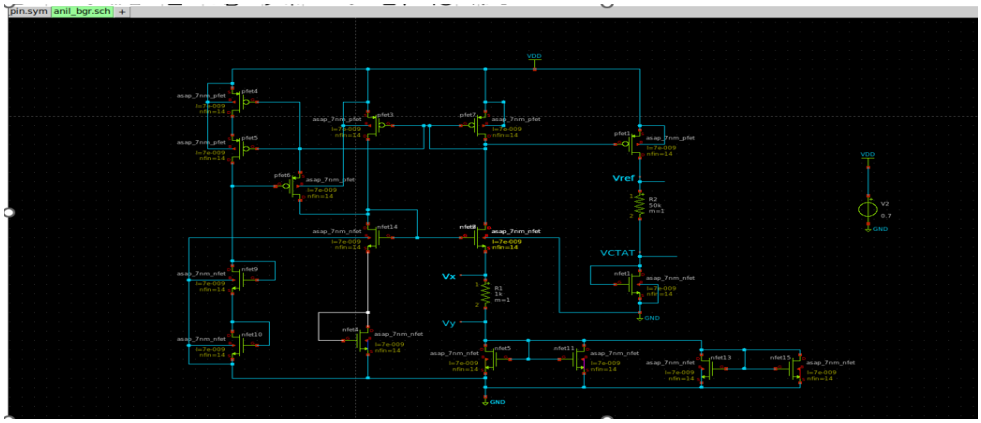
Module 3: Assignment, Bandgap Circuit Design

Name: Anil Kumar,

B. Tech: Student (ECE), NIET Greater, Noida

Bandgap Circuit:



Generated Netlist and log. -

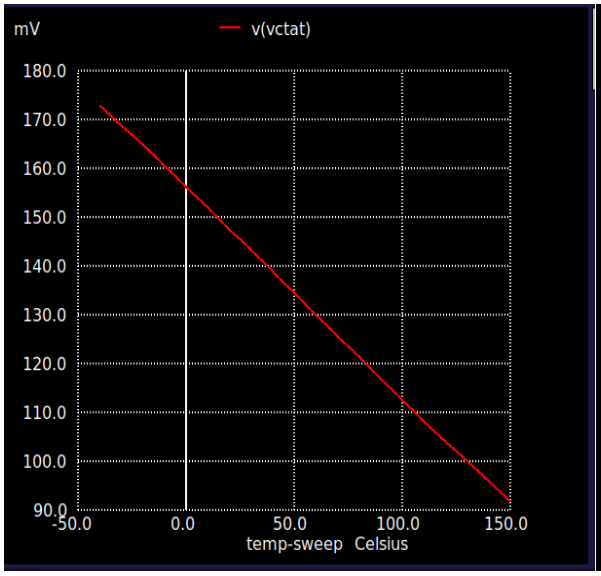
anil_bgr_ckt.spice (~/Desktop/Bandgap-Reference-Circuit

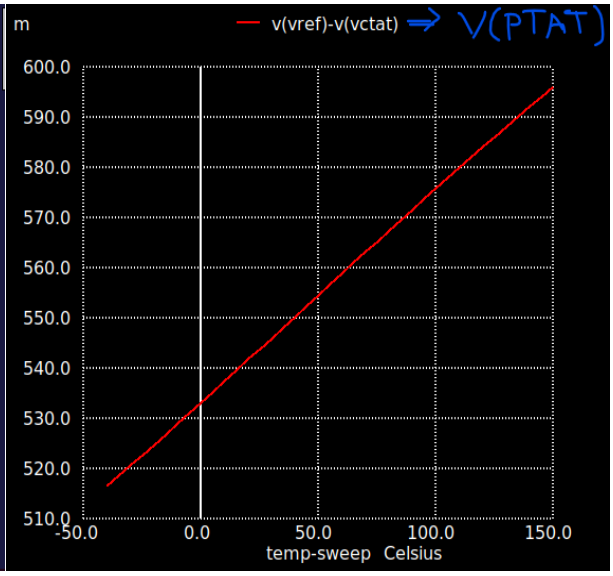
File Edit Tools Syntax Buffers Window Help

