CALIFORNIA STATE UNIVERSITY SACRAMENTO

EEE 230 – ANALOG AND MIXED SIGNAL IC DESIGN
PROJECT 2

INSTRUCTOR– Dr.PERRY L. HEEDLEY

SUBMITTED BY,

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Submitted date:
12/09/2015

INTRODUCTION:

The main objective of this project is to design an Operational Amplifier and make the necessary decisions and tradeoffs to meet the given specifications. I chose Wide swing folded Cascode Opamp because with this type of Op-amp we get wider common-mode input range and wider output swing and I used P-mos inputs as Common-mode input voltage range must go down to at least 0V, and up to at least 0.8V. I started my design with Id1 and choose the value in such a way it meets the unity gain bandwidth requirements, and made sure that all the transistors are in saturation.

REQUIRED OPAMP SPECIFICATIONS:

DC open loop voltage gain > 80 dB
Unity gain bandwidth > 100 MHz
Phase margin between 70 and 75 degrees at unity gain
Vout swing > 1.0 Vp-p (single-ended)
Common-mode input voltage range must go down to at least 0V, and up to at least 0.8V
Load capacitance = 2 pF
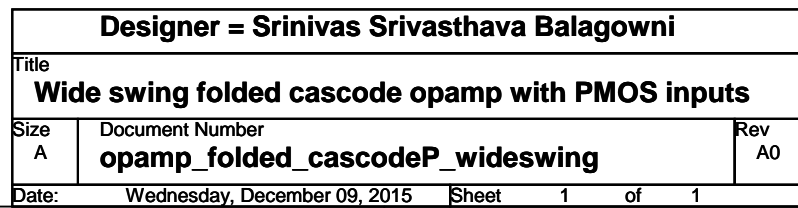Minimum Von for all saturated FETs = 150 mV
Process technology = 0.18μm CMOS
Supply voltages are VDD = 1.8V and VSS = 0V (ground)
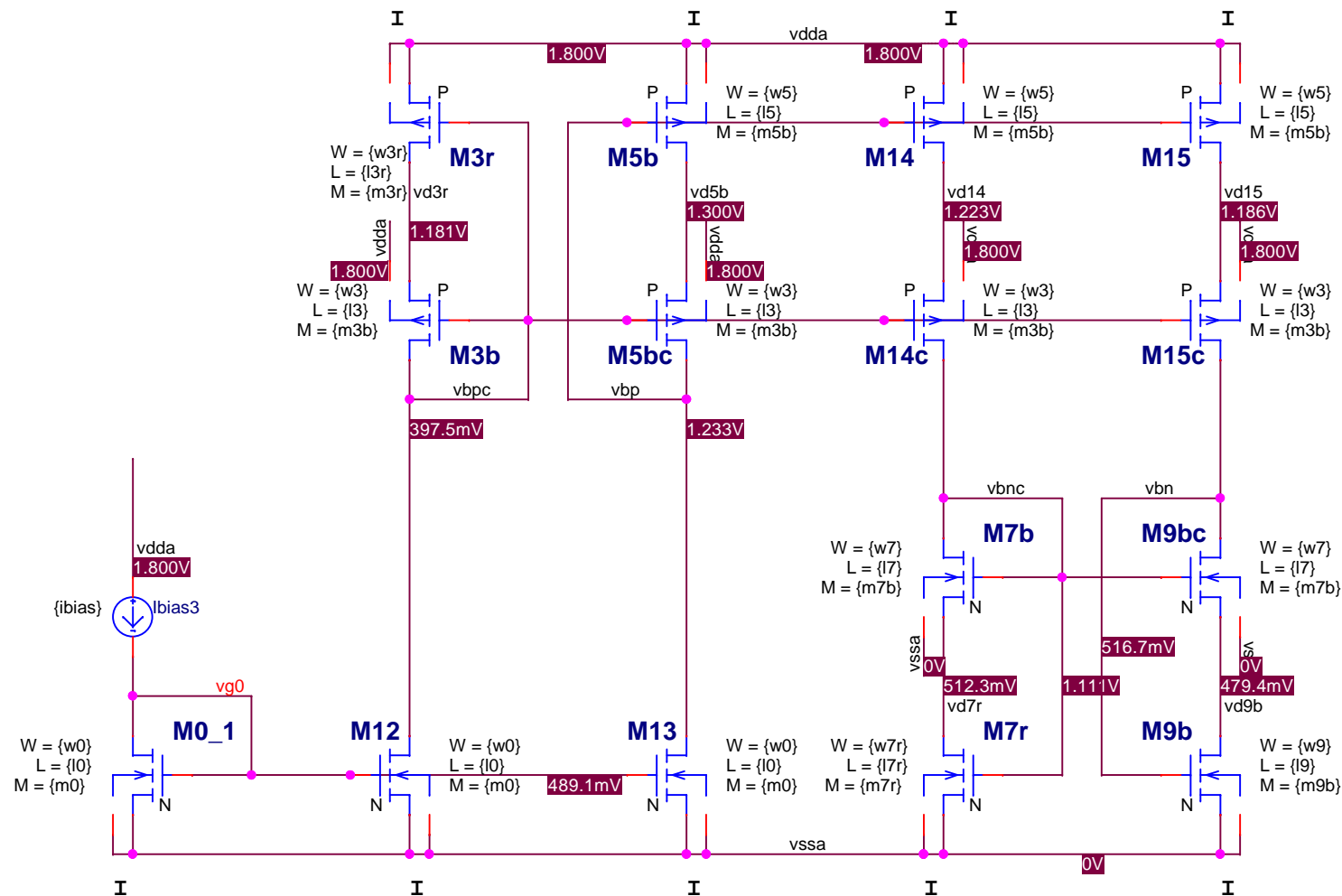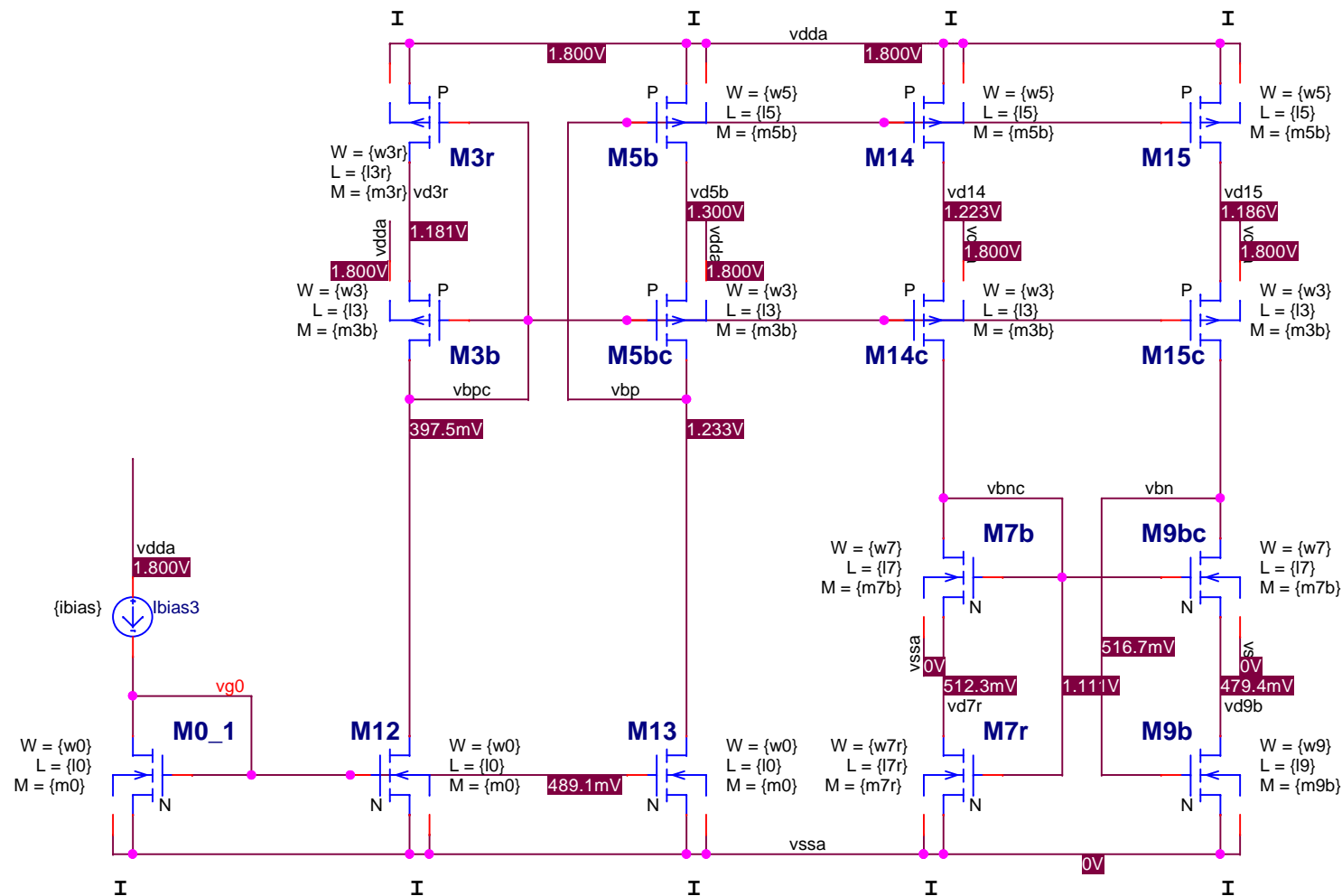Temperature = 27° C

