

## Module 3 Assignment

### Bandgap Reference Design and Simulation using Xschem

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**Date:** 19<sup>th</sup> Dec '25

**SPICE file used:** inverter\_assign\_2.spice

**Sch file used:** inverter\_assign\_2.sch

**To run DC simulations, and extracting the following metrics from simulation results:**

- Output voltage (Vref) at various VDD values and temperatures.
- Observe the startup behaviour using Transient analysis.
- Record key performance metrics in the table below.

#### Ensuring Unique Results

Including the following trick in my SPICE deck, adding a dummy voltage source:

Runiq net1 net2 <ASCII\_sum\_in\_ohms>

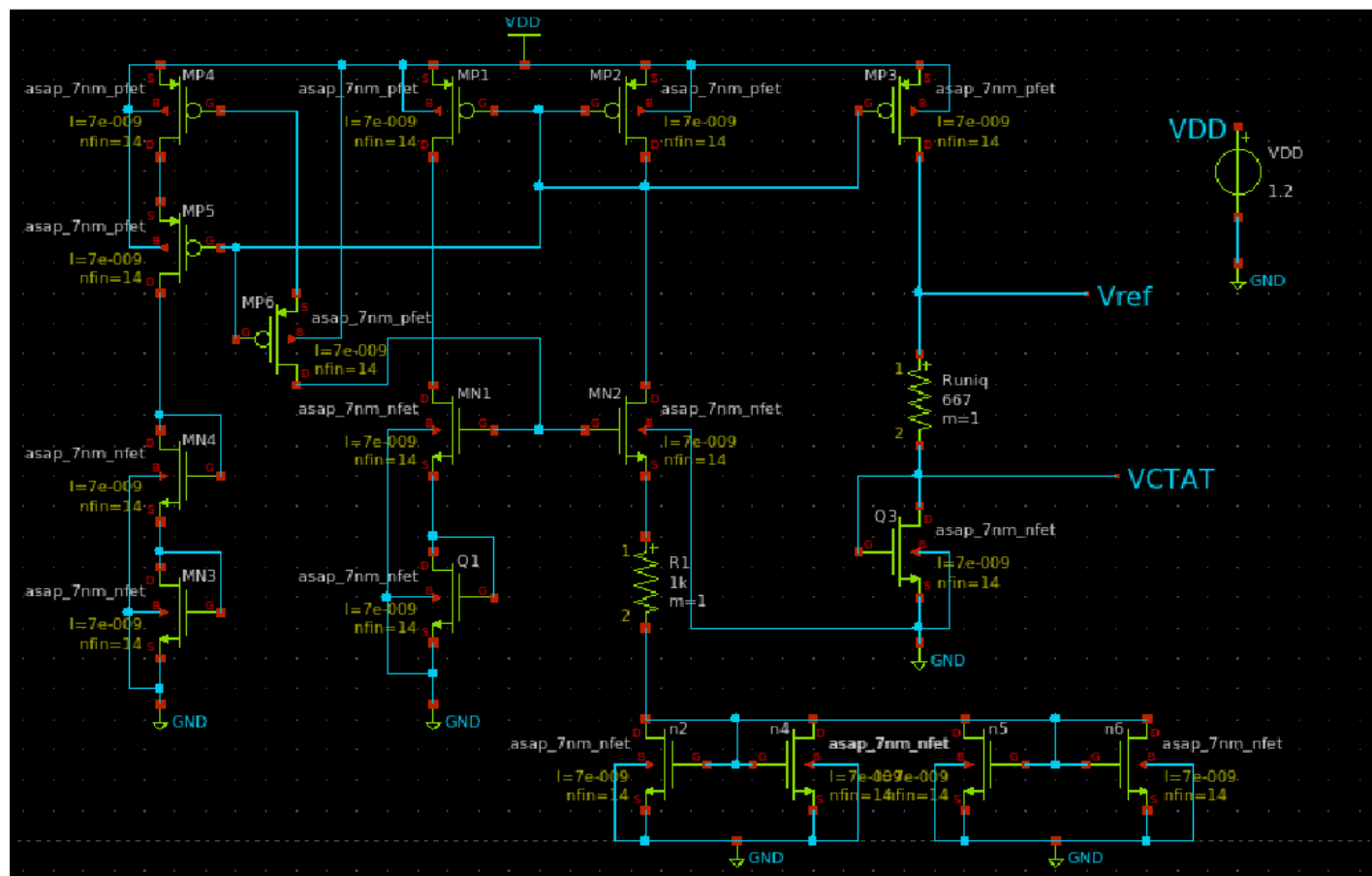
Example: My username is Indrani,

➔ convert to ASCII (73+110+100+82+97+110+105 =677)

Using: Runiq Vref Vctat 677 ac=1k m=1

[This introduces a small offset in simulation, making your result traceable and unique.]

## Xschem Screenshot of BGR Schematic:



CHARACTERIZATION TABLE

Trial no.	V <sub>DD</sub> (in V)	Temp (in °C)	Vref (in V)	Line Regulation (in mV/V)	Startup Time (in ns)
1	0.8	27	0.364217	11.13568	0.012179
2	0.9	27	0.42385	8.53902	0.0089172
3	1	27	0.48543	5.700463	0.00588235
4	1	-40	0.47298	20.1314	0.0040439
5	1.2	125	0.63135	4.851125	0.005641
6	1	60	0.49233	5.700463	0.00666