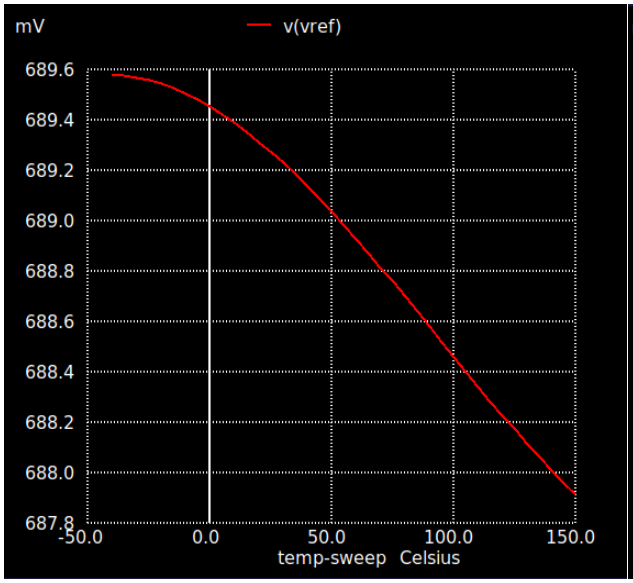
```
** sch_path: /home/vsduser/Desktop/Bandgap-Reference-Circuit-with-SCMB-with-ASAP-7nm-PDK-/anil_bgr.sch
**.subckt anil_bgr
Xpfet1 Vref net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet1 VCTAT VCTAT GND GND asap_7nm_nfet l=7e-009 nfin=14
V2 VDD GND 0.7
Xpfet3 net4 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet4 net2 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet5 net3 net1 net2 VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet6 net4 net3 net1 VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet4 net6 net6 GND net5 asap_7nm_nfet l=7e-009 nfin=14
Xnfet5 Vy Vy GND net8 asap_7nm_nfet l=7e-009 nfin=14
Xpfet7 net1 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
R1 Vx Vy 1k m=1
R2 Vref VCTAT 50k m=1
Xnfet9 net3 net3 net7 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet10 net7 net7 GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet11 Vy Vy GND net9 asap_7nm_nfet l=7e-009 nfin=14
Xnfet14 net4 net4 net6 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet13 Vy Vy GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet15 Vy Vy GND net10 asap_7nm_nfet l=7e-009 nfin=14
Xnfet2 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet3 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet6 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet7 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
**** begin user architecture code


.dc temp -40 150 5
.control
    run
    plot v(Vref)-v(VCTAT)
    plot v(Vref)
    plot v(VCTAT)
    let temp_coff = deriv(V(Vref))*10e+06
   plot temp_coff
    plot abs(v2#branch)
MEAS DC Vref_max  MAX v(Vref)
MEAS DC Vref_min  MIN v(Vref)
MEAS DC Vref_typ  find v(Vref) at =27
let Delta_Vref = Vref_max-Vref_min
print Delta_Vref
```

