
# PROJECT-2

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EEE 230

3/12/16

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# 1. INTRODUCTION

## OBJECTIVE:

The purpose of this project is to help us to understand and be able to make the decisions and trade-off's necessary to design an operational amplifier to meet a given set of specifications.

## 2. AIM:

To design an OPAMP with following specifications.

## 3. Required Specifications for all designs:

- Process technology node = 0.25 µm CMOS
- Supply voltages are VDD = 2.5V and VSS = 0V (ground)
- Temperature = 27° C
- Minimum $V_{on}$ for all saturated FETs = 150 mV
- Phase margin between 70 and 75 degrees at unity gain
- Load capacitance ≥ 2 pF
- The amount of power used by your design should be as low as possible
- The amount of silicon area used by your design should be as low as possible

## Specifications Option 2:

**Key Spec (maximize):** Unity gain bandwidth > 200 MHz
DC open loop voltage gain > 60 dB
Vout swing > 1.0 Vp-p
Common-mode input voltage range: 1.5V ≥ Vicm ≥ 1.0V

## 4. PROCESS:

This project is to help us understand and be able to make decisions and trade-offs necessary to design an operational amplifier in order to meet a given set of specifications.

To meet the required Unity Gain Bandwidth and Phase Margin (PM), there is a design constraint on the gm and common-mode input range.

The gm of the stage is directly dependent upon the ratio of Width (W) to the channel length (L) as well as $V_{on}$ of the input transistors for that stage. Since $V_{on}$ of all transistors is constrained to be at $V_{on}$ min, the required W/L ratio of the input transistors is calculated.

The gain requirement sets the value for the channel length at each stage, and the corresponding W is then calculated from the required W/L ratio.

The bias current needed for the stages is found from the W/L ratio and $V_{on}$ min of the input transistors.

All other transistors are sized according to the bias current and $V_{on}$ min.

With this approach, the circuit was simulated. The simulation results were then used as a reference to fine tweak the values in order to meet all the specifications.

# 5. SELECTION OF THE TOPOLOGY

## 1. Two-stage operational amplifier

- Provides a higher gain than just using a single stage.
- Has a wide output swing & common-mode input range.

## 2. Telescopic Cascode Operational Amplifiers

- Telescopic cascode opamps get more gain in a single stage by adding cascodes, but at the expense of limited output swing and limited common-mode input range
- Telescopic cascode op-amps increase gain by adding cascode devices instead of a second stage.
- Can use either NMOS or PMOS inputs (NMOS is faster)

## 3. Folded-Cascode Operational Amplifiers

- Both the common-mode input range and the output signal swing are larger than with a telescopic op-amp.
- Requires extra bias current (more power) and more area

## 4. Current Mirror Operational Amplifiers

- Current mirror op-amps increase gain by using a mirror with a ratio larger than 1:1 to multiply the signal current
- Can also add cascodes to increase gain even further

Based on required specifications, telescopic operational amplifier is selected since it is easy to meet given set of requirements with the help of this topology.

Using simulations in Pspice values are obtained within required range.

Below is a table comparing the specification, hand calculation and the final simulation

| Design Specifications | Required OPAPM Specifications | Hand Calculations | Simulated Results $V_{idc}$ = 1V | Simulated Results $V_{idc}$ = 1.5V |
|---|---|---|---|---|
| Unity gain bandwidth | >200MHz | 259.154MHz | 241.187Mhz | 263.979Mhz |
| DC open loop voltage gain | > 60 dB | 72.83dB | 66.169 dB | 61.307dB |
| $V_{out}$ swing | > 1.0 Vp-p | 1.33 | 1.2312 | 1.2352 |
| Phase margin | between 70 and $75^0$ | $73.286^0$ | $70.721^0$ | $70.201^0$ |

# 6. HAND CALCULATIONS

Given Data,

K'n = 120.1 µA/V
K'p = 25.6 µA/V
Lambda = 0.12
Technology/Process, L = 0.25µm

$V_{on}$ (> 150 mV) = 250mV (assume)
Ibias = 200 µA

Values of (W/L) can be calculated by,

$$(W/L) = (2*Id)/(K'n*Von^2)$$

## 1. Gain

i. Transistors M1, M2, M1c, and M2c (NMOS)
The value of W and L, depending on Id
W/L = 667
W = 300 µm, L= 0.50 µm, M =2 (assume)

ii. Transistors M3, M4, M3c and M4c (PMOS)
The value of W and L, depending on Id
W/L = 868
W = 390 µm, L= .45µm, M = 40 (assume)

iii. Transistor M5 and M6
The value of W and L are calculated using the current mirror,
Id = 250µA
W/L = 185
W = 277µm, L = 1.5µm , M =40 (assume)

iv. Transistor M1cb
W/L = 14
W = 6µm, L = 0.45µm, M =3 (assume)

Hence,
Gain Av = Av1* Av2
$= gm_1 \{[Ro_4(1+gm_4Ro_2)] \| [Ro_6(1+gm_6Ro_8)]\}$
$=20.0m \{[3.33K (67)] \| [33.33K (70.359)]\}$
$=4380.89$
$=72.83dB$

**2. Unity gain bandwidth:**

$$F= \frac{gm1}{2\pi Cl}$$

$$F=259.154Mhz$$

**3. Output Swing:**

$$Vo_{p-p} = 2(V_{bp}-V_{bn}+2V_t)$$
$$Vo_{p-p} = 1.33V_{p-p}$$

**4. Phase Margin:**

Phase margin = 90 – tan^-1(UGBW/fp3),
fp3 = (gm4)/(2*pi*Cl)
Cl = 2pF,

$$= 73.286^0$$

# 7. SIMULATION RESULTS:

- Case 1: $V_{idc}$ = 1 V

  Unity gain bandwidth = 241.187 MHz
  DC open loop voltage gain = 66.169 dB
  Vout swing = 1.2312 $V_{p-p}$
  Phase margin = $70.721^0$

- Case 2: $V_{idc}$ = 1.5 V

  Unity gain bandwidth = 263.979 MHz
  DC open loop voltage gain = 61.307 dB
  Vout swing = 1.2352 $V_{p-p}$
  Phase margin = $70.201^0$

# 8. DESIGN CHOICES AND TRADEOFF's

- A trade-off had to be made between the Id and the W/L ratio to achieve the specified open loop gain and unity gain bandwidth while keeping $V_{ON}$ above 150 mV.
- With the drain current and W/L ratio set to keep $V_{on}$ above 150 mV, the DC open loop gain and unity gain can be calculated.
- Once again it can be seen from the equations that by increasing the Id, the unity gain would increase but the output resistance would decrease which would decrease the open loop gain.
- To then increase the gain above 60 dB, the channel length need to be increased. But by increasing the channel length we have also decreased the W/L ratio which will decrease the gain and unity gain bandwidth. To maintain the same W/L ratio, W and L will need to be increased together.
- Another way to increase the gain without decreasing Id, is to increase the width of M1. However, by increasing the width we have increased the W/L ratio which could drive Von below 200mV.
- Both ways of increasing the gain has negative impacts to the other specifications.
- By increasing the width of the MOSFETs we have increased the parasitic capacitances which will decrease the second pole frequency which in turn decreases the phase margin.
- Therefore, careful consideration when increasing the drain current, the channel length and width of the MOSFETs. Increase in one parameter too much we may drive the opamps out of the design specifications.

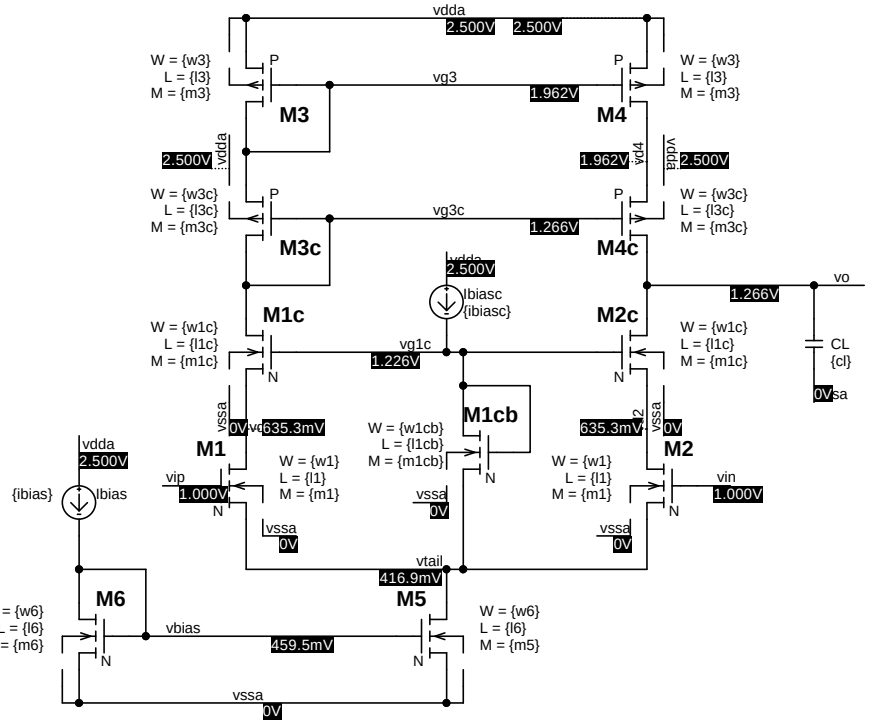
# 9. TELESCOPIC OPAMP

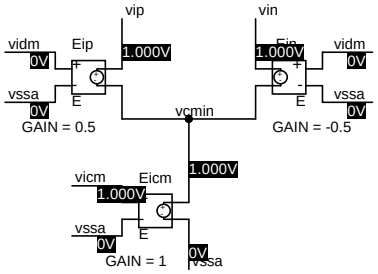
# WITH

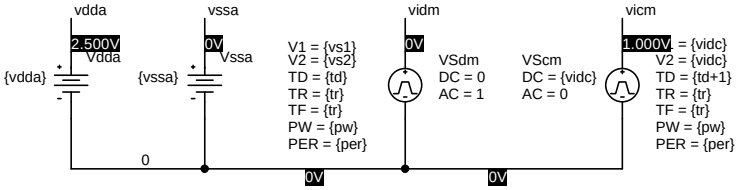
# **Vicm = 1 V**

PARAMETERS:

