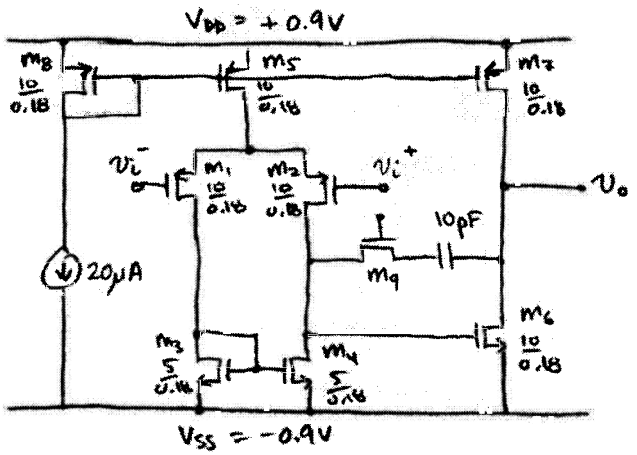
Gray and Meyer, Problem 9.21

All wells of transistors are tied to their respective Sources except for M_9, which is tied to V_{SS}.



The open-loop voltage gain is $a_0 = g_{m2}(r_{o2} \| r_{o4})\, g_{m6}(r_{o6} \| r_{o7})$

$= (108)(112) = \boxed{12\text{ k}} = \boxed{81.6\text{ dB}}$

$g_{m2} = \sqrt{2k'\left(\frac{W}{L}\right) I_{DS}} = \sqrt{2(65\mu)\left(\frac{10}{0.18}\right)(10\mu)} = 270\mu S$

$r_{o2} = \frac{1}{\lambda_p I_{DS}} \quad \frac{1}{0.15(10\mu)} \quad 666\text{ k}\Omega$, $r_{o4} = \frac{1}{\lambda_n I_{DS}} = \frac{1}{0.1(10\mu)} = 1\text{M}\Omega$

$g_{m6} = \sqrt{2(140\mu)\left(\frac{10}{0.18}\right)(20\mu)} = 560\mu S$, $r_{o6} = \frac{1}{0.1(20\mu)} = 500\text{k}$, $r_{o7} = \frac{1}{0.15(20\mu)} = 333\text{ k}$

(cont.)

The unity gain bandwidth is $\omega_u = \frac{g_{m2}}{C_c} = \frac{270\mu S}{10\,pF}$ 27 Mrad/s

$$\boxed{f_u = 4.3\ MHz}$$

The slew rate is: $\text{Slew Rate} = \frac{dV_o}{dt} = \frac{I_{ss}}{C_c} = \frac{20\mu A}{10\,pF} = \boxed{2\,V/\mu s}$

To move the RHP zero to infinity, we require that the resistance of M_9 be equal to $\frac{1}{g_{m6}}$.

$$\frac{1}{R_9} = \frac{\partial I_{DS}}{\partial V_{DS}} = \frac{\partial}{\partial V_{DS}}\left[k'\frac{W}{L}\left(V_{GS} - V_t - \frac{V_{DS}}{2}\right)V_{DS}\right]$$
$$= k'\frac{W}{L}\left(V_{GS} - V_t - \cancel{V_{DS}}^{\,0}\right)$$

The voltage at the gate of M_6 is

$$V_{66} = V_{SS} + V_{T6} + V_{DSAT6} = -0.9 + 0.5 + \sqrt{\frac{2(20\mu)}{140\mu\left(\frac{10}{0.18}\right)}} = -0.33V$$

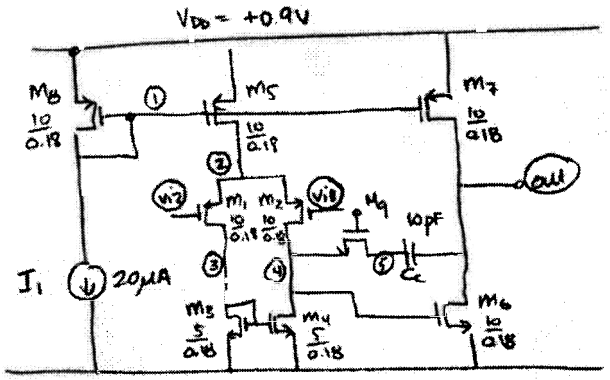
Thus, $V_{T9} = V_{T0} + \gamma\left(\sqrt{2\phi + V_{SB}} - \sqrt{2\phi}\right)$
$= 0.5 + 0.5\left(\sqrt{0.6 + 0.57} - \sqrt{0.6}\right)$
$= 0.654\ V$

So, $\left(\frac{W}{L}\right)_9 = \frac{g_{m6}}{k'(V_{DD} - V_{66} - V_{T9})} = \frac{560\mu S}{140\mu(0.9 + 0.33 - 0.654)} =$