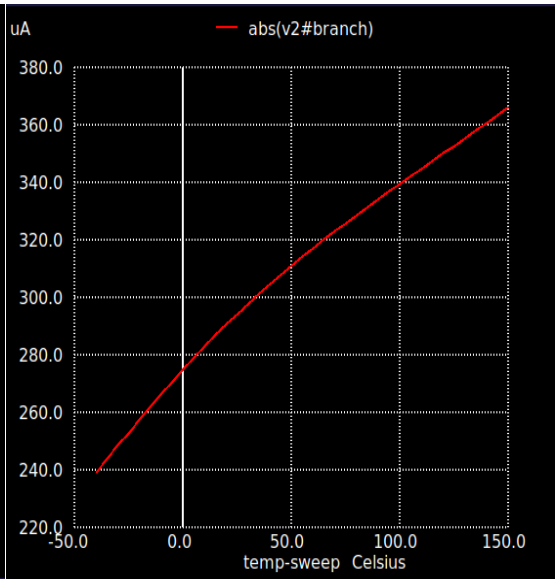
```
Circuit: ** sch_path: /home/vsduser/desktop/bandgap-reference-circuit-with

Warning: Model issue on line 58 :
  .model bsimcmg_osdi_p bsimcmg_va ( type=0 version=107 bulkmod=1 igcmod=1
unrecognized parameter (version) - ignored
unrecognized parameter (coremod) - ignored
unrecognized parameter (capmod) - ignored
unrecognized parameter (nseg) - ignored
unrecognized parameter (etaqm) - ignored

Warning: Model issue on line 133 :
  .model bsimcmg_osdi_n bsimcmg_va ( type=1 version=107 bulkmod=1 igcmod=1
unrecognized parameter (version) - ignored
unrecognized parameter (coremod) - ignored
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 :  1.15000e+02
No. of Data Rows : 39
vref_max           =  6.895768e-01 at=  -4.000000e+01
vref_min           =  6.879114e-01 at=  1.500000e+02
vref_typ           =  6.892570e-01
delta_vref = 1.665400e-03
```

Resulting plot summary (VDD= 0.7V):









Generated logs:

VDD= 0.8V:

```
vref_max            =  7.893026e-01 at=  -4.000000e+01
vref_min            =  7.873219e-01 at=  1.500000e+02
vref_typ            =  7.887858e-01
vref_m40            =  7.893026e-01
vref_125            =  7.875827e-01
delta_vref = 1.980700e-03
```

VDD=0.9V:

```
No. of Data Rows : 39
vref_max            =  8.889364e-01 at=  -4.000000e+01
vref_min            =  8.867492e-01 at=  1.500000e+02
vref_typ            =  8.882370e-01
vref_m40            =  8.889364e-01
vref_125            =  8.870076e-01
delta_vref = 2.187200e-03
```

VDD = 1 V

```
No. of Data Rows : 39
vref_max            =  9.885220e-01 at=  -4.000000e+01
vref_min            =  9.862060e-01 at=  1.500000e+02
vref_typ            =  9.876875e-01
vref_m40            =  9.885220e-01
vref_125            =  9.864741e-01
delta_vref = 2.316000e-03
```

Results Summary:

Sr.	VDD (V)	Temp (°C)	Vref (V)
1	0.8	27	0.7887
2	0.9	27	0.8882
3	1	27	0.9876
4	1	-40	0.9885
5	1	125	0.9864

Line Regulation (ΔVref/ΔVDD):

anil_bgr_ckt_LR.spice (~/Desktop/Bandg

File Edit Tools Syntax Buffers Window Help

```
** sch_path: /home/vsduser/Desktop/Bandgap-Reference-Circuit-with-SCMB-with-ASAP-7nm-PDK-/anil_bgr.sch
**.subckt anil_bgr
Xpfet1 Vref net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet1 VCTAT VCTAT GND GND asap_7nm_nfet l=7e-009 nfin=14
V2 VDD GND 0.8
Xpfet3 net4 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet4 net2 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet5 net3 net1 net2 VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet6 net4 net3 net1 VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet4 net6 net6 GND net5 asap_7nm_nfet l=7e-009 nfin=14
Xnfet5 Vy Vy GND net8 asap_7nm_nfet l=7e-009 nfin=14
Xpfet7 net1 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
R1 Vx Vy 1k m=1
R2 Vref VCTAT 50k m=1
Xnfet9 net3 net3 net7 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet10 net7 net7 GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet11 Vy Vy GND net9 asap_7nm_nfet l=7e-009 nfin=14
Xnfet14 net4 net4 net6 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet13 Vy Vy GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet15 Vy Vy GND net10 asap_7nm_nfet l=7e-009 nfin=14
Xnfet2 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet3 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet6 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet7 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
**** begin user architecture code

.dc V2 0.8 1 0.2
.temp 27
***.dc temp -40 150 5
.control
    run
    plot v(Vref)-v(VCTAT)
    plot v(Vref)
    plot v(VCTAT)
    plot abs(v2#branch)
MEAS DC Vref_max  MAX v(Vref)
MEAS DC Vref_min  MIN v(Vref)
let Delta_Vref = Vref_max-Vref_min
print Delta_Vref
```

