

Module 3 Assignment

Bandgap Reference Design and Simulation using Xschem

Name: Indrani Aekabote

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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>

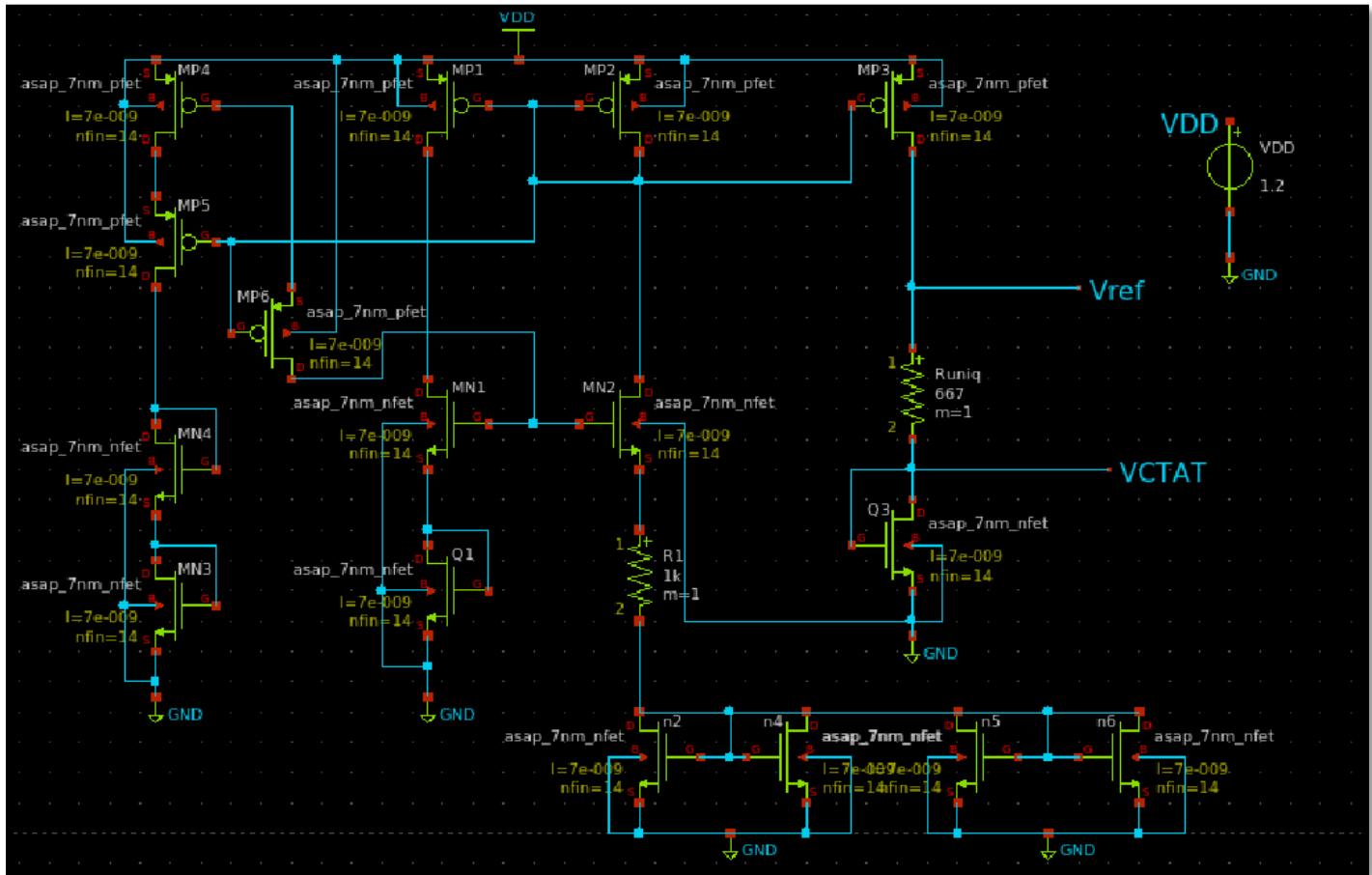
Example: My username is Indrani,

→ 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_{DD} (in V)	Temp (in °C)	V_{ref} (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
+ratemod= 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
