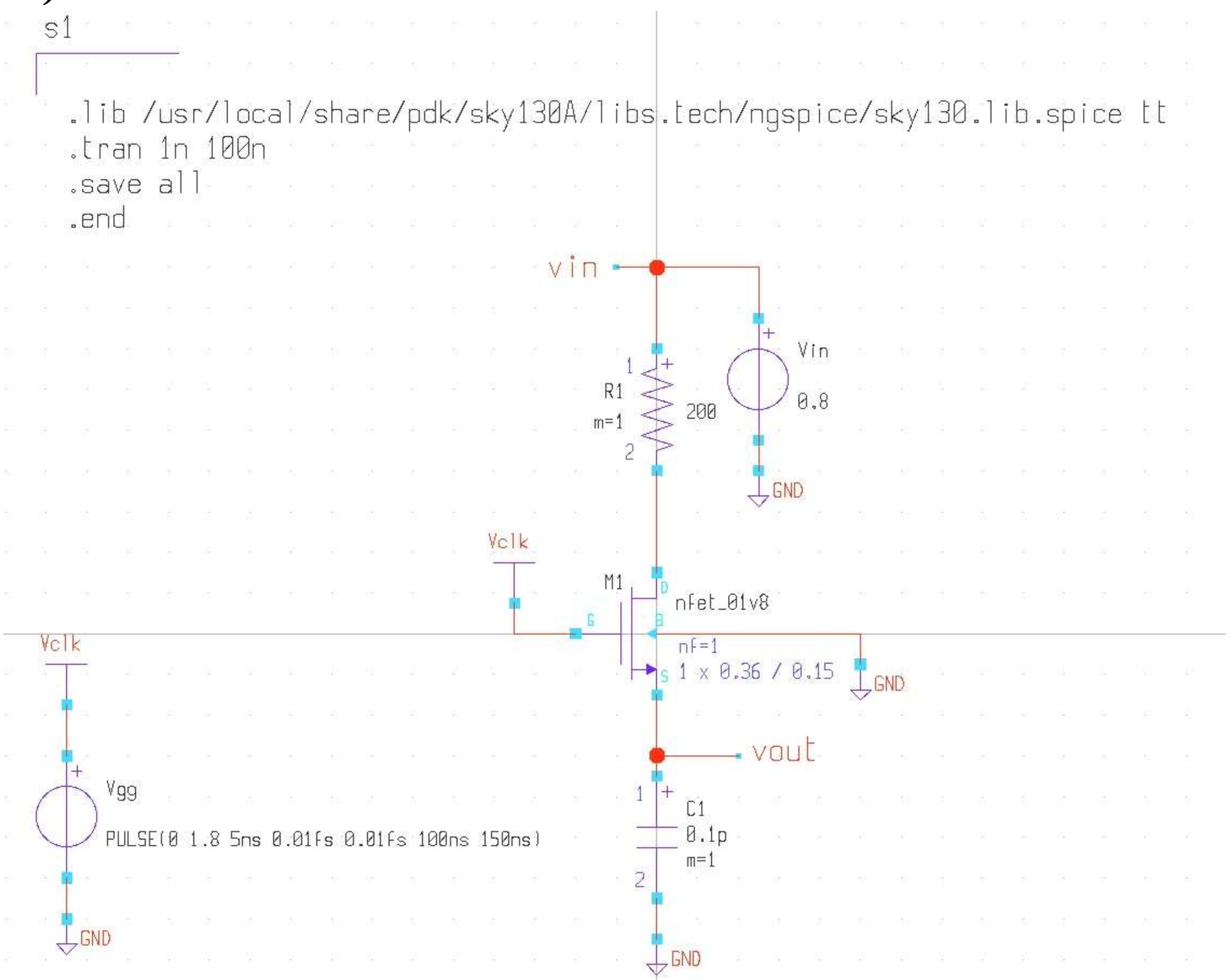
HOMEWORK3

Arda Ünal

1.)