$$\boxed{\left(\frac{W}{L}\right)_9 = 6.95}$$

From SPICE, $a_0 = 16.6\,k = 84.\,dB$ ← This is off due to λ
$f_u = 4.4\ MHz$
Slew rate = $2\,V/\mu s$

```
          miller opamp with zero compensation

.model nch nmos level=1 tox=25 vto=0.5 kp=140e-6 lambda=0.1 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.model pch pmos level=1 tox=25 vto=-0.5 kp=65e-6 lambda=0.15 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.param w1 = 10u
.param l1 = 0.18u
.param w2 = 5u
.param l2 = 0.18u
.param wz = 6.95u
.param lz = 1u
.param lam = 0.09u
.param a1 = '4*lam*w1'
.param p1 = '8*lam+w1'
.param a2 = '4*lam*w2'
.param p2 = '8*lam+w2'
.param az = '4*lam*wz'
.param pz = '8*lam+wz'
```




```
vdd     vdd 0 0.9
vss     vss 0 -0.9

* set up common mode and differential inputs
vic      vic 0 0
vid      vid 0 0 ac 1
e1       vi1 vic vid 0 0.5
e2       vi2 vic vid 0 -0.5

m1      3 vi2 2 2 pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m2      4 vi1 2 2 pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m3      3 3 vss vss nch w=w2 l=l2 ad=a2 pd=p2 as=a2 ps=p2
m4      4 3 vss vss nch w=w2 l=l2 ad=a2 pd=p2 as=a2 ps=p2
m5      2 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m6      out 4 vss vss nch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m7      out 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m8      1 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m9      5 vdd 4 vss nch w=wz l=lz ad=az pd=pz as=az ps=pz
cc      5 out 10p
i1      1 0 20u

 options post=2 nomod pztol=1e-4 unwrap accurate captab

 probe ac vdb(out) vp(out)

 op

 tf     v(out)

 pz     v(out)

 ac     dec 10 10 1g

 end
```

```
******  operating point information       tnom=  25.000 temp=  25.000
******
***** operating point status is all        simulation time is     0
   node     =voltage      node     =voltage      node     =voltage

+0:1        = 299.1973m 0:2        = 568.5477m 0:3        =-331.5465m
+0:4        =-331.5470m 0:5        =-331.5470m 0:out      = 210.0392m
+0:vdd      = 900.0000m 0:vi1      =   0.      0:vi2      =   0.
+0:vic      =   0.      0:vid      =   0.      0:vss      =-900.0000m


**** mosfets

subckt
element  0:m1        0:m2        0:m3        0:m4        0:m5        0:m6
model    0:pch       0:pch       0:nch       0:nch       0:pch       0:nch
 id       -9.6294u    -9.6294u     9.6294u     9.6294u   -19.2587u    20.2454u
 ibs       0.          0.          0.          0.          0.          0.
 ibd       9.0009f     9.0009f    -5.6845f    -5.6845f     3.3145f   -11.1004f
 vgs    -568.5477m  -568.5477m   568.4535m   568.4535m  -600.8027m   568.4530m
 vds    -900.0942m  -900.0948m   568.4535m   568.4530m  -331.4523m     1.1100
 vbs       0.          0.          0.          0.          0.          0.
 vth    -500.0000m  -500.0000m   500.0000m   500.0000m  -500.0000m   500.0000m
 vdsat   -68.5477m   -68.5477m    68.4535m    68.4535m  -100.8027m    68.4530m
 beta      4.0987m     4.0987m     4.1100m     4.1100m     3.7906m     8.6411m
 gam eff 500.0000m   500.0000m   500.0000m   500.0000m   500.0000m   500.0000m
 gm      280.9539u   280.9539u   281.3407u   281.3406u   382.1077u   591.5117u
 gds       1.2726u     1.2726u   911.1431n   911.1431n     2.7520u     1.8223u
 gmb      90.6775u    90.6775u    90.8023u    90.8023u   123.3247u   190.9096u
 cdtot     8.1535f     8.1535f     4.2840f    13.3596f    26.6472f    26.6472f
 cgtot    26.6472f    26.6472f    13.3596f    13.0116f    25.8792f    25.8792f
 cstot    25.8792f    25.8792f    13.0116f     4.0800f     8.1045f     7.3827f
 cbtot     7.5295f     7.5295f     4.0800f    10.7876f    21.5752f    21.5752f
 cgs      21.5752f    21.5752f    10.7876f     2.5000f     5.0000f     5.0000f
 cgd       5.0000f     5.0000f     2.5000f

subckt
element  0:m7        0:m8        0:m9
model    0:pch       0:pch       0:nch
 id       -20.2454u   -20.0000u  -574.1374f
 ibs        0.          0.         -5.6845f
 ibd        6.8996f     6.0080f    -5.6845f
 vgs     -600.8027m  -600.8027m     1.2315
 vds     -689.9608m  -600.8027m    -1.0202n
 vbs        0.          0.        -568.4530m
 vth     -500.0000m  -500.0000m   653.1767m
 vdsat   -100.8027m  -100.8027m     1.0202n
 beta       3.9848m     3.9365m   973.0000u
 gam eff  500.0000m   500.0000m   500.0000m
 gm       401.6828u   396.8146u   992.6813f
 gds        2.7520u     2.7520u   562.7544u
 gmb      129.6426u   128.0714u   229.5854f
 cdtot      8.3290f     8.4145f    69.9064f
 cgtot     26.6472f    26.6472f    71.3486f
 cstot     25.8792f    25.8792f     5.9078f
 cbtot      7.7050f     7.7905f     5.2655f
 cgs       21.5752f    21.5752f     3.4750f
 cgd        5.0000f     5.0000f    67.4736f
```

small-signal transfer characteristics

v(out)/vid		16.6101k ← open-loop DC gain
input resistance at	vid	1.000e+20
output resistance at v(out)		218.6150k

pole/zero analysis tnom= 25.000 temp= 25.000

input = 0:vid output = v(out

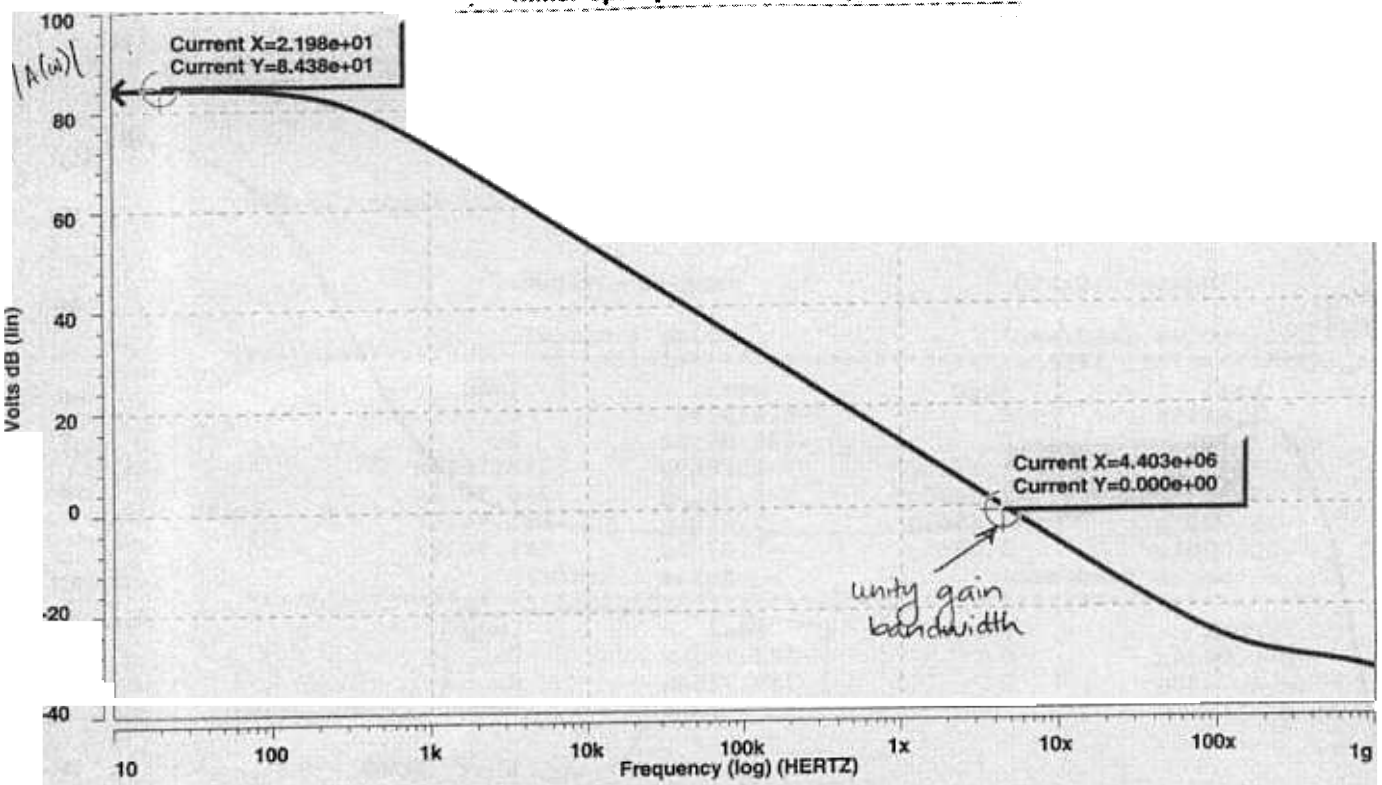
poles (rad/sec) poles (hertz)