+il = 2.1e-008      xl = 1e-009      lint = -2.5e-009      dlc = 0
+dlbin = 0      hfin = 3.2e-008      deltarw = 0      deltarwcv= 0
+sdterm = 0      epsrsp = 3.9      nfin = 1
+toxg = 1.8e-009

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


+cit = 0      cdsc = 0.003469      cdscd = 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      lrdswo = 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 cgdl = 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 nqsmod = 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
+l = 2.1e-008 xl = 1e-009 lint = -2e-009 dlc = 0
+dlbin = 0 hfin = 3.2e-008 deltarw = 0 deltarwcv= 0
+sdterm = 0 epsrsp = 3.9 nfin = 1
+toxg = 1.80e-009

* dc *

+cit = 0 cdsc = 0.01 cdscd = 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       droutr = 1          pvag   = 0
+fpitch = 2.7e-008    rth0   = 0.225       cth0   = 1.243e-006   wth0   = 2.6e-007
+lcdscd = 5e-005      lcdscdr= 5e-005      lrdsrw = 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
+cgb0  = 0          cgbl   = 0

*****
*           temperature      *
*****
+tbgasub = 0.000473    tbgbsub = 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
```

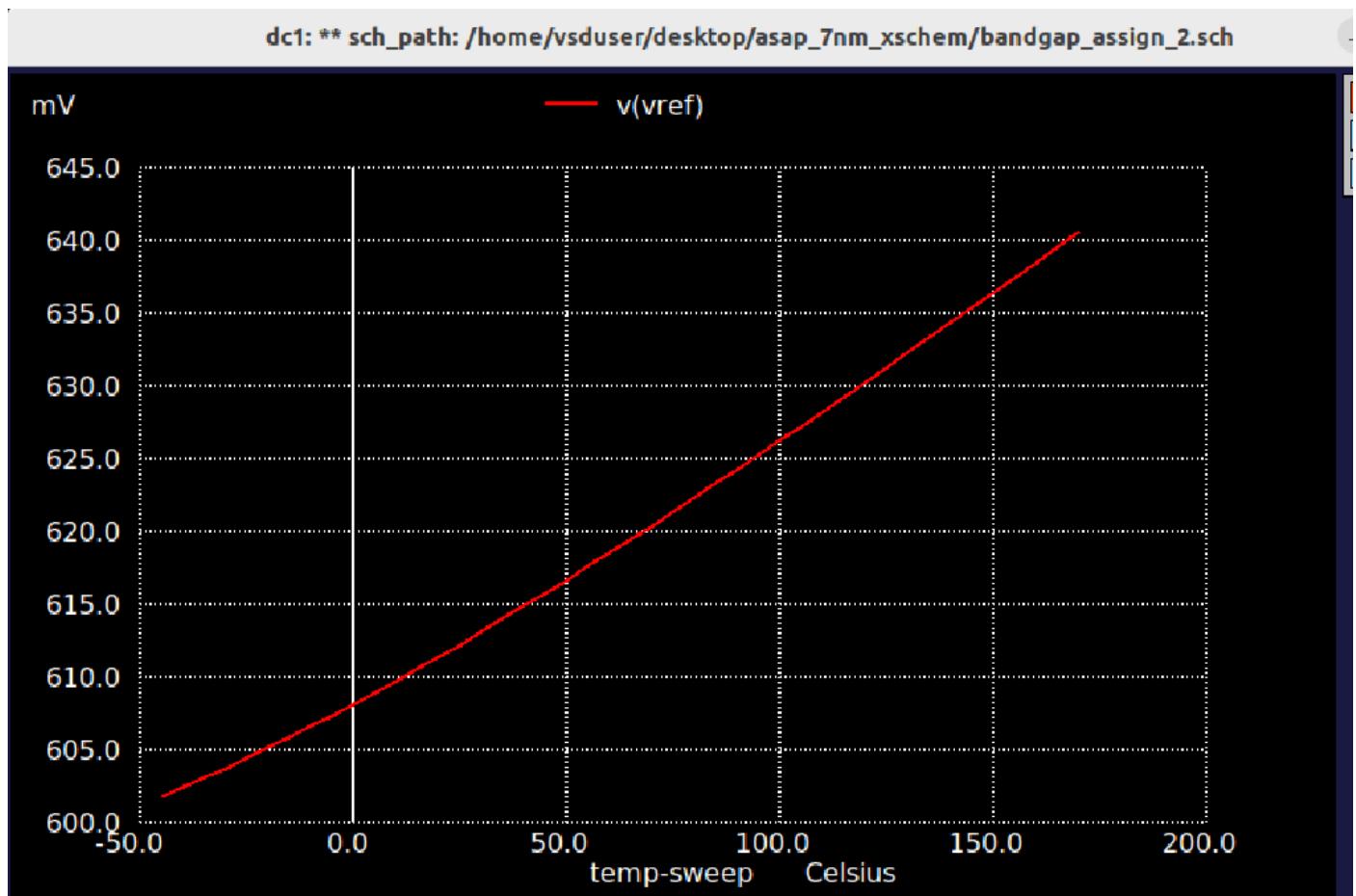
Graphs for the BGR Sims:

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	0.000000e+00	6.082177e-01	2.082243e-01	3.999934e-01
10	5.000000e+00	6.090109e-01	2.086991e-01	4.003118e-01
11	1.000000e+01	6.098190e-01	2.091889e-01	4.006300e-01