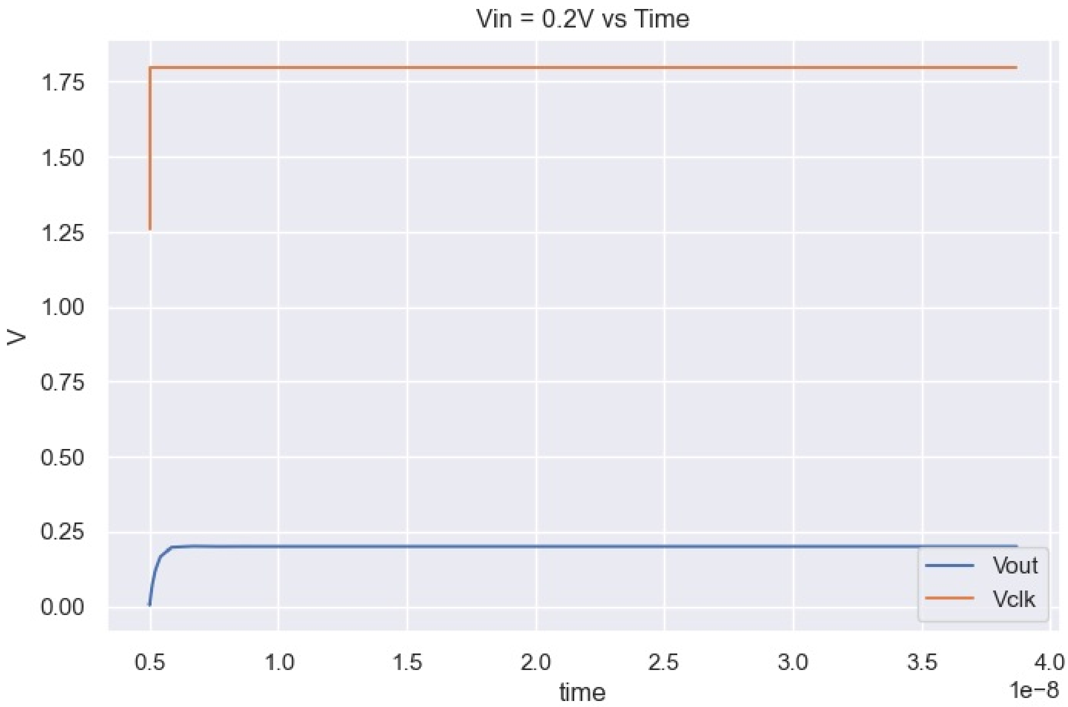


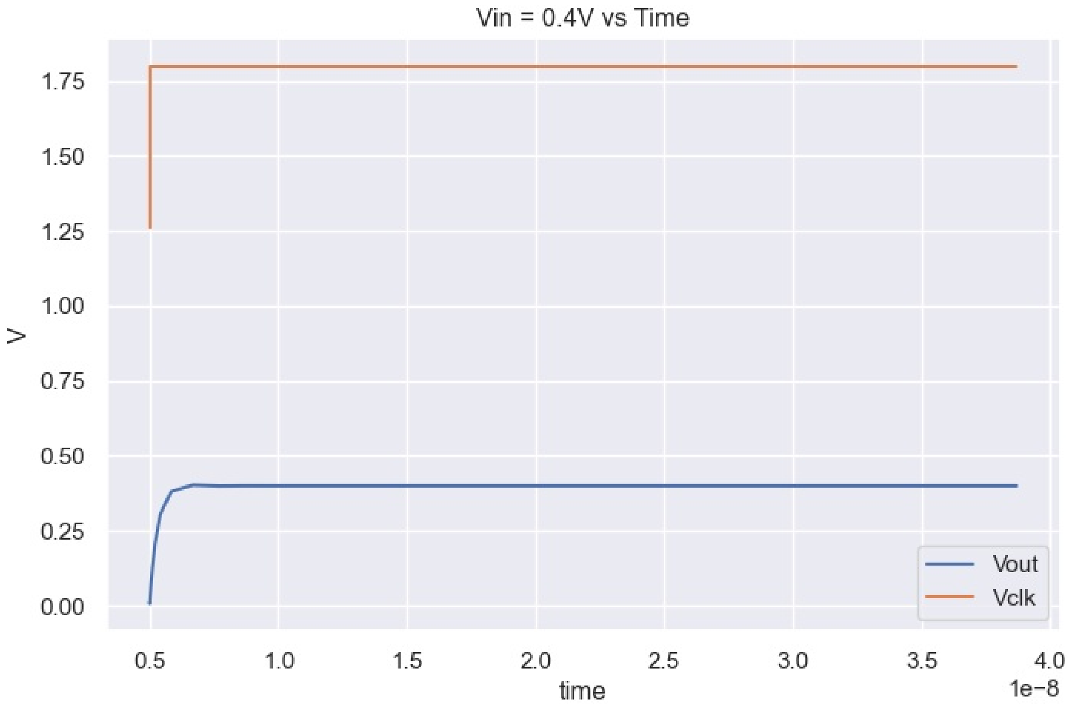
In [1]:
```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import warnings
warnings.filterwarnings("ignore")
sns.set_theme()
```

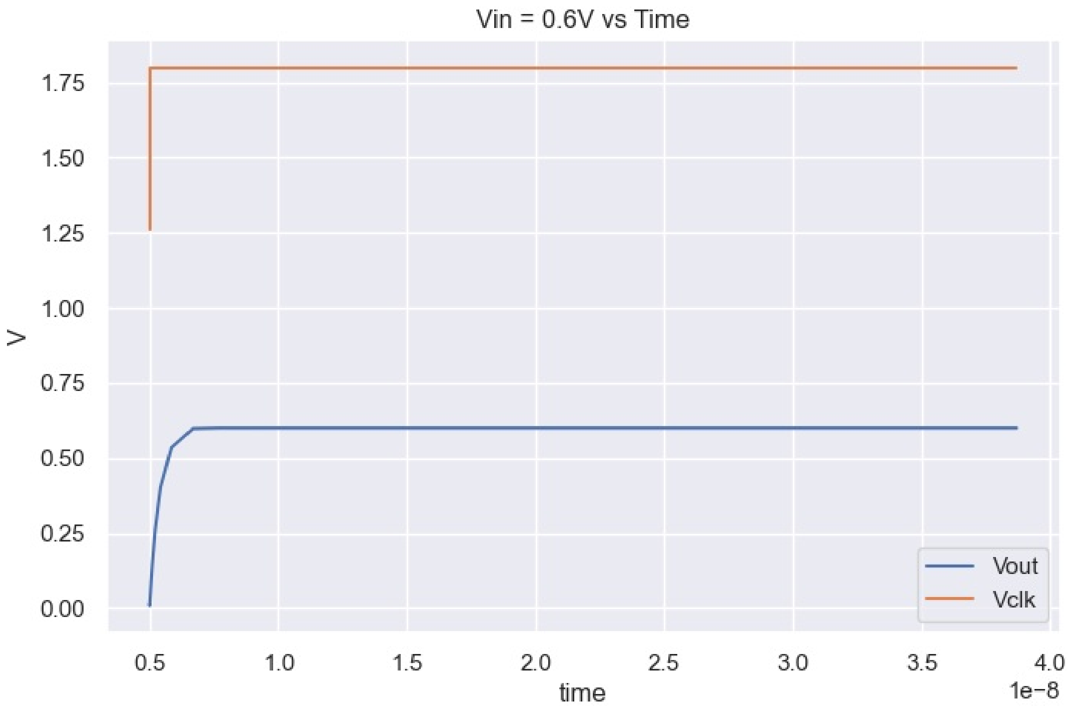
In [2]:
```
data1 = pd.read_csv("hw31_02.txt", delimiter=",")
data2 = pd.read_csv("hw31_04.txt", delimiter=",")
data3 = pd.read_csv("hw31_06.txt", delimiter=",")
data4 = pd.read_csv("hw31_08.txt", delimiter=",")
data5 = pd.read_csv("hw31_1.txt", delimiter=",")
df_list = [data1, data2, data3, data4, data5]
name_list = ["0.2V", "0.4V", "0.6V", "0.8V", "1V"]
```

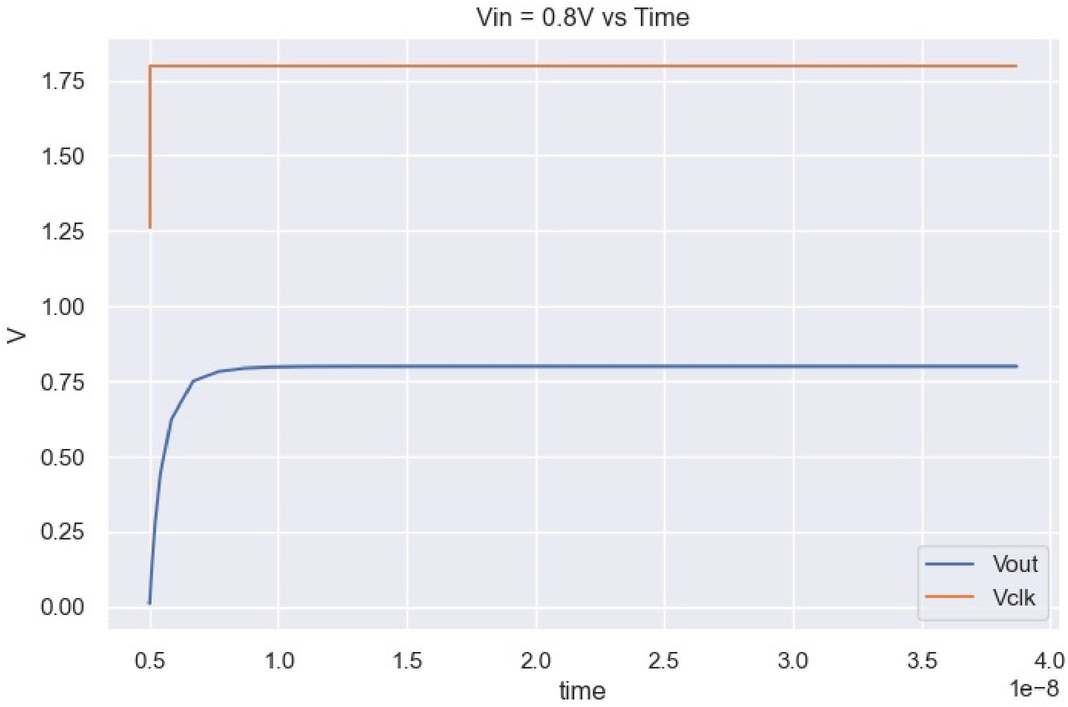
In [3]:
```
for df in df_list:
    df["v(vin)"] = [float(i) for i in df["v(vin)"]]
    df["v(vclk)"] = [float(i) for i in df["v(vclk)"]]
    df["v(vout)"] = [float(i) for i in df["v(vout)"]]
    df["i(vin)"] = [-1*float(i) for i in df["i(vin)"]]
```

