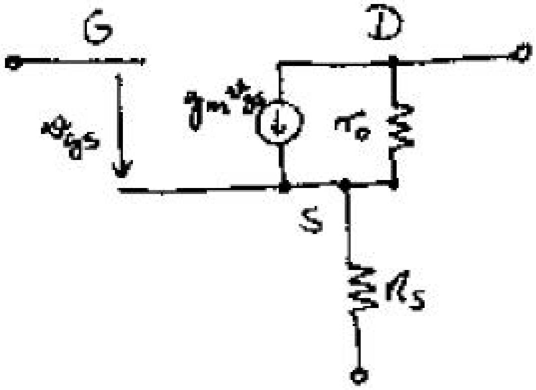
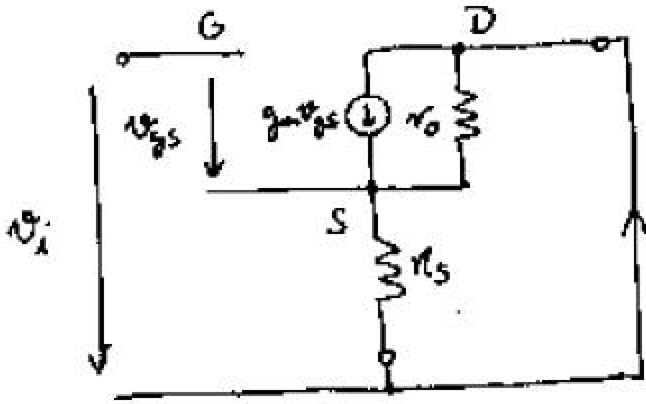
Solution HW4

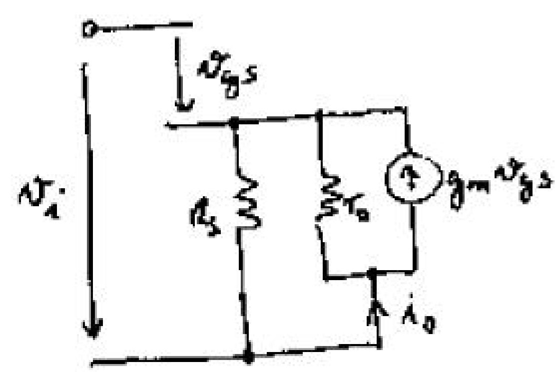
(1) (a) small signal model for compound device:



$\rightarrow$ to find G_m, short output: $G_m = \frac{i_o}{v_i}$



$\Rightarrow$



$$\Rightarrow v_i = v_{gs} + g_m v_{gs} \left(r_o \| R_S \right) \qquad r_o \| R_S \doteq R_p$$

$$i_o = g_m v_{gs} + g_m v_{gs} R_p / r_o$$

$$\Rightarrow \frac{i_o}{v_i} = G_m = \frac{g_m \cancel{v_{gs}} + g_m \cancel{v_{gs}} R_p / r_o}{\cancel{v_{gs}} + g_m \cancel{v_{gs}} R_p} = \frac{1 + \frac{R_p}{r_o}}{\frac{1}{g_m} + R_p}$$

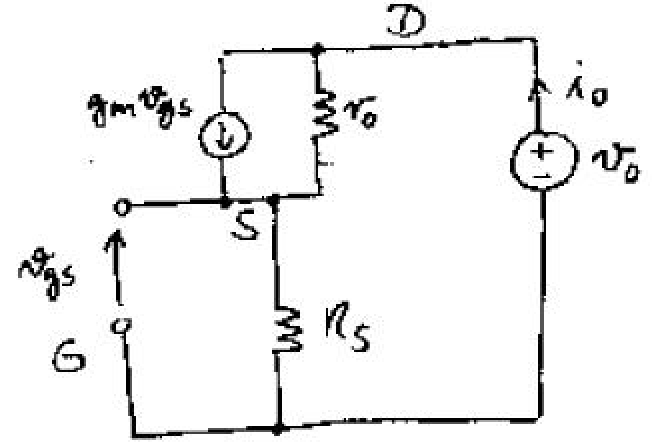
Since $R_S \ll r_o \Rightarrow R_p \approx R_S$

$\Rightarrow R_p / r_o \rightarrow 0$

$$\Rightarrow \underline{\underline{G_m \cong \frac{1}{R_S + 1/g_m}}}$$

① a) ctd.