When Sweeping DC Supply VDD from 0.8V to 1V. (ΔVDD =0.2)

At temp 27C,

```
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

No. of Data Rows : 3
vref_max            =  9.876871e-01 at=  1.000000e+00
vref_min            =  7.887861e-01 at=  8.000000e-01
delta_vref = 1.989010e-01
```

➔ΔVref/ΔVDD = 0.1989/0.2 = 0.9945 = 994.5m

When Sweeping DC Supply VDD from 0.8V to 1V. (ΔVDD =0.2)

At temp -40C,

```
Doing analysis at TEMP = -40.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver
Note: Starting dynamic gmin stepping
Note: Dynamic gmin stepping completed

No. of Data Rows : 3
vref_max            =  9.885220e-01 at=  1.000000e+00
vref_min            =  7.893026e-01 at=  8.000000e-01
delta_vref = 1.992194e-01
```

➔ΔVref/ΔVDD = 0.1992/0.2 = 0.996 = 996m

At temp 125C,

```
Doing analysis at TEMP = 125.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

No. of Data Rows : 3
vref_max            =  9.864738e-01 at=  1.000000e+00
vref_min            =  7.875823e-01 at=  8.000000e-01
delta_vref = 1.988915e-01
```

➔ΔVref/ΔVDD = 0.19889/0.2 = 0.99445 = 994.45m

Results Summary:

Sr.	VDD (V)	Temp (°C)	Vref (V)	Line Reg. (mV/V)
1	0.8	27	0.7887	994.5
2	0.9	27	0.8882	994.5
3	1	27	0.9876	994.5
4	1	-40	0.9885	996
5	1	125	0.9864	994.45

TRAN simulation:

Generated Netlist:

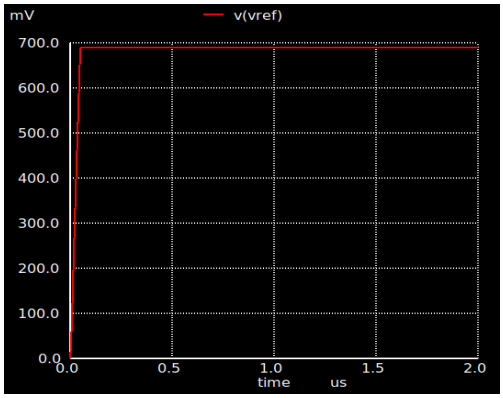
anil_bgr_ckt_TRAN.spice + (~/Desktop/B

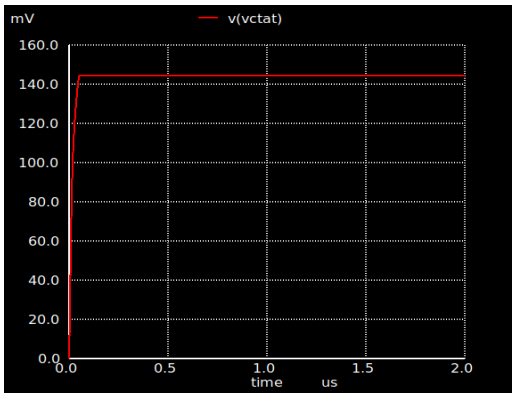
File Edit Tools Syntax Buffers Window Help