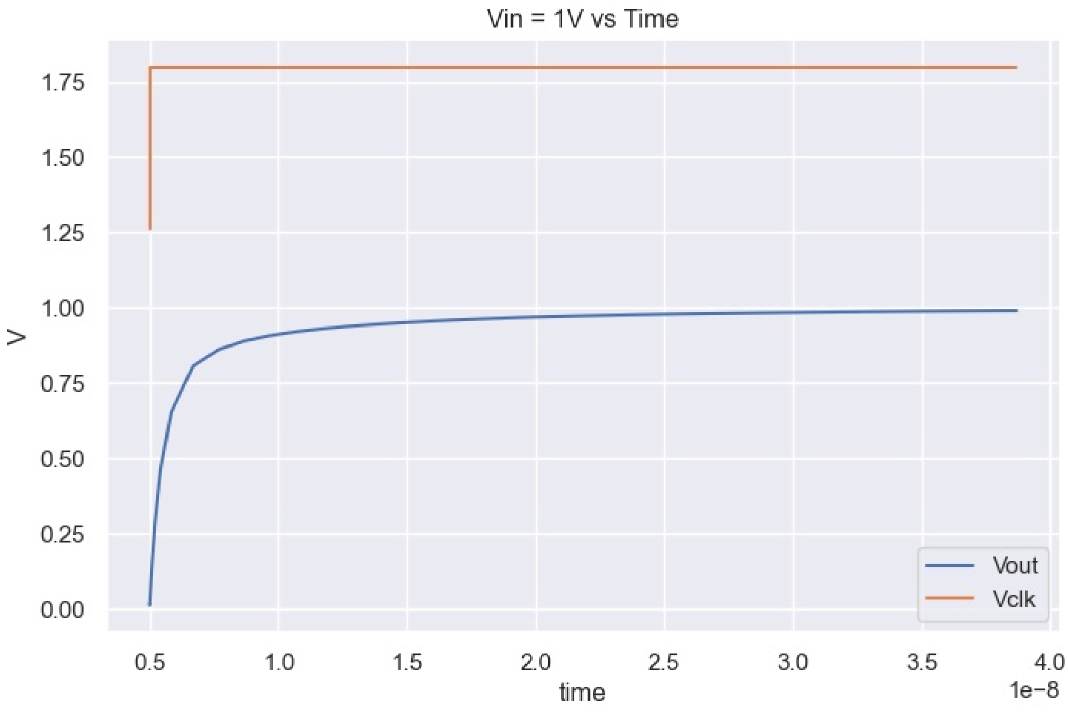
In [9]:
```
count = 0
for df in df_list:
    plt.figure(figsize = (8, 5))
    plt.plot(df["time"][15:80], df["v(vout)"][15:80], label = "Vout")
    plt.plot(df["time"][15:80], df["v(vclk)"][15:80], label = "Vclk")
    plt.title("Vin = " + name_list[count] + " vs Time" )
    plt.xlabel("time")
    plt.ylabel("V")
    plt.legend()
    plt.show()
    count += 1
```




Vin = 0.4V vs Time
V
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
time
1e−8
Vout
Vclk


Vin = 0.6V vs Time
V
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
time
1e−8
Vout
Vclk





In [17]:
```
for df in df_list:
    max_val = max(df["v(vout)"])
    min_val =
    print(df.index[df["v(vout)"] == max_val])
```

```
Index([47], dtype='int64')
Index([47], dtype='int64')
Index([140], dtype='int64')
Index([140], dtype='int64')
Index([141], dtype='int64')
```

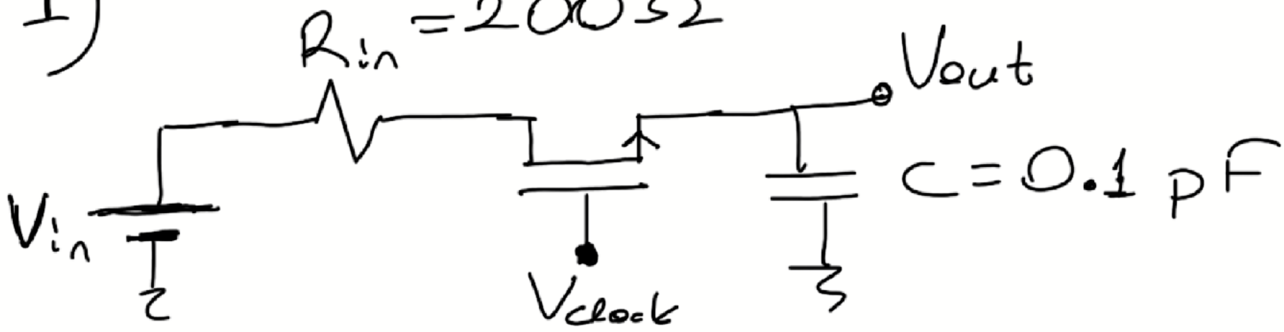
In [20]:
```
print(df["time"][46] - 0.5e-8)
print(df["time"][46] - 0.5e-8)
print(df["time"][139] - 0.5e-8)
print(df["time"][139] - 0.5e-8)
print(df["time"][140] - 0.5e-8)
```

```
8.437631999999998e-10
8.437631999999998e-10
9.36875263e-08
9.36875263e-08
9.46875263e-08
```

hw31

Oct 30, 19:40 Uncategorized

1)



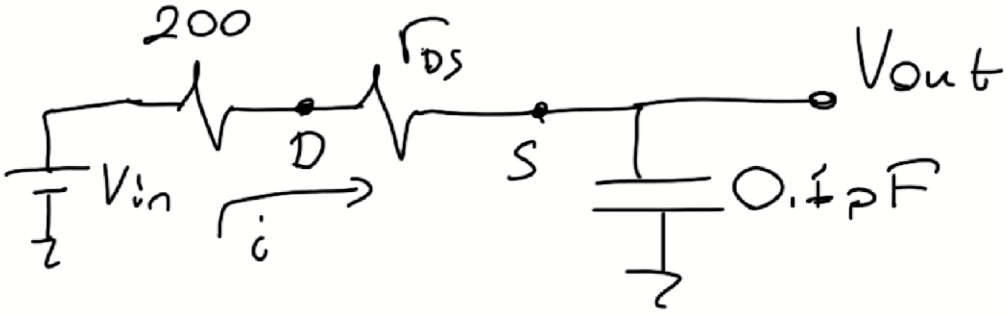
Let us take $V_{in} = 0.6V$, $W = 0.36\mu m$
$L = 0.15\mu m$ and $V_T = 0.6\,V$

$V_{clock} = 1.8\,V$ $\quad V_{DS} < V_{GS} - V_T$

$\rightarrow$ Since $I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_T)^2$

$\Rightarrow$ For $V_{GS} = 1.5V$, $I_D = 0.12807\,mA$
by using $W = 0.36\,\mu m$ and $L = 0.15\,\mu m$
nfet_01v8, $\mu_n C_{ox} = 1.06725 \times 10^{-4}$