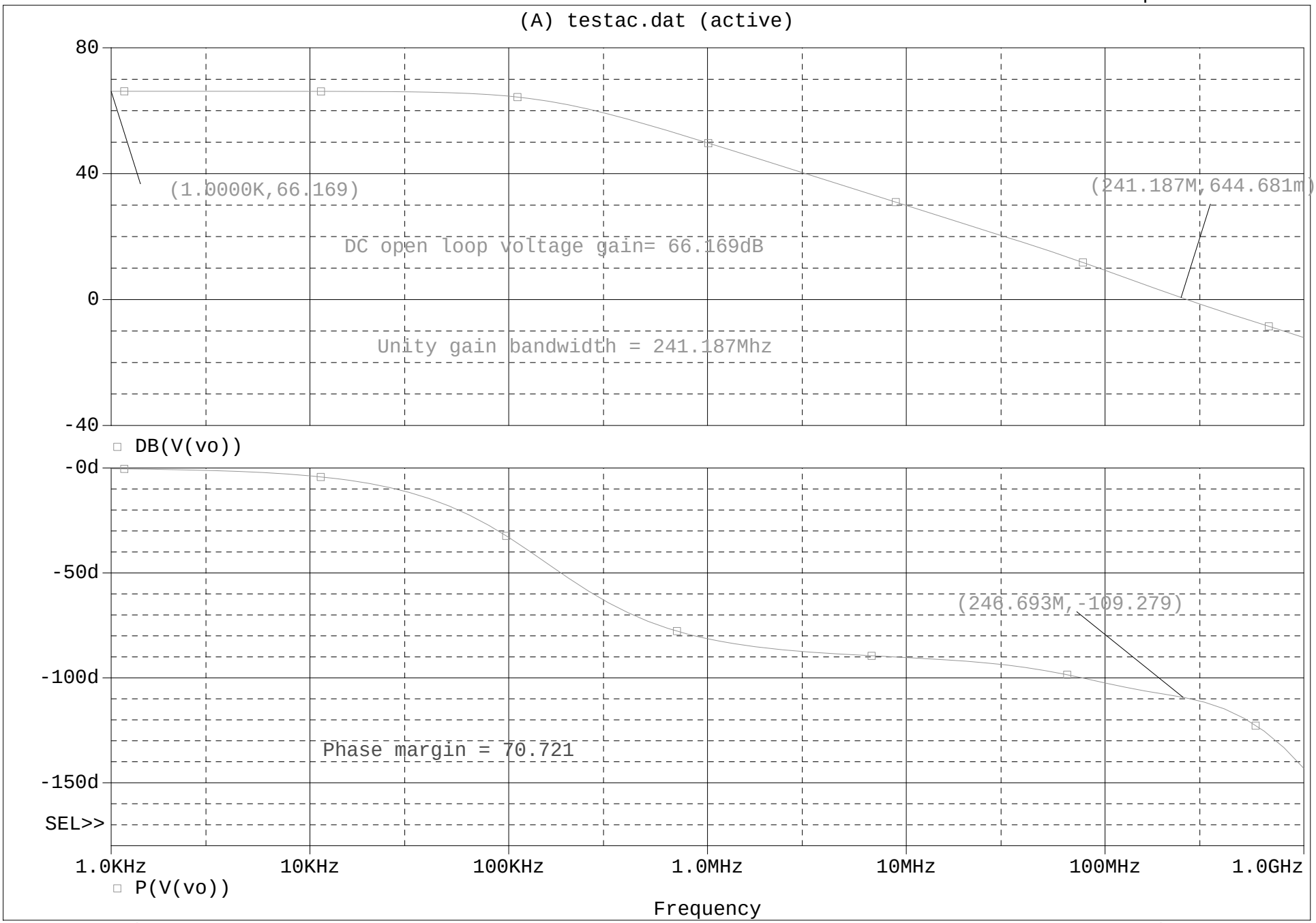
| | |
|---|---|
| w1 = 350u | vdda = 2.5 |
| w1c = {w1} | vssa = 0.0 |
| w1cb = 5u | vidc = 1 |
| w3 = 300u | ibias = 250u |
| w3c = {w3} | ibiasc = {ibias} |
| w6 = 270.0u | |
| l1 = 0.45u | vstep = 1m |
| l1c = {l1} | vs1 = {(vstep/2)*(-1)} |
| l1cb = {l1} | vs2 = {(vstep/2)} |
| l3 = 0.45u | per = 10us |
| l3c = {l3} | pw = {per/2 - tr} |
| l6 = 2u | tr = {0.01*per} |
| m1 = 5 | td = {per/2} |
| m1c = 8 | |
| m1cb = 2.75 | cl = 2pF |
| m3 = 50 | |
| m3c = 50 | |
| m5 = 40 | |
| m6 = 2 | |

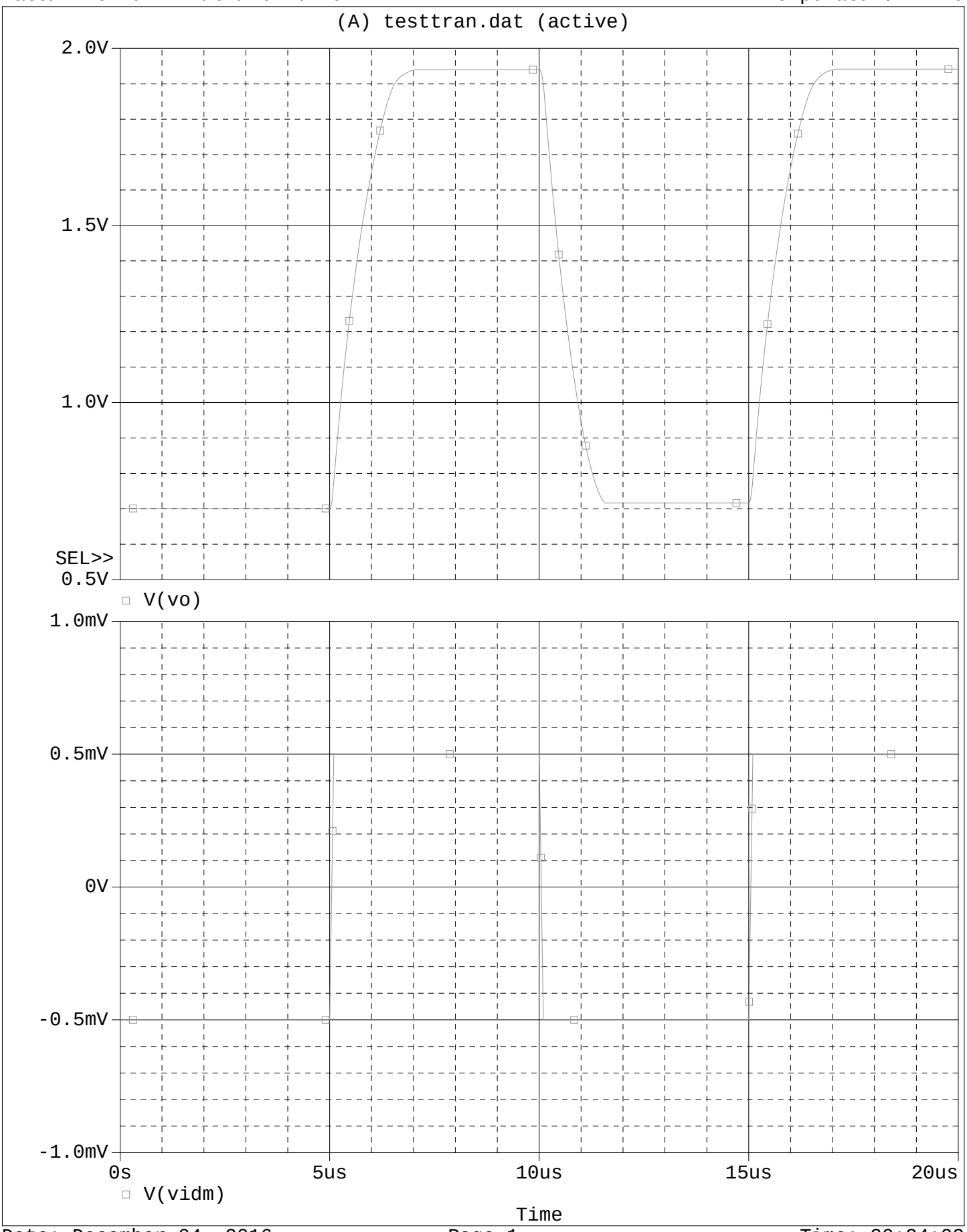


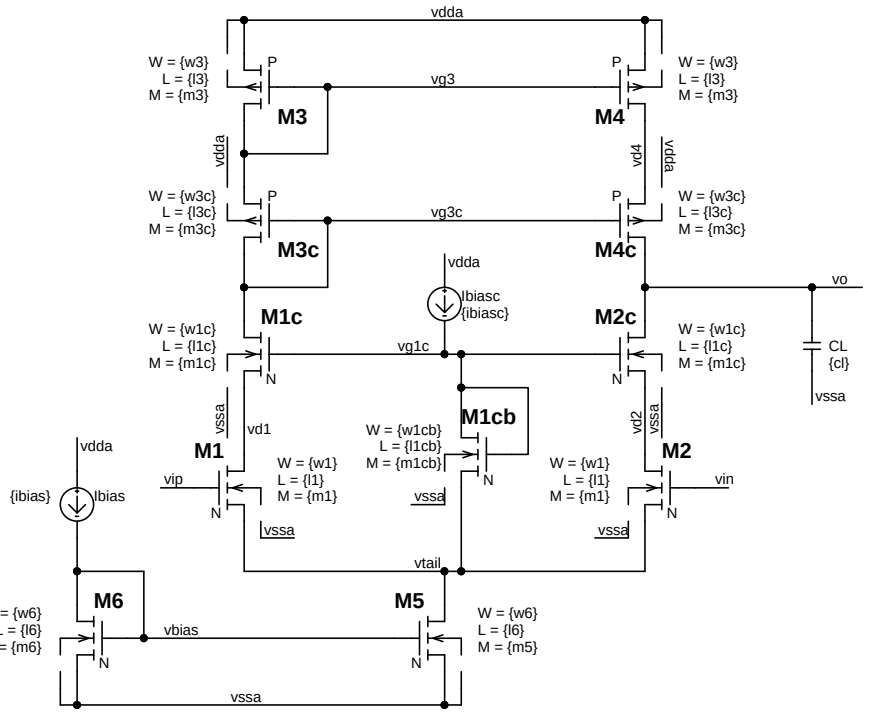

| | | | |
|---|---|---|---|
| | **Designer = Sriharsha** | | |
| Title | **Project-2** | | |
| Size A | Document Number **opamp_telescopicN** | | Rev A0 |
| Date: Friday, December 02, 2016 | | Sheet 1 of 1 | |

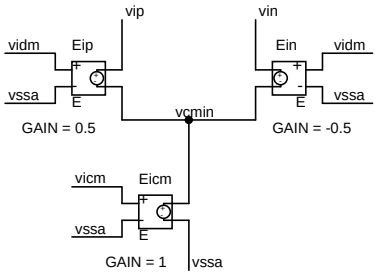

(A) testac.dat (active)
80
40
0
-40
(1.0000K,66.169)
(241.187M,644.681m)
DC open loop voltage gain= 66.169dB
Unity gain bandwidth = 241.187Mhz
DB(V(vo))
-0d
-50d
-100d
-150d
SEL>>
(246.693M,-109.279)
Phase margin = 70.721
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
100MHz
1.0GHz
P(V(vo))
Frequency