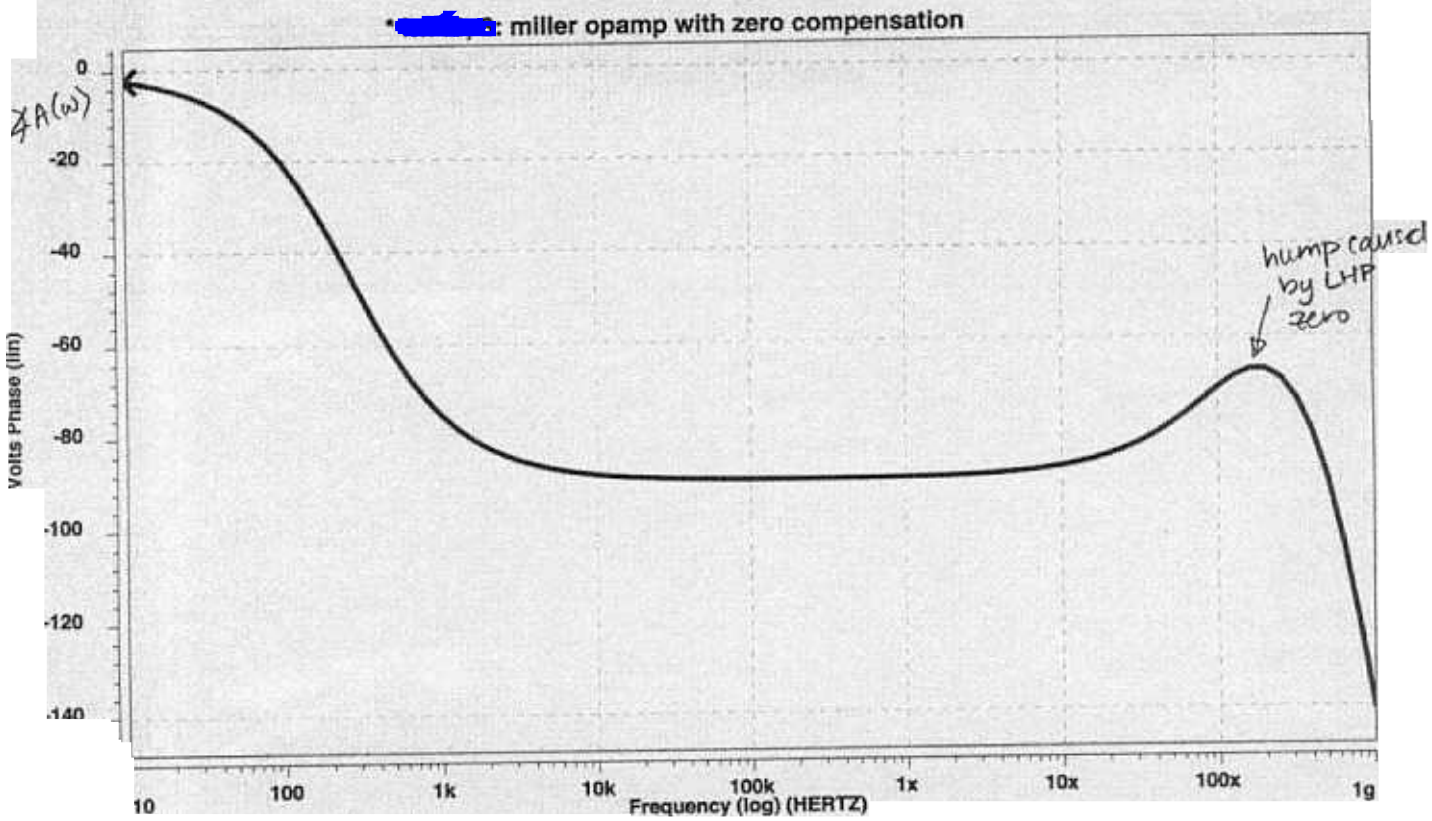
real	imag	real	imag
-1.6649k	0.	-264.9742	0.
-4.3093g	0.	-685.8519x	0.
-7.3316g	1.5630g	-1.1669g	248.7634x
-7.3316g	-1.5630g	-1.1669g	-248.7634x
-11.7501g	-3.6565g	-1.8701g	-581.9436x
-11.7501g	3.6565g	-1.8701g	581.9436x

zeros (rad/sec) zeros (hertz)

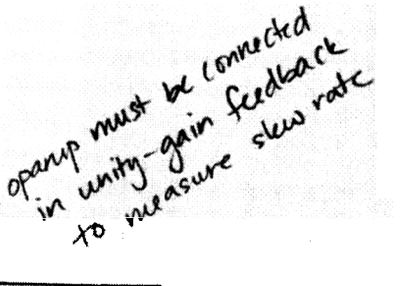
real	imag	real	imag
-896.6426x	0.	-142.7051x	0.
-4.7170g	0.	-750.7354x	0.

no RHP zero


miller opamp with zero compensation
|A(ω)|
Current X=2.198e+01
Current Y=8.438e+01
Current X=4.403e+06
Current Y=0.000e+00
unity gain bandwidth
Volts dB (lin)
100
80
60
40
20
0
-20
-40
10
100
1k
10k
100k
1x
10x
100x
1g
Frequency (log) (HERTZ)