$\rightarrow$ In triode region,

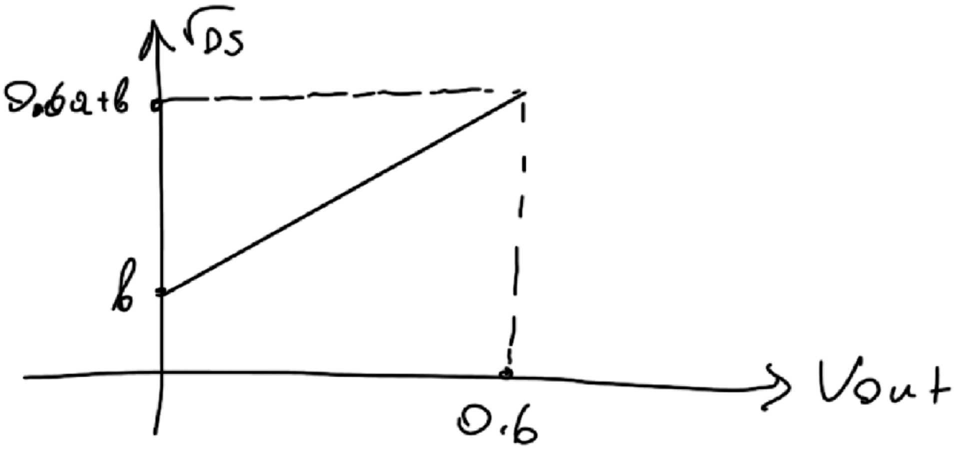


$$r_{DS} = \frac{V_{DS}}{I_D} = \frac{1}{\mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_T) - \frac{1}{2} V_{DS} \right]}$$

$$i = \frac{V_{in} - V_{out}}{200 + r_{DS}} = 10^{-13} \frac{dV_{out}}{dt}$$

$$\Rightarrow \frac{dV_{out}}{dt} = 10^{13}\left[\frac{V_{in} - V_{out}}{200 + r_{DS}}\right]$$

This is a very hard nonlinear diff. eqn to solve, so let us assume $r_{DS} = aV_{out} + b$



when $V_{out} = 0$, $V_{DS} = V_D$

$$\Rightarrow V_D = V_{in} - 200\frac{V_{in}}{200 + r_{DS}}$$

$$\Rightarrow r_{DS} = \frac{1}{\mu_n C_{ox}\frac{W}{L}\left[1.2 - \frac{1}{2}\left(V_{in} - 200\frac{V_{in}}{200+r_{DS}}\right)\right]}$$

$$\Rightarrow r_{DS}(0) \cong 4.274k \qquad , k = \mu_n C_{ox}\frac{W}{L}$$

For $V_{out} = 0.6$ $\quad V_{DS} = V_D - 0.6$

$$\Rightarrow r_{DS} = \frac{1}{k\left[1.8 - 0.6 - 0.6 - \frac{1}{2}\left(V_{in} - \frac{200V_{in}}{200+r_{DS}} - V_{in}\right)\right]}$$

$$\Rightarrow r_{DS} = \frac{1/k}{0.6 + 0.3\frac{200}{200+r_{DS}}} \Rightarrow r_{DS} = 6.41k\Omega$$

$b = 4274$

$0.6a + b = 6415$, b

$\Rightarrow a = 3560$

$\Rightarrow r_{DS} = 3560 V_{out} + 4274$ so for $V_{out} = 0.999 V_{in}$

$\Rightarrow r_{DS} \cong 6408\,\Omega$

$$\frac{dV_{out}}{dt} = 10^{13}\left[\frac{0.6 - V_{out}}{200 + 3560V_{out} + 4274}\right]$$

$\Rightarrow V_{out} = 661 * W\left(0, -\left[1068 \exp\left(-\frac{10^{12}}{661}t - 0.323\right)\right]\right)$

↳ By using MATLAB

$\Rightarrow V_{out} = \frac{661}{356} W\left(0, -\left[0.323 \exp\left(-\frac{10^{12}}{661}t - 0.323\right)\right]\right) + 0.6$

→ where W is Lambert func.

→ $\boxed{t = 4.3526\ ns}$ to $V_{out} = 0.999 V_{in}$

$\tau = RC = (200 + r_t)10^{-13}$

$\Rightarrow \tau = (3560 V_{out} + 4474) \times 10^{-13}$

2) i) $f_{max} = \frac{1}{t_{settle}} = \frac{1}{3 * \tau} = 504.286\ MHz$ for $V_{out} = 0.6V$

Settling time error $= \frac{t_{settle} - T_{sample}}{T_{sample} \times 100}$ %

MOSFET On-Resistance Error : $I_{sample} \times R_{DS(on)}$

+ Capacitor discharge error due to the leakage current.

$$\text{Error} = \frac{(504.286\times 10^6)^{-1} - (5\times 10^6)^{-1}}{(5\times 10^6)^{-1}} \times 100$$

assuming that $T_{sample} = \frac{1}{5MHz}$!