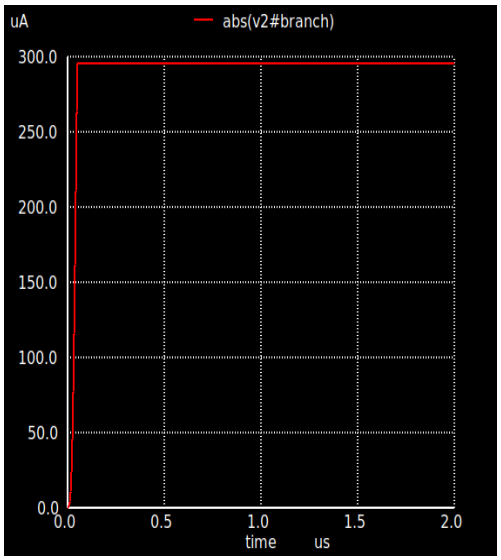
```
** sch_path: /home/vsduser/Desktop/Bandgap-Reference-Circuit-with-SCMB-with-ASAP-7nm-PDK-/anil_bgr.sch
**.subckt anil_bgr
Xpfet1 Vref net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet1 VCTAT VCTAT GND GND asap_7nm_nfet l=7e-009 nfin=14
V2 VDD GND pwl(0 0 50n 0.7)
*V2 VDD GND 0.7
Xpfet3 net4 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet4 net2 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet5 net3 net1 net2 VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet6 net4 net3 net1 VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet4 net6 net6 GND net5 asap_7nm_nfet l=7e-009 nfin=14
Xnfet5 Vy Vy GND net8 asap_7nm_nfet l=7e-009 nfin=14
Xpfet7 net1 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
R1 Vx Vy 1k m=1
R2 Vref VCTAT 50k m=1
Xnfet9 net3 net3 net7 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet10 net7 net7 GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet11 Vy Vy GND net9 asap_7nm_nfet l=7e-009 nfin=14
Xnfet14 net4 net4 net6 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet13 Vy Vy GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet15 Vy Vy GND net10 asap_7nm_nfet l=7e-009 nfin=14
Xnfet2 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet3 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet6 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet7 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
**** begin user architecture code
.tran 100p 2u 0
.temp 27
***.dc temp -40 150 5
.control
    run
    plot v(Vref)-v(VCTAT)
    plot v(Vref)
    plot v(VCTAT)
    plot abs(v2#branch)
MEAS TRAN  Vref_avg  AVG v(Vref) From = 1.5u TO =2u
MEAS TRAN  Vref_final  find v(Vref) at = 1.5u
***measuring Tstartup for within 1% tolerance band for final Vref
MEAS TRAN Ts_test WHEN v(Vref)= '0.99*6.892567e-01' RISE=1
let Tstartup =50n -Ts_test
print Tstartup
***measuring Tstartup for reaching  90% of Vref
*MEAS TRAN Tstrt_test WHEN v(Vref)= '0.9*Vref_final ' RISE=1
*MEAS TRAN T_startup2 WHEN v(Vref)= '0.9*6.892567e-01' FALL=1
*MEAS TRAN T_startup2 at v(Vref)= '0.9*6.892567e-01' RISE=1
```

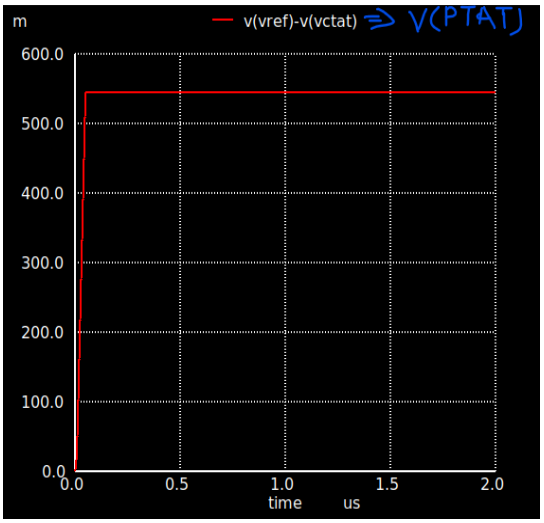
```
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.99475e-06
No. of Data Rows : 20011
vref_avg            =  6.892567e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final          =  6.892567e-01
ts_test             =  4.950578e-08
tstartup = 4.942200e-10
```

Generated Plots- From above logs, **Tstartup** is 0.494ns.