DESIGN ISSUES:

The most important part of this project is choosing the type of amplifier to meet the design specification. First I started my design with folded Cascode Op- amp with Nmos inputs, but I got to know that I cannot get Common-mode input voltage range must go down to at least 0V and then I started over my design again by using P-mos inputs.

PARAMETERS:

w0 = 45u	vdda = 1.8
w1 = 270u	vssa = 0.0
w3 = 195u	
w5 = 220u	ibias = 203u
w7 = 325u	
w9 = 80u	vidc = 0
w3r = 4.6u	vodc = 0.9
w7r = 2.4u	vls = {vidc - vodc}
l0 = 2u	vstep = 1
l1 = 0.18u	vs1 = {vidc - (vstep/2)}
l3 = 1.2u	vs2 = {vidc + (vstep/2)}
l5 = 1.8u	
l7 = 2.6u	per = 100ns
l9 = 0.8u	pw = {per/2 - tr}
l3r = 0.5u	tr = {0.01*per}
l7r = 0.5u	td = {per/2}
m1 = 2	m0 = 8
m3 = 6	m3b = 1
m5 = 4	m5b = 2
m7 = 6	m7b = 2
m9 = 6	m9b = 2
m11 = 46	m3r = 1
	m7r = 1
cl = 2pF	

Designer = Srinivas Srivasthava Balagowni

Title
Wide swing folded cascode opamp with PMOS inputs

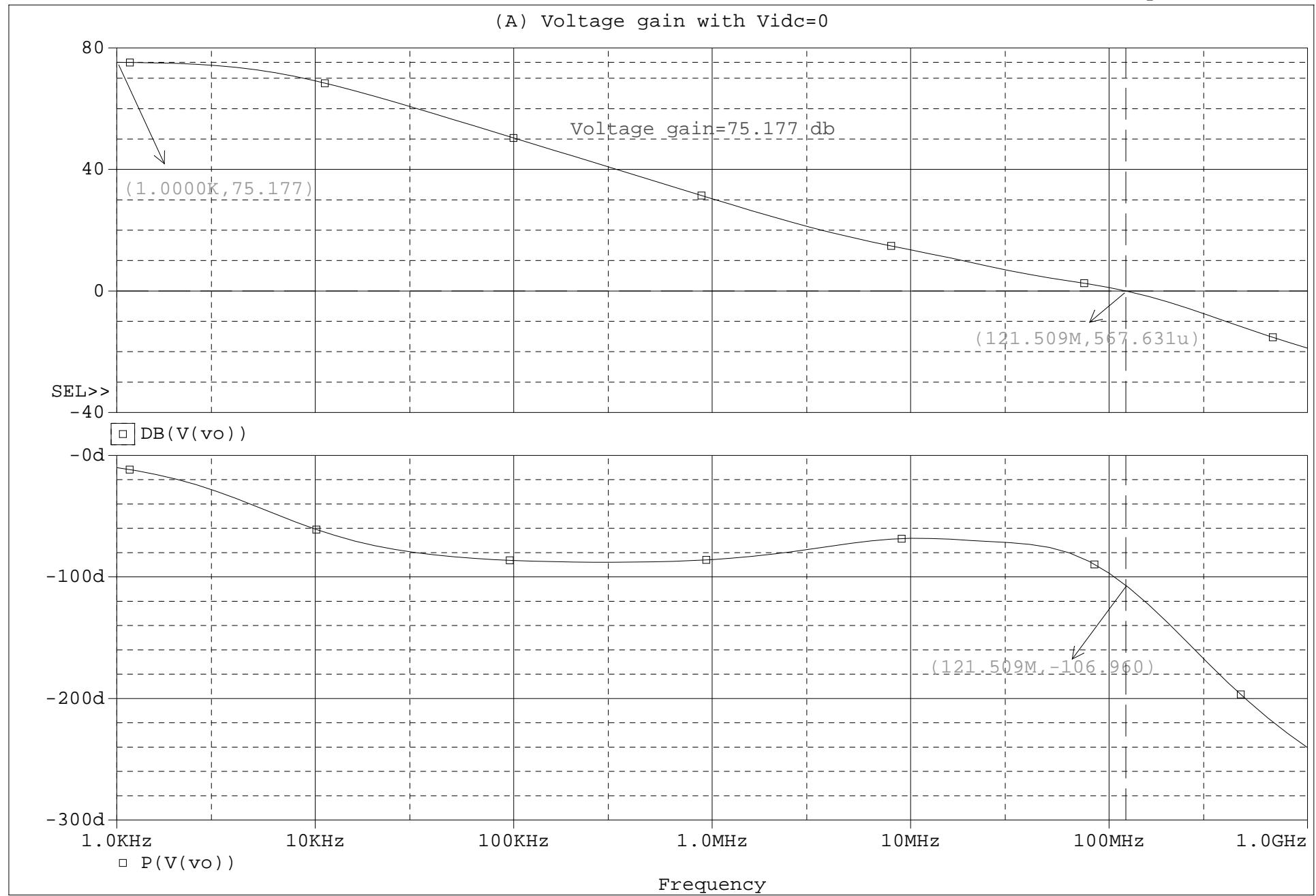| Size A	Document Number **opamp_folded_cascodeP_wideswing**	Rev A0

Date: Wednesday, December 09, 2015   Sheet   1   of   1

Designer = Srinivas Srivasthava Balagowni

Title
Wide swing folded cascode opamp with PMOS inputs

Size	Document Number	Rev
A	**opamp_folded_cascodeP_wideswing**	A0

Date: Tuesday, December 08, 2015 | Sheet 1 of 1

Wide swing folded cascode opamp with PMOS inputs

PARAMETERS:

w0 = 45u	vdda = 1.8
w1 = 270u	vssa = 0.0
w3 = 195u	
w5 = 220u	ibias = 203u
w7 = 325u	
w9 = 80u	vidc = 0.8
w3r = 4.6u	vodc = 0.9
w7r = 2.4u	vls = {vidc - vodc}
l0 = 2u	vstep = 1
l1 = 0.18u	vs1 = {vidc - (vstep/2)}
l3 = 1.2u	vs2 = {vidc + (vstep/2)}
l5 = 1.8u	
l7 = 2.6u	per = 100ns
l9 = 0.8u	pw = {per/2 - tr}
l3r = 0.5u	tr = {0.01*per}
l7r = 0.5u	td = {per/2}
m1 = 2	m0 = 8
m3 = 6	m3b = 1
m5 = 4	m5b = 2
m7 = 6	m7b = 2
m9 = 6	m9b = 2
m11 = 46	m3r = 1
	m7r = 1
cl = 2pF	