→ to find R_o, short input and analyze $\frac{v_o}{i_o}$



$$\Rightarrow v_o = i_o R_S + r_o\left(i_o - g_m v_{gs}\right)$$

$$= i_o R_S + r_o\left(i_o + g_m i_o R_S\right)$$

$$\Rightarrow \frac{v_o}{i_o} = R_o = \underbrace{\cancel{R_S}}_{\ll r_o} + \underline{\underline{r_o\left(1 + g_m R_S\right)}}$$

b) $$a_{vo} = -G_m R_o = -\frac{r_o\left(1 + g_m R_S\right)}{R_S + 1/g_m} = \underline{\underline{-g_m r_o}}\ !$$

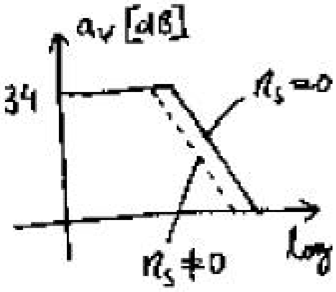
$$f_p = \frac{1}{2\pi R_o C_L} = \frac{1}{2\pi C_L r_o\left(1 + g_m R_S\right)} \quad //$$

$$f_u = \frac{1}{2\pi}\frac{G_m}{C_L} = \frac{1}{2\pi C_L\left(R_S + \frac{1}{g_m}\right)} = \frac{1}{2\pi}\frac{g_m}{C_L\left(1 + g_m R_S\right)} \quad //$$

→ note that both f_p and f_u are reduced by the factor $\frac{1}{1 + g_m R_S}$ compared to a non-degenerated amplifier.

① ⓒ

	$R_S = 0$		$R_S = 500\Omega$
a_{v0}	50	$\xrightarrow{\text{no change!}}$	50
f_p	1.59 MHz	$\xrightarrow{\cdot 0.8}$	1.27 MHz
f_u	79.6 MHz	$\xrightarrow{\cdot 0.8}$	63.7 MHz



$$\frac{1}{1 + g_m R_S} = \frac{1}{1 + 500\mu S \cdot 500\Omega} = \underline{\underline{0.8}}$$

ⓓ $$g_m \cong \sqrt{2 I_D k' \frac{W}{L}} = \sqrt{1mA \cdot 200 \frac{\mu A}{V^2} \cdot 10} = 1.414\ mS$$

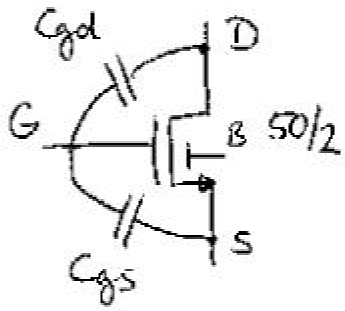
$$f_u(R_S = 0) = \frac{1}{2\pi} \frac{g_m}{C_L} = \frac{1.414\ mS}{2\pi \cdot 1pF} = 225\ MHz$$

$$\frac{f_u(R_{S1} = 0)}{f_u(R_{S2} = 50\Omega)} = \frac{1}{1 + g_m R_S} = \frac{1}{1 + 1.414\ mS \cdot 50\Omega} = \underline{\underline{0.93}}$$

$$\rightarrow f_u(R_S = 50\Omega) = 210\ MHz$$

→ Lost about 7% in bandwidth due to insufficient number of source contacts ...

(2) a)



INTRINSIC

forward active:

$C_{gs} \cong \frac{2}{3} W L C_{ox} = \frac{2}{3} \cdot 100 (\mu m)^2 \frac{5 fF}{(\mu m)^2} = \underline{\underline{333 fF}}$

$C_{gd} \cong \underline{\underline{0}}$

triode:

$C_{gs} \cong C_{gd} \cong \frac{1}{2} W L C_{ox} = \underline{\underline{250 fF}}$

b) HSPICE printout see attached

	SIM	CALC	SIM	CALC
C_{gs}	333 fF	333 fF	296 fF	250 fF
C_{gd}	2 fF	0	185 fF	250 fF
	SAT		TRIODE	

→ discrepancies:

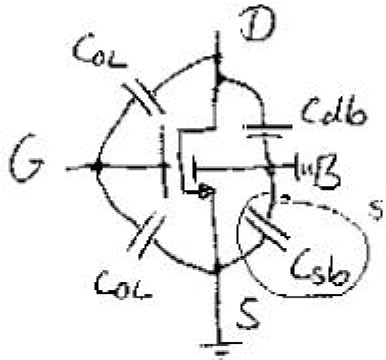
1) SAT, TRIODE: HSPICE uses by default more accurate expressions than the one we used in our hand analysis. → see next page

Especially in the triode region, our equation $C_{gs} = \frac{1}{2} W L C_{ox}$ assumes that D and S have about the same potential → which is not true for this case...