When **VDD**=0.8V

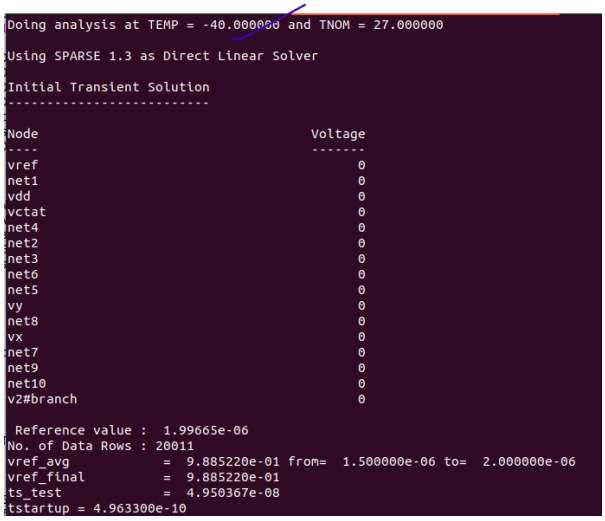
When **VDD**=0.9V

```
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.99255e-06
No. of Data Rows : 20011
vref_avg             =  7.887855e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final           =  7.887855e-01
ts_test              =  4.950448e-08
tstartup = 4.955200e-10
```

```
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.99555e-06
No. of Data Rows : 20011
vref_avg             =  8.882367e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final           =  8.882367e-01
ts_test              =  4.950378e-08
tstartup = 4.962200e-10
```

VDD=1V, Temp =-40C

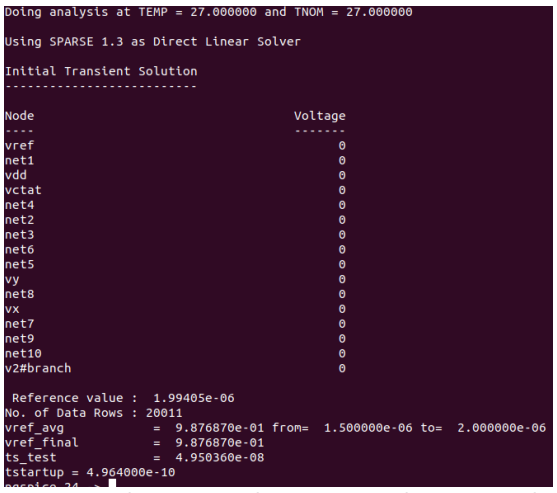
VDD=1V, Temp =125C



```
Doing analysis at TEMP = -40.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.99665e-06
No. of Data Rows : 20011
vref_avg            =  9.885220e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final          =  9.885220e-01
ts_test             =  4.950367e-08
tstartup = 4.963300e-10
```

```
Doing analysis at TEMP = 125.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.98905e-06
No. of Data Rows : 20011
vref_avg            =  9.864737e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final          =  9.864737e-01
ts_test             =  4.950427e-08
tstartup = 4.957300e-10
```

VDD=1V, temp= 27C

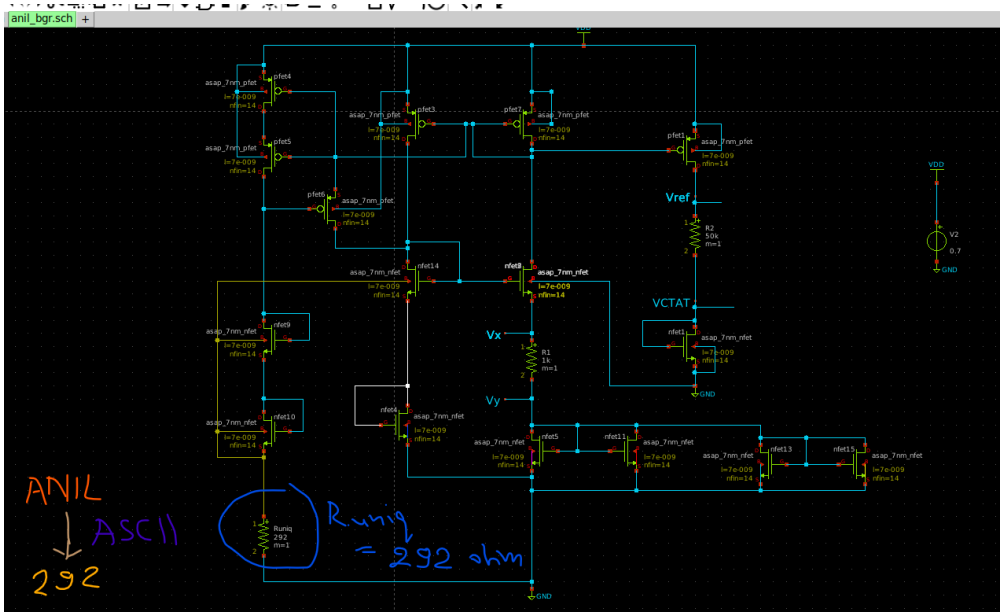


```
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.99405e-06
No. of Data Rows : 20011
vref_avg            =  9.876870e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final          =  9.876870e-01
ts_test             =  4.950360e-08
tstartup = 4.964000e-10
```