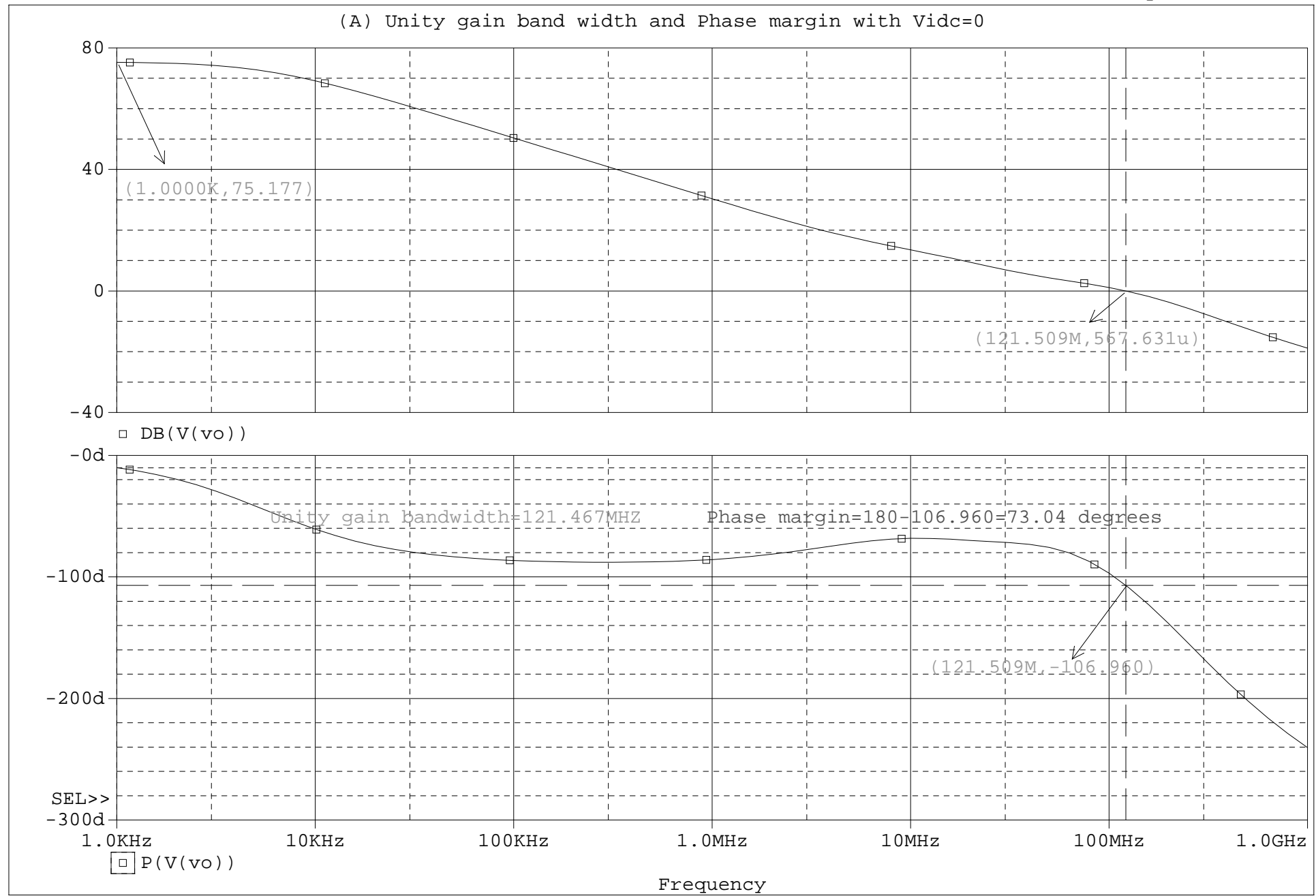Designer = Srinivas Srivasthava Balagowni

Title
Wide swing folded cascode opamp with PMOS inputs

Size	Document Number	Rev
A	**opamp_folded_cascodeP_wideswing**	A0

Date: Wednesday, December 09, 2015 Sheet 1 of 1

vdda
1.800V 1.800V

P M3r — W = {w3r} L = {l3r} M = {m3r} vd3r
P M5b — W = {w5} L = {l5} M = {m5b}
P M14 — W = {w5} L = {l5} M = {m5b} vd14
P M15 — W = {w5} L = {l5} M = {m5b} vd15

vd3r 1.181V
vdda 1.800V
W = {w3} L = {l3} M = {m3b}
M3b
vd5b 1.300V
vdda 1.800V
P M5bc — W = {w3} L = {l3} M = {m3b}
vd14 1.223V ve 1.800V
P M14c — W = {w3} L = {l3} M = {m3b}
vd15 1.186V ve 1.800V
P M15c — W = {w3} L = {l3} M = {m3b}

vbpc 397.5mV
vbp 1.233V

vbnc
vbn
M7b — W = {w7} L = {l7} M = {m7b} N
M9bc — W = {w7} L = {l7} M = {m7b} N

vssa 0V
512.3mV vd7r
516.7mV
1.111V
vssa 0V
479.4mV vd9b

vdda 1.800V
{ibias} Ibias3
vg0

M0_1 — W = {w0} L = {l0} M = {m0} N
M12 — N
M13 — W = {w0} L = {l0} M = {m0} 489.1mV N
W = {w0} L = {l0} M = {m0}
W = {w7r} L = {l7r} M = {m7r}
M7r — N
M9b — W = {w9} L = {l9} M = {m9b} N

vssa
0V

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Title
Wide swing folded cascode opamp with PMOS inputs

Size A
Document Number
opamp_folded_cascodeP_wideswing
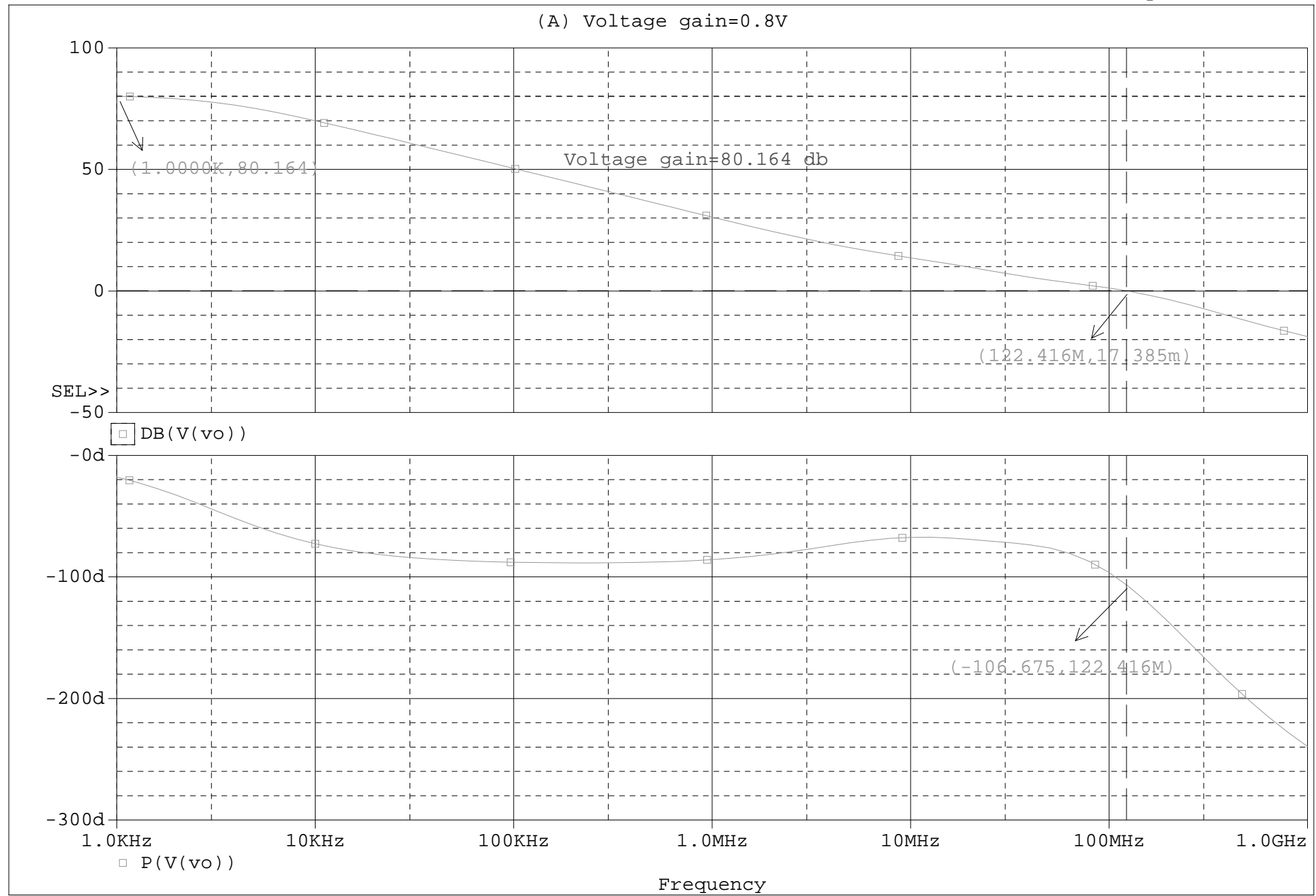
Rev A0