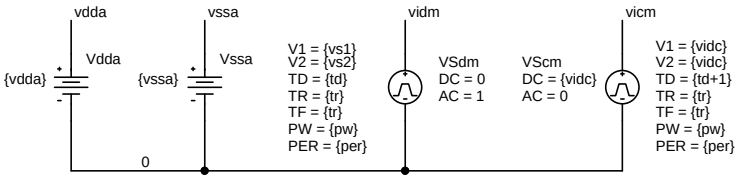

(A) testtran.dat (active)
2.0V
1.5V
1.0V
SEL>>
0.5V
V(vo)
1.0mV
0.5mV
0V
-0.5mV
-1.0mV
0s
5us
10us
15us
20us
V(vidm)
Time

PARAMETERS:

| | |
|---|---|
| w1 = 350u | vdda = 2.5 |
| w1c = {w1} | vssa = 0.0 |
| w1cb = 5u | vidc = 1 |
| w3 = 300u | ibias = 250u |
| w3c = {w3} | ibiasc = {ibias} |
| w6 = 270.0u | |
| l1 = 0.45u | vstep = 1m |
| l1c = {l1} | vs1 = {(vstep/2)*(-1)} |
| l1cb = {l1} | vs2 = {(vstep/2)} |
| l3 = 0.45u | per = 10us |
| l3c = {l3} | pw = {per/2 - tr} |
| l6 = 2u | tr = {0.01*per} |
| m1 = 5 | td = {per/2} |
| m1c = 8 | |
| m1cb = 2.75 | cl = 2pF |
| m3 = 50 | |
| m3c = 50 | |
| m5 = 40 | |
| m6 = 2 | |

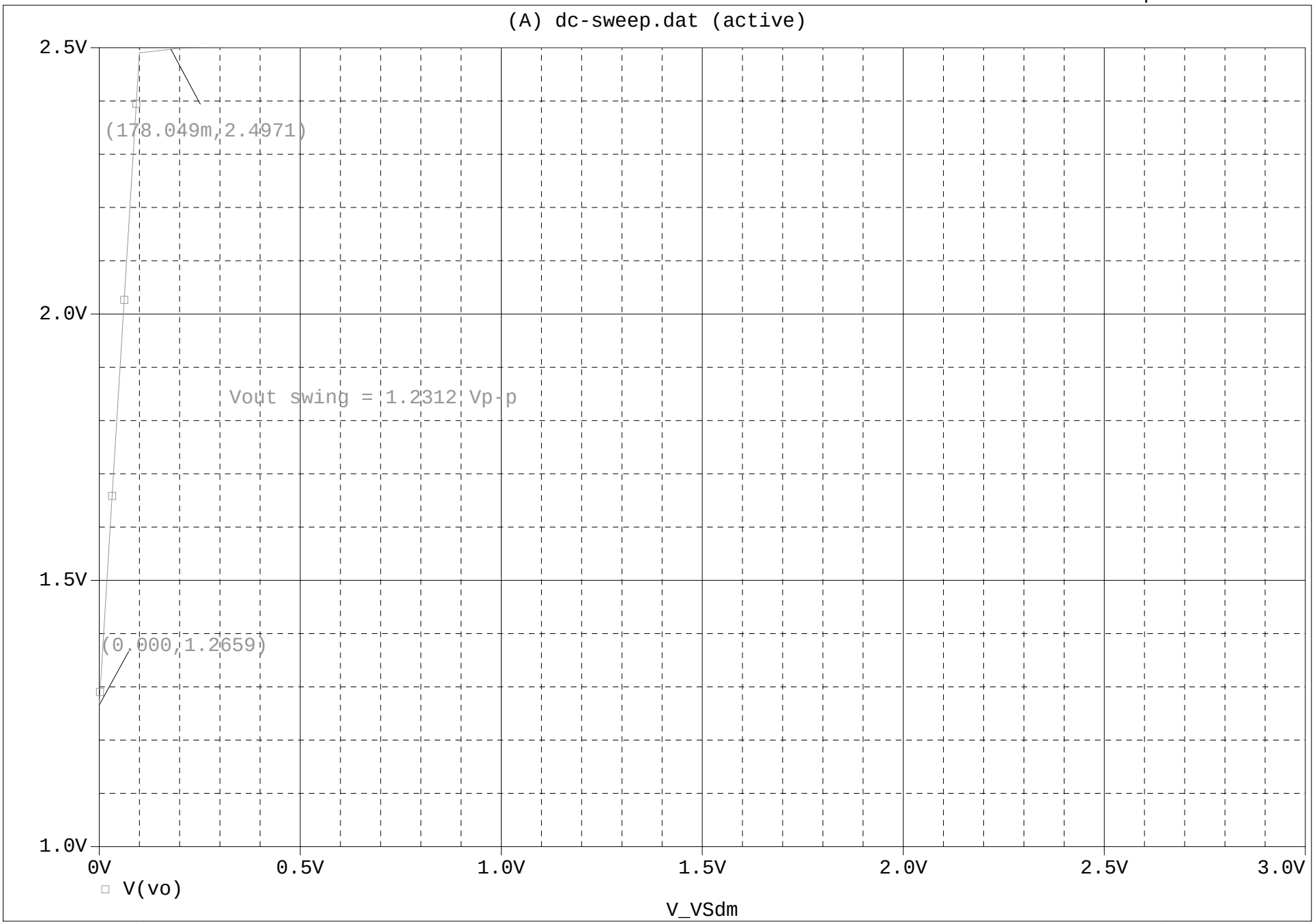



| | | | |
|---|---|---|---|
| Designer = Sriharsha | | | |
| Title: Project-2 | | | |
| Size: A | Document Number: opamp_telescopicN | | Rev: A0 |
| Date: Friday, December 02, 2016 | Sheet 1 of 1 | | |

** Profile: "SCHEMATIC1-dc-sweep"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_telescopicN\opam...
Date/Time run: 12/02/16 22:37:26 Temperature: 27.0



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•
**** 12/04/16 15:52:35 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_te
lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     CIRCUIT DESCRIPTION


******************************************************************************




** Creating circuit file "testac.cir"
** WARNING: THIS AUTOMATICALLY GENERATED FILE MAY BE OVERWRITTEN BY SUBSEQUENT SIMULATIONS

*Libraries:
* Profile Libraries :
* Local Libraries :
.LIB "../../../opamp telescopicn-pspicefiles/opamp telescopicn.lib"
* From [PSPICE NETLIST] section of C:\Users\jadhavs\cdssetup\OrCAD_PSpice/16.6.0/PSpice.in
i file:
.lib "nom.lib"

*Analysis directives:
.AC DEC 10 1k 1g
.OP
.OPTIONS ADVCONV
.OPTIONS NUMDGT= 5
.OPTIONS RELTOL= 0.0001
.PROBE64 V(alias(*)) I(alias(*)) W(alias(*)) D(alias(*)) NOISE(alias(*))
.INC "..\SCHEMATIC1.net"



**** INCLUDING SCHEMATIC1.net ****
* source OPAMP TELESCOPICN
M M1          VD1 VIP VTAIL VSSA N
+ L={l1}
+ W={w1}
+ M={m1}
M M2          VD2 VIN VTAIL VSSA N
+ L={l1}
+ W={w1}
+ M={m1}
M M5          VTAIL VBIAS VSSA VSSA N
+ L={l6}
+ W={w6}
+ M={m5}
M M6          VBIAS VBIAS VSSA VSSA N
+ L={l6}
+ W={w6}
+ M={m6}
M M3          VG3 VG3 VDDA VDDA P
+ L={l3}
+ W={w3}
+ M={m3}
M M4          VD4 VG3 VDDA VDDA P
+ L={l3}
+ W={w3}
+ M={m3}
I Ibias          VDDA VBIAS DC {ibias}
V Vdda          VDDA 0 {vdda}
V Vssa          VSSA 0 {vssa}
V VSdm          VIDM 0 DC 0 AC 1
+PULSE {vs1} {vs2} {td} {tr} {tr} {pw} {per}
```

```
C CL         VSSA VO  {cl}  TC=0,0
E Eip         VIP VCMIN VIDM VSSA 0.5
E Eicm         VCMIN VSSA VICM VSSA 1
E Ein         VIN VCMIN VIDM VSSA -0.5
V VScm         VICM 0 DC {vidc} AC 0
+PULSE {vidc} {vidc} {td+1} {tr} {tr} {pw} {per}
M M3c         VG3C VG3C VG3 VDDA P
+ L={l3c}
+ W={w3c}
+ M={m3c}
M M4c         VO VG3C VD4 VDDA P
+ L={l3c}
+ W={w3c}
+ M={m3c}
M M2c         VO VG1C VD2 VSSA N
+ L={l1c}
+ W={w1c}
+ M={m1c}
M M1c         VG3C VG1C VD1 VSSA N
+ L={l1c}
+ W={w1c}
+ M={m1c}
M M1cb         VG1C VG1C VTAIL VSSA N
+ L={l1cb}
+ W={w1cb}
+ M={m1cb}
I Ibiasc          VDDA VG1C DC {ibiasc}
.PARAM  w3=300u td={per/2} vs1={(vstep/2)*(-1)} vs2={(vstep/2)} l3c={l3}
+  vidc=1.0 w6=270.0u ibiasc={ibias} m3c=50 l1c={l1} m1c=8 per=10us m1cb=2.75 pw=
+ {per/2 - tr} l1cb={l1} m1=5 l1=0.45u cl=2pf m3=50 vstep=1m ibias=250u l3=0.45u
+  m5=40 vssa=0.0 vdda=2.5 m6=2 w1cb=5u w3c={w3} l6=2u tr={0.01*per} w1=350u w1c=
+ {w1}

