HW7 solution Mithe Chen

1.

$K_n' = \mu_n C_{ox} = \frac{a}{2.6n} \cdot 250' = 332\ \mu A/V^2$. $\lambda_n = 0.2$. $\lambda_p = 0.15$.

$K_p' = \mu_p \cdot C_{ox} = 132.8\ \mu A/V^2$.

$g_{m1,2} \cong \sqrt{2 \cdot (\frac{19}{0.13-2L_D}) \cdot 132.8\mu \cdot 19\mu} = 576\ \mu S$

$g_{m6} = \sqrt{2 \cdot (\frac{19}{0.13-2L_D}) \cdot 332\mu \cdot 29\mu} = 1.29\ mS$.

$r_{o1,2} = \frac{1}{0.15 \cdot 19\mu} = 666.7\ k\Omega$

$r_{o3,4} = \frac{1}{0.2 \cdot 10\mu} = 500\ k\Omega$.

$r_{o6} = \frac{1}{0.2 \cdot 29\mu} = 250\ k\Omega$.

$r_{o7} = \frac{1}{0.15 \cdot 29\mu} = 333.3\ k\Omega$..

$\therefore A_{vo} = -g_{m12} \cdot (r_{o2} \| r_{o4}) \cdot g_{m6} \cdot (r_{o6} \| r_{o7}) \cong -30k$

spice → 9K . ∵ current flow M1, M2 not exactly 10μA.

Unity Gain BW:

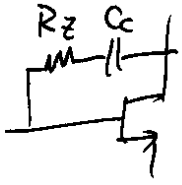
$V_o = V_{in} \cdot g_{m12} \cdot \frac{1}{sC_c}$

$\therefore \frac{V_o}{V_{in}} = 1 \Rightarrow \omega_u = \frac{g_{m12}}{C_c}$ $f_u = 18.33\ MHz$

Spice: 18.9 MHz

slew rate:

$$\frac{dV_o}{dt} = \frac{I_{SS}}{C_c} = \frac{20\mu A}{5pf} = 4\ V/\mu s.$$



$$z = \frac{-1}{C_c\left(R_z - \frac{1}{g_{m6}}\right)}$$

∴ should make $R_z = \frac{1}{g_{m6}} = 775\Omega$.

$$\frac{1}{R_z} = \frac{\partial I_D}{\partial V_{ds}} = K_n'\left(\frac{W}{L}\right)(V_{GS} - V_t - V_{ds}) = \frac{1}{775\Omega}$$

$\left(\frac{W}{L_{eff}}\right) = 6.8$

Spice $\frac{W}{L_{eff}} = 7.37$

zero will be cancel, (push to ∞)

From Spice Zero 44 MHz → 1.47 GHz.

EE140 HW7 Spring 2004 for 1st problem

```
.model nch nmos LEVEL=1 tox=2.6n vt0=0.3 gamma=0.2 phi=0.6 u0=250 ld=0.025u
+ capop=0 acm=3 ldif=0 hdif=0.2u cj=8e-4 cjsw=8e-12 cjgate=8e-11
+ lambda=0.2

.model pch pmos LEVEL=1 tox=2.6n vt0=-0.3 gamma=0.2 phi=0.6 u0=100 ld=0.025u
+ capop=0 acm=3 ldif=0 hdif=0.2u cj=8e-4 cjsw=8e-12 cjgate=8e-11
+ lambda=0.15


*----------------------------------------
vdd vdd 0 1.2

vic vic 0 dc=0.6
vid vid 0 dc=0 ac=1
e1 vi1 vic vid 0 0.5
e2 vi2 vic vid 0 -0.5

m1 g3 vi1 s1 vdd pch w=10u l=0.13u
m2 g6 vi2 s1 vdd pch w=10u l=0.13u
m3 g3 g3 0 0 nch w=5u l=0.13u
m4 g6 g3 0 0 nch w=5u l=0.13u
m5 s1 g5 vdd vdd pch w=10u l=0.13u
m6 vout g6 0 0 nch w=10u l=0.13u
m7 vout g5 vdd vdd pch w=10u l=0.13u
m8 g5 g5 vdd vdd pch w=10u l=0.13u

m9 d9 vdd g6 g6 nch w=0.59u l=0.13u
c1 d9 vout 5p

iss g5 0 20u

*----------------------------------------

.ac dec 100 1 1T
.pz v(vout) vid

.option nomod post

.op

.probe ac vout1=vdb(vout) vp1=vp(vout)
.tf v(vout) vid

.end
```