12	1.500000e+01	6.106414e-01	2.096929e-01	4.009485e-01
13	2.000000e+01	6.114776e-01	2.102100e-01	4.012676e-01
14	2.500000e+01	6.123271e-01	2.107394e-01	4.015877e-01
15	3.000000e+01	6.131893e-01	2.112803e-01	4.019090e-01
16	3.500000e+01	6.140636e-01	2.118318e-01	4.022318e-01
17	4.000000e+01	6.149495e-01	2.123931e-01	4.025564e-01
18	4.500000e+01	6.158467e-01	2.129636e-01	4.028831e-01
19	5.000000e+01	6.167544e-01	2.135425e-01	4.032119e-01
20	5.500000e+01	6.176724e-01	2.141291e-01	4.035432e-01
21	6.000000e+01	6.186000e-01	2.147229e-01	4.038771e-01
22	6.500000e+01	6.195369e-01	2.153231e-01	4.042138e-01
23	7.000000e+01	6.204826e-01	2.159292e-01	4.045533e-01
24	7.500000e+01	6.214366e-01	2.165407e-01	4.048959e-01
25	8.000000e+01	6.223986e-01	2.171569e-01	4.052417e-01
26	8.500000e+01	6.233681e-01	2.177775e-01	4.055907e-01
27	9.000000e+01	6.243448e-01	2.184018e-01	4.059430e-01
28	9.500000e+01	6.253282e-01	2.190294e-01	4.062988e-01
29	1.000000e+02	6.263180e-01	2.196599e-01	4.066581e-01