NTS: Note to self

## SPICE code:

```
** sch_path: /home/vsduser/Desktop/asap_7nm_Xschem/bandgap_assign_2.sch

**.subckt bandgap_assign_2

Xnfet1 net3 net1 net7 net10 asap_7nm_nfet l=7e-009 nfin=14

Xnfet2 net2 net1 net9 net11 asap_7nm_nfet l=7e-009 nfin=14

Xpfet1 net3 net2 VDD net12 asap_7nm_pfet l=7e-009 nfin=14

Xpfet2 net2 net2 VDD net13 asap_7nm_pfet l=7e-009 nfin=14

Xpfet3 Vref net2 VDD net14 asap_7nm_pfet l=7e-009 nfin=14

Xpfet4 net4 net2 VDD net15 asap_7nm_pfet l=7e-009 nfin=14

Xpfet5 net5 net2 net4 net16 asap_7nm_pfet l=7e-009 nfin=14

Xpfet6 net1 net2 net2 net17 asap_7nm_pfet l=7e-009 nfin=14

Xnfet3 net5 net5 net6 net18 asap_7nm_nfet l=7e-009 nfin=14

Xnfet4 net6 net6 GND net19 asap_7nm_nfet l=7e-009 nfin=14

Xnfet5 net7 net7 GND net20 asap_7nm_nfet l=7e-009 nfin=14

Xnfet6 net8 net8 GND GND asap_7nm_nfet l=7e-009 nfin=14

Xnfet7 net8 net8 GND GND asap_7nm_nfet l=7e-009 nfin=14

Xnfet8 net8 net8 GND GND asap_7nm_nfet l=7e-009 nfin=14

Xnfet9 net8 net8 GND GND asap_7nm_nfet l=7e-009 nfin=14

R1 net9 net8 1k ac=1k m=1

Runiq Vref Vctat 677 ac=1k m=1

Xnfet10 Vctat Vctat GND net21 asap_7nm_nfet l=7e-009 nfin=14

V2 vdd GND 1.0           //change/vary the VDD here

**** begin user architecture code
*running dc sweep      (NTS: don't run transient when running DC)
```

```

.dc temp -45 150 5

.control

run

plot v(Vref)

plot v(Vctat)

let vptat = v(Vref) - v(Vctat)

plot vptat

let tc = deriv(v(Vref))/1.24

plot tc

print vref vptat vctat tc

meas dc Vref_max max v(Vref)

meas dc Vref_min min v(Vref)

* Line regulation (mV/V) (NTS: don't run dc when running transient)

let line = (((Vref_max-Vref_min)/(1.2-0.7))*1e3)

meas dc Line_Reg max line

tran 0.1 8n          //NTS: for startup time, graphically

plot v(Vref)

.endc

**** end user architecture code

**.ends

.GLOBAL GND
.GLOBAL VDD

**** begin user architecture code

```

```
.subckt asap_7nm_pfet S G D B l=7e-009 nfin=14
```

```
    npmos_finfet S G D B BSIMCMG_osdi_P l=7e-009 nfin=14
```

```
.ends asap_7nm_pfet
```

```
.model BSIMCMG_osdi_P BSIMCMG_va (
```

```
+ TYPE = 0
```

```
*****
```

```
*          general          *
```

```
*****
```

```
+version = 107      bulkmod = 1      igcmod = 1      igbmod = 0
```

```
+gidlmod = 1      iimod = 0      geomod = 1      rdsmod = 0
```

```
+rgatemod= 0      rgeomod = 0      shmod = 0      nqsmod = 0
```

```
+coremod = 0      cgeomod = 0      capmod = 0      tnom = 25
```

```
+eot = 1e-009      eotbox = 1.4e-007      eotacc = 3e-010      tfin = 6.5e-009
```

```
+toxp = 2.1e-009      nbody = 1e+022      phig = 4.9278      epsrox = 3.9
```

```
+epsrsub = 11.9      easub = 4.05      ni0sub = 1.1e+016      bg0sub = 1.17
```

```
+nc0sub = 2.86e+025      nsd = 2e+026      ngate = 0      nseg = 5
```

```
+l = 2.1e-008      xl = 1e-009      lint = -2.5e-009      dlc = 0
```

```
+dlbin = 0      hfin = 3.2e-008      deltaw = 0      deltawcv= 0
```

```
+sdterm = 0      epsrsp = 3.9      nfin = 1
```

```
+toxg = 1.8e-009
```

```
*****
```

```
*          dc          *
```

```
*****
```

```
+cit = 0      cdsc = 0.003469      cdsd = 0.001486      dvt0 = 0.05
```

```
+dvt1 = 0.36      phin = 0.05      eta0 = 0.094      dsub = 0.24
```

```

+k1rsce = 0      lpe0  = 0      dvtshift= 0      qmfactor= 0

+etaqm  = 0.54      qm0   = 2.183e-012      pqm   = 0.66      u0    = 0.0237

+etamob = 4      up    = 0      ua    = 1.133      eu    = 0.05

+ud     = 0.0105      ucs   = 0.2672      rdswmin = 0      rdsw   = 200

+wr     = 1      rswmin = 0      rdwmin = 0      rshs   = 0

+rshd   = 0      vsat   = 60000      deltavsat= 0.17      ksativ = 1.592

+mexp   = 2.491      ptwg  = 25      pclm   = 0.01      pclmg  = 1

+pdibl1 = 800      pdibl2 = 0.005704      drout  = 4.97      pvag   = 200

+fpitch = 2.7e-008      rth0   = 0.15      cth0   = 1.243e-006      wth0   = 2.6e-007

+lcdscd = 0      lcdscdr = 0      lrdsw  = 1.3      lvsat  = 1441

*****
*              leakage              *
*****

+aigc   = 0.007      bigc   = 0.0015      cigc   = 1      dlcigs = 5e-009

+dlcigd = 5e-009      aigs   = 0.006      aigd   = 0.006      bigs   = 0.001944

+bigd   = 0.001944      cigs   = 1      cigd   = 1      poxedge = 1.152

+agidl  = 2e-012      agisl  = 2e-012      bgidl  = 1.5e+008      bgisl  = 1.5e+008

+egidl  = 1.142      egisl  = 1.142

*****
*              rf              *
*****
*****
*              junction              *
*****
*****
*              capacitance              *
*****