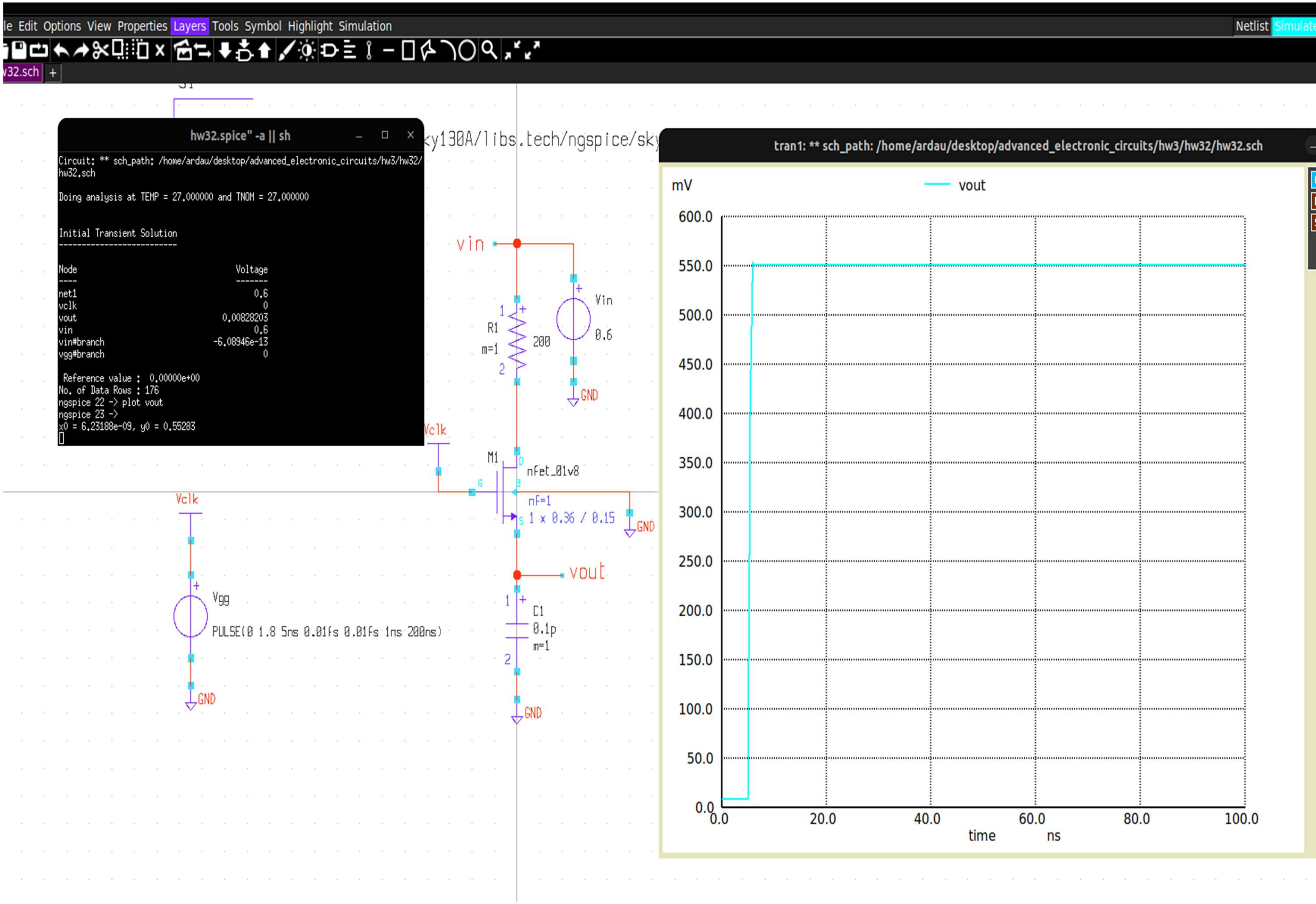
$\Rightarrow$ Error = 9.9%

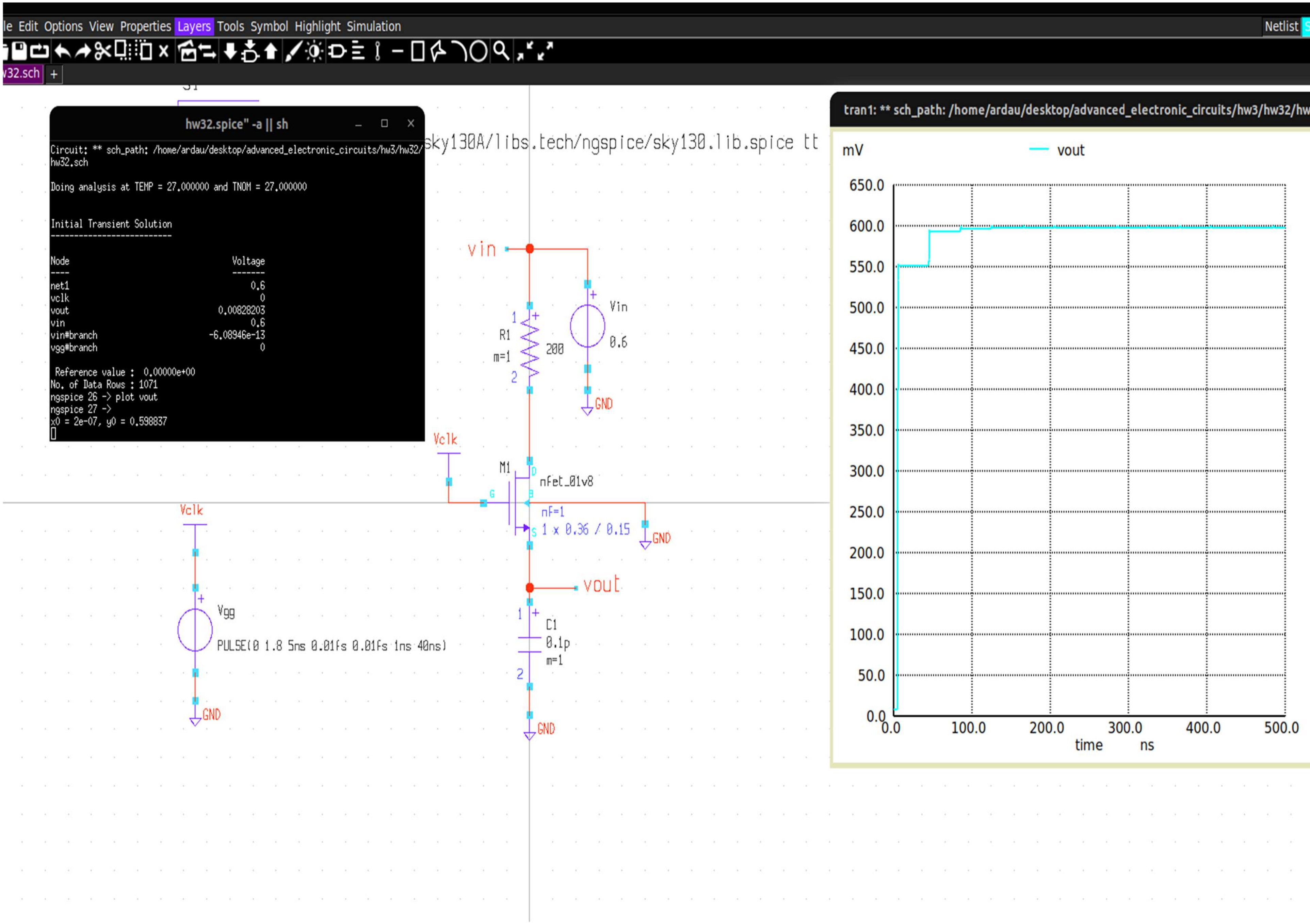
$\Rightarrow$ For $V_{in} = 0.6V$ $V_{out} = 0.5406\ V$