Date: Tuesday, December 08, 2015 Sheet 1 of 1

(A) Voltage gain with Vidc=0

Voltage gain=75.177 db

(1.0000K,75.177)

(121.509M,567.631u)

SEL>>

□ DB(V(vo))

(121.509M,-106.960)

□ P(V(vo))

Frequency

A1:(1.0000K,75.254)   A2:(121.509M,567.631u)   DIFF(A):(-121.508M,75.254)

(A) Unity gain band width and Phase margin with Vidc=0

DB(V(vo))

(1.0000K,75.177)

(121.509M,567.631u)

Unity gain bandwidth=121.467MHZ   Phase margin=180-106.960=73.04 degrees

(121.509M,-106.960)

SEL>>

P(V(vo))

Frequency

(A) Voltage gain=0.8V

(1.0000K,80.164)   Voltage gain=80.164 db

(122.416M,17.385m)

SEL>>

DB(V(vo))

(-106.675,122.416M)

P(V(vo))

Frequency

A1:(1.0000K,80.164)   A2:(122.416M,17.385m)   DIFF(A):(-122.415M,80.147)

(A) Bandwidth and Phase margin at Vidc=0.8V

SEL>>

□ DB(V(vo))

(1.0000K,80.164)

(122.416M,17.385m)

Unity gain bandwidth=122.415MHZ Phase margin=180-106.675=73.325 degrees

(-106.675,122.416M)

□ P(V(vo))

Frequency

A1:(1.0000K,80.164)   A2:(122.416M,17.385m)   DIFF(A):(-122.415M,80.147)

(A) Vout swing

□ V(vsin)

(204.100n,1.3462)

(295.500n,160.086m)

Vout swing peak to peak=1.3462-.160086=1.1861V

Time

□ V(vo)
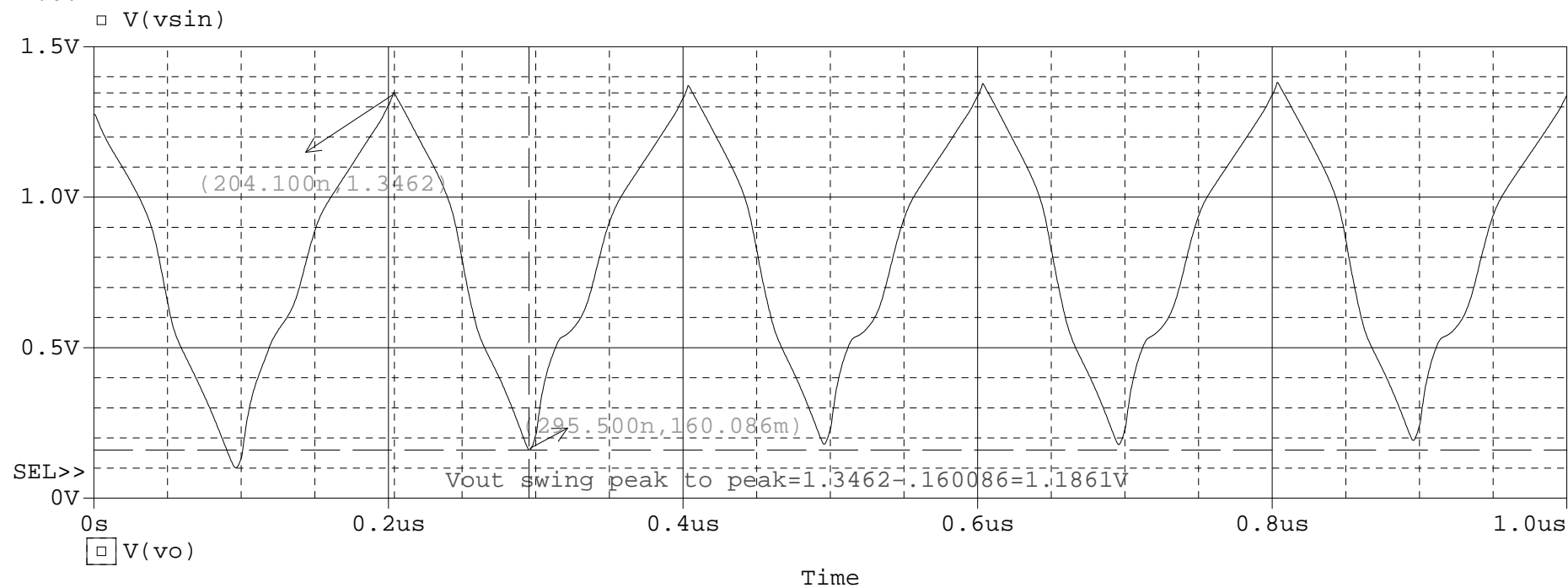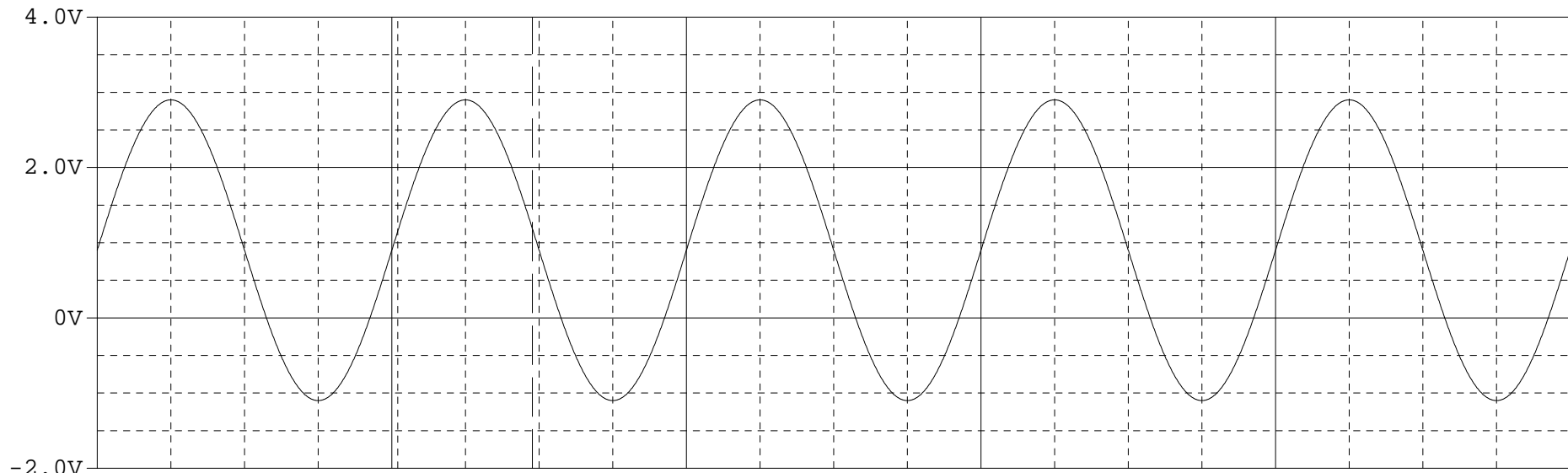
A1:(204.100n,1.3462)   A2:(295.500n,160.086m)   DIFF(A):(-91.400n,1.1861)