```

+cfs = 0            cfd = 0            cgso = 1.6e-010      cgdo = 1.6e-010

+cgsl = 0            cgdI = 0            ckappas = 0.6          ckappad = 0.6

+cgbo = 0            cgbl = 0

\*\*\*\*\*

\*                    temperature                    \*

\*\*\*\*\*

+tbgasub = 0.000473      tbgbsub = 636            kt1 = 0            kt1l = 0

+ute = -1.2            utl = 0            ua1 = 0.001032      ud1 = 0

+ucste = -0.004775      at = 0.001          ptwgt = 0.004          tmexp = 0

+prt = 0            tgidl = -0.007      igt = 2.5

\*\*\*\*\*

\*                    noise                    \*

\*\*\*\*\*

\*\*) )

.control

pre\_osdi /home/vsduser/Desktop/asap\_7nm\_Xschem/bsimcmg.osdi

.endc

.subckt asap\_7nm\_nfet S G D B l=7e-009 nfin=14

        nnmos\_finfet S G D B BSIMCMG\_osdi\_N l=7e-009 nfin=14

.ends asap\_7nm\_nfet

.model BSIMCMG\_osdi\_N BSIMCMG\_va (

+ TYPE = 1

\*\*\*\*\*

\*                    general                    \*

\*\*\*\*\*

```

+version = 107      bulkmod = 1      igcmod = 1      igbmod = 0

+gidlmod = 1      iimod = 0      geomod = 1      rdsmod = 0

+rgatemod= 0      rgeomod = 0      shmod = 0      nqsmode = 0

+coremod = 0      cgeomod = 0      capmod = 0      tnom = 25

+eot = 1e-009      eotbox = 1.4e-007      eotacc = 1e-010      tfin = 6.5e-009

+toxp = 2.1e-009      nbody = 1e+022      phig = 4.2466      epsrox = 3.9

+epsrsub = 11.9      easub = 4.05      ni0sub = 1.1e+016      bg0sub = 1.17

+nc0sub = 2.86e+025      nsd = 2e+026      ngate = 0      nseg = 5

+li = 2.1e-008      xli = 1e-009      lint = -2e-009      dlc = 0

+dlbin = 0      hfin = 3.2e-008      deltaw = 0      deltawcv= 0

+sdterm = 0      epsrsp = 3.9      nfin = 1

+toxg = 1.80e-009

```

```

*****
*              dc              *
*****

```

```

+cit = 0      cdsc = 0.01      cdsd = 0.01      dvt0 = 0.05

+dvt1 = 0.47      phin = 0.05      eta0 = 0.07      dsub = 0.35

+k1rsce = 0      lpe0 = 0      dvtshift= 0      qmfactor= 2.5

+etaqm = 0.54      qm0 = 0.001      pqm = 0.66      u0 = 0.0303

+etamob = 2      up = 0      ua = 0.55      eu = 1.2

+ud = 0      ucs = 1      rdswmin = 0      rdsw = 200

+wr = 1      rswmin = 0      rdwmin = 0      rshs = 0

+rshd = 0      vsat = 70000      deltavsat= 0.2      ksativ = 2

```



+mexp = 4            ptwg = 30            pclm = 0.05            pclmg = 0  
+pdibl1 = 0            pdibl2 = 0.002            drout = 1            pvag = 0  
+fpitch = 2.7e-008            rth0 = 0.225            cth0 = 1.243e-006            wth0 = 2.6e-007  
+lcdscd = 5e-005            lcdscdr = 5e-005            lrdsw = 0.2            lvsat = 0

\*\*\*\*\*  
\*                    leakage                    \*  
\*\*\*\*\*

+aigc = 0.014            bigc = 0.005            cigc = 0.25            dlcigs = 1e-009  
+dlcigd = 1e-009            aigs = 0.0115            aigd = 0.0115            bigs = 0.00332  
+bigd = 0.00332            cigs = 0.35            cigd = 0.35            poxedge = 1.1  
+agidl = 1e-012            agisl = 1e-012            bgidl = 10000000            bgisl = 10000000  
+egidl = 0.35            egisl = 0.35

\*\*\*\*\*  
\*                    rf                    \*  
\*\*\*\*\*  
\*\*\*\*\*  
\*                    junction                    \*  
\*\*\*\*\*  
\*\*\*\*\*  
\*                    capacitance                    \*  
\*\*\*\*\*

+cfs = 0            cfd = 0            cgso = 1.6e-010            cgdo = 1.6e-010  
+cgsl = 0            cgdl = 0            ckappas = 0.6            ckappad = 0.6  
+cgbo = 0            cgbl = 0

\*\*\*\*\*  
\*                    temperature                    \*  
\*\*\*\*\*  
+tbgasub = 0.000473            tbgasub = 636            kt1 = 0            kt1l = 0

+ute = -0.7            utl = 0            ua1 = 0.001032            ud1 = 0  
+ucste = -0.004775            at = 0.001            ptwgt = 0.004            tmexp = 0

+prt = 0            tgidl = -0.007            igt = 2.5

\*\*\*\*\*

\*                    noise                    \*

\*\*\*\*\*)