30	1.050000e+02	6.273137e-01	2.202928e-01	4.070210e-01
31	1.100000e+02	6.283152e-01	2.209277e-01	4.073875e-01
32	1.150000e+02	6.293219e-01	2.215642e-01	4.077578e-01
33	1.200000e+02	6.303337e-01	2.222019e-01	4.081318e-01
34	1.250000e+02	6.313501e-01	2.228405e-01	4.085096e-01
35	1.300000e+02	6.323700e-01	2.234706e-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

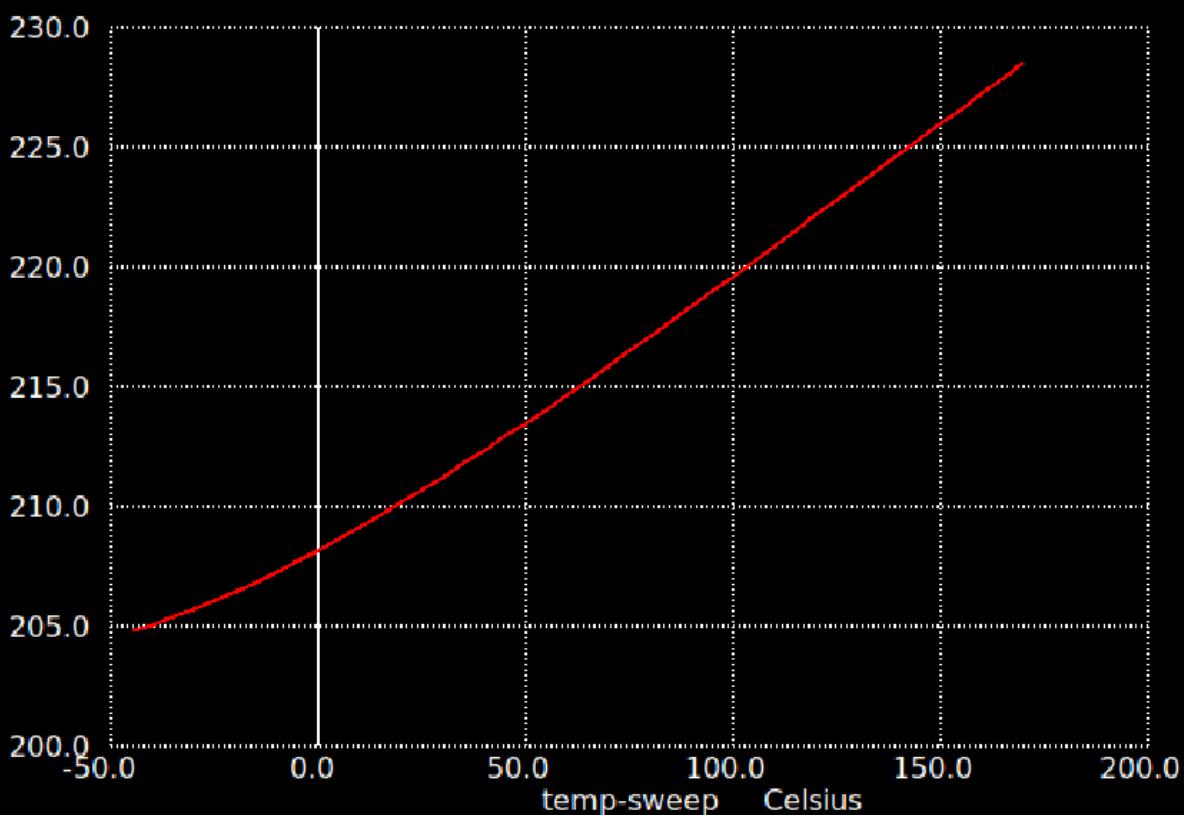
Temperature Sweep with Temperature-Coefficient values