[redacted]: miller opamp with zero compensation
∠A(ω)
hump caused by LHP zero
Volts Phase (lin)
0
-20
-40
-60
-80
-100
-120
-140
10
100
1k
10k
100k
1x
10x
100x
1g
Frequency (log) (HERTZ)

```
            miller opamp with zero compensation

 .model nch nmos level=1 tox=25 vto=0.5 kp=140e-6 lambda=0.1 gamma=0.5 phi=0.6
 +capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

 .model pch pmos level=1 tox=25 vto=-0.5 kp=65e-6 lambda=0.15 gamma=0.5 phi=0.6
 +capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

 .param w1 = 10u
 .param l1 = 0.18u
 .param w2 = 5u
 .param l2 = 0.18u
 .param wz = 6.95u
 .param lz = 1u
  param lam = 0.09u
  param a1 = '4*lam*w1'
  param p1 = '8*lam+w1'
  param a2 = '4*lam*w2'
  param p2 = '8*lam+w2'
  param az = '4*lam*wz'
  param pz = '8*lam+wz'

vdd     vdd 0 0.9
vss     vss 0 -0.9

* connect amp in unity-gain feedback and set step input
vin     vi1 0 0 pwl 0n 0v, 1u 0v, 1.01u -0.5v, 2u -0.5v, 2.01u 0v, 3u 0v
vshort out vi2 0

m1      3 vi2 2 2 pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m2      4 vi1 2 2 pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m3      3 3 vss vss nch w=w2 l=l2 ad=a2 pd=p2 as=a2 ps=p2
m4      4 3 vss vss nch w=w2 l=l2 ad=a2 pd=p2 as=a2 ps=p2
m5      2 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m6      out 4 vss vss nch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m7      out 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m8      1 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m9      5 vdd 4 vss nch w=wz l=lz ad=az pd=pz as=az ps=pz
cc      5 out 10p
i1      1 0 20u

 options post=2 nomod pztol=1e-4 unwrap accurate captab

 op

 tran  0.01u 3u

 end


 ******  operating point information      tnom=  25.000 temp=  25.000
 *****
 **** operating point status is all       simulation time is     0
   node    =voltage      node    =voltage      node    =voltage

+0:1       = 299.1973m 0:2       = 568.5577m 0:3       =-331.5492m
+0:4       =-329.9111m 0:5       =-329.9111m 0:out     =  12.7373u
+0:vdd     = 900.0000m 0:vi1     =   0.      0:vi2     =  12.7373u
+0:vss     =-900.0000m
```