==========Without M9 compensation==========

poles (rad/sec) poles (hertz)

****

real	imag	real	imag
-2.9881k	0.	-475.5753	0.
-19.0211g	0.	-3.0273g	0.
-22.9217g	0.	-3.6481g	0.
-52.0193g	10.5942g	-8.2791g	1.6861g
-52.0193g	-10.5942g	-8.2791g	-1.6861g

node=e2 real= 8.0962E-17 imaginary= 0.

warning underflow 1 time(s) in pole/zero analysis

zeros (rad/sec) zeros (hertz)

****

real	imag	real	imag
277.4201x	0.	**44.1528x**	0.
-18.3979g	0.	-2.9281g	0.
-42.2575g	0.	-6.7255g	0.
-72.0742g	0.	-11.4710g	0.
180.1588g	0.	28.6732g	0.

==========With M9 compensation==========

poles (rad/sec) poles (hertz)

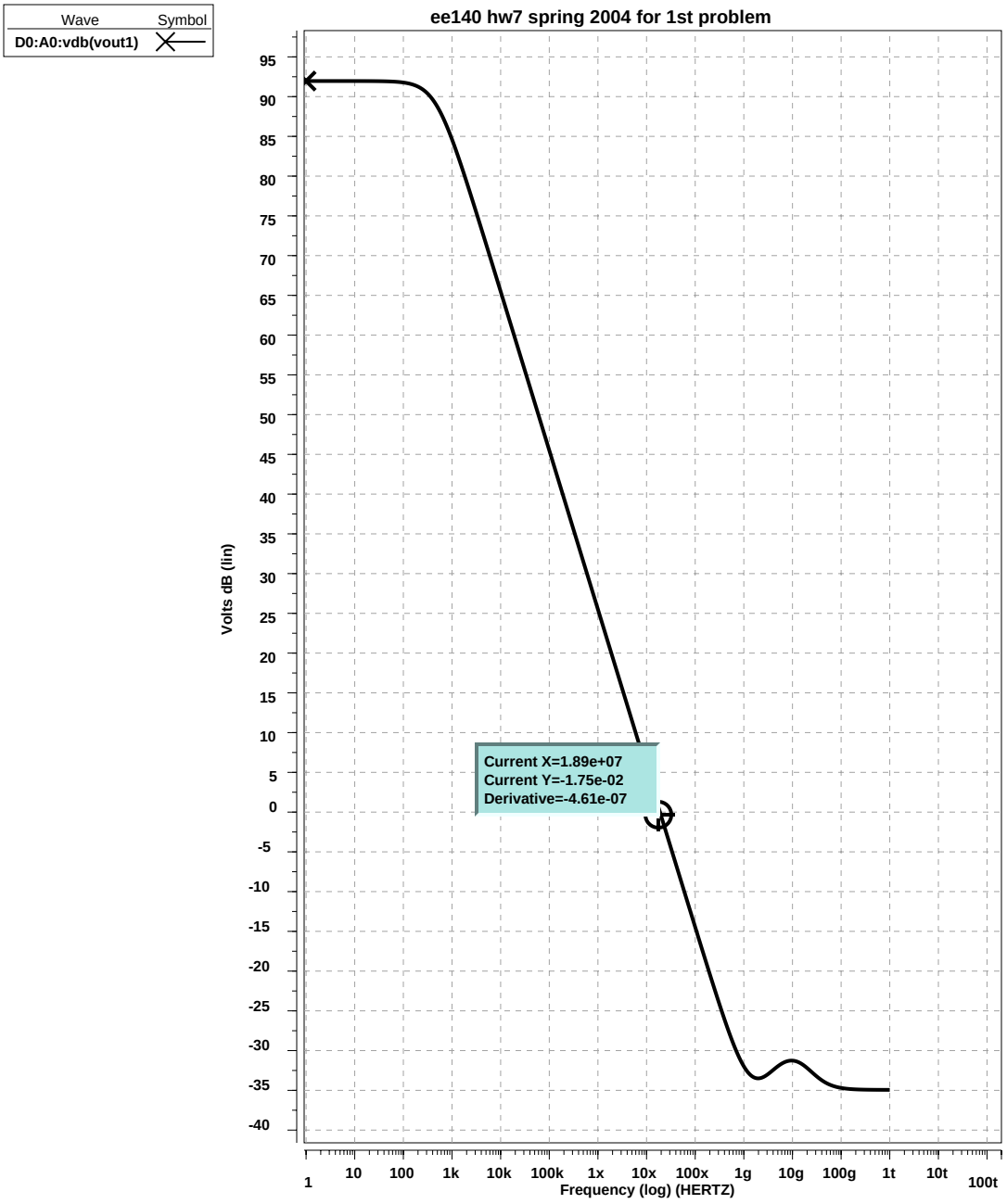
****

real	imag	real	imag
-2.9881k	0.	-475.5699	0.
-17.4903g	0.	-2.7837g	0.
-31.8379g	0.	-5.0672g	0.
-39.5285g	0.	-6.2912g	0.
-84.5776g	19.4522g	-13.4609g	3.0959g
-84.5776g	-19.4522g	-13.4609g	-3.0959g

zeros (rad/sec) zeros (hertz)

****

real	imag	real	imag
9.2409g	0.	**1.4707g**	0.
-11.7546g	0.	-1.8708g	0.
-18.4015g	0.	-2.9287g	0.
