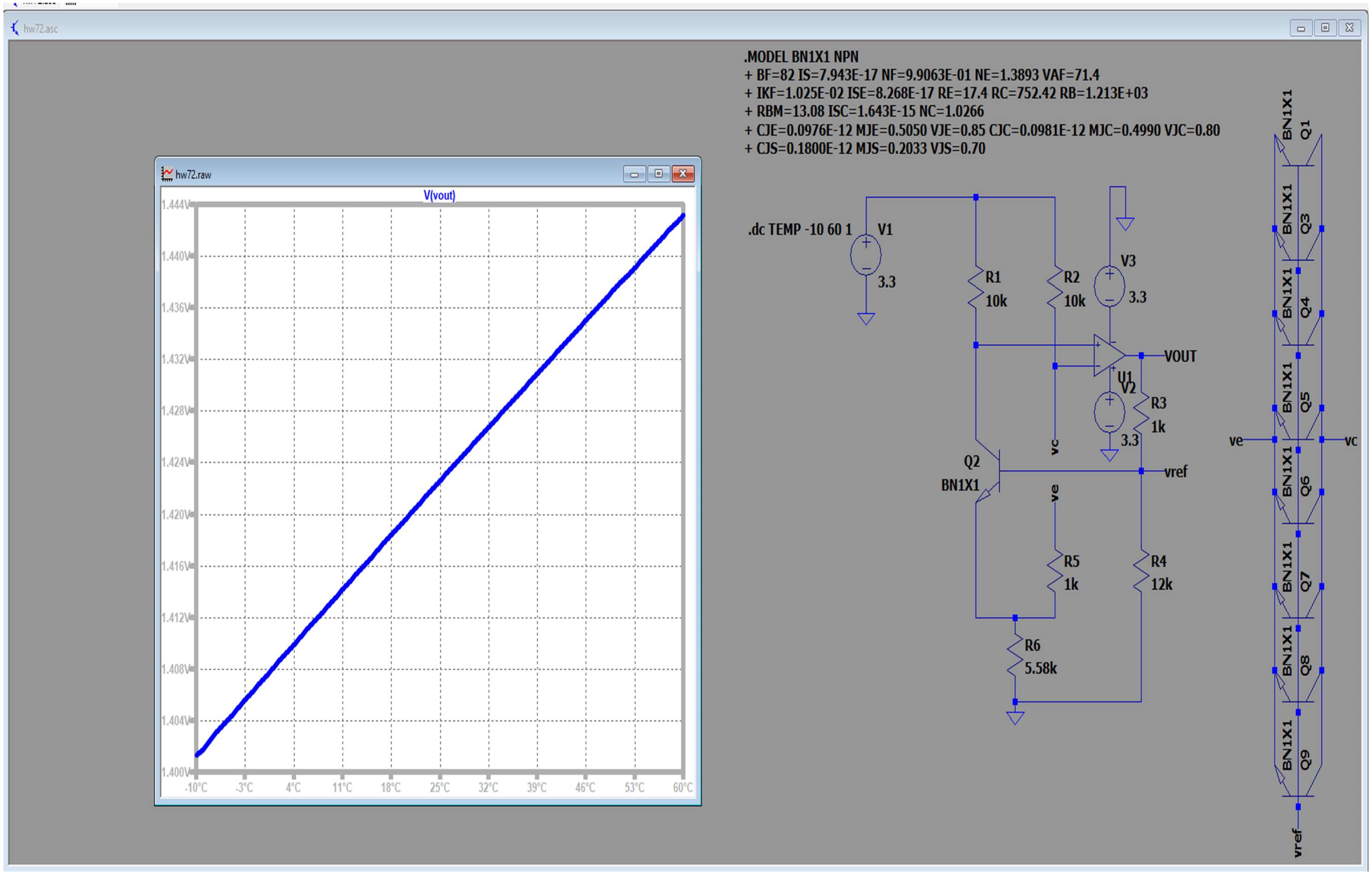
$$\frac{\partial V_{BE}}{\partial T} = -2mV \Rightarrow 2\frac{R_1}{R_2}\frac{k}{q}\ln 8 = 2\times 10^{-3}$$

$$\Rightarrow \frac{R_1}{R_2} = 5.58 \Rightarrow \begin{array}{l} R_1 = 5.58k\Omega \\ R_2 = 1k\Omega \end{array}$$