**** RESUMING testac.cir ****
.END

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Ps = 0 is less than W

WARNING(ORPSIM-15236): Parameter XW in model N is invalid - Ignored

WARNING(ORPSIM-15235): Mosfet M_M2, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M2, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M6, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M6, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M2c, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M2c, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1c, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1c, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Pd = 0 is less than W
```

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Ps = 0 is less than W

WARNING(ORPSIM-15236): Parameter XW in model P is invalid - Ignored

WARNING(ORPSIM-15235): Mosfet M_M4, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M4, model P: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3c, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3c, model P: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M4c, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M4c, model P: Ps = 0 is less than W

INFO(ORPSIM-15454): Model N: Using BSIM VERSION 3.1 or lower

INFO(ORPSIM-15454): Model P: Using BSIM VERSION 3.1 or lower

•

**** 12/04/16 15:52:35 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_telescopicN\opamp_telescopicn-pspicefiles\sch

 ****     MOSFET MODEL PARAMETERS

**********

| | N | P |
|---|---|---|
| | NMOS | PMOS |
| T Measured | 27 | 27 |
| T Current | 27 | 27 |
| LEVEL | 7 | 7 |
| L | 100.000000E-06 | 100.000000E-06 |
| W | 100.000000E-06 | 100.000000E-06 |
| VTO | .355168 | -.547882 |
| KP | 357.221800E-06 | 357.221800E-06 |
| GAMMA | 0 | 0 |
| LAMBDA | 0 | 0 |
| RSH | 3.8 | 2.9 |
| IS | 1.000000E-15 | 1.000000E-15 |
| JS | 100.000000E-06 | 100.000000E-06 |
| PB | .99 | .961669 |
| PBSW | .981431 | .8 |
| CJ | 1.556442E-03 | 1.870360E-03 |
| CJSW | 421.795200E-12 | 311.598500E-12 |
| MJ | .422704 | .475679 |
| MJSW | .19742 | .268452 |
| CGSO | 457.000000E-12 | 559.000000E-12 |
| CGDO | 457.000000E-12 | 559.000000E-12 |
| CGBO | 1.000000E-12 | 1.000000E-12 |
| TOX | 5.800000E-09 | 5.800000E-09 |
| XJ | 100.000000E-09 | 100.000000E-09 |
| UCRIT | 10.000000E+03 | 10.000000E+03 |
| DELTA | .01 | .01 |
| DIOMOD | 2 | 2 |
| K1 | .488168 | .645808 |
| K2 | -1.465714E-06 | -1.621568E-03 |
| LETA | 0 | 0 |
| WETA | 0 | 0 |
| U0 | 305.8067 | 100 |
| XPART | .5 | .5 |

| | | |
|---|---|---|
| VTH0 | .355168 | -.547882 |
| K3 | 1.000000E-03 | .096322 |
| W0 | 100.000000E-09 | 1.000000E-06 |
| NLX | 192.736100E-09 | 14.689740E-09 |
| DVT0 | .575129 | 2.726151 |
| DVT1 | .566083 | .74709 |
| UA | -1.152667E-09 | 875.490400E-12 |
| UB | 2.428080E-18 | 1.000000E-21 |
| UC | 41.273400E-12 | -100.000000E-12 |
| VSAT | 128.759100E+03 | 129.251900E+03 |
| RDSW | 175 | 839.1661 |
| VOFF | -.109017 | -.129264 |
| NFACTOR | 1.531998 | .936195 |
| PCLM | 1.620562 | 1.397517 |
| PDIBL1 | .959482 | 4.013259E-03 |
| PDIBL2 | 2.748496E-03 | 5.534487E-06 |
| DROUT | 1 | .059113 |
| PSCBE1 | 683.743800E+06 | 5.132455E+09 |
| PSCBE2 | 231.977200E-06 | 1.189024E-09 |
| A0 | 1.795768 | .903978 |
| A1 | 456.914600E-06 | .03521 |
| A2 | .531924 | .3 |
| NPEAK | 235.490000E+15 | 415.890000E+15 |
| LDD | 0 | 0 |
| LITL | 41.713310E-09 | 41.713310E-09 |
| UA1 | 4.310000E-09 | 4.310000E-09 |
| UB1 | -7.610000E-18 | -7.610000E-18 |
| UC1 | -56.000000E-12 | -56.000000E-12 |
| PVAG | 9.534150E-03 | |
| KETA | -9.762332E-03 | 7.291800E-03 |
| ETA0 | 6.182294E-03 | .243084 |
| ETAB | 269.257900E-06 | -.020463 |
| K3B | 3.222249 | 5.987855 |
| DVT2 | -.302613 | -.114714 |
| DSUB | .045455 | .997855 |
| MOBMOD | 1 | 1 |
| AGS | .359392 | .084443 |
| DVT1W | 0 | 0 |
| DVT2W | 0 | 0 |
| PRWG | .15 | .233163 |
| PRWB | -.124343 | -.051475 |
| PDIBLCB | -.022086 | -1.000000E-03 |
| DWG | -15.000000E-09 | -47.227750E-09 |
| DWB | 2.371290E-09 | -16.212000E-09 |
| B0 | 127.264200E-12 | 1.473225E-06 |
| B1 | 4.171173E-09 | 5.000000E-06 |
| LINT | 2.800000E-09 | 33.490790E-09 |
| DLC | 2.800000E-09 | 33.490790E-09 |
| DWC | 0 | 0 |
| CF | 0 | 0 |
| NOIA | 100.000000E+18 | 9.900001E+18 |
| NOIB | 50.000000E+03 | 2.400000E+03 |
| NOIC | -1.400000E-12 | 1.400000E-12 |
| LKETA | 879.276400E-06 | -3.261413E-03 |
| WKETA | 3.502570E-03 | 1.257100E-03 |
| PVTH0 | -6.690647E-03 | 6.913576E-03 |
| PRDSW | -8.4 | 10.49393 |
| PK2 | 1.959318E-03 | 1.392595E-03 |
| VTM | .025864 | .025864 |
| VERSION | 3.1 | 3.1 |
| PBSWG | .851594 | .8 |
| MJSWG | .268491 | .278699 |
| CJSWG | 329.000000E-12 | 250.000000E-12 |

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Ps = 0 is less than W

```
WARNING(ORPSIM-15236): Parameter XW in model N is invalid - Ignored

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Ps = 0 is less than W

WARNING(ORPSIM-15236): Parameter XW in model P is invalid - Ignored
•
**** 12/04/16 15:52:35 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_te
lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     SMALL SIGNAL BIAS SOLUTION       TEMPERATURE =   27.000 DEG C

*******************************************************************************


 NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE

(   VO)   1.26591  (  VD1)    .63528  (  VD2)    .63528  (  VD4)   1.96206

(  VG3)   1.96206  (  VIN)   1.00000  (  VIP)   1.00000  ( VDDA)   2.50000

( VG1C)   1.22629  ( VG3C)   1.26591  ( VICM)   1.00000  ( VIDM)   0.00000

( VSSA)   0.00000  (VBIAS)    .45947  (VCMIN)   1.00000  (VTAIL)    .41692



    VOLTAGE SOURCE CURRENTS
    NAME         CURRENT

    V Vdda      -5.231E-03
    V Vssa       5.231E-03
    V VSdm       0.000E+00
    V_VScm       0.000E+00

    TOTAL POWER DISSIPATION   1.31E-02  WATTS

•
**** 12/04/16 15:52:35 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_te
lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     OPERATING POINT INFORMATION      TEMPERATURE =   27.000 DEG C

*******************************************************************************
```

**** VOLTAGE-CONTROLLED VOLTAGE SOURCES

| NAME | E Eip | E Eicm | E Ein |
|---|---|---|---|
| V-SOURCE | 0.000E+00 | 1.000E+00 | 0.000E+00 |
| I-SOURCE | 0.000E+00 | 0.000E+00 | 0.000E+00 |

**** MOSFETS

| NAME | M M1 | M M2 | M M5 | M M6 | M M3 |
|---|---|---|---|---|---|
| MODEL | N | N | N | N | P |
| ID | 2.37E-03 | 2.37E-03 | 4.98E-03 | 2.50E-04 | -2.37E-03 |
| VGS | 5.83E-01 | 5.83E-01 | 4.59E-01 | 4.59E-01 | -5.38E-01 |
| VDS | 2.18E-01 | 2.18E-01 | 4.17E-01 | 4.59E-01 | -5.38E-01 |
| VBS | -4.17E-01 | -4.17E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| VTH | 5.36E-01 | 5.36E-01 | 3.75E-01 | 3.75E-01 | -5.56E-01 |
| VDSAT | 8.51E-02 | 8.51E-02 | 9.75E-02 | 9.76E-02 | -6.66E-02 |
| Lin0/Sat1 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| if | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| ir | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| TAU | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| GM | 4.10E-02 | 4.10E-02 | 7.61E-02 | 3.82E-03 | 4.49E-02 |
| GDS | 1.30E-03 | 1.30E-03 | 4.58E-04 | 2.19E-05 | 3.72E-04 |
| GMB | 8.15E-03 | 8.15E-03 | 1.84E-02 | 9.22E-04 | 1.51E-02 |
| CBD | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CBS | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CGSOV | 8.00E-13 | 8.00E-13 | 4.94E-12 | 2.47E-13 | 8.39E-12 |
| CGDOV | 8.00E-13 | 8.00E-13 | 4.94E-12 | 2.47E-13 | 8.39E-12 |
| CGBOV | 4.50E-19 | 4.50E-19 | 2.00E-18 | 2.00E-18 | 4.50E-19 |
| Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges | | | | | |
| DQGDVGB | 4.81E-12 | 4.81E-12 | 1.07E-10 | 5.35E-12 | 3.28E-11 |
| DQGDVDB | -7.71E-13 | -7.71E-13 | -4.75E-12 | -2.37E-13 | -8.38E-12 |
| DQGDVSB | -3.70E-12 | -3.70E-12 | -9.35E-11 | -4.68E-12 | -1.78E-11 |
| DQDDVGB | -2.05E-12 | -2.05E-12 | -4.41E-11 | -2.20E-12 | -1.26E-11 |
| DQDDVDB | 7.92E-13 | 7.92E-13 | 4.88E-12 | 2.44E-13 | 8.38E-12 |
| DQDDVSB | 1.52E-12 | 1.52E-12 | 4.95E-11 | 2.48E-12 | 5.70E-12 |
| DQBDVGB | -7.16E-13 | -7.16E-13 | -1.89E-11 | -9.45E-13 | -7.57E-12 |
| DQBDVDB | -1.32E-14 | -1.32E-14 | -8.29E-14 | -3.65E-15 | -3.90E-15 |
| DQBDVSB | -1.39E-13 | -1.39E-13 | -1.05E-11 | -5.23E-13 | -1.97E-12 |

| NAME | M M4 | M M3c | M M4c | M M2c | M M1c |
|---|---|---|---|---|---|
| MODEL | P | P | P | N | N |
| ID | -2.37E-03 | -2.37E-03 | -2.37E-03 | 2.37E-03 | 2.37E-03 |
| VGS | -5.38E-01 | -6.96E-01 | -6.96E-01 | 5.91E-01 | 5.91E-01 |
| VDS | -5.38E-01 | -6.96E-01 | -6.96E-01 | 6.31E-01 | 6.31E-01 |
| VBS | 0.00E+00 | 5.38E-01 | 5.38E-01 | -6.35E-01 | -6.35E-01 |
| VTH | -5.56E-01 | -7.13E-01 | -7.13E-01 | 5.74E-01 | 5.74E-01 |
| VDSAT | -6.66E-02 | -6.95E-02 | -6.95E-02 | 7.23E-02 | 7.23E-02 |
| Lin0/Sat1 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| if | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| ir | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| TAU | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| GM | 4.49E-02 | 4.54E-02 | 4.54E-02 | 4.61E-02 | 4.61E-02 |
| GDS | 3.72E-04 | 3.31E-04 | 3.31E-04 | 7.68E-04 | 7.68E-04 |
| GMB | 1.51E-02 | 1.20E-02 | 1.20E-02 | 8.49E-03 | 8.49E-03 |
| CBD | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CBS | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CGSOV | 8.39E-12 | 8.39E-12 | 8.39E-12 | 1.28E-12 | 1.28E-12 |
| CGDOV | 8.39E-12 | 8.39E-12 | 8.39E-12 | 1.28E-12 | 1.28E-12 |
| CGBOV | 4.50E-19 | 4.50E-19 | 4.50E-19 | 4.50E-19 | 4.50E-19 |
| Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges | | | | | |
| DQGDVGB | 3.28E-11 | 3.17E-11 | 3.17E-11 | 6.78E-12 | 6.78E-12 |
| DQGDVDB | -8.38E-12 | -8.38E-12 | -8.38E-12 | -1.23E-12 | -1.23E-12 |