-42.2543g	0.	-6.7250g	0.
-72.0751g	0.	-11.4711g	0.
180.1588g	0.	28.6732g	0.


Wave
Symbol
D0:A0:vdb(vout1)
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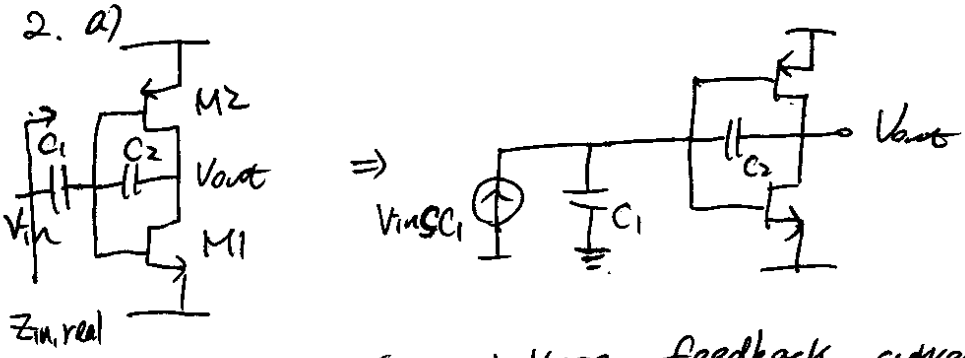
Volts dB (lin)
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Current X=1.89e+07
Current Y=-1.75e-02
Derivative=-4.61e-07
1
10
100
1k
10k
100k
1x
10x
100x
1g
10g
100g
1t
10t
100t
Frequency (log) (HERTZ)

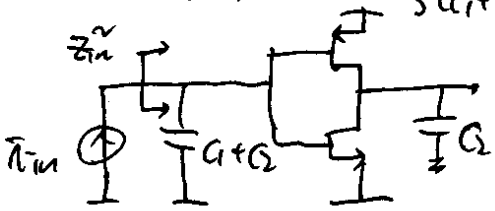
2. a)



sense voltage, feedback current.

⇒ Shunt-Shunt FB. (Ignoring ~~feedforward~~ thru C_2.)

$$\therefore a_R(s) = \frac{1}{s(C_1+C_2)} \cdot (g_{m1}+g_{m2}) \cdot (r_{o1} \| r_{o2} \| \frac{1}{sC_2})$$



$$f = sC_2.$$

$$T(s) = a_R(s) \cdot f = \frac{C_2}{C_1+C_2}(g_{m1}+g_{m2}) \cdot (r_{o1} \| r_{o2} \| \frac{1}{sC_2}.$$

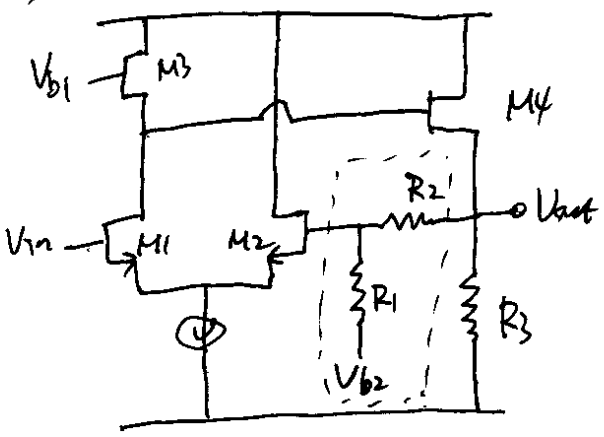
$$A = \frac{a_R}{1+f a_R} \approx \frac{1}{sC_2} = \frac{V_{out}}{I_{in}} \Rightarrow \frac{V_{out}}{V_{in}} = \frac{C_1}{C_2}$$