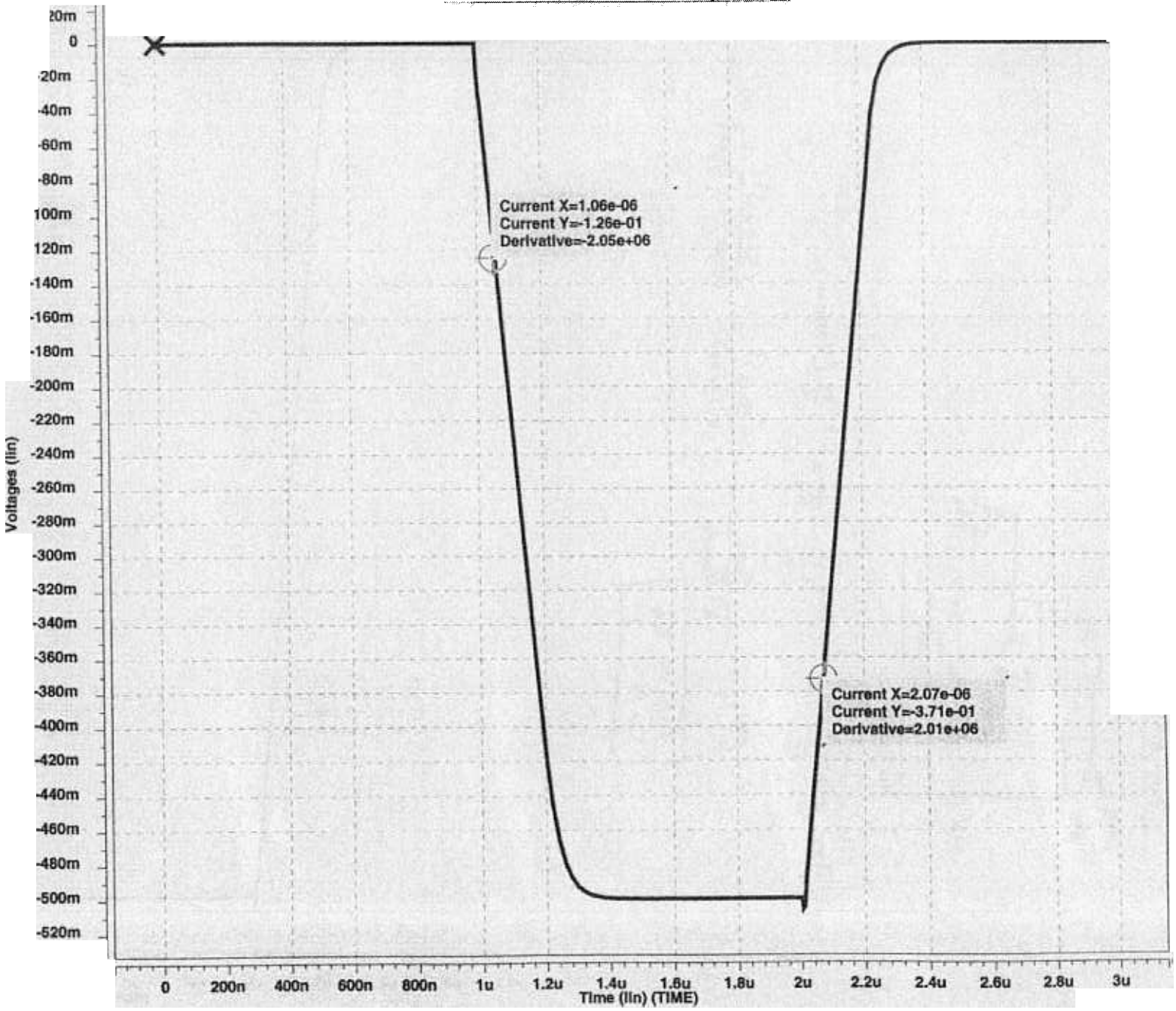


**** mosfets

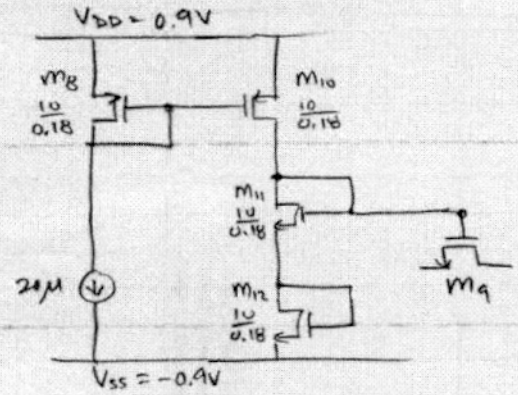
subckt element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6
model	0:pch	0:pch	0:nch	0:nch	0:pch	0:nch
id	-9.6286u	-9.6301u	9.6286u	9.6301u	-19.2587u	20.8234u
ibs	0.	0.	0.	0.	0.	0.
ibd	9.0011f	8.9847f	-5.6845f	-5.7009f	3.3144f	-9.0001f
vgs	-568.5449m	-568.5577m	568.4508m	568.4508m	-600.8027m	570.0889m
vds	-900.1069m	-898.4688m	568.4508m	570.0889m	-331.4423m	900.0127m
vbs	0.	0.	0.	0.	0.	0.
vth	-500.0000m	-500.0000m	500.0000m	500.0000m	-500.0000m	500.0000m
vdsat	-68.5449m	-68.5577m	68.4508m	68.4508m	-100.8027m	70.0889m
beta	4.0987m	4.0978m	4.1100m	4.1106m	3.7906m	8.4778m
gam eff	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m
gm	280.9430u	280.9344u	281.3295u	281.3731u	382.1071u	594.1985u
gds	1.2725u	1.2730u	911.0714n	911.0714n	2.7520u	1.9104u
gmb	90.6740u	90.6712u	90.7987u	90.8128u	123.3245u	191.7768u
cdtot	8.1535f	8.1548f	4.2840f	4.2832f	8.7285f	8.1536f
cgtot	26.6472f	26.6472f	13.3596f	13.3596f	26.6472f	26.6472f
cstot	25.8792f	25.8792f	13.0116f	13.0116f	25.8792f	25.8792f
cbtot	7.5295f	7.5308f	4.0800f	4.0792f	8.1045f	7.5296f
cgs	21.5752f	21.5752f	10.7876f	10.7876f	21.5752f	21.5752f
cgd	5.0000f	5.0000f	2.5000f	2.5000f	5.0000f	5.0000f

subckt element	0:m7	0:m8	0:m9
model	0:pch	0:pch	0:nch
id	-20.8234u	-20.0000u	-575.7898f
ibs	0.	0.	-5.7009f
ibd	8.9999f	6.0080f	-5.7009f
vgs	-600.8027m	-600.8027m	1.2299
vds	-899.9873m	-600.8027m	-1.0267n
vbs	0.	0.	-570.0889m
vth	-500.0000m	-500.0000m	653.5549m
vdsat	-100.8027m	-100.8027m	1.0267n
beta	4.0986m	3.9365m	973.0000u
gam eff	500.0000m	500.0000m	500.0000m
gm	413.1505u	396.8146u	999.0171f
gds	2.7520u	2.7520u	560.7946u
gmb	133.3438u	128.0714u	230.8891f
cdtot	8.1536f	8.4145f	69.9052f
cgtot	26.6472f	26.6472f	71.3486f
cstot	25.8792f	25.8792f	5.9066f
cbtot	7.5296f	7.7905f	5.2631f
cgs	21.5752f	21.5752f	3.4750f
cgd	5.0000f	5.0000f	67.4736f

miller opamp with zero compensation



2) Gray and Meyer, Problem 9.22



The resistance of M_9 is: $\frac{1}{R_9} = k' \frac{W}{L} (V_{DSAT11})$

$$\therefore \left(\frac{W}{L}\right)_9 = \frac{g_{m1}}{k' V_{DSAT11}} = \frac{(g_{m6})^2}{k'(2I_{D3})} = \frac{(560\mu)^2}{140\mu\,(2 \times 20\mu)}$$

$$\boxed{\left(\frac{W}{L}\right)_9 = 56}$$

```
          miller opamp with zero compensation

.model nch nmos level=1 tox=25 vto=0.5 kp=140e-6 lambda=0.1 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.model pch pmos level=1 tox=25 vto=-0.5 kp=65e-6 lambda=0.15 gamma=0.5 phi=0.6
+capop=0 cgso=5e-10 cgdo=5e-10 cgbo=4e-10 cj=6e-4 cjsw=2e-10

.param w1 = 10u
.param l1 = 0.18u
.param w2 = 5u
.param l2 = 0.18u
.param wz = 56u
.param lz = 1u
.param lam = 0.09u
.param a1 = '4*lam*w1'
.param p1 = '8*lam+w1'
.param a2 = '4*lam*w2'
.param p2 = '8*lam+w2'
.param az = '4*lam*wz'
.param pz = '8*lam+wz'

vdd    vdd 0 0.9
vss    vss 0 -0.9

* set up common mode and differential inputs
vic     vic 0 0
vid     vid 0 0 ac 1
e1      vi1 vic vid 0 0.5
e2      vi2 vic vid 0 -0.5

m1      3 vi2 2 2 pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m2      4 vi1 2 2 pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m3      3 3 vss vss nch w=w2 l=l2 ad=a2 pd=p2 as=a2 ps=p2
m4      4 3 vss vss nch w=w2 l=l2 ad=a2 pd=p2 as=a2 ps=p2
m5      2 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m6      out 4 vss vss nch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m7      out 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m8      1 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m9      5 vb 4 vss nch w=wz l=lz ad=az pd=pz as=az ps=pz
m10     vb 1 vdd vdd pch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m11     vb vb 6 vss nch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
m12     6 6 vss vss nch w=w1 l=l1 ad=a1 pd=p1 as=a1 ps=p1
cc      5 out 10p
i1      1 0 20u

.options post=2 nomod pztol=1e-4 unwrap accurate captab

 probe ac vdb(out) vp(out)

.op

 tf     v(out) vid

 pz     v(out) vid

 ac     dec 10 10 1g

 end
```

****** operating point information tnom= 25.000 temp= 25.000
******
***** operating point status is all simulation time is 0.

node	=voltage	node	=voltage	node	=voltage
+0:1	= 299.1973m	0:2	= 568.5477m	0:3	=-331.5465m
+0:4	=-331.5470m	0:5	=-331.5470m	0:6	=-330.6888m
+0:out	= 210.0392m	0:vb	= 391.5016m	0:vdd	= 900.0000m
+0:vi1	= 0.	0:vi2	= 0.	0:vic	= 0.
+0:vid	= 0.	0:vss	=-900.0000m		