```
DQGDVSB     -1.78E-11   -1.78E-11   -1.78E-11   -4.85E-12   -4.85E-12
DQDDVGB     -1.26E-11   -1.26E-11   -1.26E-11   -2.81E-12   -2.81E-12
DQDDVDB      8.38E-12    8.38E-12    8.38E-12    1.26E-12    1.26E-12
DQDDVSB      5.70E-12    5.36E-12    5.36E-12    1.85E-12    1.85E-12
DQBDVGB     -7.57E-12   -6.44E-12   -6.44E-12   -1.15E-12   -1.15E-12
DQBDVDB     -3.90E-15   -3.15E-15   -3.15E-15   -1.24E-14   -1.24E-14
DQBDVSB     -1.97E-12   -1.31E-12   -1.31E-12   -1.25E-13   -1.25E-13

NAME         M M1cb
MODEL        N
ID           2.50E-04
VGS          8.09E-01
VDS          8.09E-01
VBS         -4.17E-01
VTH          5.25E-01
VDSAT        2.29E-01
Lin0/Sat1   -1.00E+00
if          -1.00E+00
ir          -1.00E+00
TAU         -1.00E+00
GM           1.55E-03
GDS          3.29E-05
GMB          2.92E-04
CBD          0.00E+00
CBS          0.00E+00
CGSOV        6.28E-15
CGDOV        6.28E-15
CGBOV        4.50E-19
 Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges
DQGDVGB      4.23E-14
DQGDVDB     -5.96E-15
DQGDVSB     -3.47E-14
DQDDVGB     -1.84E-14
DQDDVDB      6.16E-15
DQDDVSB      1.48E-14
DQBDVGB     -5.46E-15
DQBDVDB     -6.60E-17
DQBDVSB     -1.13E-15

          JOB CONCLUDED
•
**** 12/04/16 15:52:35 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_te
lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     JOB STATISTICS SUMMARY