.control

pre\_osdi /home/vsduser/Desktop/asap\_7nm\_Xschem/bsimcmg.osdi

.endc

\*\*\*\* end user architecture code

.end

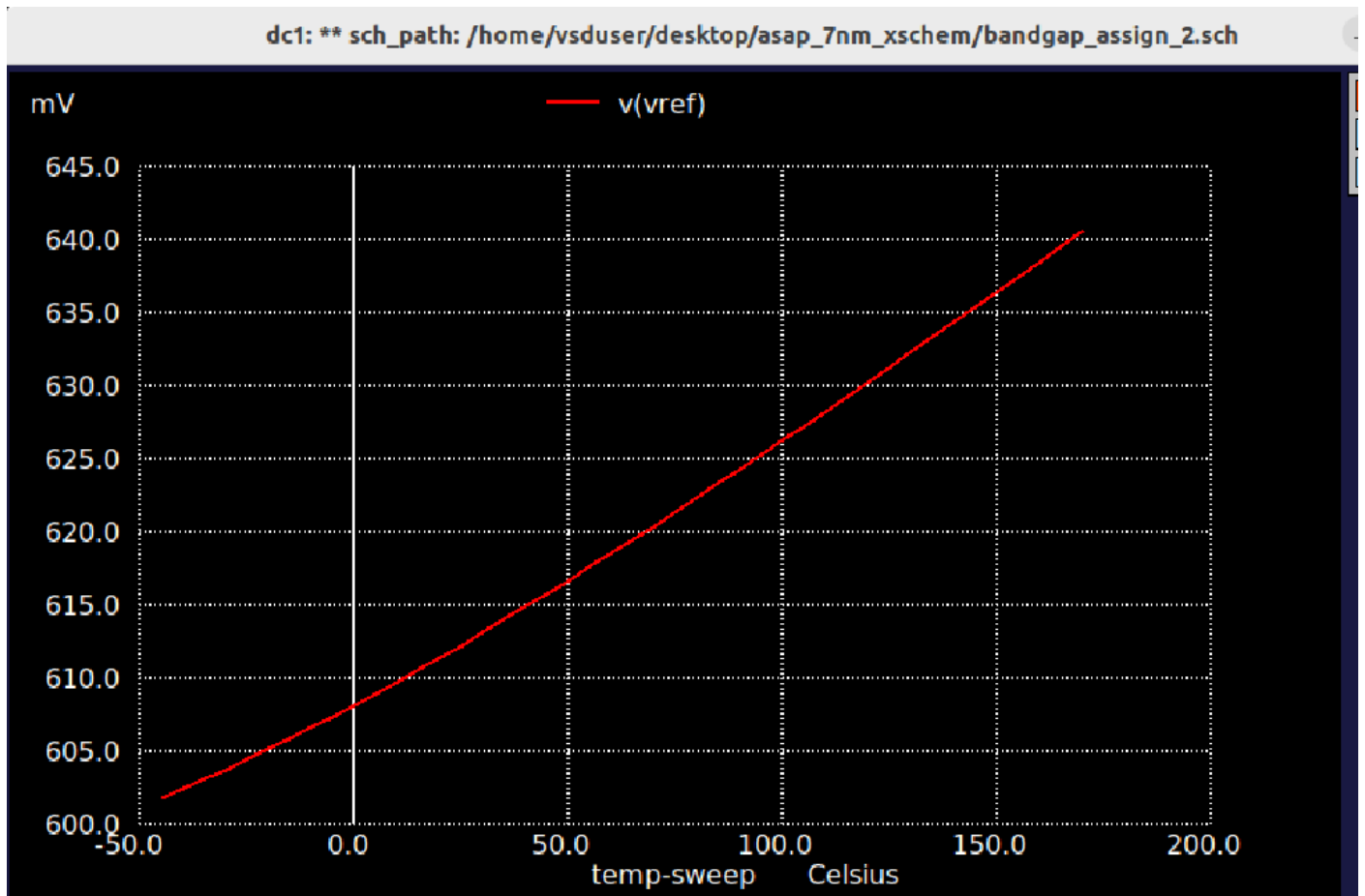
## Graphs for the BGR Sims:

Index	temp-sweep	vref	vptat	vctat
0	-4.50000e+01	6.018565e-01	2.048193e-01	3.970372e-01
1	-4.00000e+01	6.024848e-01	2.051042e-01	3.973806e-01
2	-3.50000e+01	6.031357e-01	2.054165e-01	3.977192e-01
3	-3.00000e+01	6.038068e-01	2.057538e-01	3.980530e-01
4	-2.50000e+01	6.044973e-01	2.061146e-01	3.983827e-01
5	-2.00000e+01	6.052065e-01	2.064974e-01	3.987091e-01
6	-1.50000e+01	6.059339e-01	2.069010e-01	3.990328e-01
7	-1.00000e+01	6.066786e-01	2.073242e-01	3.993544e-01
8	-5.00000e+00	6.074401e-01	2.077656e-01	3.996744e-01
9	0.00000e+00	6.082177e-01	2.082243e-01	3.999934e-01
10	5.00000e+00	6.090109e-01	2.086991e-01	4.003118e-01
11	1.00000e+01	6.098190e-01	2.091889e-01	4.006300e-01
12	1.50000e+01	6.106414e-01	2.096929e-01	4.009485e-01
13	2.00000e+01	6.114776e-01	2.102100e-01	4.012676e-01
14	2.50000e+01	6.123271e-01	2.107394e-01	4.015877e-01
15	3.00000e+01	6.131893e-01	2.112803e-01	4.019090e-01
16	3.50000e+01	6.140636e-01	2.118318e-01	4.022318e-01
17	4.00000e+01	6.149495e-01	2.123931e-01	4.025564e-01
18	4.50000e+01	6.158467e-01	2.129636e-01	4.028831e-01
19	5.00000e+01	6.167544e-01	2.135425e-01	4.032119e-01
20	5.50000e+01	6.176724e-01	2.141291e-01	4.035432e-01
21	6.00000e+01	6.186000e-01	2.147229e-01	4.038771e-01
22	6.50000e+01	6.195369e-01	2.153231e-01	4.042138e-01
23	7.00000e+01	6.204826e-01	2.159292e-01	4.045533e-01
24	7.50000e+01	6.214366e-01	2.165407e-01	4.048959e-01
25	8.00000e+01	6.223986e-01	2.171569e-01	4.052417e-01
26	8.50000e+01	6.233681e-01	2.177775e-01	4.055907e-01
27	9.00000e+01	6.243448e-01	2.184018e-01	4.059430e-01
28	9.50000e+01	6.253282e-01	2.190294e-01	4.062988e-01
29	1.00000e+02	6.263180e-01	2.196599e-01	4.066581e-01
30	1.05000e+02	6.273137e-01	2.202928e-01	4.070210e-01
31	1.10000e+02	6.283152e-01	2.209277e-01	4.073875e-01
32	1.15000e+02	6.293219e-01	2.215642e-01	4.077578e-01
33	1.20000e+02	6.303337e-01	2.222019e-01	4.081318e-01
34	1.25000e+02	6.313501e-01	2.228405e-01	4.085096e-01
35	1.30000e+02	6.323700e-01	2.234796e-01	4.088914e-01