**** mosfets

subckt element	0:m1	0:m2	0:m3	0:m4	0:m5	0:m6
model	0:pch	0:pch	0:nch	0:nch	0:pch	0:nch
id	-9.6294u	-9.6294u	9.6294u	9.6294u	-19.2587u	20.2454u
ibs	0.	0.	0.	0.	0.	0.
ibd	9.0009f	9.0009f	-5.6845f	-5.6845f	3.3145f	-11.1004f
vgs	-568.5477m	-568.5477m	568.4535m	568.4535m	-600.8027m	568.4530m
vds	-900.0942m	-900.0948m	568.4535m	568.4530m	-331.4523m	1.1100
vbs	0.	0.	0.	0.	0.	0.
vth	-500.0000m	-500.0000m	500.0000m	500.0000m	-500.0000m	500.0000m
vdsat	-68.5477m	-68.5477m	68.4535m	68.4535m	-100.8027m	68.4530m
beta	4.0987m	4.0987m	4.1100m	4.1100m	3.7906m	8.6411m
gam eff	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m
gm	280.9539u	280.9539u	281.3407u	281.3406u	382.1077u	591.5117u
gds	1.2726u	1.2726u	911.1431n	911.1431n	2.7520u	1.8223u
gmb	90.6775u	90.6775u	90.8023u	90.8023u	123.3247u	190.9096u
cdtot	8.1535f	8.1535f	4.2840f	4.2840f	8.7285f	8.0067f
cgtot	26.6472f	26.6472f	13.3596f	13.3596f	26.6472f	26.6472f
cstot	25.8792f	25.8792f	13.0116f	13.0116f	25.8792f	25.8792f
cbtot	7.5295f	7.5295f	4.0800f	4.0800f	8.1045f	7.3827f
cgs	21.5752f	21.5752f	10.7876f	10.7876f	21.5752f	21.5752f
cgd	5.0000f	5.0000f	2.5000f	2.5000f	5.0000f	5.0000f

subckt element	0:m7	0:m8	0:m9	0:m10	0:m11	0:m12
model	0:pch	0:pch	0:nch	0:pch	0:nch	0:nch
id	-20.2454u	-20.0000u	-574.1375f	-19.7460u	19.7460u	19.7460u
ibs	0.	0.	-5.6845f	0.	-5.6931f	0.
ibd	6.8996f	6.0080f	-5.6845f	5.0850f	-12.9150f	-5.6931f
vgs	-600.8027m	-600.8027m	723.0486m	-600.8027m	722.1904m	569.3112m
vds	-689.9608m	-600.8027m	-1.0481n	-508.4984m	722.1904m	569.3112m
vbs	0.	0.	-568.4530m	0.	-569.3112m	0.
vth	-500.0000m	-500.0000m	653.1767m	-500.0000m	653.3751m	500.0000m
vdsat	-100.8027m	-100.8027m	1.0481n	-100.8027m	68.8153m	69.3112m
beta	3.9848m	3.9365m	7.8400m	3.8865m	8.3395m	8.2206m
gam eff	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m	500.0000m
gm	401.6828u	396.8146u	8.2170p	391.7746u	573.8836u	569.7777u
gds	2.7520u	2.7520u	547.7959u	2.7520u	1.8416u	1.8682u
gmb	129.6426u	128.0714u	1.9004p	126.4447u	132.6780u	183.8949u
cdtot	8.3290f	8.4145f	562.4229f	8.5116f	7.8972f	8.4466f
cgtot	26.6472f	26.6472f	572.0721f	26.6472f	26.6472f	26.6472f
cstot	25.8792f	25.8792f	46.7508f	25.8792f	25.0217f	25.8792f
cbtot	7.7050f	7.7905f	37.9017f	7.8876f	6.4158f	7.8226f
cgs	21.5752f	21.5752f	28.0000f	21.5752f	21.5752f	21.5752f
cgd	5.0000f	5.0000f	543.6721f	5.0000f	5.0000f	5.0000f

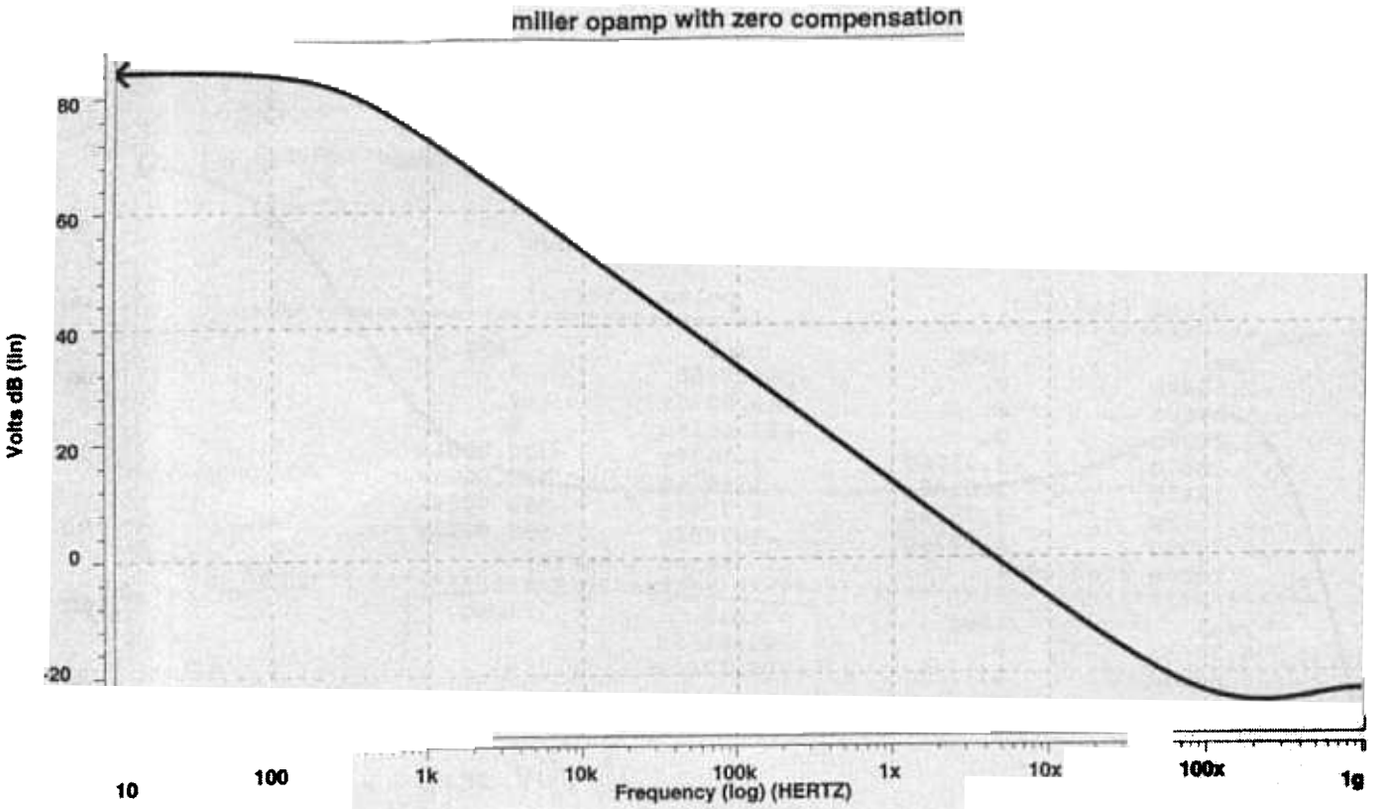
miller opamp with zero compensation
pole/zero analysis tnom= 25.000 temp= 25.000