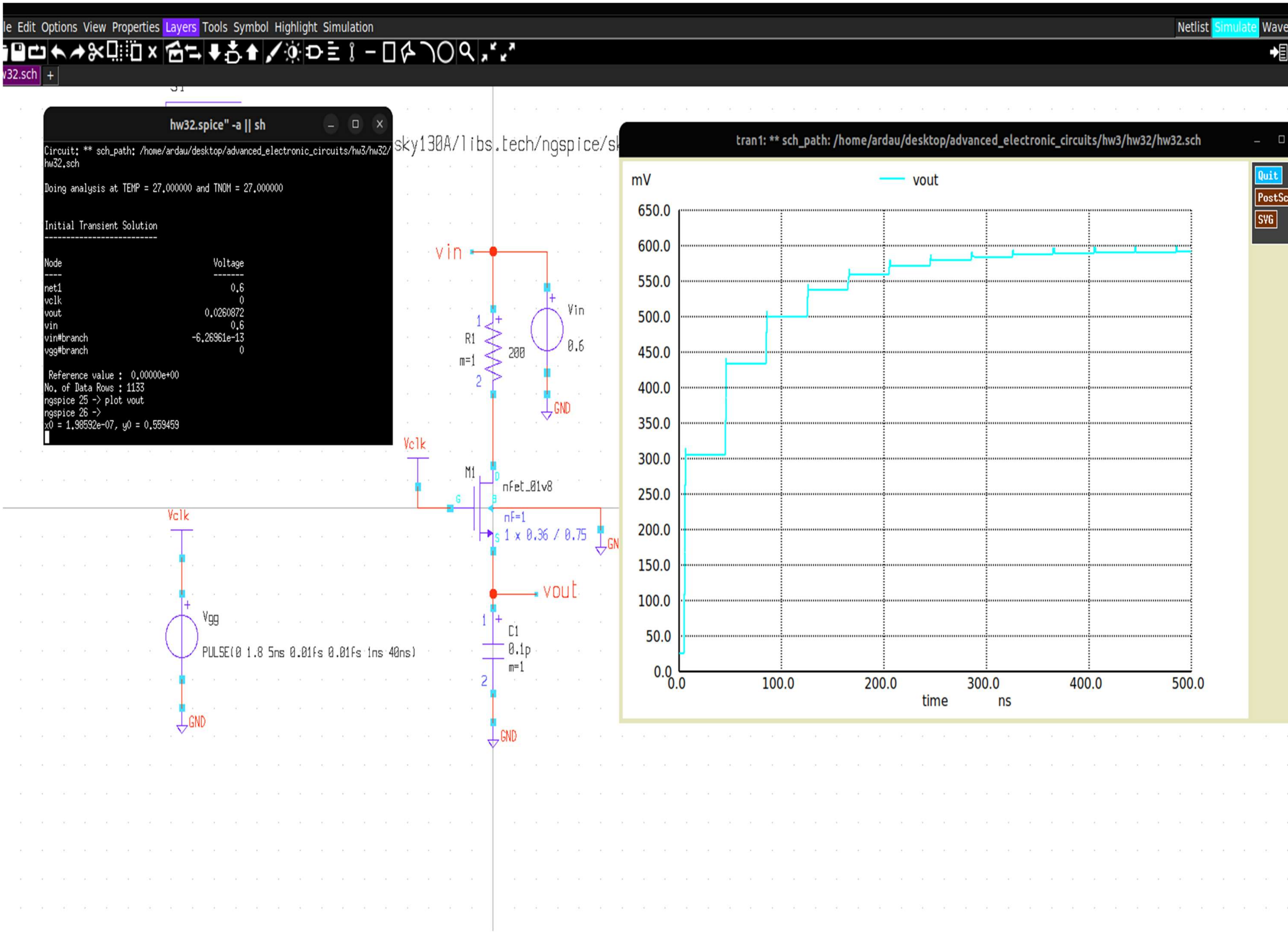
ii) If $f = 25MHz$, then

Error = 0.09715%

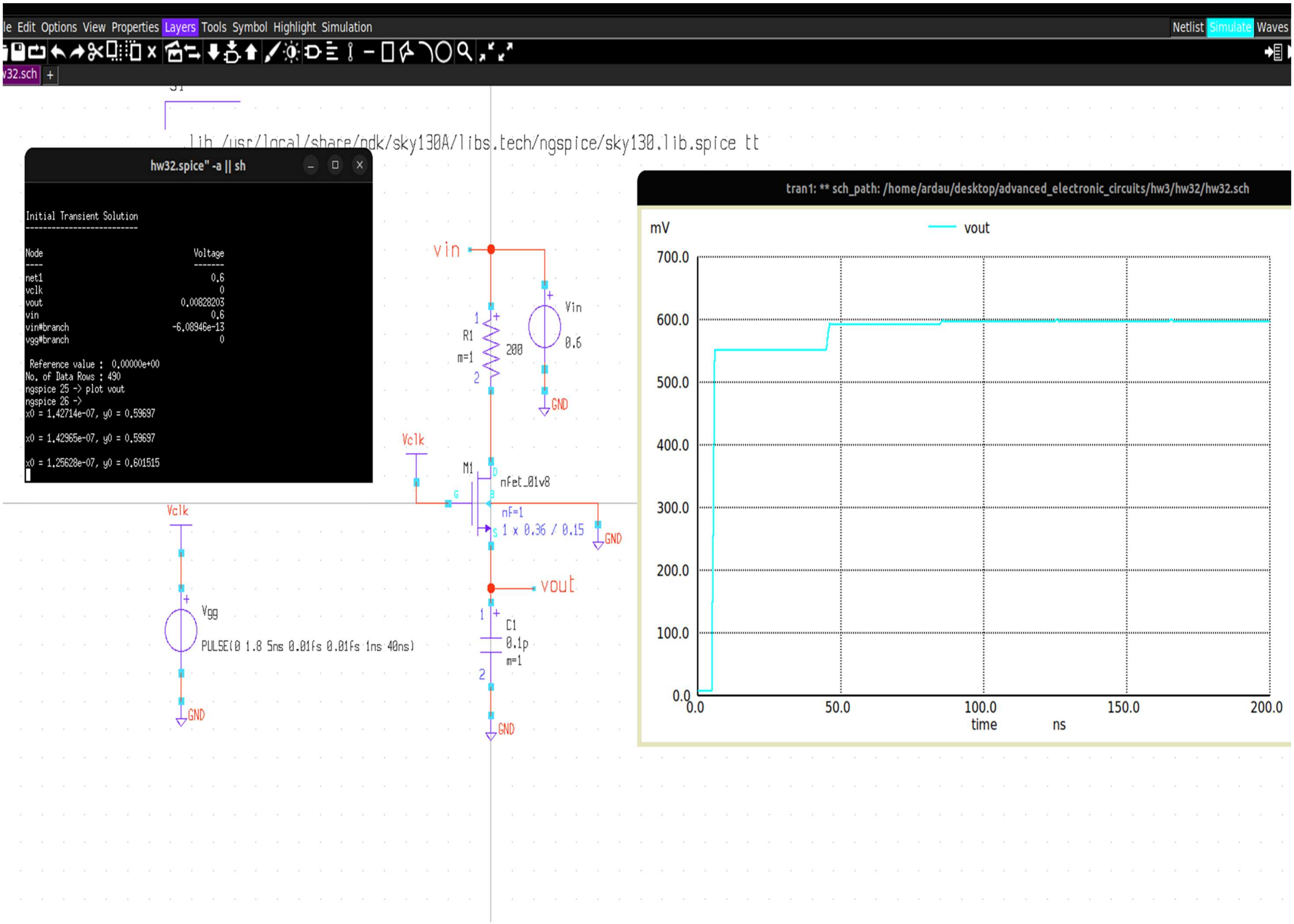
$\Rightarrow$ For $V_{in} = 0.6V$ $V_{out} = 0.5994171V$


le Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate
hw32.spice" -a || sh
Circuit: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw32.sch
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Initial Transient Solution
Node Voltage
net1 0.6
vclk 0
vout 0.00828203
vin 0.6
vin#branch -6.08946e-13
vgg#branch 0
Reference value : 0.00000e+00
No. of Data Rows : 176
ngspice 22 -> plot vout
ngspice 23 ->
x0 = 6.23188e-09, y0 = 0.55283
ky130A/libs.tech/ngspice/sky
vin
R1
m=1
200
Vin
0.6
GND
Vclk
M1
nfet_01v8
nf=1
1 x 0.36 / 0.15
vout
C1
0.1p
m=1
Vgg
PULSE(0 1.8 5ns 0.01fs 0.01fs 1ns 200ns)
tran1: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw32.sch
mV
vout
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
time ns


le Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist
32.sch
hw32.spice" -a || sh
Circuit: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw32.sch
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Initial Transient Solution
Node Voltage
net1 0.6
vclk 0
vout 0.00828203
vin 0.6
vin#branch -6.08946e-13
vgg#branch 0
Reference value : 0.00000e+00
No. of Data Rows : 1071
ngspice 26 -> plot vout
ngspice 27 ->
x0 = 2e-07, y0 = 0.598837
sky130A/libs.tech/ngspice/sky130.lib.spice tt
vin
Vin
0.6
R1
m=1
200
GND
Vclk
M1
nfet_01v8
nf=1
1 x 0.36 / 0.15
vout
C1
0.1p
m=1
Vgg
PULSE(0 1.8 5ns 0.01fs 0.01fs 1ns 40ns)
tran1: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw
mV
vout
time ns