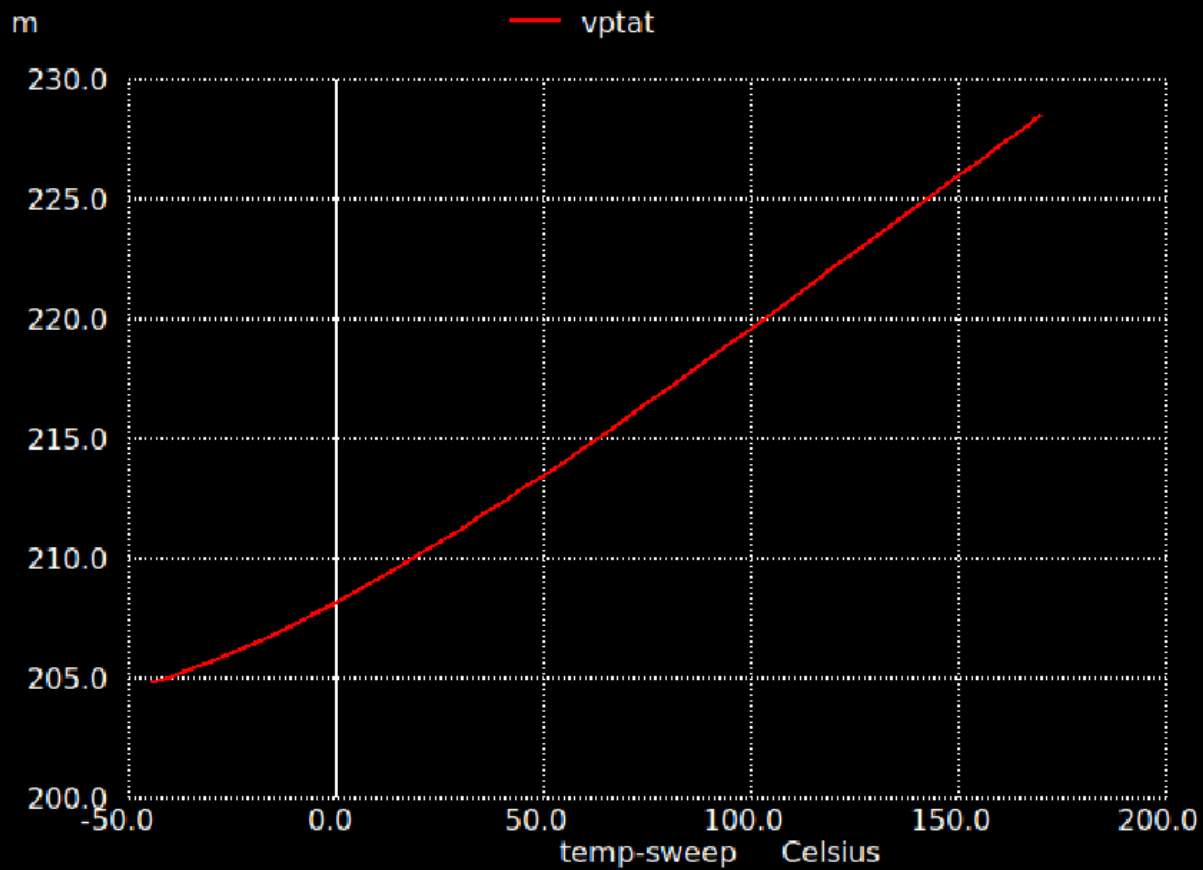
Temperature Sweep with Vref, VCTAT and VPTAT values

Index	temp-sweep	tc
0	-4.50000e+01	9.952843e-05
1	-4.00000e+01	1.031663e-04
2	-3.50000e+01	1.066106e-04
3	-3.00000e+01	1.098035e-04
4	-2.50000e+01	1.128827e-04
5	-2.00000e+01	1.158516e-04
6	-1.50000e+01	1.187128e-04
7	-1.00000e+01	1.214689e-04
8	-5.00000e+00	1.241227e-04
9	0.00000e+00	1.266766e-04
10	5.00000e+00	1.291332e-04
11	1.00000e+01	1.314950e-04
12	1.50000e+01	1.337641e-04
13	2.00000e+01	1.359430e-04
14	2.50000e+01	1.380336e-04
15	3.00000e+01	1.400382e-04
16	3.50000e+01	1.419586e-04
17	4.00000e+01	1.437968e-04
18	4.50000e+01	1.455547e-04
19	5.00000e+01	1.472342e-04
20	5.50000e+01	1.488372e-04
21	6.00000e+01	1.503654e-04
22	6.50000e+01	1.518207e-04
23	7.00000e+01	1.532049e-04
24	7.50000e+01	1.545199e-04
25	8.00000e+01	1.557676e-04
26	8.50000e+01	1.569499e-04
27	9.00000e+01	1.580687e-04
28	9.50000e+01	1.591261e-04
29	1.00000e+02	1.601239e-04
30	1.05000e+02	1.610644e-04
31	1.10000e+02	1.619497e-04
32	1.15000e+02	1.627819e-04
33	1.20000e+02	1.635632e-04
34	1.25000e+02	1.642959e-04