dc1: ** sch_path: /home/vsduser/Desktop/asap_7nm_xschem/bandgap_assign_2.sch

m

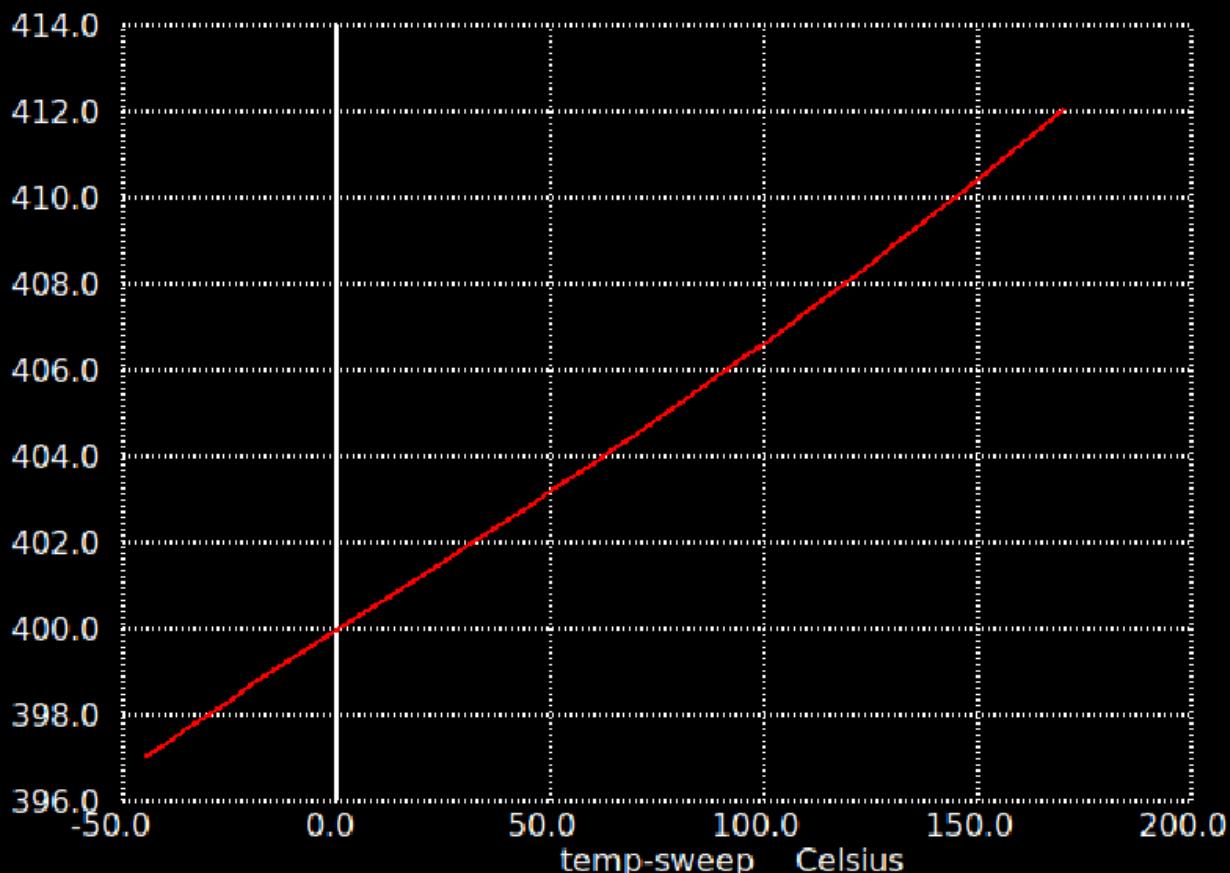
— vptat

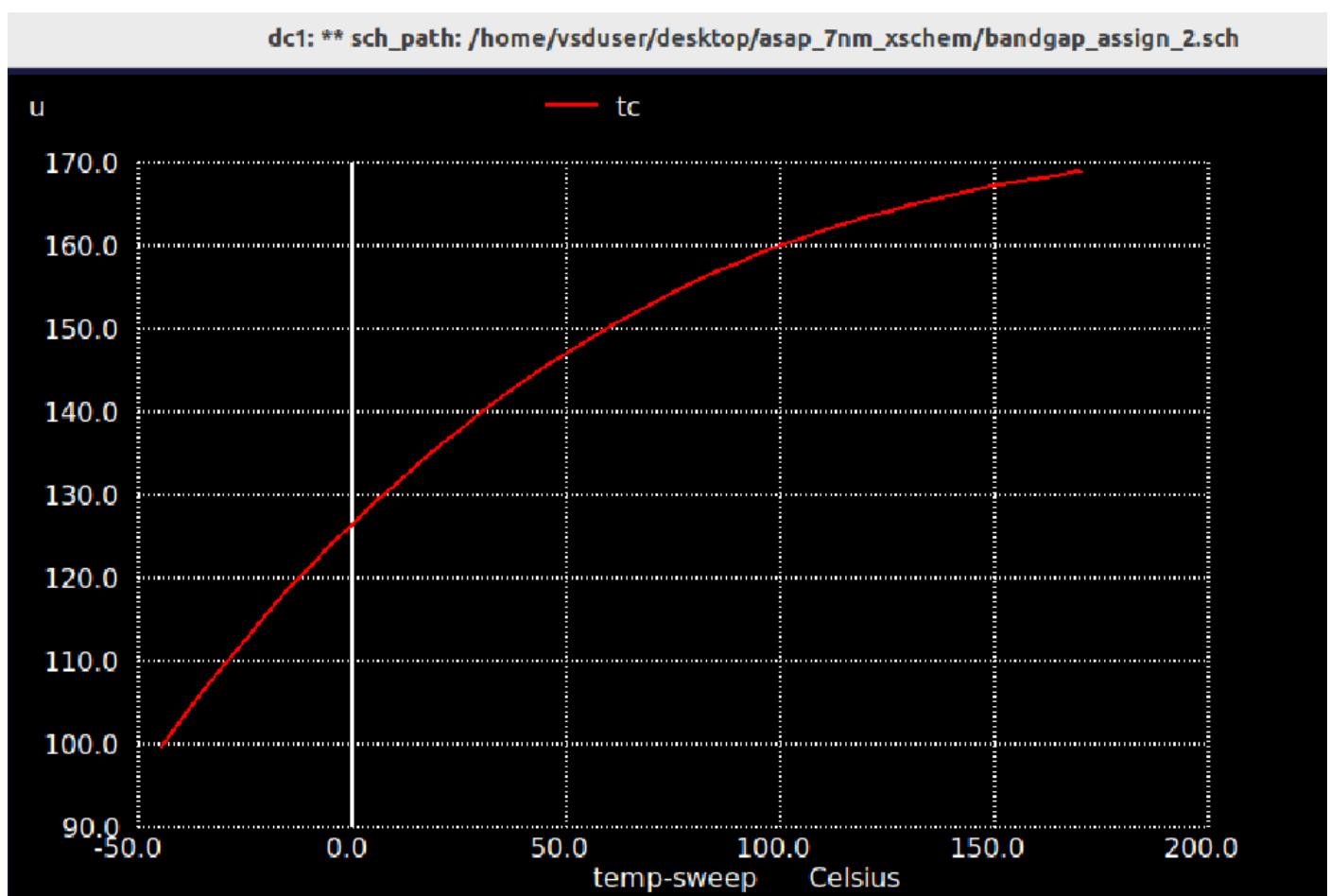
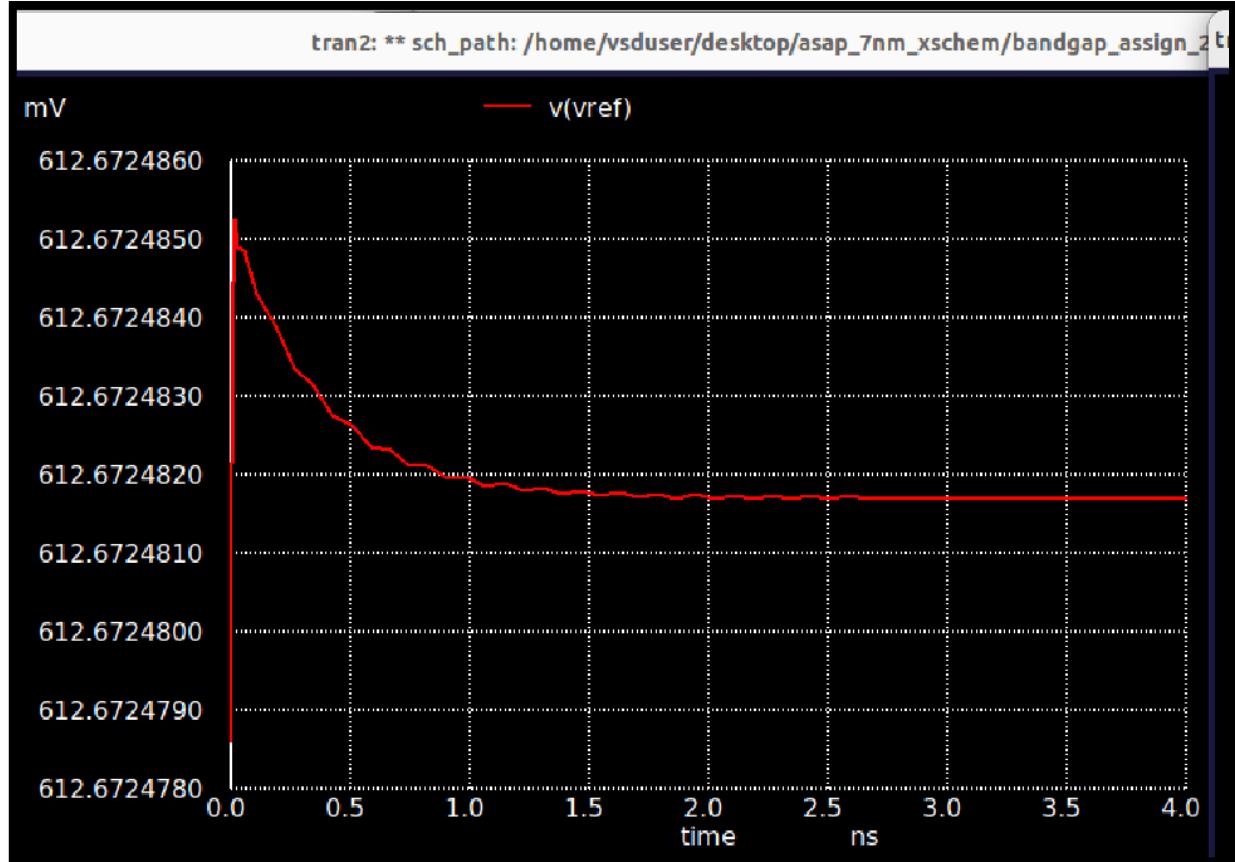


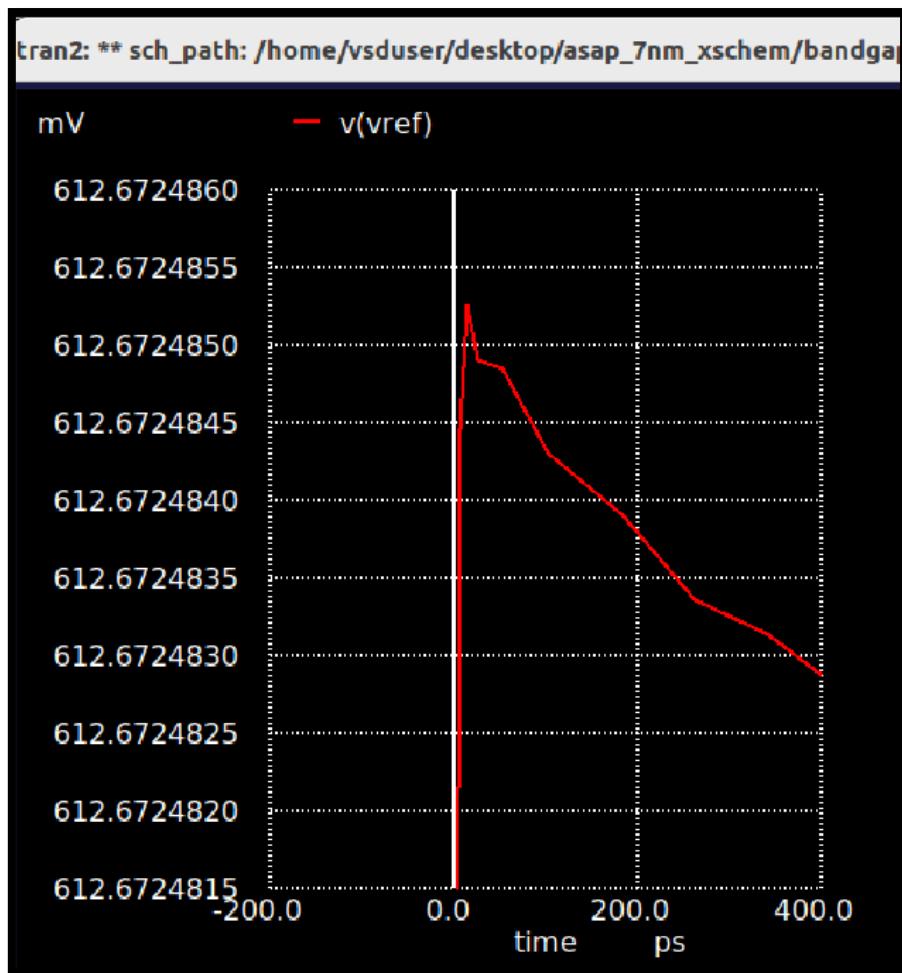
dc1: ** sch_path: /home/vsduser/Desktop/asap_7nm_xschem/bandgap_assign_2.sch

mV

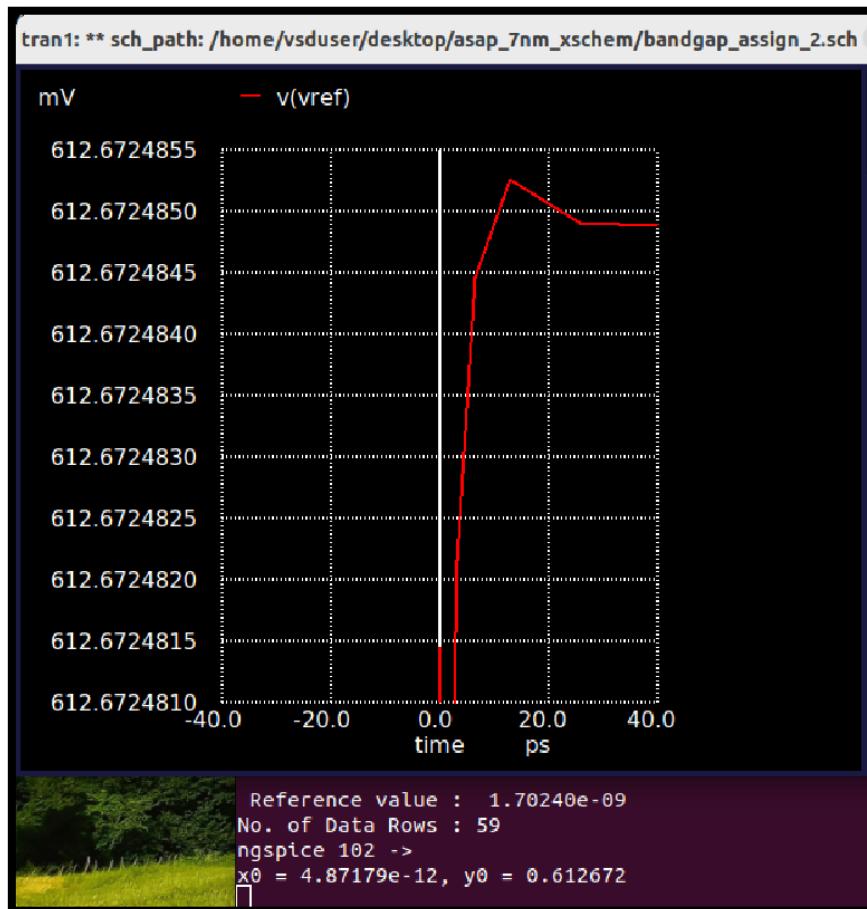
— v(vctat)







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
nospice 157 ->
```

Line regulation computed