Results Summary:

Sr.	VDD (V)	Temp (°C)	Vref (V)	Line Reg. (mV/V)	Startup Time (ns)
1	0.8	27	0.7887	994.5	0.495
2	0.9	27	0.8882	994.5	0.496
3	1	27	0.9876	994.5	0.4964
4	1	-40	0.9885	996	0.4963
5	1	125	0.9864	994.45	0.4957

Test_Case with Vuniq Resister:



Generated Reports:

anil_bgr_ckt_TRAN.spice (~/Desktop/Bandgap-Ref

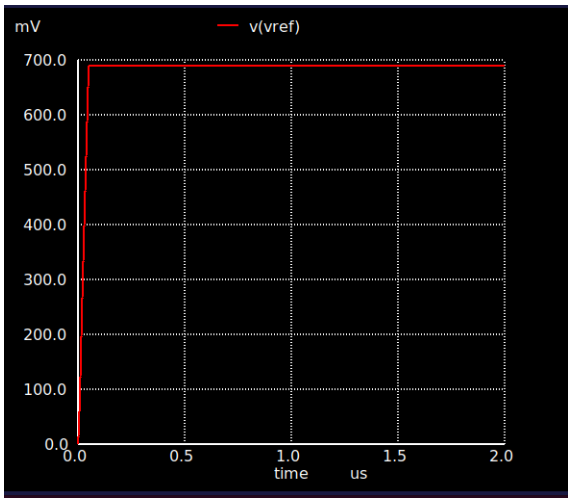
File Edit Tools Syntax Buffers Window Help

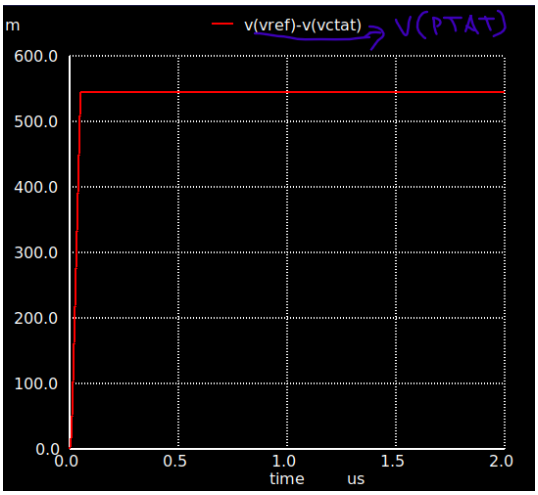
```
** sch_path: /home/vsduser/Desktop/Bandgap-Reference-Circuit-with-SCMB-with-ASAP-7nm-PDK-/anil_bgr.sch
**.subckt anil_bgr
Xpfet1 Vref net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet1 VCTAT VCTAT GND GND asap_7nm_nfet l=7e-009 nfin=14
V2 VDD GND pwl(0 0 50n 0.7)
*V2 VDD GND 0.7
Xpfet3 net4 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet4 net2 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet5 net3 net1 net2 VDD asap_7nm_pfet l=7e-009 nfin=14
Xpfet6 net4 net3 net1 VDD asap_7nm_pfet l=7e-009 nfin=14
Xnfet4 net6 net6 GND net5 asap_7nm_nfet l=7e-009 nfin=14
Xnfet5 Vy Vy GND net8 asap_7nm_nfet l=7e-009 nfin=14
Xpfet7 net1 net1 VDD VDD asap_7nm_pfet l=7e-009 nfin=14
R1 Vx Vy 1k m=1
R2 Vref VCTAT 50k m=1
Runiq net8 GND 292 m=1
Xnfet9 net3 net3 net7 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet10 net7 net7 GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet11 Vy Vy GND net9 asap_7nm_nfet l=7e-009 nfin=14
Xnfet14 net4 net4 net6 GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet13 Vy Vy GND GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet15 Vy Vy GND net10 asap_7nm_nfet l=7e-009 nfin=14
Xnfet2 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet3 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet6 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
Xnfet7 net1 net4 Vx GND asap_7nm_nfet l=7e-009 nfin=14
**** begin user architecture code
.tran 100p 2u 0
.temp 27
***.dc temp -40 150 5
.control
    run
    plot v(Vref)-v(VCTAT)
    plot v(Vref)
    plot v(VCTAT)
    plot abs(v2#branch)
MEAS TRAN  Vref_avg  AVG v(Vref) From = 1.5u TO =2u
MEAS TRAN  Vref_final  find v(Vref) at = 1.5u
```