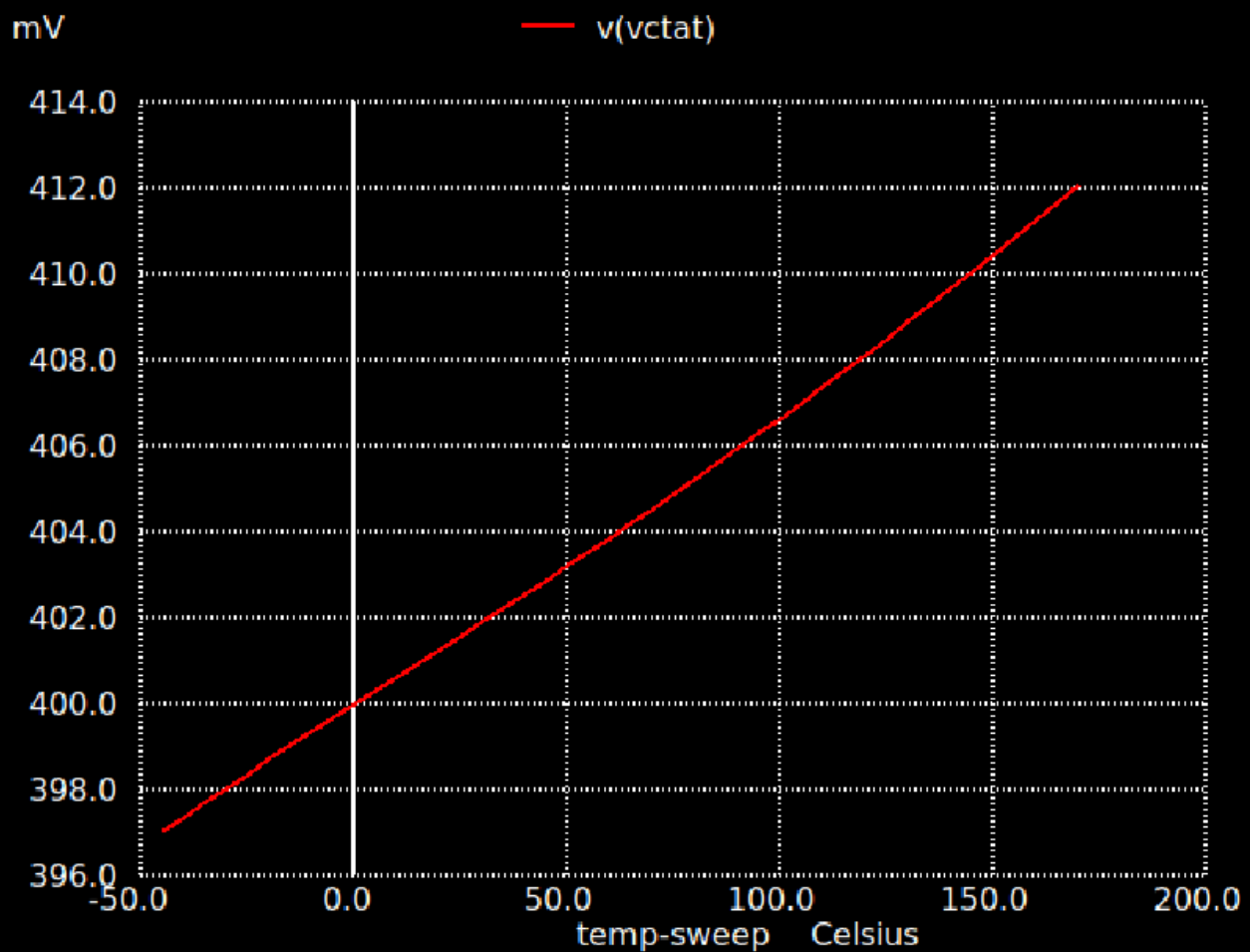
Temperature Sweep with Temperature-Coefficient values