******************************************************************************



  Total job time (using Solver 1)   =         .14
•
```

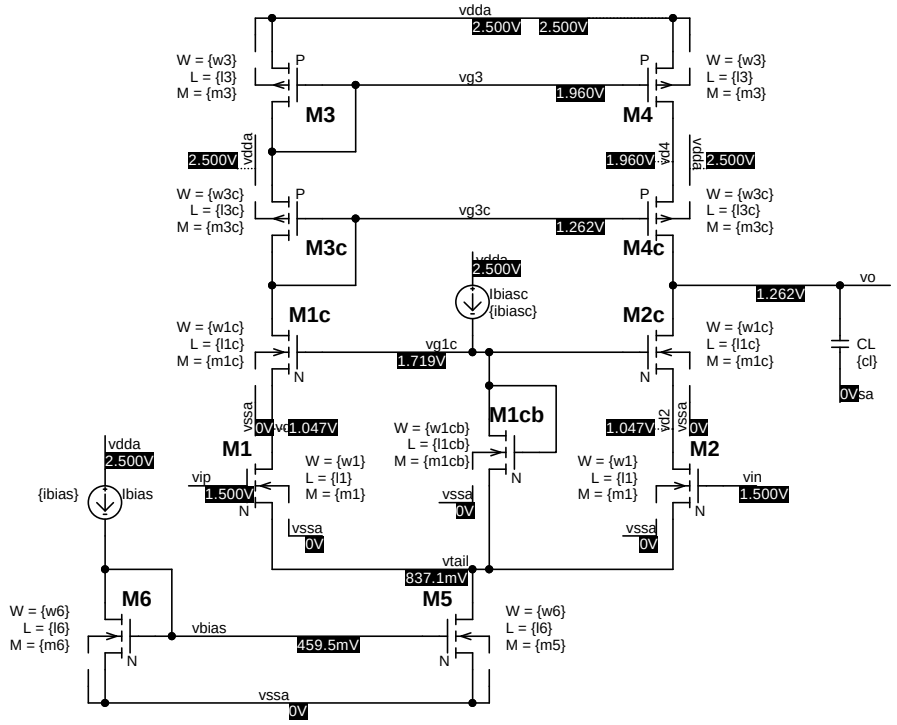
# 10. TELESCOPIC OPAMP

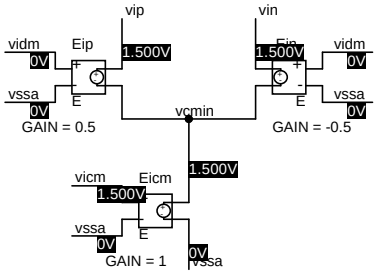
# WITH

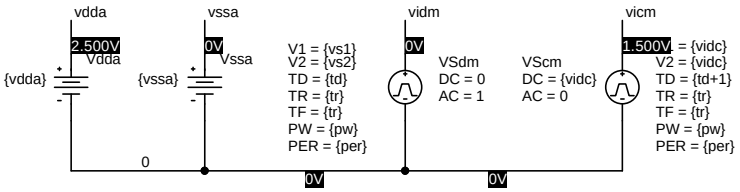
# **Vicm = 1.5 V**

PARAMETERS:

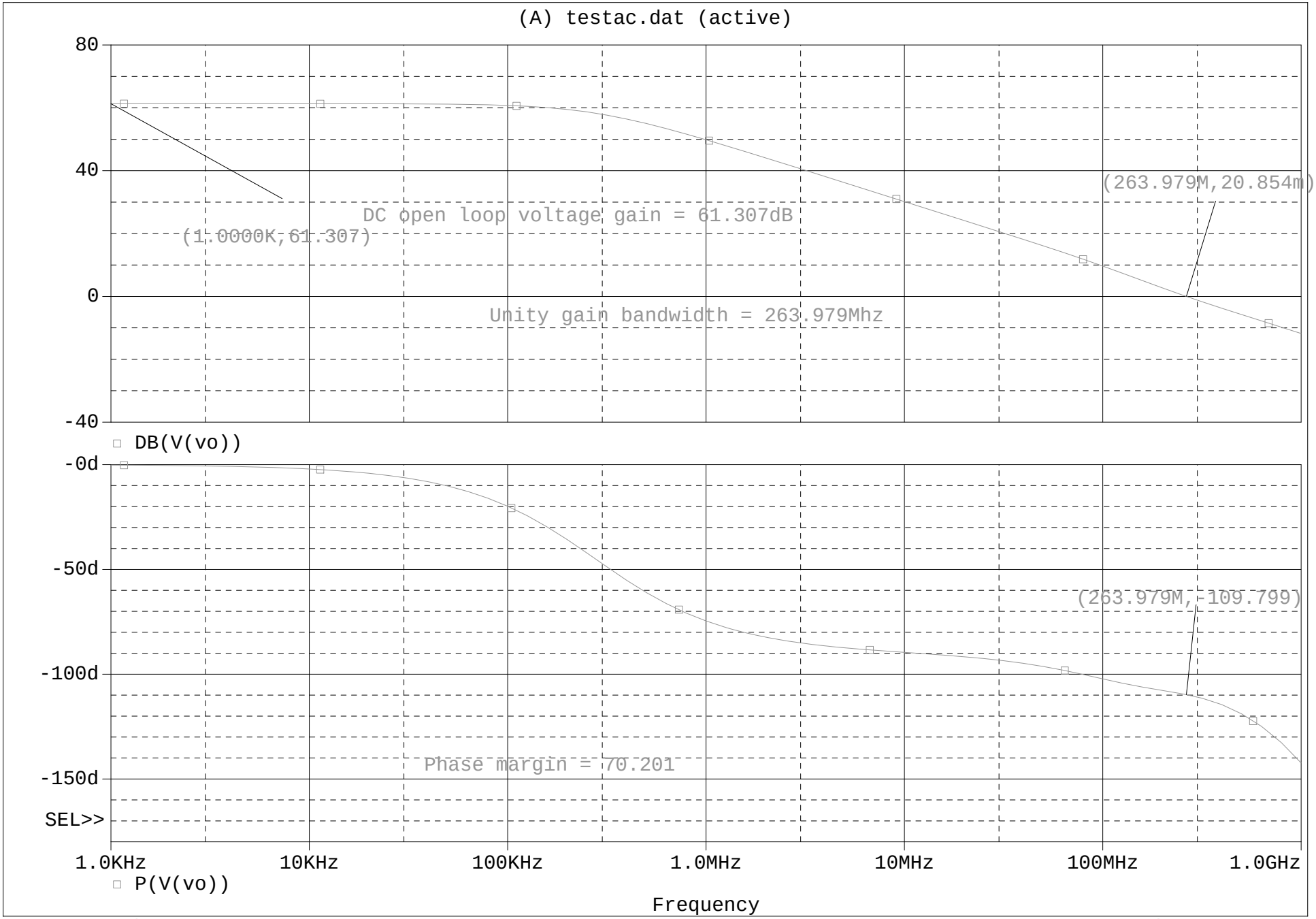
| | |
|---|---|
| w1 = 350u | vdda = 2.5 |
| w1c = {w1} | vssa = 0.0 |
| w1cb = 5u | vidc = 1.5 |
| w3 = 300u | ibias = 250u |
| w3c = {w3} | ibiasc = {ibias} |
| w6 = 270.0u | |
| l1 = 0.45u | vstep = 1m |
| l1c = {l1} | vs1 = {(vstep/2)*(-1)} |
| l1cb = {l1} | vs2 = {(vstep/2)} |
| l3 = 0.45u | per = 10us |
| l3c = {l3} | pw = {per/2 - tr} |
| l6 = 2u | tr = {0.01*per} |
| m1 = 5 | td = {per/2} |
| m1c = 8 | |
| m1cb = 2.75 | cl = 2pF |
| m3 = 50 | |
| m3c = 50 | |
| m5 = 40 | |
| m6 = 2 | |

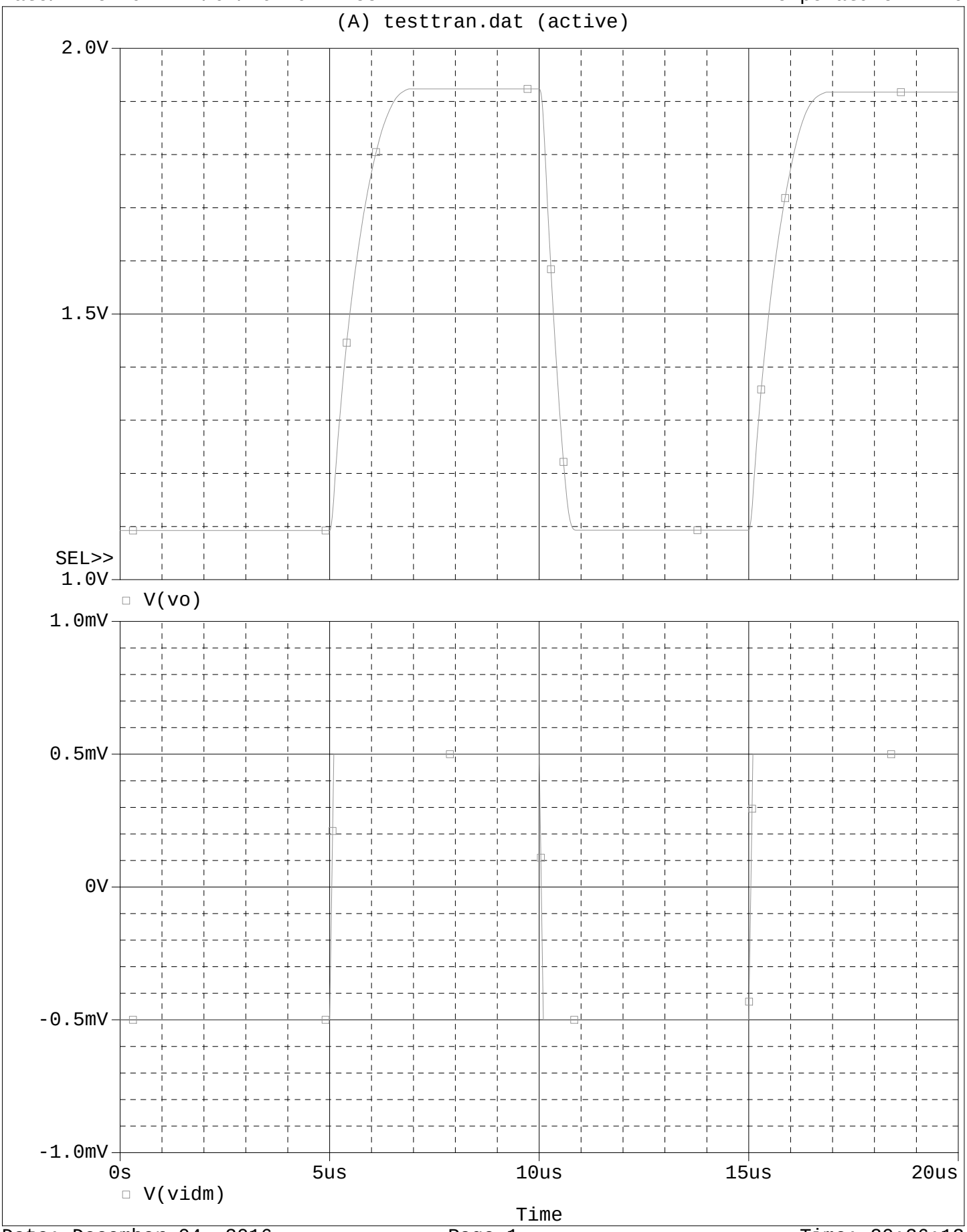


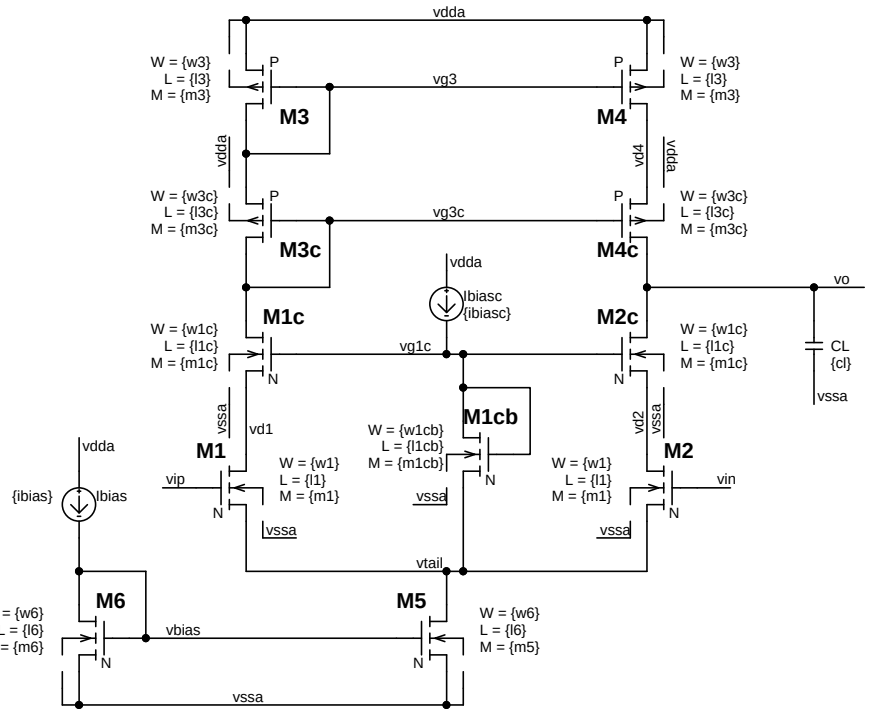

| | | | |
|---|---|---|---|
| Designer = Sriharsha | | | |
| Title: Project-2 | | | |
| Size: A | Document Number: opamp_telescopicN | | Rev: A0 |
| Date: Friday, December 02, 2016 | Sheet 1 of 1 | | |

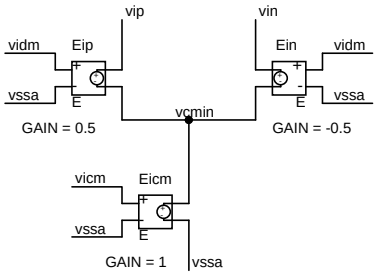

(A) testac.dat (active)
80
40
0
-40
DC open loop voltage gain = 61.307dB
(1.0000K,61.307)
(263.979M,20.854m)
Unity gain bandwidth = 263.979Mhz
DB(V(vo))
-0d
-50d
-100d
-150d
SEL>>
Phase margin = 70.201
(263.979M,-109.799)
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
100MHz
1.0GHz
P(V(vo))
Frequency

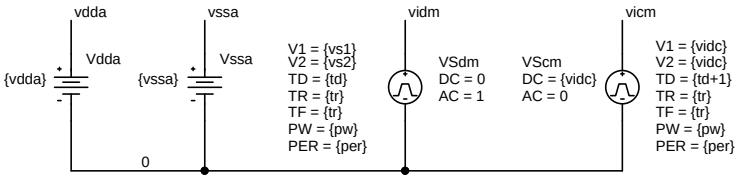

(A) testtran.dat (active)
2.0V
1.5V
SEL>>
1.0V
V(vo)
1.0mV
0.5mV
0V
-0.5mV
-1.0mV
0s
5us
10us
15us
20us
V(vidm)
Time

PARAMETERS:

| | |
|---|---|
| w1 = 350u | vdda = 2.5 |
| w1c = {w1} | vssa = 0.0 |
| w1cb = 5u | vidc = 1.5 |
| w3 = 300u | ibias = 250u |
| w3c = {w3} | ibiasc = {ibias} |
| w6 = 270.0u | |
| l1 = 0.45u | vstep = 1m |
| l1c = {l1} | vs1 = {(vstep/2)*(-1)} |
| l1cb = {l1} | vs2 = {(vstep/2)} |
| l3 = 0.45u | per = 10us |
| l3c = {l3} | pw = {per/2 - tr} |
| l6 = 2u | tr = {0.01*per} |
| m1 = 5 | td = {per/2} |
| m1c = 8 | |
| m1cb = 2.75 | cl = 2pF |
| m3 = 50 | |
| m3c = 50 | |
| m5 = 40 | |
| m6 = 2 | |

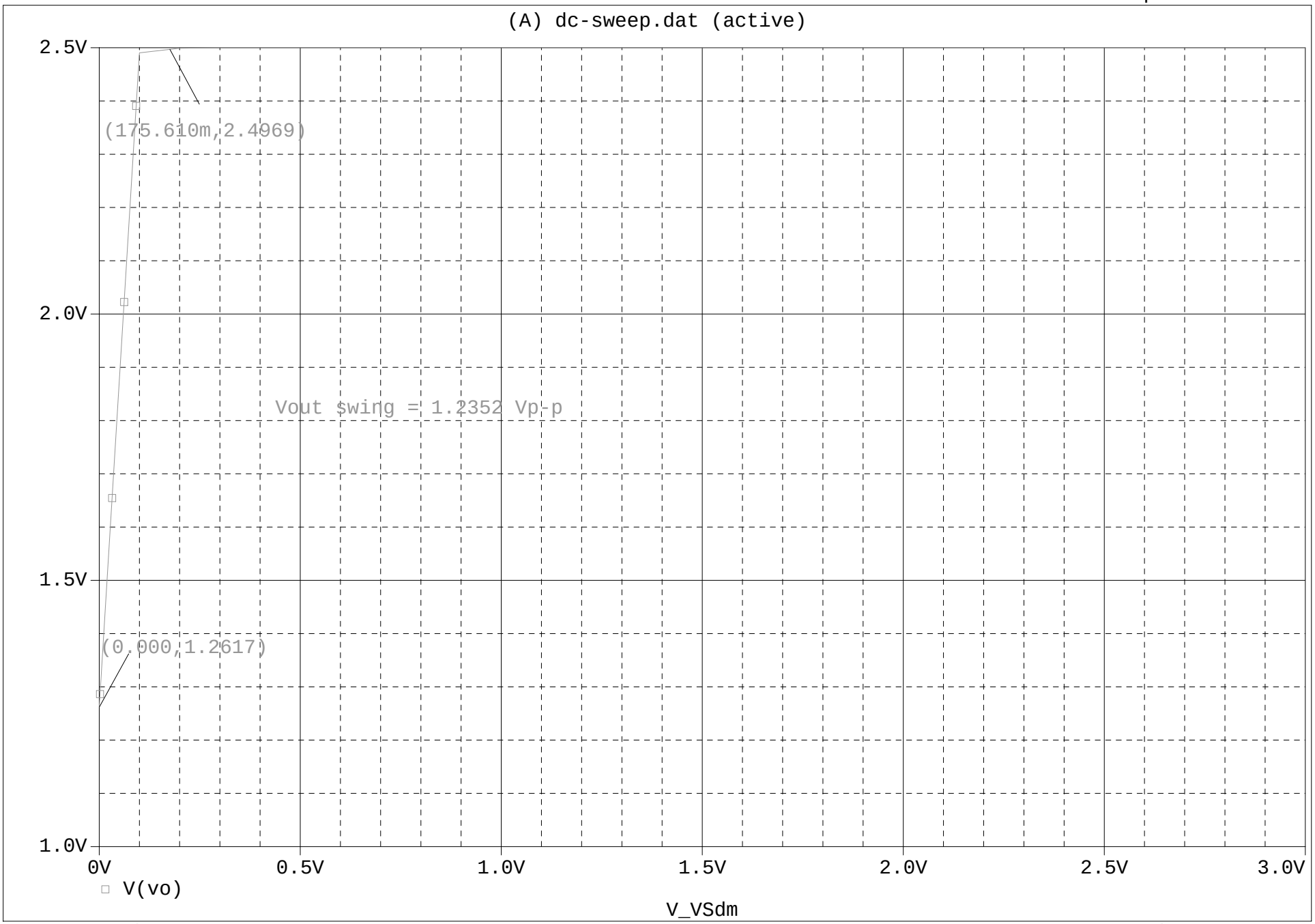



| | | | |
|---|---|---|---|
| Designer = Sriharsha | | | |
| Title: Project-2 | | | |
| Size: A | Document Number: opamp_telescopicN | | Rev: A0 |
| Date: Friday, December 02, 2016 | Sheet 1 of 1 | | |

** Profile: "SCHEMATIC1-dc-sweep"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_telescopicN\opam...
Date/Time run: 12/02/16 22:25:29 Temperature: 27.0