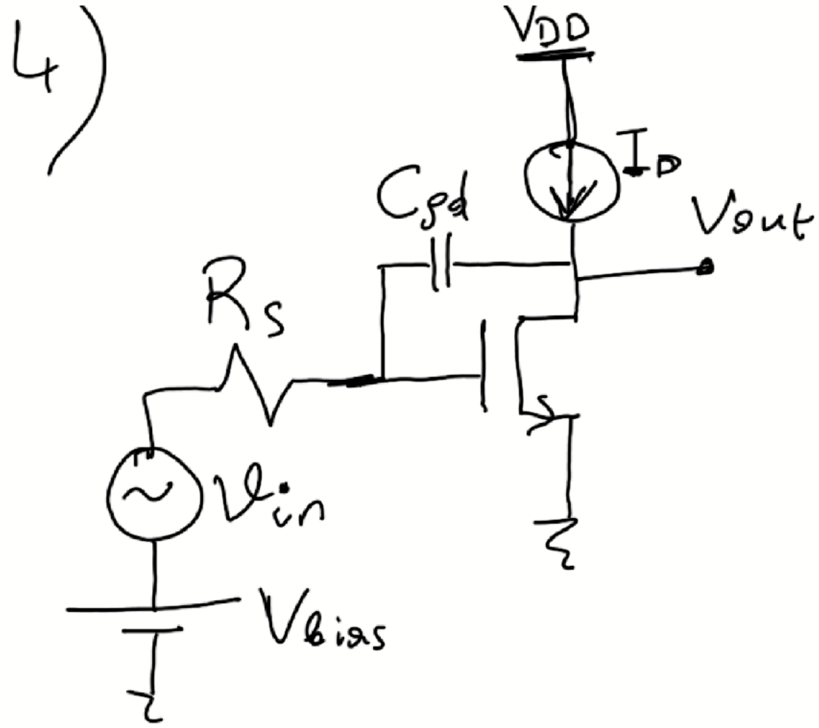
le Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Wave
32.sch
hw32.spice" -a || sh
Circuit: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw32.sch
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Initial Transient Solution
Node Voltage
net1 0.6
vclk 0
vout 0.0260872
vin 0.6
vin#branch -6.26961e-13
vgg#branch 0
Reference value : 0.00000e+00
No. of Data Rows : 1133
ngspice 25 -> plot vout
ngspice 26 ->
x0 = 1.98592e-07, y0 = 0.559459
sky130A/libs.tech/ngspice/s
vin
R1
m=1
200
Vin
0.6
GND
Vclk
M1
nfet_01v8
nf=1
1 x 0.36 / 0.75
vout
C1
0.1p
m=1
Vgg
PULSE(0 1.8 5ns 0.01fs 0.01fs 1ns 40ns)
tran1: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw32.sch
mV
vout
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0
100.0
200.0
300.0
400.0
500.0
time ns
Quit
PostSc
SVG


le Edit Options View Properties Layers Tools Symbol Highlight Simulation
Netlist Simulate Waves
32.sch
.lib /usr/local/share/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
hw32.spice" -a || sh
Initial Transient Solution
Node Voltage
net1 0.6
vclk 0
vout 0.00828203
vin 0.6
vin#branch -6.08946e-13
vgg#branch 0
Reference value : 0.00000e+00
No. of Data Rows : 490
ngspice 25 -> plot vout
ngspice 26 ->
x0 = 1.42714e-07, y0 = 0.59697
x0 = 1.42965e-07, y0 = 0.59697
x0 = 1.25628e-07, y0 = 0.601515
vin
R1
m=1
200
Vin
0.6
GND
Vclk
M1
nfet_01v8
nf=1
1 x 0.36 / 0.15
vout
C1
0.1p
m=1
Vgg
PULSE(0 1.8 5ns 0.01fs 0.01fs 1ns 40ns)
tran1: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw32/hw32.sch
mV
vout
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.0
50.0
100.0
150.0
200.0
time
ns

hw34

Today 01:12 Uncategorized

4)



Let DC operating point is $V_{DD}/2$. Intrinsic gain is

$$A_V = -\frac{2V_A' L}{V_{ov}}$$

Let $V_{ov} = 0.3\ V$

→ Let us take $V_T = 0.6\ V$ for $W = 0.36\mu m$ and $L = 0.15\mu m$

⇒ $V_A = 1.34$ at $V_{GS} = 0.9V$ for this cap., so $A_V = -\frac{2V_A}{V_{ov}} = -\frac{2V_E L}{V_{ov}}$

$$-\frac{2V_E L}{0.3} = -80 \Rightarrow V_E L = 12$$

Let us choose $L = 1{,}75\mu m$, then

$V_E = 6.857\ V/\mu m$ → I do not know if it is possible or not.

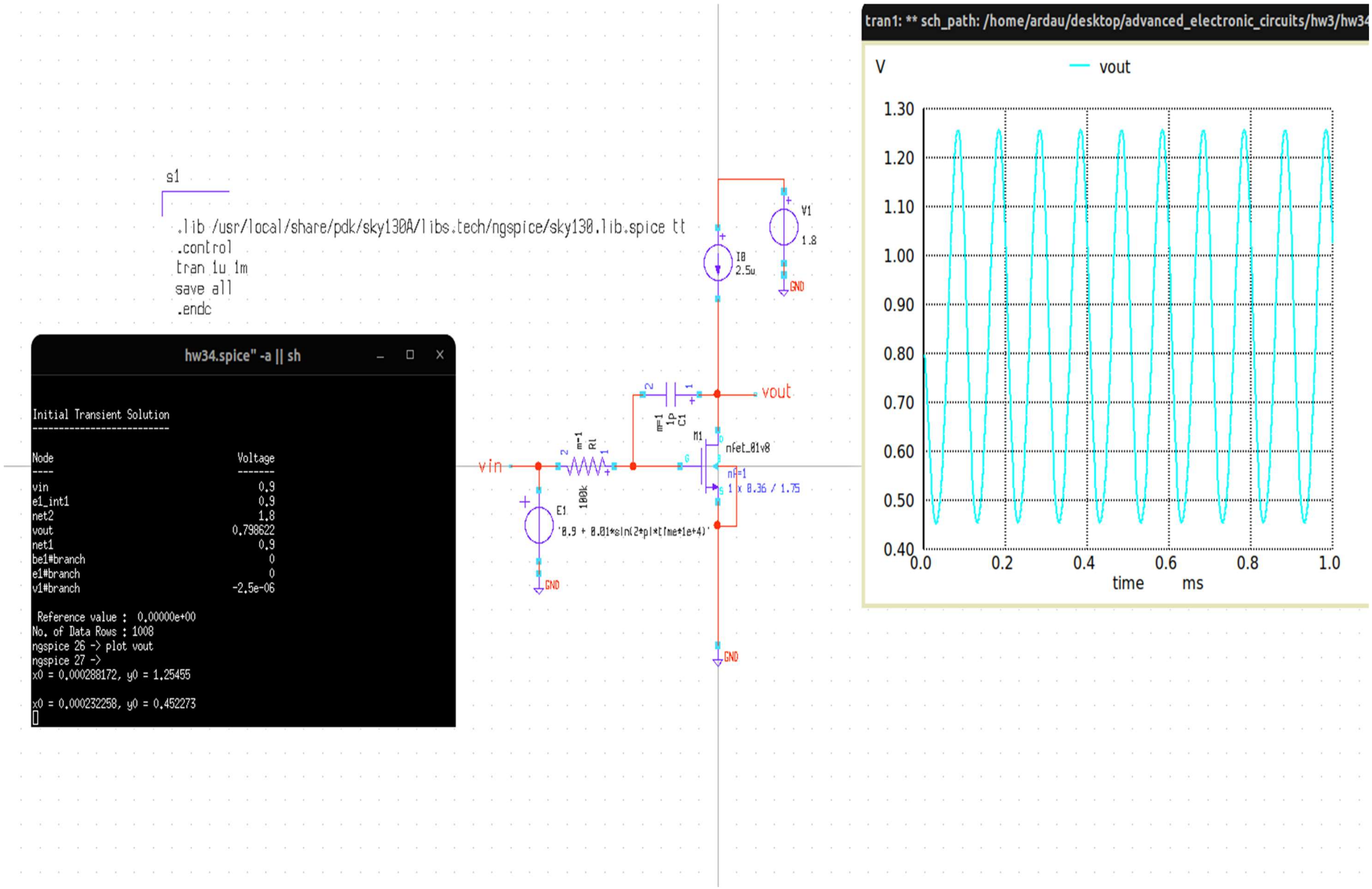
5) Since there is a Miller capacitor, then GB and GBW is limited by capacitance of