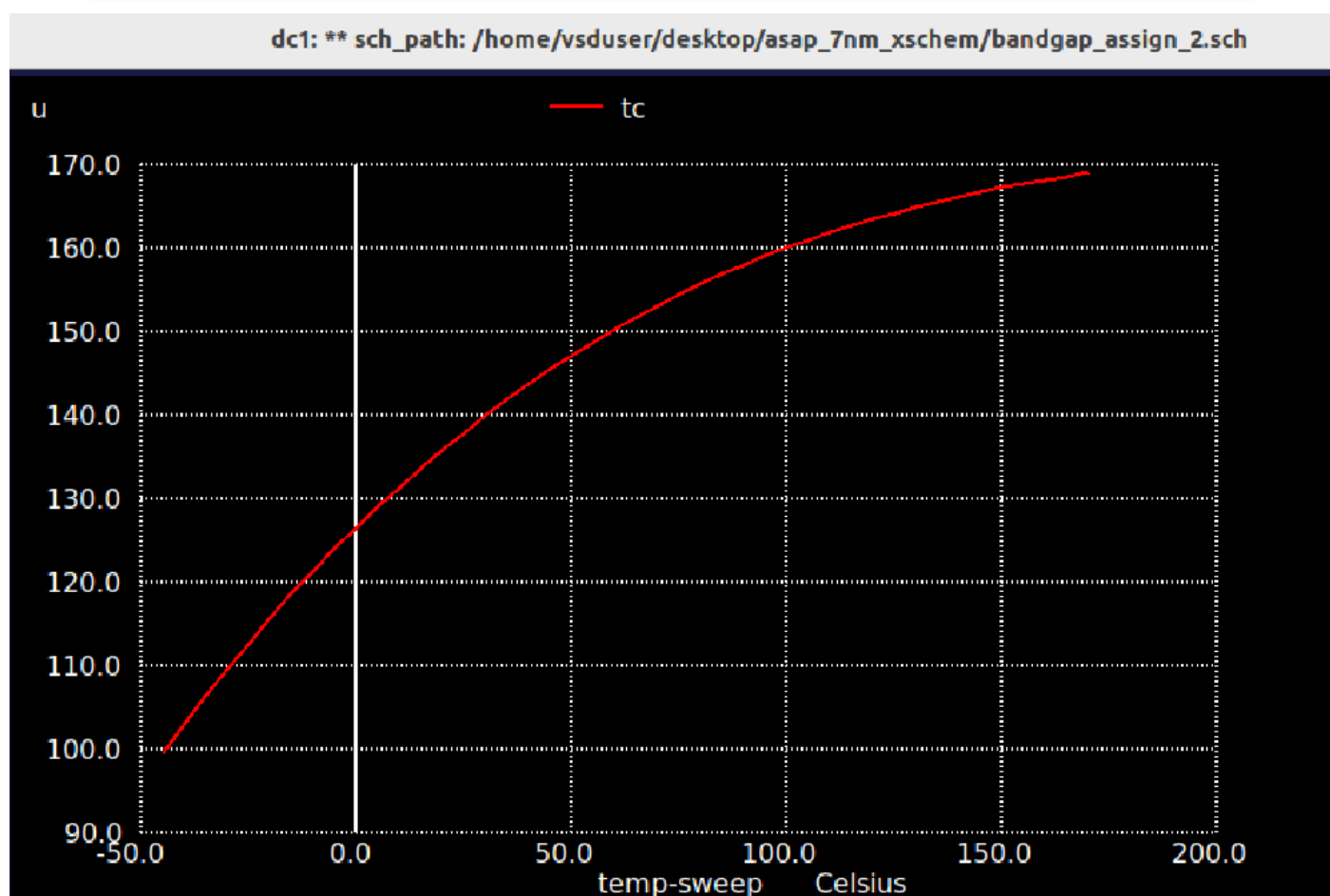
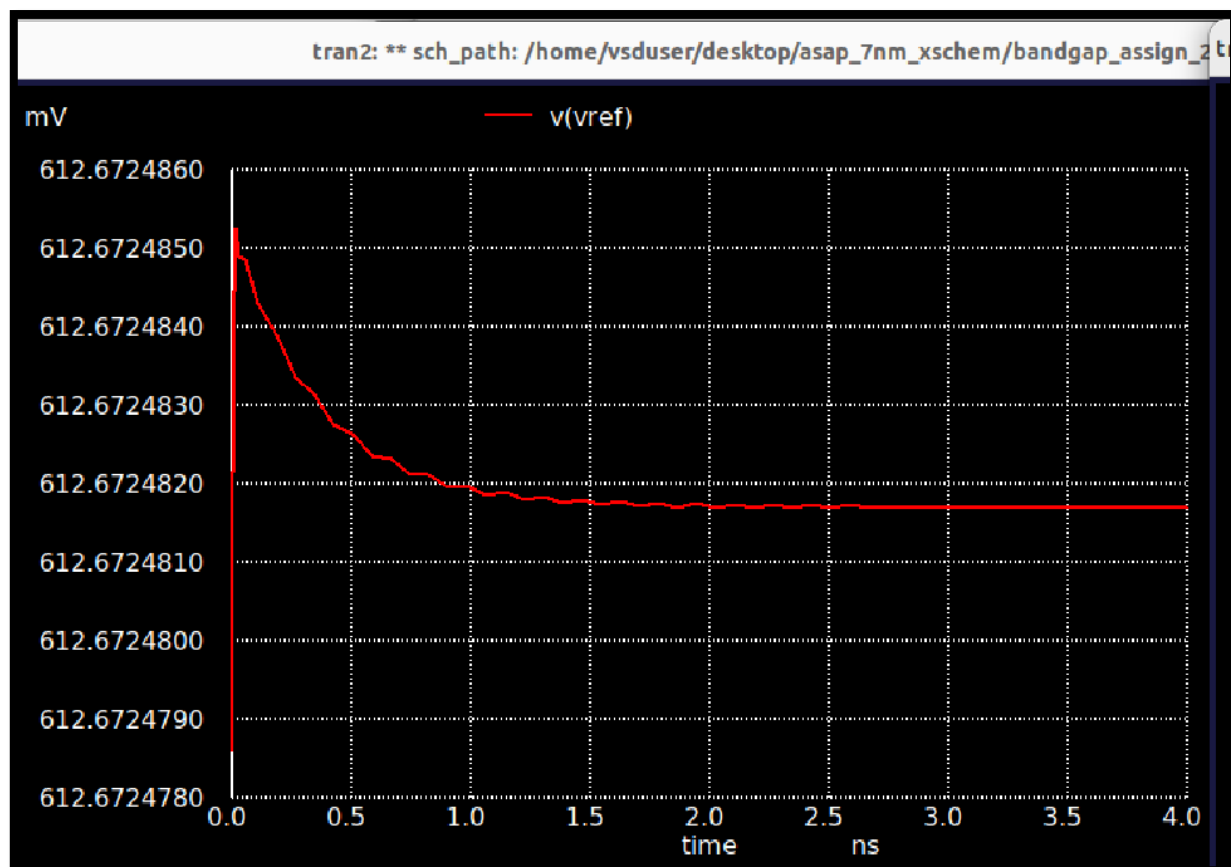