•
**** 12/09/15 19:48:57 ******* PSpice 16.3.0 (June 2009) ****** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac" [\\gaia\balagows\bvsdkbglj\opamp_folded_cascoden_wideswing\opamp_folded_cascoden_wide
swing-pspicef

  ****   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_folded_cascoden_wideswing-pspicefiles/opamp_folded_cascoden_wideswing.lib"
* From [PSPICE NETLIST] section of t:\Cadence\SPB_16.3\tools\PSpice\PSpice.ini file:
.lib "nom.lib"

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

**** INCLUDING SCHEMATIC1.net ****
* source OPAMP_FOLDED_CASCODEN_WIDESWING
M_M9   N232110 N139587 VDDA VDDA P
+ L={l9}
+ W={w9}
+ M={m9}
V_Vdda   VDDA 0 {vdda}
V_Vssa   VSSA 0 {vssa}
C_CL   VSSA VO {cl} TC=0,0
M_M7   N139587 VBPC N232110 VDDA P
+ L={l7}
+ W={w7}
+ M={m7}
M_M10   N213862 N139587 VDDA VDDA P
+ L={l9}

Page: 1

```
+ W={w9}
+ M={m9}
M_M8            VO VBPC N213862 VDDA P
+ L={l7}
+ W={w7}
+ M={m7}
M_M4            VO VBNC VD10 VSSA N
+ L={l3}
+ W={w3}
+ M={m3}
M_M3            N139587 VBNC VD1 VSSA N
+ L={l3}
+ W={w3}
+ M={m3}
M_M6            VD10 VBN VSSA VSSA N
+ L={l5}
+ W={w5}
+ M={m5}
M_M5            VD1 VBN VSSA VSSA N
+ L={l5}
+ W={w5}
+ M={m5}
M_M12            VBPC VG0 VSSA VSSA N
+ L={l0}
+ W={w0}
+ M={m0}
M_M3r            VD3R VBPC VDDA VDDA P
+ L={l3r}
+ W={w3r}
+ M={m3r}
M_M3b            VBPC VBPC VD3R VDDA P
+ L={l3}
+ W={w3}
+ M={m3b}
M_M13            VBP VG0 VSSA VSSA N
+ L={l0}
+ W={w0}
+ M={m0}
M_M5b            VD5B VBP VDDA VDDA P
+ L={l5}
+ W={w5}
+ M={m5b}
M_M5bc            VBP VBPC VD5B VDDA P
+ L={l3}
+ W={w3}
+ M={m3b}
M_M14            VD14 VBP VDDA VDDA P
+ L={l5}
+ W={w5}
+ M={m5b}
```

```
M_M14c            VBNC VBPC VD14 VDDA P
+ L={l3}
+ W={w3}
+ M={m3b}
M_M15c            VBN VBPC VD15 VDDA P
+ L={l3}
+ W={w3}
+ M={m3b}
M_M15             VD15 VBP VDDA VDDA P
+ L={l5}
+ W={w5}
+ M={m5b}
M_M7r             VD7R VBNC VSSA VSSA N
+ L={l7r}
+ W={w7r}
+ M={m7r}
M_M7b             VBNC VBNC VD7R VSSA N
+ L={l7}
+ W={w7}
+ M={m7b}
M_M9b             VD9B VBN VSSA VSSA N
+ L={l9}
+ W={w9}
+ M={m9b}
M_M9bc            VBN VBNC VD9B VSSA N
+ L={l7}
+ W={w7}
+ M={m7b}
L_Lbig            VIAC VIDC  1e12
C_Cbig            VSSA VIAC  1e12  TC=0,0
V_Vs            VIP 0 DC {vidc} AC 1
+PULSE {vs1} {vs2} {td} {tr} {tr} {pw} {per}
V_Vlevel_shift          VIDC VO {vls}
M_M1        VD1 VIP VTAIL VDDA P
+ L={l1}
+ W={w1}
+ M={m1}
M_M2             VTAIL VIAC VD10 VDDA P
+ L={l1}
+ W={w1}
+ M={m1}
M_M11             VTAIL N219745 VDDA VDDA P
+ L={l0}
+ W={w0}
+ M={m11}
M_M12A1             N219745 N219745 VDDA VDDA P
+ L={l0}
+ W={w0}
+ M={m0}
M_M16             N219741 N219741 VSSA VSSA N
```

```
+ L={l0}
+ W={w0}
+ M={m0}
I_Ibias2          N219745 N219741 DC {ibias}
I_Ibias3          VDDA VG0 DC {ibias}
M_M0_1            VG0 VG0 VSSA VSSA N
+ L={l0}
+ W={w0}
+ M={m0}
V_V2             VSIN1 0  AC 1
+SIN 0 2 5MEG 0 0 180
V_V1             VSIN 0  AC 1
+SIN 0 2 5MEG 0 0 0
R_R1             VO N230922 1k
C_C1             N230922 N139587 12p TC=0
C_C3             VO N231068 12p TC=0
R_R2             VD1 N231068 2k
.PARAM  l9=0.8u w3=195u l3r=0.5u m5b=2 vs1={vidc - (vstep/2)} td={per/2} m3r=1
+  w5=220u vs2={vidc + (vstep/2)} vidc=0 m3b=1 w7=325u vls={vidc - vodc} w9=80u
+  per=100ns m11=46 pw={per/2 - tr} m0=8 l0=2u m1=2 w7r=2.4u vodc=0.9 cl=2pf
+  l1=0.18u m3=6 l3=1.2u ibias=203u vstep=1 m5=4 w3r=4.6u l5=1.8u vdda=1.8
+  vssa=0.0 l7r=0.5u m7=6 w0=45u m9b=2 m7r=1 l7=2.6u w1=270u tr={0.01*per} m7b=2
+  m9=6

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

WARNING -- Mosfet M_M9, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M9, model P: Ps = 0 is less than W
WARNING -- Parameter XW in model P is invalid - Ignored
WARNING -- Mosfet M_M7, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M7, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M10, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M10, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M8, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M8, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M3r, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M3r, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M3b, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M3b, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M5b, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M5b, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M5bc, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M5bc, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M14, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M14, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M14c, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M14c, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M15c, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M15c, model P: Ps = 0 is less than W
```

```
WARNING -- Mosfet M_M15, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M15, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M1, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M1, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M2, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M2, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M11, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M11, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M12A1, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M12A1, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M4, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M4, model N: Ps = 0 is less than W
WARNING -- Parameter XW in model N is invalid - Ignored
WARNING -- Mosfet M_M3, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M3, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M6, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M6, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M5, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M5, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M12, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M12, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M13, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M13, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M7r, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M7r, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M7b, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M7b, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M9b, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M9b, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M9bc, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M9bc, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M16, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M16, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M0_1, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M0_1, model N: Ps = 0 is less than W
Model P: Using BSIM VERSION 3.1 or lower
Model N: Using BSIM VERSION 3.1 or lower•
**** 12/09/15 19:48:57 ******* PSpice 16.3.0 (June 2009) ****** ID# 0 ********


 ** Profile: "SCHEMATIC1-testac"  [ \\gaia\balagows\bvsdkbglj\opamp_folded_cascoden_wideswing\opamp_folded_cascoden_wide
swing-pspicef


 ****      MOSFET MODEL PARAMETERS


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