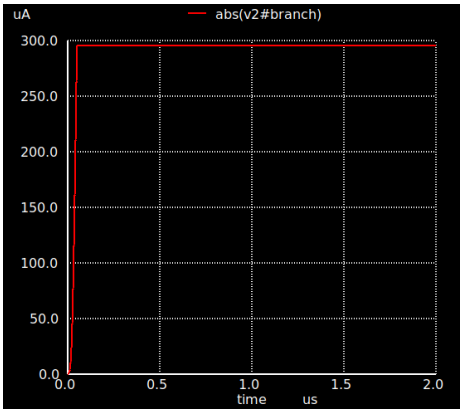
```
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Using SPARSE 1.3 as Direct Linear Solver

Initial Transient Solution
--------------------------

Node                                   Voltage
----                                   -------
vref                                         0
net1                                         0
vdd                                          0
vctat                                        0
net4                                         0
net2                                         0
net3                                         0
net6                                         0
net5                                         0
vy                                           0
net8                                         0
vx                                           0
net7                                         0
net9                                         0
net10                                        0
v2#branch                                    0

 Reference value :  1.99685e-06
No. of Data Rows : 20011
vref_avg           =  6.892567e-01 from=  1.500000e-06 to=  2.000000e-06
vref_final         =  6.892567e-01
ts_test            =  4.950578e-08
tstartup = 4.942200e-10
```

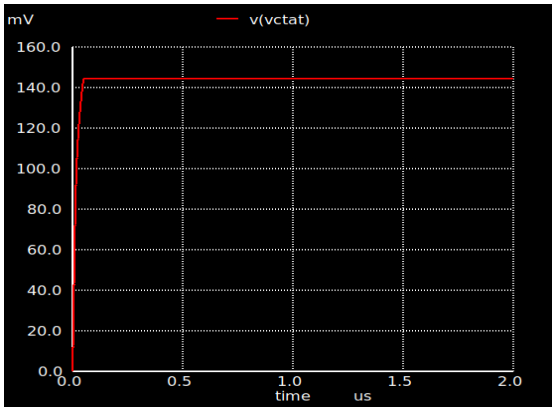
Vref = 0.68925V, **Tstartup** = 0.495ns

Plots:


mV
v(vref)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.0
0.5
1.0
1.5
2.0
time
us


m
v(vref)-v(vctat)
V(PTAT)
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.0
0.5
1.0
1.5
2.0
time
us


uA
abs(v2#branch)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
0.0
0.5
1.0
1.5
2.0
time
us


mV
v(vctat)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
0.5
1.0
1.5
2.0
time
us