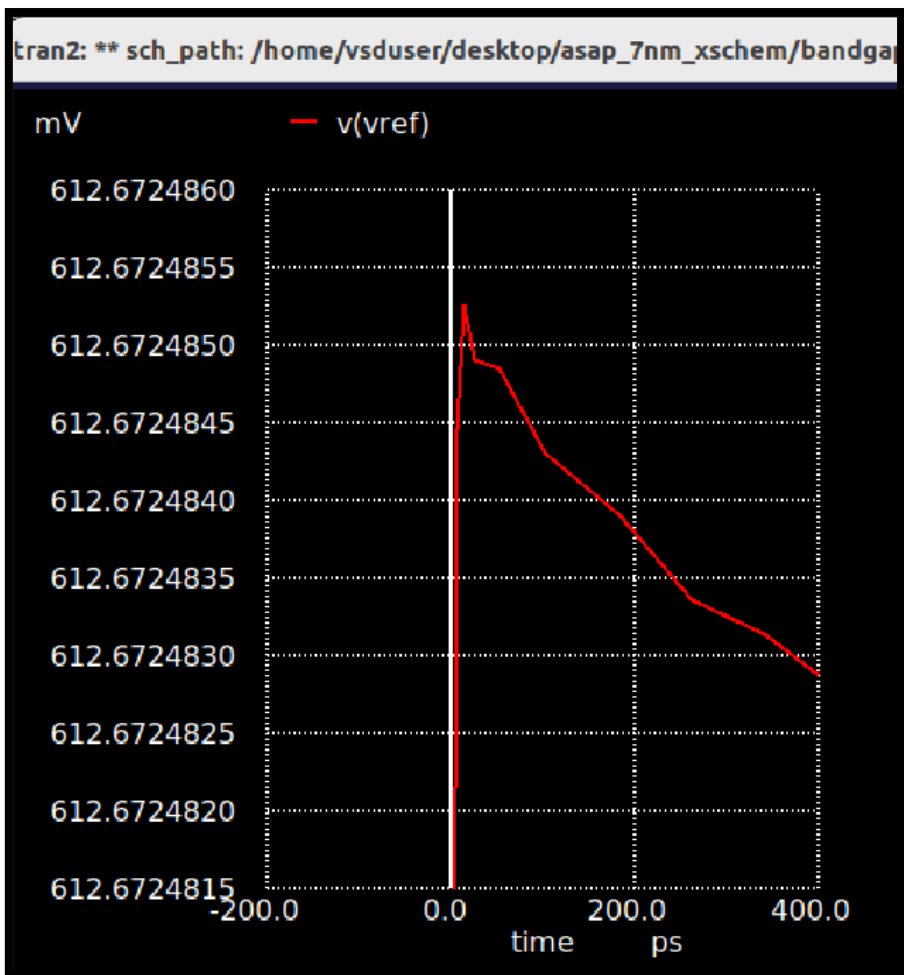
dc1: \*\* sch\_path: /home/vsduser/desktop/asap\_7nm\_xschem/bandgap\_assign\_2.sch



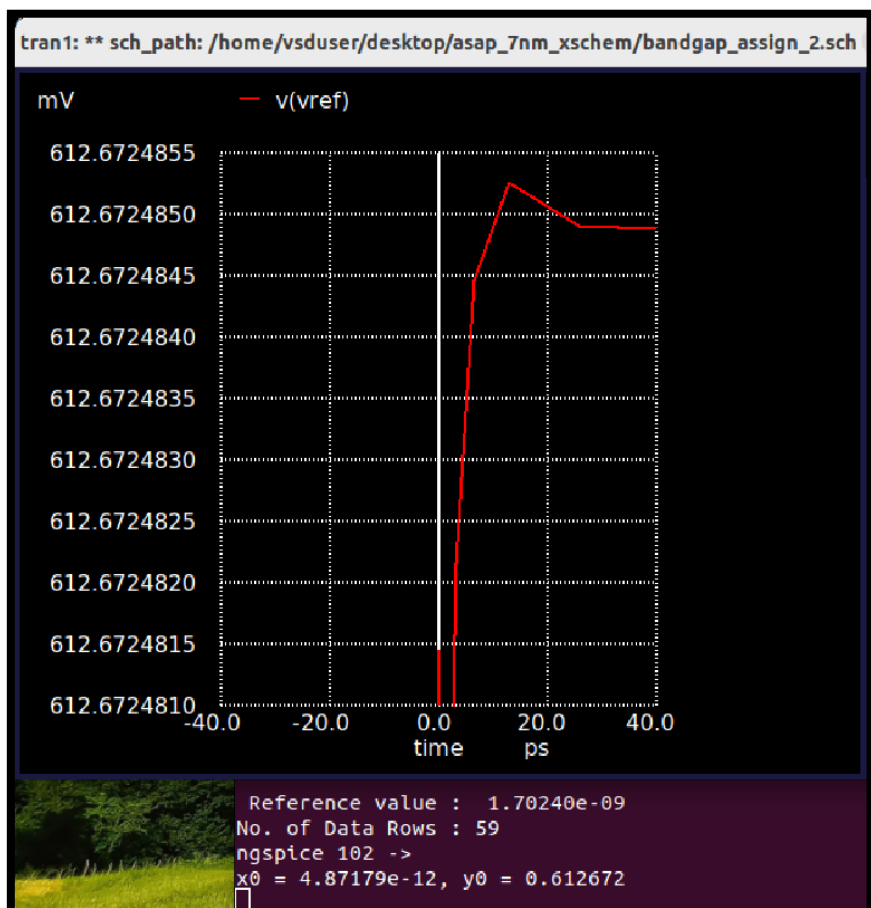
dc1: \*\* sch\_path: /home/vsduser/desktop/asap\_7nm\_xschem/bandgap\_assign\_2.sch







Vref - Transient Graph



Start-up time obtained graphically

```
unrecognized parameter (capmod) - ignored
unrecognized parameter (nseg) - ignored
unrecognized parameter (etaqm) - ignored

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver
Note: Starting dynamic gmin stepping
Note: Dynamic gmin stepping completed
Reference value : -4.50000e+01
No. of Data Rows : 40
vref_max      = 4.521347e-01 at= 1.500000e+02
vref_min      = 4.094396e-01 at= -4.500000e+01
line_reg      = 8.539020e+01 at= -4.500000e+01
ngspice 157 ->
```

Line regulation computed