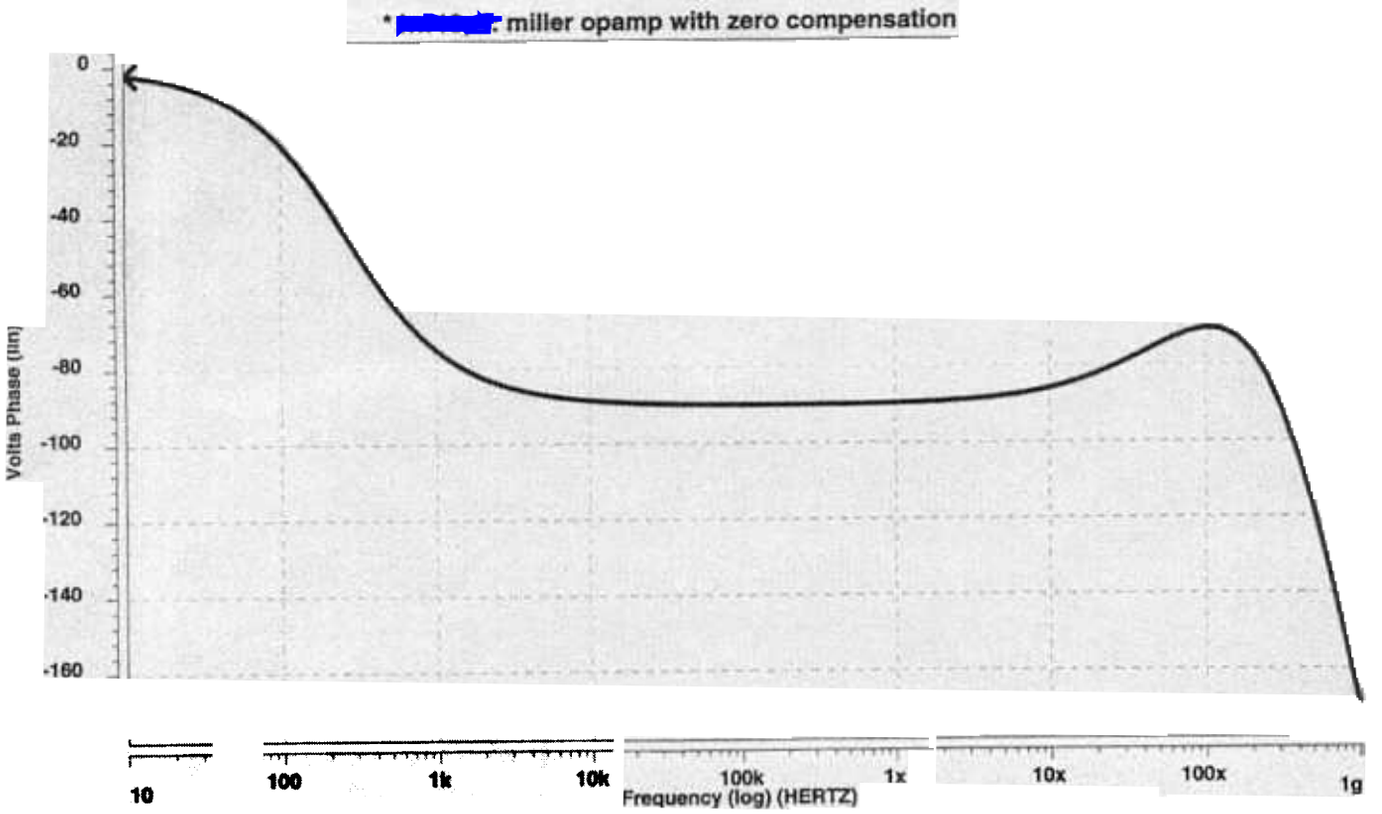
input = 0:vid output = v(out

poles (rad/sec)		poles (hertz)	
real	imag	real	imag
-1.6642k	0.	-264.8660	0.
-313.0764x	0.	-49.8277x	0.
-3.2899g	0.	-523.6115x	0.
-7.1841g	-2.0106g	-1.1434g	-320.0001x
-7.1841g	2.0106g	-1.1434g	320.0001x
-10.7339g	-3.7574g	-1.7084g	-598.0024x
-10.7339g	3.7574g	-1.7084g	598.0024x

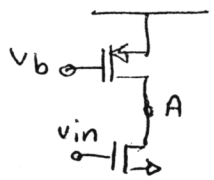
zeros (rad/sec)		zeros (hertz)	
real	imag	real	imag
-276.5765x	0.	-44.0185x	0.
-679.6797x	0.	-108.1744x	0.

no RHP zero


miller opamp with zero compensation
Volts dB (lin)
80
60
40
20
0
-20
10
100
1k
10k
100k
1x
10x
100x
1g
Frequency (log) (HERTZ)


* [redacted] miller opamp with zero compensation
Volts Phase (lin)
0
-20
-40
-60
-80
-100
-120
-140
-160
10
100
1k
10k
100k
1x
10x
100x
1g
Frequency (log) (HERTZ)

8.18



a) $I_{D_n} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GSn}-V_{THn})^2 \Rightarrow V_{GSn} = 0.973\,V$