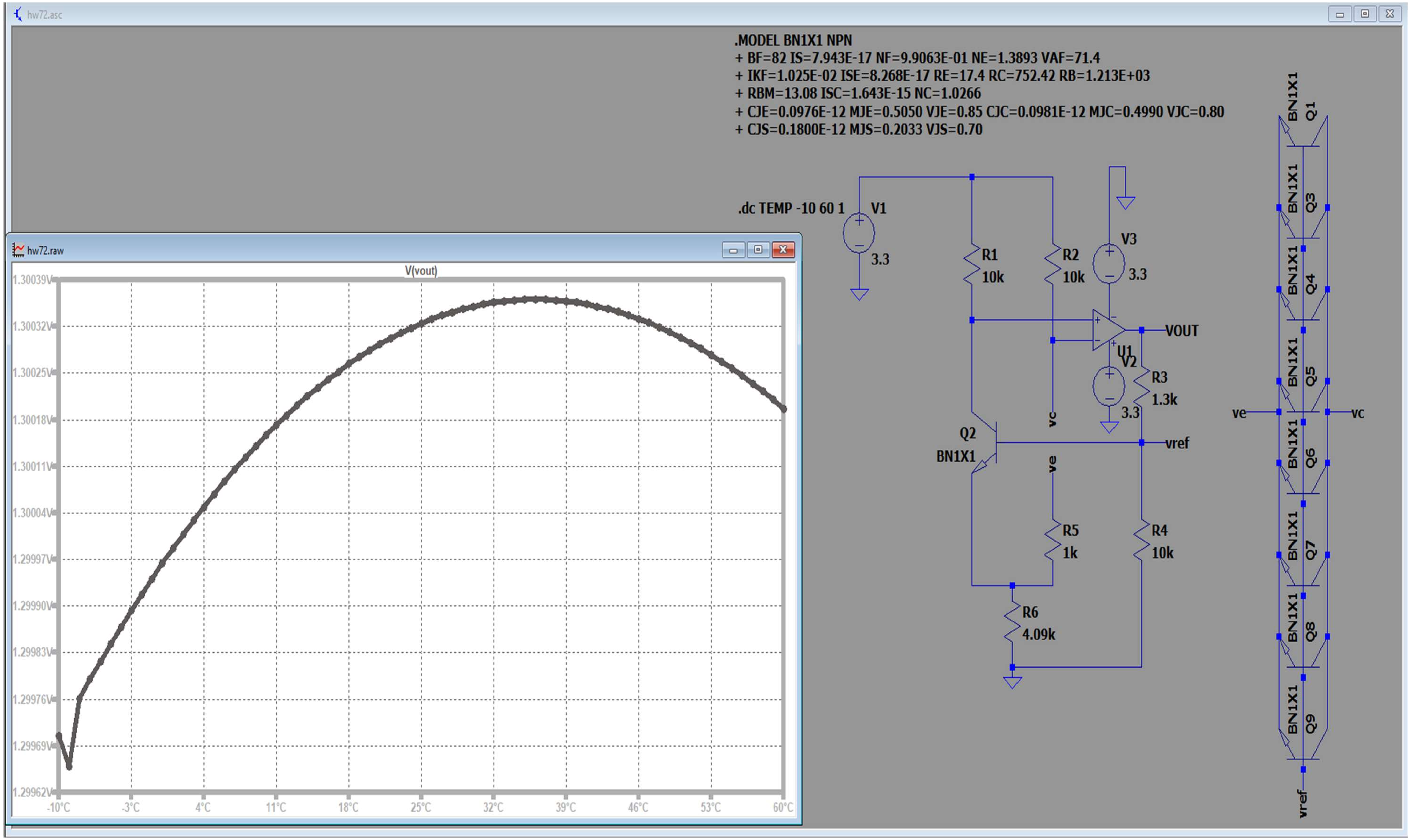
$$\Rightarrow V_{ref} \cong 1.2V \Rightarrow \frac{1.3}{1.2} = 1 + \frac{R_4}{R_3} \Rightarrow \frac{R_4}{R_3} = 0.0833$$

$$\Rightarrow \frac{R_3}{R_4} = 12$$ → There was a PTAT slope, so I decreased ratio of R_1/R_2 and V_{ref} was 1.149V thus I also play with ratio of $\frac{R_3}{R_4}$ to have $V_{out} = 1.3V$.

Calculated values have PTAT slope



After play with values, I had less than 0.1% error from −10°C to 60°C. Op-Amp is ideal.



Op-Amp with gain 50. Error is still less than 0.1%, but the output voltage is decreased.