```
                  P                 N
                  PMOS              NMOS
    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      -.382344          .36943
            KP    505.338100E-06    505.338100E-06
         GAMMA    0                 0
        LAMBDA    0                 0
           RSH    8.1               7
            IS    1.000000E-15      1.000000E-15
            JS    100.000000E-06    100.000000E-06
            PB      .846161           .8
          PBSW      .8                .8
            CJ    1.214428E-03      947.109700E-06
          CJSW    216.564200E-12    190.590100E-12
            MJ      .419208           .372616
          MJSW      .320287           .136976
          CGSO    782.000000E-12    858.000000E-12
          CGDO    782.000000E-12    858.000000E-12
          CGBO    1.000000E-12      1.000000E-12
           TOX    4.100000E-09      4.100000E-09
            XJ    100.000000E-09    100.000000E-09
         UCRIT    10.000000E+03     10.000000E+03
         DELTA      .01               .01
        DIOMOD    2                 2
            K1      .572205           .578912
            K2      .021972          1.110723E-03
          LETA    0                 0
          WETA    0                 0
            U0    109.4682          293.1688
         XPART      .5                .5
          VTH0     -.382344           .36943
            K3      .157675          1.000000E-03
            W0    1.000000E-06      100.000000E-09
           NLX    110.421200E-09    203.774800E-09
          DVT0      .623484          1.295363
          DVT1      .247926           .342155
            UA    1.316460E-09      -1.219420E-09
            UB    1.000000E-21      2.325738E-18
            UC   -100.000000E-12    70.612890E-12
          VSAT    105.489200E+03    167.616400E+03
          RDSW    199.1594          105.6133
          VOFF     -.093565          -.094802
       NFACTOR    2                 2.186007
          PCLM      .96422          1.746064
        PDIBL1    3.026627E-03       .325819
```

```
 PDIBL2    -10.000000E-06      2.701992E-03
  DROUT   111.701600E-06        .978723
 PSCBE1    79.999860E+09      44.947780E+09
 PSCBE2   827.189700E-12      36.720740E-09
     A0     1.579686           2
     A1      .388689           1.091680E-03
     A2      .401038            .330303
  NPEAK   415.890000E+15     235.490000E+15
    LDD     0                  0
   LITL    35.071360E-09      35.071360E-09
    UA1     4.310000E-09       4.310000E-09
    UB1    -7.610000E-18      -7.610000E-18
    UC1   -56.000000E-12     -56.000000E-12
   PVAG     .019012            .012276
   KETA     .029861           -.013855
   ETA0   351.539200E-06       2.665034E-03
   ETAB  -480.433800E-06      60.289750E-06
    K3B     4.276364           .029712
   DVT2     .1                 .039559
   DSUB    12.150870E-06       .044222
 MOBMOD     1                  1
    AGS     .311502            .476455
  DVT1W     0                  0
  DVT2W     0                  0
   PRWG     .5                 .5
   PRWB    -.494703           -.2
 PDIBLCB   -1.000000E-03      -.1
    DWG   -19.980340E-09       2.754317E-09
    DWB    -2.481453E-09      -3.690793E-09
     B0   472.929700E-09     161.710100E-09
     B1     1.446715E-06       5.000000E-06
   LINT    29.394800E-09      17.156220E-09
   WINT                        2.885735E-09
    DLC    29.394800E-09      17.156220E-09
    DWC     0                  2.885735E-09
     CF     0                  0
   NOIA     9.900001E+18     100.000000E+18
   NOIB     2.400000E+03      50.000000E+03
   NOIC     1.400000E-12      -1.400000E-12
   LKETA   -3.648003E-03     532.492200E-06
   WKETA    .013323           -5.071892E-03
  PVSAT    50                  2.000000E+03
  PKETA   -1.822724E-03      -2.090695E-03
  PVTH0  516.791300E-06      -5.105777E-03
    PUA  -43.082600E-12     -44.823200E-12
    PUB    1.000000E-21       5.018589E-24
    PU0   -1.067435          -4.020608
   PRDSW   9.506882          -1.101173
   PETA0 100.000000E-06     100.000000E-06
    PK2    1.095907E-03       2.247806E-03
```

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        VTM      .025864         .025864
    VERSION    3.1             3.1
      PBSWG      .8              .8
     MJSWG      .320287         .136976
     CJSWG  422.000000E-12  330.000000E-12


WARNING -- Mosfet M_M9, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M9, model P: Ps = 0 is less than W
WARNING -- Parameter XW in model P is invalid - Ignored
WARNING -- Mosfet M_M7, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M7, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M3r, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M3r, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M3b, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M3b, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M5b, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M5b, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M1, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M1, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M11, model P: Pd = 0 is less than W
WARNING -- Mosfet M_M11, model P: Ps = 0 is less than W
WARNING -- Mosfet M_M4, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M4, model N: Ps = 0 is less than W
WARNING -- Parameter XW in model N is invalid - Ignored
WARNING -- Mosfet M_M6, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M6, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M12, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M12, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M7r, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M7r, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M7b, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M7b, model N: Ps = 0 is less than W
WARNING -- Mosfet M_M9b, model N: Pd = 0 is less than W
WARNING -- Mosfet M_M9b, model N: Ps = 0 is less than W•
**** 12/09/15 19:48:57 ******* PSpice 16.3.0 (June 2009) ****** ID# 0 ********
```

 ** Profile: "SCHEMATIC1-testac" [\\gaia\balagows\bvsdkbglj\opamp_folded_cascoden_wideswing\opamp_folded_cascoden_wide
swing-pspicef