$V_{GSp} = 1.311 \Rightarrow 3 - V_b = 1.311 \Rightarrow V_b = 1.69$

$V_{in} = R_1 \times I + V_{GSn}$

M_3: saturation $\Rightarrow -V_A + V_b > |V_{THp}| \Rightarrow V_A < 1.689 - 0.8 = 0.889$

M_4: saturation $\Rightarrow -V_{out} + V_b > V_{THP} \Rightarrow V_{out} < 0.889 \Rightarrow R_1 I < 0.889 \Rightarrow R_1 < 177$

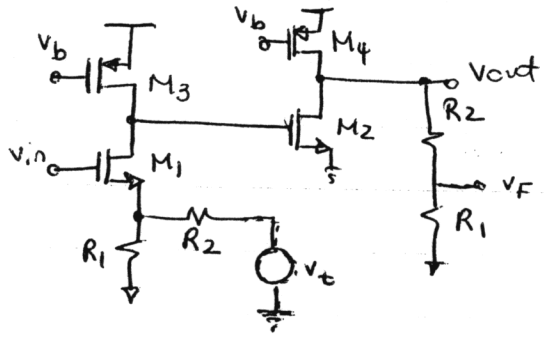
M_1: saturation $\Rightarrow V_A > R_1 I + (V_{GS_1} - V_{THn}) \Rightarrow 0.273 + R \times 0.5m < 0.889$

$\Rightarrow R_1 < 1232$

M_2: Saturation: $V_{out} = R_1 I > V_A - V_{tn} \Rightarrow R_1 > \frac{0.889 - 0.7}{0.5\times10^{-3}} = 378\,\Omega$

$378 \leqslant R_1 \leqslant 1232 \Rightarrow 1.162 \leqslant V_{in} \leqslant 1.589$

b)



$R_1 = 805\,\Omega$ $\quad r_{o1} = r_{o2} = 20k$

$g_{m1} = 3.66\,m\mho$ $\quad r_{o3} = r_{o4} = 10k$

$g_{m2} = 3.66\,m\mho$

Open loop gain $= \frac{r_{o3}}{R_1 \| R_2 + \frac{1}{g_{m_1}}} \times g_{m2}(r_{o4} \| (R_1+R_2) \| r_{o2}) = 97.6$

Output impedance $= r_{o4} \| (R_1+R_2) \| r_{o2} = 2422\,\Omega$

loop gain: $\frac{V_t}{R_2} \times (R_1 \| R_2) \times \frac{r_{o3}}{R_1 \| R_2 + \frac{1}{g_{m_1}}} \times g_{m2}(r_{o4} \| (R_1+R_2) \| r_{o2}) \frac{R_1}{R_1+R_2} = V_F$

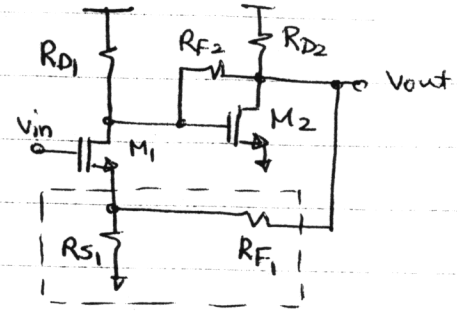
$\Rightarrow$ loop gain $= \frac{1}{3000} \times 635 \times 97.6 \times \frac{805}{3805} = 4.37$

$A_V = \frac{97.6}{1+4.37} = 18.17$

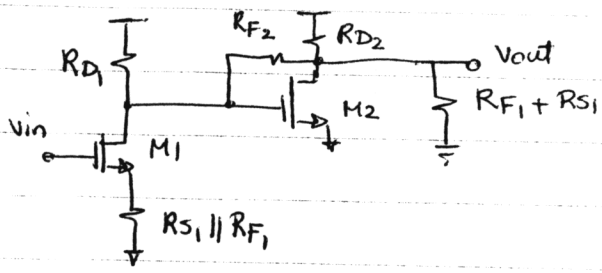
$R_{out} = \frac{2422}{1+4.37} = 451\,\Omega$

8.15

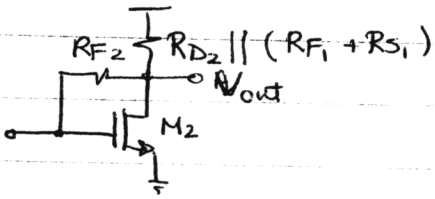
8.19



Voltage – Voltage



next we consider



$$R_{in_2} = \frac{R_{F2}}{1 + g_{m2}\left[R_{D2} \| (R_{F1}+R_{S1})\right]} = 261\,\Omega$$

$$R_{out_2} = \frac{R_{D2} \| (R_{F1}+R_{S1})}{1 + g_{m2}\left[R_{D2} \| (R_{F1}+R_{S1})\right]} = 174\,\Omega$$

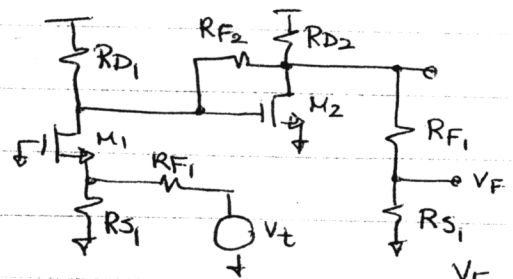
$$A_{V2} = \frac{R_D}{R_D + R_{F2}}(-g_{m2}R_{F2} + 1) = -3.6$$

$$R_D = R_{D2} \| (R_{F1}+R_{S1}) = 1333$$

$$\text{Open loop gain} = -\frac{R_{D1} \| R_{in2}}{R_{S1} \| R_{F1} + \frac{1}{g_{m1}}} \cdot A_{V2} = \frac{231}{1000 + 200} \times 3.6 = 0.69$$

Open loop output impedance = $R_{out_2} = 174\,\Omega$

loop gain:



$$\frac{V_t}{R_{F1}} \times (R_{S1} \| R_{F1}) \times \frac{R_{D1}}{R_{S1} \| R_{F1} + \frac{1}{g_{m1}}} \times A_{V2} \times \frac{R_{S1}}{R_{S1} + R_{F1}} = V_F$$

$$\frac{V_F}{V_t} = \frac{1}{2000} \times 1000 \times \frac{1000}{1200} \times 3.6 \times \frac{1}{2} = 0.75$$

$$A_{V_{closed}} = \frac{0.69}{1 + 0.75} = 0.394 \qquad R_{out_{closed}} = \frac{174}{1 + 0.75} = 99.5\,\Omega$$