```
**** 12/04/16 15:48:21 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac"  [ \\gaia.ecs.csus.edu\jadhavs\eee_230\project-2\opamp_te
lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     CIRCUIT DESCRIPTION


******************************************************************************




** Creating circuit file "testac.cir"
** WARNING: THIS AUTOMATICALLY GENERATED FILE MAY BE OVERWRITTEN BY SUBSEQUENT SIMULATIONS

*Libraries:
* Profile Libraries :
* Local Libraries :
.LIB "../../../opamp telescopicn-pspicefiles/opamp telescopicn.lib"
* From [PSPICE NETLIST] section of C:\Users\jadhavs\cdssetup\OrCAD_PSpice/16.6.0/PSpice.in
i file:
.lib "nom.lib"

*Analysis directives:
.AC DEC 10 1k 1g
.OP
.OPTIONS ADVCONV
.OPTIONS NUMDGT= 5
.OPTIONS RELTOL= 0.0001
.PROBE64 V(alias(*)) I(alias(*)) W(alias(*)) D(alias(*)) NOISE(alias(*))
.INC "..\SCHEMATIC1.net"



**** INCLUDING SCHEMATIC1.net ****
* source OPAMP TELESCOPICN
M M1          VD1 VIP VTAIL VSSA N
+ L={l1}
+ W={w1}
+ M={m1}
M M2          VD2 VIN VTAIL VSSA N
+ L={l1}
+ W={w1}
+ M={m1}
M M5          VTAIL VBIAS VSSA VSSA N
+ L={l6}
+ W={w6}
+ M={m5}
M M6          VBIAS VBIAS VSSA VSSA N
+ L={l6}
+ W={w6}
+ M={m6}
M M3          VG3 VG3 VDDA VDDA P
+ L={l3}
+ W={w3}
+ M={m3}
M M4          VD4 VG3 VDDA VDDA P
+ L={l3}
+ W={w3}
+ M={m3}
I Ibias          VDDA VBIAS DC {ibias}
V Vdda          VDDA 0 {vdda}
V Vssa          VSSA 0 {vssa}
V VSdm          VIDM 0 DC 0 AC 1
+PULSE {vs1} {vs2} {td} {tr} {tr} {pw} {per}
```

```
C CL         VSSA VO  {cl}  TC=0,0
E Eip         VIP VCMIN VIDM VSSA 0.5
E Eicm         VCMIN VSSA VICM VSSA 1
E Ein         VIN VCMIN VIDM VSSA -0.5
V VScm         VICM 0 DC {vidc} AC 0
+PULSE {vidc} {vidc} {td+1} {tr} {tr} {pw} {per}
M M3c         VG3C VG3C VG3 VDDA P
+ L={l3c}
+ W={w3c}
+ M={m3c}
M M4c         VO VG3C VD4 VDDA P
+ L={l3c}
+ W={w3c}
+ M={m3c}
M M2c         VO VG1C VD2 VSSA N
+ L={l1c}
+ W={w1c}
+ M={m1c}
M M1c         VG3C VG1C VD1 VSSA N
+ L={l1c}
+ W={w1c}
+ M={m1c}
M M1cb         VG1C VG1C VTAIL VSSA N
+ L={l1cb}
+ W={w1cb}
+ M={m1cb}
I Ibiasc          VDDA VG1C DC {ibiasc}
.PARAM  w3=300u vs1={(vstep/2)*(-1)} td={per/2} vs2={(vstep/2)} ibiasc={ibias}
+  w6=270.0u vidc=1.5 l3c={l3} m3c=50 l1c={l1} per=10us m1c=8 pw={per/2 - tr}
+  m1cb=2.75 m1=5 l1cb={l1} cl=2pf l1=0.45u m3=50 l3=0.45u ibias=250u vstep=1m
+  m5=40 m6=2 vdda=2.5 vssa=0.0 l6=2u w3c={w3} w1cb=5u w1=350u tr={0.01*per} w1c=
+ {w1}

**** RESUMING testac.cir ****
.END

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Ps = 0 is less than W

WARNING(ORPSIM-15236): Parameter XW in model N is invalid - Ignored

WARNING(ORPSIM-15235): Mosfet M_M2, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M2, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M6, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M6, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M2c, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M2c, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1c, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1c, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Pd = 0 is less than W
```

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Ps = 0 is less than W

WARNING(ORPSIM-15236): Parameter XW in model P is invalid - Ignored

WARNING(ORPSIM-15235): Mosfet M_M4, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M4, model P: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3c, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3c, model P: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M4c, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M4c, model P: Ps = 0 is less than W

INFO(ORPSIM-15454): Model N: Using BSIM VERSION 3.1 or lower

INFO(ORPSIM-15454): Model P: Using BSIM VERSION 3.1 or lower

•

**** 12/04/16 15:48:21 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

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 ****     MOSFET MODEL PARAMETERS

**********

| | N | P |
|---|---|---|
| | NMOS | PMOS |
| T Measured | 27 | 27 |
| T Current | 27 | 27 |
| LEVEL | 7 | 7 |
| L | 100.000000E-06 | 100.000000E-06 |
| W | 100.000000E-06 | 100.000000E-06 |
| VTO | .355168 | -.547882 |
| KP | 357.221800E-06 | 357.221800E-06 |
| GAMMA | 0 | 0 |
| LAMBDA | 0 | 0 |
| RSH | 3.8 | 2.9 |
| IS | 1.000000E-15 | 1.000000E-15 |
| JS | 100.000000E-06 | 100.000000E-06 |
| PB | .99 | .961669 |
| PBSW | .981431 | .8 |
| CJ | 1.556442E-03 | 1.870360E-03 |
| CJSW | 421.795200E-12 | 311.598500E-12 |
| MJ | .422704 | .475679 |
| MJSW | .19742 | .268452 |
| CGSO | 457.000000E-12 | 559.000000E-12 |
| CGDO | 457.000000E-12 | 559.000000E-12 |
| CGBO | 1.000000E-12 | 1.000000E-12 |
| TOX | 5.800000E-09 | 5.800000E-09 |
| XJ | 100.000000E-09 | 100.000000E-09 |
| UCRIT | 10.000000E+03 | 10.000000E+03 |
| DELTA | .01 | .01 |
| DIOMOD | 2 | 2 |
| K1 | .488168 | .645808 |
| K2 | -1.465714E-06 | -1.621568E-03 |
| LETA | 0 | 0 |
| WETA | 0 | 0 |
| U0 | 305.8067 | 100 |
| XPART | .5 | .5 |

| | | |
|---|---|---|
| VTH0 | .355168 | -.547882 |
| K3 | 1.000000E-03 | .096322 |
| W0 | 100.000000E-09 | 1.000000E-06 |
| NLX | 192.736100E-09 | 14.689740E-09 |
| DVT0 | .575129 | 2.726151 |
| DVT1 | .566083 | .74709 |
| UA | -1.152667E-09 | 875.490400E-12 |
| UB | 2.428080E-18 | 1.000000E-21 |
| UC | 41.273400E-12 | -100.000000E-12 |
| VSAT | 128.759100E+03 | 129.251900E+03 |
| RDSW | 175 | 839.1661 |
| VOFF | -.109017 | -.129264 |
| NFACTOR | 1.531998 | .936195 |
| PCLM | 1.620562 | 1.397517 |
| PDIBL1 | .959482 | 4.013259E-03 |
| PDIBL2 | 2.748496E-03 | 5.534487E-06 |
| DROUT | 1 | .059113 |
| PSCBE1 | 683.743800E+06 | 5.132455E+09 |
| PSCBE2 | 231.977200E-06 | 1.189024E-09 |
| A0 | 1.795768 | .903978 |
| A1 | 456.914600E-06 | .03521 |
| A2 | .531924 | .3 |
| NPEAK | 235.490000E+15 | 415.890000E+15 |
| LDD | 0 | 0 |
| LITL | 41.713310E-09 | 41.713310E-09 |
| UA1 | 4.310000E-09 | 4.310000E-09 |
| UB1 | -7.610000E-18 | -7.610000E-18 |
| UC1 | -56.000000E-12 | -56.000000E-12 |
| PVAG | 9.534150E-03 | |
| KETA | -9.762332E-03 | 7.291800E-03 |
| ETA0 | 6.182294E-03 | .243084 |
| ETAB | 269.257900E-06 | -.020463 |
| K3B | 3.222249 | 5.987855 |
| DVT2 | -.302613 | -.114714 |
| DSUB | .045455 | .997855 |
| MOBMOD | 1 | 1 |
| AGS | .359392 | .084443 |
| DVT1W | 0 | 0 |
| DVT2W | 0 | 0 |
| PRWG | .15 | .233163 |
| PRWB | -.124343 | -.051475 |
| PDIBLCB | -.022086 | -1.000000E-03 |
| DWG | -15.000000E-09 | -47.227750E-09 |
| DWB | 2.371290E-09 | -16.212000E-09 |
| B0 | 127.264200E-12 | 1.473225E-06 |
| B1 | 4.171173E-09 | 5.000000E-06 |
| LINT | 2.800000E-09 | 33.490790E-09 |
| DLC | 2.800000E-09 | 33.490790E-09 |
| DWC | 0 | 0 |
| CF | 0 | 0 |
| NOIA | 100.000000E+18 | 9.900001E+18 |
| NOIB | 50.000000E+03 | 2.400000E+03 |
| NOIC | -1.400000E-12 | 1.400000E-12 |
| LKETA | 879.276400E-06 | -3.261413E-03 |
| WKETA | 3.502570E-03 | 1.257100E-03 |
| PVTH0 | -6.690647E-03 | 6.913576E-03 |
| PRDSW | -8.4 | 10.49393 |
| PK2 | 1.959318E-03 | 1.392595E-03 |
| VTM | .025864 | .025864 |
| VERSION | 3.1 | 3.1 |
| PBSWG | .851594 | .8 |
| MJSWG | .268491 | .278699 |
| CJSWG | 329.000000E-12 | 250.000000E-12 |

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1, model N: Ps = 0 is less than W