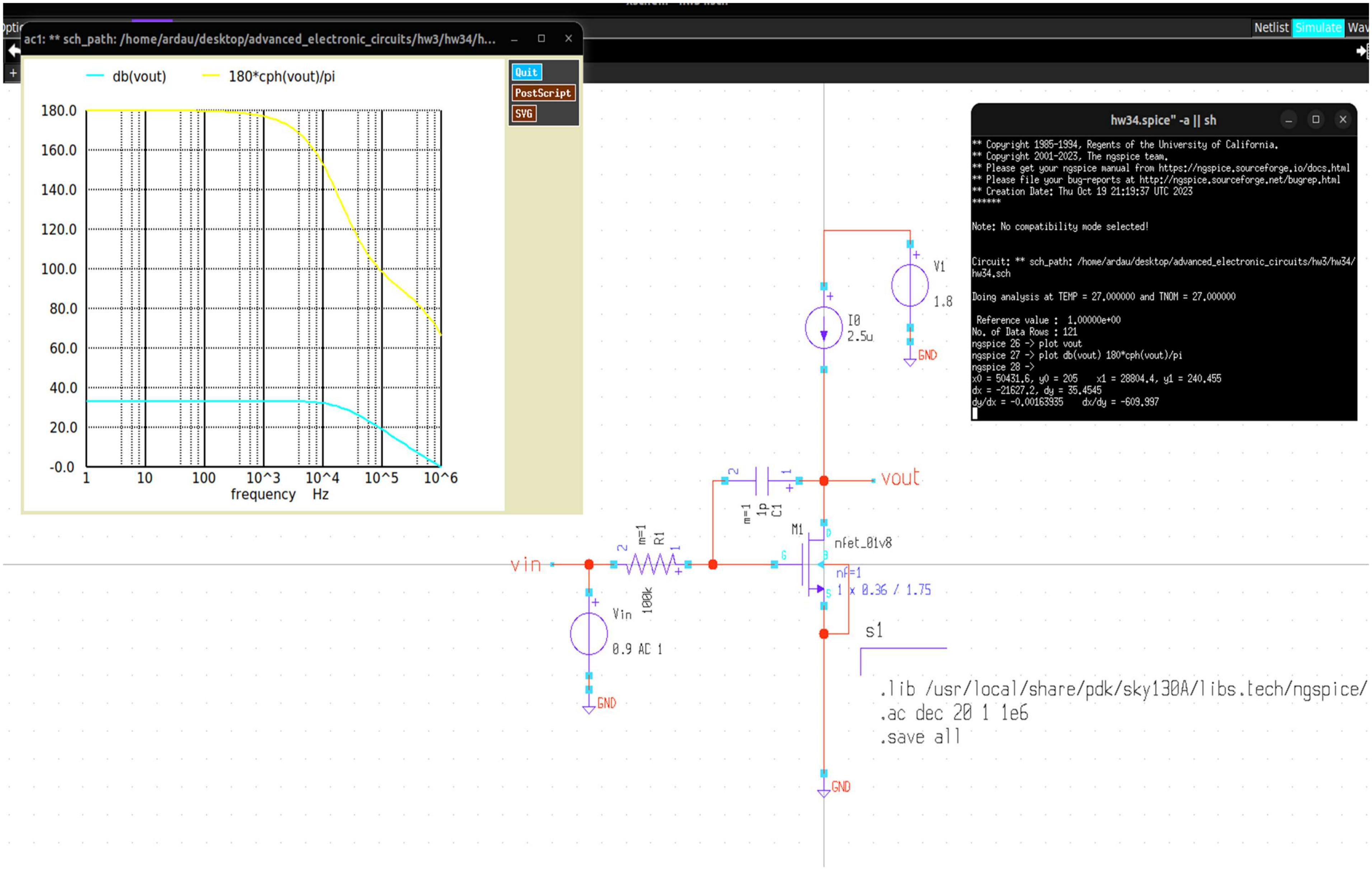
Miller capacitor:

$$BW = \frac{1}{2\pi R_s A_{vo} C_F} = 19884.36 \approx 20kHz$$

$$GBW = \frac{1}{2\pi R_s C_F} = 1591549.4\,Hz$$
$$\cong 1{,}6MHz$$

→ This is the case which feedback cap. is dominant.


s1
.lib /usr/local/share/pdk/sky130A/libs.tech/ngspice/sky130.lib.spice tt
.control
tran 1u 1m
save all
.endc
hw34.spice" -a || sh
Initial Transient Solution
Node Voltage
vin 0.9
e1_int1 0.9
net2 1.8
vout 0.798622
net1 0.9
be1#branch 0
e1#branch 0
v1#branch -2.5e-06
Reference value : 0.00000e+00
No. of Data Rows : 1008
ngspice 26 -> plot vout
ngspice 27 ->
x0 = 0.000288172, y0 = 1.25455
x0 = 0.000232258, y0 = 0.452273
vin
vout
E1
'0.9 + 0.01*sin(2*pi*time*1e+4)'
100k
Rl
m=1
C1
1p
M1
nfet_01v8
nf=1
1 x 0.36 / 1.75
IB
2.5u
V1
1.8
GND
tran1: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw34
V
vout
time ms


ac1: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw34/h...
db(vout)
180*cph(vout)/pi
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
-0.0
1
10
100
10^3
10^4
10^5
10^6
frequency Hz
Quit
PostScript
SVG
Netlist
Simulate
hw34.spice" -a || sh
** 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: Thu Oct 19 21:19:37 UTC 2023
******
Note: No compatibility mode selected!
Circuit: ** sch_path: /home/ardau/desktop/advanced_electronic_circuits/hw3/hw34/hw34.sch
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
Reference value : 1.00000e+00
No. of Data Rows : 121
ngspice 26 -> plot vout
ngspice 27 -> plot db(vout) 180*cph(vout)/pi
ngspice 28 ->
x0 = 50431.6, y0 = 205 x1 = 28804.4, y1 = 240.455
dx = -21627.2, dy = 35.4545
dy/dx = -0.00163935 dx/dy = -609.997
V1
1.8
GND
I0
2.5u
vout
m=1
1p
C1
M1
nfet_01v8
nf=1
1 x 0.36 / 1.75
vin
m=1
R1
100k
Vin
0.9 AC 1
GND
s1
.lib /usr/local/share/pdk/sky130A/libs.tech/ngspice/
.ac dec 20 1 1e6
.save all
GND