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

****

 NODE   VOLTAGE   NODE   VOLTAGE   NODE   VOLTAGE   NODE   VOLTAGE

```
(   VO)    .90048  (  VBN)    .51675  (  VBP)   1.23248  (  VD1)    .54626

(  VG0)    .48905  (  VIP)   0.00000  ( VBNC)   1.11140  ( VBPC)    .39746

( VD10)    .54395  ( VD14)   1.22320  ( VD15)   1.18599  ( VD3R)   1.18083

( VD5B)   1.29969  ( VD7R)    .51229  ( VD9B)    .47943  ( VDDA)   1.80000

( VIAC) 480.83E-06 ( VIDC) 480.83E-06 ( VSIN)   0.00000  ( VSSA)   0.00000

(VSIN1)   0.00000  (VTAIL)    .78669  (N139587)  1.28095

(N213862)  1.08503           (N219741)   .48905

(N219745)  1.20829           (N230922)   .90048

(N231068)   .54626           (N232110)  1.29522




     VOLTAGE SOURCE CURRENTS
     NAME           CURRENT

     V_Vdda        -2.896E-03
     V_Vssa         2.896E-03
     V_Vs           0.000E+00
     V_Vlevel_shift   0.000E+00
     V_V2           0.000E+00
     V_V1           0.000E+00

     TOTAL POWER DISSIPATION   5.21E-03  WATTS
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•
**** 12/09/15 19:48:57 ******* PSpice 16.3.0 (June 2009) ****** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac" [\\gaia\balagows\bvsdkbglj\opamp_folded_cascoden_wideswing\opamp_folded_cascoden_wide
swing-pspicef

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

****

**** MOSFETS

NAME	M_M9	M_M7	M_M10	M_M8	M_M4
MODEL	P	P	P	P	N
ID	-2.28E-04	-2.28E-04	-2.33E-04	-2.33E-04	2.33E-04
VGS	-5.19E-01	-8.98E-01	-5.19E-01	-6.88E-01	5.67E-01
VDS	-5.05E-01	-1.43E-02	-7.15E-01	-1.85E-01	3.57E-01
VBS	0.00E+00	5.05E-01	0.00E+00	7.15E-01	-5.44E-01
VTH	-4.18E-01	-5.41E-01	-4.18E-01	-5.94E-01	5.63E-01
VDSAT	-1.02E-01	-3.00E-01	-1.02E-01	-1.05E-01	5.50E-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	3.50E-03	6.33E-04	3.56E-03	3.63E-03	5.37E-03
GDS	2.34E-05	1.56E-02	2.21E-05	5.97E-05	3.18E-05
GMB	1.09E-03	1.98E-04	1.11E-03	9.04E-04	1.26E-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	3.75E-13	1.52E-12	3.75E-13	1.52E-12	1.00E-12
CGDOV	3.75E-13	1.52E-12	3.75E-13	1.52E-12	1.00E-12
CGBOV	8.00E-19	2.60E-18	8.00E-19	2.60E-18	1.20E-18

 Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges

	M_M9	M_M7	M_M10	M_M8	M_M4
DQGDVGB	3.11E-12	4.48E-11	3.11E-12	3.48E-11	8.05E-12
DQGDVDB	-3.74E-13	-2.00E-11	-3.73E-13	-1.77E-12	-9.94E-13
DQGDVSB	-2.57E-12	-2.56E-11	-2.57E-12	-3.13E-11	-5.70E-12
DQDDVGB	-1.31E-12	-2.23E-11	-1.31E-12	-1.49E-11	-3.05E-12
DQDDVDB	3.75E-13	1.62E-11	3.75E-13	1.74E-12	1.00E-12
DQDDVSB	1.24E-12	1.17E-11	1.24E-12	1.64E-11	2.56E-12
DQBDVGB	-4.85E-13	-1.58E-13	-4.85E-13	-5.04E-12	-1.96E-12
DQBDVDB	-1.15E-15	-1.08E-11	-7.11E-16	-1.83E-13	-4.98E-15
DQBDVSB	-2.82E-13	7.35E-13	-2.81E-13	-3.05E-12	-4.19E-13

NAME	M_M3	M_M6	M_M5	M_M12	M_M3r
MODEL	N	N	N	N	P
ID	2.28E-04	8.26E-04	8.27E-04	2.02E-04	-2.02E-04
VGS	5.65E-01	5.17E-01	5.17E-01	4.89E-01	-1.40E+00
VDS	7.35E-01	5.44E-01	5.46E-01	3.97E-01	-6.19E-01
VBS	-5.46E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VTH	5.63E-01	3.99E-01	3.99E-01	3.96E-01	-4.32E-01
VDSAT	5.44E-02	1.01E-01	1.01E-01	8.62E-02	-7.20E-01
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	5.26E-03	1.24E-02	1.24E-02	3.41E-03	3.03E-04
GDS	2.54E-05	4.75E-05	4.74E-05	1.39E-05	1.03E-04
GMB	1.24E-03	3.48E-03	3.48E-03	9.66E-04	1.08E-04

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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            1.00E-12     7.55E-13     7.55E-13     3.09E-13     3.60E-15
CGDOV            1.00E-12     7.55E-13     7.55E-13     3.09E-13     3.60E-15
CGBOV            1.20E-18     1.80E-18     1.80E-18     2.00E-18     5.00E-19
 Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges
DQGDVGB          7.94E-12     1.21E-11     1.21E-11     5.30E-12     2.17E-14
DQGDVDB         -9.92E-13    -7.47E-13    -7.47E-13    -3.08E-13    -4.01E-15
DQGDVSB         -5.55E-12    -1.05E-11    -1.05E-11    -4.58E-12    -1.74E-14
DQDDVGB         -2.98E-12    -4.97E-12    -4.97E-12    -2.16E-12    -9.54E-15
DQDDVDB          1.00E-12     7.54E-13     7.54E-13     3.10E-13     4.01E-15
DQDDVSB          2.48E-12     5.54E-12     5.54E-12     2.44E-12     7.39E-15
DQBDVGB         -1.97E-12    -2.12E-12    -2.12E-12    -9.76E-13    -2.59E-15
DQBDVDB         -3.87E-15    -4.95E-15    -4.91E-15    -3.34E-15    -4.08E-16
DQBDVSB         -4.02E-13    -1.32E-12    -1.32E-12    -5.97E-13    -9.77E-16

NAME             M_M3b        M_M13        M_M5b        M_M5bc       M_M14
MODEL            P            N            P            P            P
ID              -2.02E-04     2.11E-04    -2.11E-04    -2.11E-04    -2.12E-04
VGS             -7.83E-01     4.89E-01    -5.68E-01    -9.02E-01    -5.68E-01
VDS             -7.83E-01     1.23E+00    -5.00E-01    -6.72E-02    -5.77E-01
VBS              6.19E-01     0.00E+00     0.00E+00     5.00E-01     0.00E+00
VTH             -5.83E-01     3.95E-01    -3.99E-01    -5.53E-01    -3.99E-01
VDSAT           -1.84E-01     8.67E-02    -1.46E-01    -2.96E-01    -1.46E-01
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               1.84E-03     3.52E-03     2.34E-03     6.58E-04     2.35E-03
GDS              1.30E-05     1.02E-05     1.26E-05     2.73E-03     1.22E-05
GMB              4.77E-04     9.97E-04     7.38E-04     2.01E-04     7.40E-04
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            1.52E-13     3.09E-13     3.44E-13     1.52E-13     3.44E-13
CGDOV            1.52E-13     3.09E-13     3.44E-13     1.52E-13     3.44E-13
CGBOV            1.20E-18     2.00E-18     1.80E-18     1.20E-18     1.80E-18
 Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges
DQGDVGB          1.80E-12     5.30E-12     5.88E-12     2.15E-12     5.88E-12
DQGDVDB         -1.50E-13    -3.05E-13    -3.43E-13    -8.45E-13    -3.41E-13
DQGDVSB         -1.60E-12    -4.58E-12    -5.26E-12    -1.34E-12    -5.25E-12
DQDDVGB         -7.76E-13    -2.16E-12    -2.48E-12    -1.06E-12    -2.47E-12
DQDDVDB          1.52E-13     3.07E-13     3.45E-13     7.31E-13     3.44E-13
DQDDVSB          7.82E-13     2.43E-12     2.82E-12     5.69E-13     2.82E-12
DQBDVGB         -2.52E-13    -9.81E-13    -9.28E-13    -2.67E-14    -9.30E-13
DQBDVDB         -7.03E-16    -8.76E-16    -3.80E-15    -4.65E-13    -2.70E-15
DQBDVSB         -1.21E-13    -5.93E-13    -7.37E-13     4.39E-14    -7.36E-13

NAME             M_M14c       M_M15c       M_M15        M_M7r        M_M7b
MODEL            P            P            P            N            N
ID              -2.12E-04    -2.12E-04    -2.12E-04     2.12E-04     2.12E-04
```

VGS	-8.26E-01	-7.89E-01	-5.68E-01	1.11E+00	5.99E-01
VDS	-1.12E-01	-6.69E-01	-6.14E-01	5.12E-01	5.99E-01
VBS	5.77E-01	6.14E-01	0.00E+00	0.00E+00	-5.12E-01
VTH	-5.73E-01	-5.82E-01	-3.99E-01	4.54E-01	5.32E-01
VDSAT	-2.23E-01	-1.89E-01	-1.47E-01	3.71E-01	8.14E-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	1.11E-03	1.88E-03	2.35E-03	5.15E-04	3.94E-03
GDS	1.25E-03	1.39E-05	1.20E-05	6.35E-05	1.11E-05
GMB	3.08E-04	4.90E-04	7.41E-04	1.36E-04	9.24E-04
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	1.52E-13	1.52E-13	3.44E-13	2.06E-15	5.58E-13
CGDOV	1.52E-13	1.52E-13	3.44E-13	2.06E-15	5.58E-13
CGBOV	1.20E-18	1.20E-18	1.80E-18	5.00E-19	2.60E-18

Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges

DQGDVGB	2.04E-12	1.81E-12	5.88E-12	1.21E-14	1.14E-11
DQGDVDB	-5.29E-13	-1.50E-13	-3.41E-13	-2.11E-15	-5.54E-13
DQGDVSB	-1.51E-12	-1.60E-12	-5.25E-12	-9.63E-15	-9.87E-12
DQDDVGB	-9.66E-13	-7.77E-13	-2.47E-12	-5.25E-15	-4.68E-12
DQDDVDB	4.66E-13	1.52E-13	3.44E-13	2.14E-15	5.57E-13
DQDDVSB	7.08E-13	7.83E-13	2.82E-12	4.08E-15	5.15E-12
DQBDVGB	-1.03E-13	-2.52E-13	-9.30E-13	-1.57E-15	-2.01E-12
DQBDVDB	-2.51E-13	-8.86E-16	-2.37E-15	-1.06E-16	-1.96E-15
DQBDVSB	-6.26E-14	-1.21E-13	-7.35E-13	-5.81E-16	-9.87E-13

NAME	M_M9b	M_M9bc	M_M1	M_M2	M_M11
MODEL	N	N	P	P	P
ID	2.12E-04	2.12E-04	-5.98E-04	5.93E-04	-1.19E-03
VGS	5.17E-01	6.32E-01	-7.87E-01	-5.43E-01	-5.92E-01
VDS	4.79E-01	3.73E-02	-2.40E-01	2.43E-01	-1.01E+00
VBS	0.00E+00	-4.79E-01	1.01E+00	1.26E+00	0.00E+00
VTH	4.33E-01	5.24E-01	-7.49E-01	-7.49E-01	-3.96E-01
VDSAT	8.27E-02	1.05E-01	-8.27E-02	-8.24E-02	-1.65E-01
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	3.70E-03	2.36E-03	1.16E-02	1.15E-02	1.16E-02
GDS	2.64E-05	4.42E-03	3.07E-04	3.01E-04	5.61E-05
GMB	1.05E-03	5.67E-04	2.66E-03	2.64E-03	3.66E-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	1.37E-13	5.58E-13	4.22E-13	4.22E-13	1.62E-12
CGDOV	1.37E-13	5.58E-13	4.22E-13	4.22E-13	1.62E-12
CGBOV	8.00E-19	2.60E-18	1.80E-19	1.80E-19	2.00E-18

Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges

DQGDVGB	1.08E-12	1.40E-11	1.22E-12	1.22E-12	3.05E-11

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DQGDVDB        -1.35E-13   -3.78E-12   -4.22E-13   -7.64E-13   -1.59E-12
DQGDVSB        -8.75E-13   -9.97E-12   -7.66E-13   -4.22E-13   -2.75E-11
DQDDVGB        -4.51E-13   -6.71E-12   -5.60E-13   -5.60E-13   -1.28E-11
DQDDVDB         1.37E-13    3.24E-12    4.22E-13    5.91E-13    1.61E-12
DQDDVSB         4.13E-13    5.00E-12    1.70E-13    8.67E-17    1.49E-11
DQBDVGB        -1.81E-13   -6.35E-13   -9.73E-14   -9.73E-14   -4.83E-12
DQBDVDB        -7.69E-16   -2.15E-12   -7.17E-16    4.38E-15   -6.57E-15
DQBDVSB        -8.83E-14   -5.99E-13    4.38E-15   -7.00E-16   -3.90E-12
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NAME            M_M12A1     M_M16       M_M0_1
MODEL           P           N           N
ID             -2.03E-04    2.03E-04    2.03E-04
VGS            -5.92E-01    4.89E-01    4.89E-01
VDS            -5.92E-01    4.89E-01    4.89E-01
VBS             0.00E+00    0.00E+00    0.00E+00
VTH            -3.97E-01    3.96E-01    3.96E-01
VDSAT          -1.65E-01    8.63E-02    8.63E-02
Lin0/Sat1      -1.00E+00   -1.00E+00   -1.00E+00
if             -1.00E+00   -1.00E+00   -1.00E+00
ir             -1.00E+00   -1.00E+00   -1.00E+00
TAU            -1.00E+00   -1.00E+00   -1.00E+00
GM              1.99E-03    3.42E-03    3.42E-03
GDS             1.03E-05    1.23E-05    1.23E-05
GMB             6.28E-04    9.70E-04    9.70E-04
CBD             0.00E+00    0.00E+00    0.00E+00
CBS             0.00E+00    0.00E+00    0.00E+00
CGSOV           2.82E-13    3.09E-13    3.09E-13
CGDOV           2.82E-13    3.09E-13    3.09E-13
CGBOV           2.00E-18    2.00E-18    2.00E-18
 Derivatives of gate (dQg/dVxy) and bulk (dQb/dVxy) charges
DQGDVGB         5.31E-12    5.30E-12    5.30E-12
DQGDVDB        -2.79E-13   -3.06E-13   -3.06E-13
DQGDVSB        -4.78E-12   -4.58E-12   -4.58E-12
DQDDVGB        -2.24E-12   -2.16E-12   -2.16E-12
DQDDVDB         2.82E-13    3.09E-13    3.09E-13
DQDDVSB         2.59E-12    2.43E-12    2.43E-12
DQBDVGB        -8.37E-13   -9.78E-13   -9.78E-13
DQBDVDB        -2.69E-15   -2.13E-15   -2.13E-15
DQBDVSB        -6.79E-13   -5.95E-13   -5.95E-13
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            JOB CONCLUDED
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**** 12/09/15 19:48:57 ******* PSpice 16.3.0 (June 2009) ****** ID# 0 ********

 ** Profile: "SCHEMATIC1-testac" [\\gaia\balagows\bvsdkbglj\opamp_folded_cascoden_wideswing\opamp_folded_cascoden_wide
swing-pspicef

 ****   JOB STATISTICS SUMMARY

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  Total job time (using Solver 1)   =   .70
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DESIGN APPROACH:

Hand calculations:

The equation that governs $\left(\frac{W}{L}\right)$, I_D, V_{on} is :

$$I_d = \frac{K'}{2} \frac{W}{L} V_{on}^2$$

The gain of the op-Amp is:

$$A_{DM} = g_{m1} * R_0$$
$$R_0 = [r_{04}(1 + g_{m4}(r_{02}||r_{06}))]||[r_{08}(1 + g_{m8} * r_{10})]$$

here $r_0 = \dfrac{1}{g_{ds}}$

$$r_{04} = \frac{1}{3.18 * 10^{-5}} = 31446.54 \ \Omega$$

$$r_{02} = \frac{1}{3.01 * 10^{-4}} = 3322.2 \ \Omega$$

$$r_{06} = \frac{1}{4.75 * 10^{-5}} = 21052.83 \ \Omega$$

$$r_{08} = \frac{1}{5.97 * 10^{-5}} = 16750.41 \ \Omega$$

$$g_{m8} = 3.63 * 10^{-3} \ \frac{mA}{V}$$

$$r_{10} = \frac{1}{2.21 * 10^{-5}} = 45248.9 \ \Omega$$

$$g_{m4} = 5.37 * 10^{-3} \frac{mA}{V}$$

$$g_{m1} = 1.16 * 10^{-2} \ \frac{mA}{V}$$

Plugging in all the values we get

$$A_{DM} = g_{m1} * R_0 = 5868.13 = 20\log(5868.13) = 75.37 \ dB$$

I Hand calculated value of gain was found to be 75.37dB and the Unity gain Bandwidth is 128.242MHz. The phase at the unity gain frequency was 107. Thus the Phase Margin is

(180-107) =72.3 degrees. And the output swing is 1.2V

Comparing Hand calculations vs PSPICE:

	Hand calculations	PSPICE
DC open loop gain	75.37 dB	75.177dB
Unity gain frequency	128.242MHz	121.467MHz
Phase margin between	72.3°	73.04°

Conclusion:

This project gave me a better understanding of the functioning of the differential amplifiers, and   the type of amplifier to choose based on the specifications. I found that hand calculations won't always match with the simulation results. Understood how the second pole affects the phase margin and understood how to cancel RHP Zero.