```
WARNING(ORPSIM-15236): Parameter XW in model N is invalid - Ignored

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M5, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M1cb, model N: Ps = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Pd = 0 is less than W

WARNING(ORPSIM-15235): Mosfet M_M3, model P: Ps = 0 is less than W

WARNING(ORPSIM-15236): Parameter XW in model P is invalid - Ignored
•
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lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     SMALL SIGNAL BIAS SOLUTION       TEMPERATURE =   27.000 DEG C

*******************************************************************************


 NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE     NODE   VOLTAGE

(   VO)   1.26173  (  VD1)   1.04695  (  VD2)   1.04695  (  VD4)   1.96021

(  VG3)   1.96021  (  VIN)   1.50000  (  VIP)   1.50000  ( VDDA)   2.50000

( VG1C)   1.71894  ( VG3C)   1.26173  ( VICM)   1.50000  ( VIDM)   0.00000

( VSSA)   0.00000  (VBIAS)    .45947  (VCMIN)   1.50000  (VTAIL)    .83714



    VOLTAGE SOURCE CURRENTS
    NAME         CURRENT

    V Vdda      -5.401E-03
    V Vssa       5.401E-03
    V VSdm       0.000E+00
    V_VScm       0.000E+00

    TOTAL POWER DISSIPATION   1.35E-02  WATTS

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lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     OPERATING POINT INFORMATION      TEMPERATURE =   27.000 DEG C

*******************************************************************************
```

**** VOLTAGE-CONTROLLED VOLTAGE SOURCES

| NAME | E Eip | E Eicm | E Ein |
|---|---|---|---|
| V-SOURCE | 0.000E+00 | 1.500E+00 | 0.000E+00 |
| I-SOURCE | 0.000E+00 | 0.000E+00 | 0.000E+00 |

**** MOSFETS

| NAME | M M1 | M M2 | M M5 | M M6 | M M3 |
|---|---|---|---|---|---|
| MODEL | N | N | N | N | P |
| ID | 2.45E-03 | 2.45E-03 | 5.15E-03 | 2.50E-04 | -2.45E-03 |
| VGS | 6.63E-01 | 6.63E-01 | 4.59E-01 | 4.59E-01 | -5.40E-01 |
| VDS | 2.10E-01 | 2.10E-01 | 8.37E-01 | 4.59E-01 | -5.40E-01 |
| VBS | -8.37E-01 | -8.37E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| VTH | 6.16E-01 | 6.16E-01 | 3.74E-01 | 3.75E-01 | -5.56E-01 |
| VDSAT | 8.79E-02 | 8.79E-02 | 9.81E-02 | 9.76E-02 | -6.73E-02 |
| Lin0/Sat1 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| if | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| ir | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| TAU | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| GM | 4.25E-02 | 4.25E-02 | 7.81E-02 | 3.82E-03 | 4.63E-02 |
| GDS | 1.42E-03 | 1.42E-03 | 3.82E-04 | 2.19E-05 | 3.83E-04 |
| GMB | 7.29E-03 | 7.29E-03 | 1.89E-02 | 9.22E-04 | 1.56E-02 |
| CBD | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CBS | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CGSOV | 8.00E-13 | 8.00E-13 | 4.94E-12 | 2.47E-13 | 8.39E-12 |
| CGDOV | 8.00E-13 | 8.00E-13 | 4.94E-12 | 2.47E-13 | 8.39E-12 |
| CGBOV | 4.50E-19 | 4.50E-19 | 2.00E-18 | 2.00E-18 | 4.50E-19 |
| Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges | | | | | |
| DQGDVGB | 4.77E-12 | 4.77E-12 | 1.07E-10 | 5.35E-12 | 3.31E-11 |
| DQGDVDB | -7.73E-13 | -7.73E-13 | -4.70E-12 | -2.37E-13 | -8.38E-12 |
| DQGDVSB | -3.69E-12 | -3.69E-12 | -9.37E-11 | -4.68E-12 | -1.82E-11 |
| DQDDVGB | -2.05E-12 | -2.05E-12 | -4.41E-11 | -2.20E-12 | -1.28E-11 |
| DQDDVDB | 7.93E-13 | 7.93E-13 | 4.84E-12 | 2.44E-13 | 8.38E-12 |
| DQDDVSB | 1.48E-12 | 1.48E-12 | 4.96E-11 | 2.48E-12 | 5.90E-12 |
| DQBDVGB | -6.65E-13 | -6.65E-13 | -1.89E-11 | -9.45E-13 | -7.52E-12 |
| DQBDVDB | -1.29E-14 | -1.29E-14 | -4.94E-14 | -3.65E-15 | -3.90E-15 |
| DQBDVSB | -8.18E-14 | -8.18E-14 | -1.04E-11 | -5.23E-13 | -2.03E-12 |

| NAME | M M4 | M M3c | M M4c | M M2c | M M1c |
|---|---|---|---|---|---|
| MODEL | P | P | P | N | N |
| ID | -2.45E-03 | -2.45E-03 | -2.45E-03 | 2.45E-03 | 2.45E-03 |
| VGS | -5.40E-01 | -6.98E-01 | -6.98E-01 | 6.72E-01 | 6.72E-01 |
| VDS | -5.40E-01 | -6.98E-01 | -6.98E-01 | 2.15E-01 | 2.15E-01 |
| VBS | 0.00E+00 | 5.40E-01 | 5.40E-01 | -1.05E+00 | -1.05E+00 |
| VTH | -5.56E-01 | -7.14E-01 | -7.14E-01 | 6.52E-01 | 6.52E-01 |
| VDSAT | -6.73E-02 | -7.01E-02 | -7.01E-02 | 7.60E-02 | 7.60E-02 |
| Lin0/Sat1 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| if | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| ir | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| TAU | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 | -1.00E+00 |
| GM | 4.63E-02 | 4.68E-02 | 4.68E-02 | 4.73E-02 | 4.73E-02 |
| GDS | 3.83E-04 | 3.41E-04 | 3.41E-04 | 1.36E-03 | 1.36E-03 |
| GMB | 1.56E-02 | 1.23E-02 | 1.23E-02 | 7.65E-03 | 7.65E-03 |
| CBD | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CBS | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| CGSOV | 8.39E-12 | 8.39E-12 | 8.39E-12 | 1.28E-12 | 1.28E-12 |
| CGDOV | 8.39E-12 | 8.39E-12 | 8.39E-12 | 1.28E-12 | 1.28E-12 |
| CGBOV | 4.50E-19 | 4.50E-19 | 4.50E-19 | 4.50E-19 | 4.50E-19 |
| Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges | | | | | |
| DQGDVGB | 3.31E-11 | 3.20E-11 | 3.20E-11 | 6.84E-12 | 6.84E-12 |
| DQGDVDB | -8.38E-12 | -8.38E-12 | -8.38E-12 | -1.24E-12 | -1.24E-12 |

```
DQGDVSB     -1.82E-11   -1.81E-11   -1.81E-11   -4.99E-12   -4.99E-12
DQDDVGB     -1.28E-11   -1.28E-11   -1.28E-11   -2.89E-12   -2.89E-12
DQDDVDB      8.38E-12    8.38E-12    8.38E-12    1.27E-12    1.27E-12
DQDDVSB      5.90E-12    5.55E-12    5.55E-12    1.89E-12    1.89E-12
DQBDVGB     -7.52E-12   -6.40E-12   -6.40E-12   -1.06E-12   -1.06E-12
DQBDVDB     -3.90E-15   -3.14E-15   -3.14E-15   -1.58E-14   -1.58E-14
DQBDVSB     -2.03E-12   -1.35E-12   -1.35E-12   -7.91E-14   -7.91E-14

NAME         M M1cb
MODEL        N
ID           2.50E-04
VGS          8.82E-01
VDS          8.82E-01
VBS         -8.37E-01
VTH          6.04E-01
VDSAT        2.32E-01
Lin0/Sat1   -1.00E+00
if          -1.00E+00
ir          -1.00E+00
TAU         -1.00E+00
GM           1.57E-03
GDS          3.13E-05
GMB          2.57E-04
CBD          0.00E+00
CBS          0.00E+00
CGSOV        6.28E-15
CGDOV        6.28E-15
CGBOV        4.50E-19
 Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges
DQGDVGB      4.20E-14
DQGDVDB     -5.97E-15
DQGDVSB     -3.45E-14
DQDDVGB     -1.84E-14
DQDDVDB      6.16E-15
DQDDVSB      1.44E-14
DQBDVGB     -5.18E-15
DQBDVDB     -6.00E-17
DQBDVSB     -6.17E-16

          JOB CONCLUDED
•
**** 12/04/16 15:48:21 ***** PSpice 16.6.0 (October 2012) ***** ID# 0 ********

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lescopicN\opamp_telescopicn-pspicefiles\sch


 ****     JOB STATISTICS SUMMARY


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  Total job time (using Solver 1)   =         .56
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# 11. CONCLUSION

In this project first thing is to decide a particular type of an op-amp from the four topologies. It helped me in understanding various op-amp topologies in detail. Each has its own advantages and disadvantages. There is tradeoff between various parameters and had to compromise one to achieve the other.

After understanding the design requirements, the decision was made to build a telescopic Opamp with NMOS inputs.

One of the important design issue faced during the design was the trade-off between output swing and limited common-mode input range of telescopic Opamp was observed.

After completion of the project, all the specifications were met