$$\tilde{Z_{in}} = \frac{1}{s(C_1+C_2)} \cdot \frac{1}{1+T}$$

$$Z_{in,real} = \frac{1}{sC_1} + (\tilde{Z_{in}}^{-1} - sC_1)^{-1}$$

$$Z_{out} = (r_{o1} \| r_{o2} \| \frac{1}{sC_2}) \cdot \frac{1}{1+T} \sim \frac{C_1+C_2}{C_2} \cdot \frac{1}{g_{m1}+g_{m2}}$$

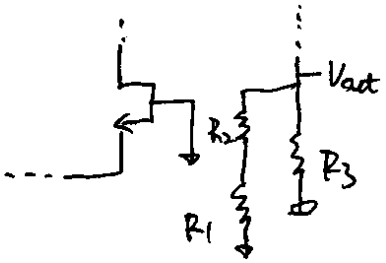
b)



sense voltage. fb voltage

⇒ series - shunt.

$$a = \underbrace{\frac{g_{m1}}{1+g_{m1}\frac{1}{g_{m2}}} \cdot (r_{o3} \parallel r_{o1}(1+\frac{g_{m1}}{g_{m2}}))}_{\text{1st stage}} \cdot \underbrace{g_{m4} \cdot (R_3 \parallel (R_1+R_2))}_{\text{2nd stage}}$$



$$f = \frac{R_1}{R_1+R_2}.$$

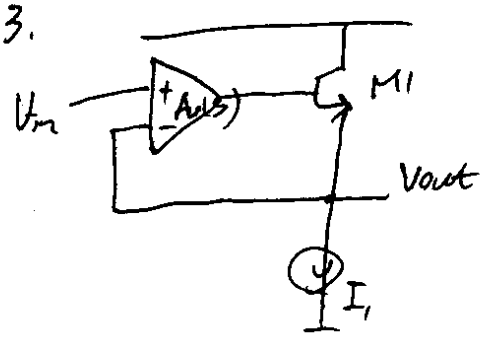
$$T = a \cdot f$$

$$Z_{in} = \infty$$

$$Z_{out} = \frac{r_{o4} \parallel R_3 \parallel (R_1+R_2)}{1+T}$$

$$A = \frac{a}{1+af} \sim \frac{1}{f} = \frac{R_1+R_2}{R_1}.$$

3.



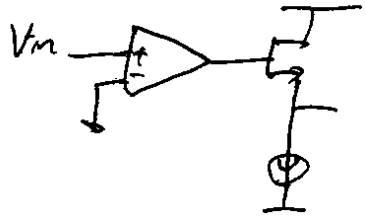
sense voltage, FB. voltage

⇒ series - shunt.

$$A_v(s) = \frac{K}{1+\frac{s}{\omega_p}}$$

open loop.

$$a(s) = A_v(s) \cdot \frac{g_m}{g_m + g_{mb}}$$



$f = 1$.

$$T(s) = \frac{K}{1+\frac{s}{\omega_p}} \cdot \frac{g_m}{g_m+g_{mb}} \sim \frac{K}{1+\frac{s}{\omega_p}}$$

for $g_{mb} \ll g_m$.

$Z_{in} = \infty$.

$$Z_{out} = \frac{1}{g_m+g_{mb}} \cdot \frac{1}{1+T} \approx \frac{1}{g_m+g_{mb}} \cdot \frac{1}{1+\frac{K}{1+\frac{s}{\omega_p}}}$$

↑ original C.D. output impedance.

reduction due to feedback.

Lost the reduction of impedance when.

$$\frac{K}{1+\frac{s}{\omega_p}} \ll 1.$$

$\frac{s}{\omega_p}$ dominate

$$\frac{s}{\omega_p} \gg 1.$$

$$\frac{K}{s/\omega_p} \ll 1. \Rightarrow \omega \gg K \cdot \omega_p = \text{Gain BW product of } A_v(s)$$

∴ Once freq. goes beyond GBW of $A_v(s)$, output impedance goes back to $\frac{1}{g_m+g_{mb}}$.