For the forward active region, the agreement is good enough to predict the frequency response through hand analysis!

c) EXTRINSIC:

$C_{OL} = C_{OL}' \cdot W = \underline{\underline{25 fF}}$



$C_{db} = AD \dfrac{C_{db0}}{\sqrt{1 + \frac{V_{db}}{\psi_0}}} \Rightarrow C_{db}\Big|_{(V_{db} = 1V)} = \underline{\underline{28.9 fF}}$

$C_{db}\Big|_{(V_{db} = 3V)} = \underline{\underline{18.9 fF}}$

$C_{sb} = AS \dfrac{C_{db0}}{\sqrt{1 + \frac{V_{sb}}{\psi_0}}} = \underline{\underline{50 fF}}$

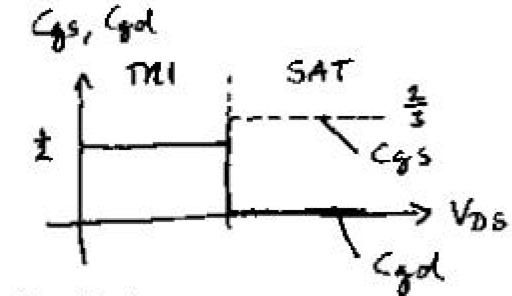
$V_{sb} = 0$

EECS140 HW4 Problem 2b -> HSPICE output

***** Transistor bias info for VG=1.5V, VD=3V

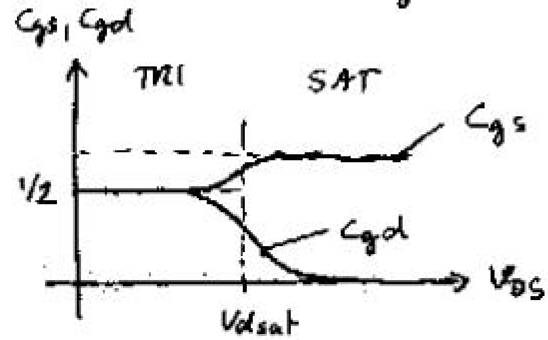
element	0:m1
model	0:nmos2
id	718.7500u
ibs	0.
ibd	-30.0000f
vgs	1.5000
vds	3.0000
vbs	0.
vth	1.0000
vdsat	500.0000m
beta	5.7500m
gam eff	500.0000m
gm	2.8750m
gds	31.2500u
gmb	927.9023u
cdtot	2.0018f
cgtot	340.3371f
cstot	333.6388f
cbtot	4.6966f
cgs	333.6388f
cgd	2.0018f

Our cap model:



HSPICE default:

"smooth" transition



→ you get zero here if you set "capop = Ø" in the device model!
(or "capop = 4")

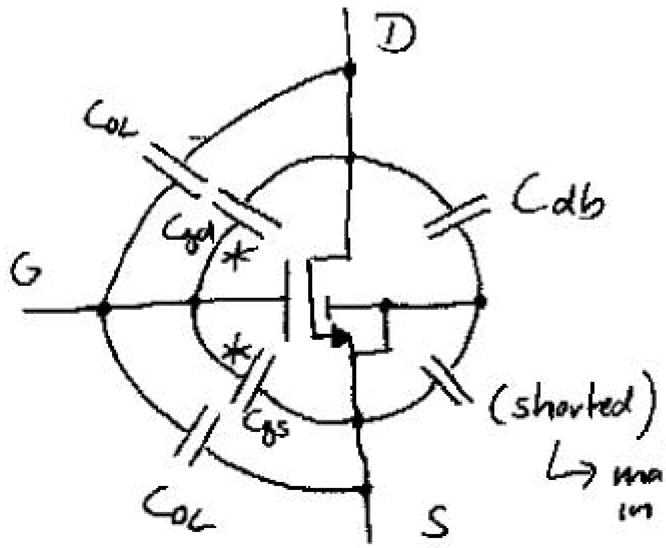
***** Transistor bias info for VG=3V, VD=1V

element	0:m1
model	0:nmos2
id	7.8750m
ibs	0.
ibd	-10.0000f
vgs	3.0000
vds	1.0000
vbs	0.
vth	1.0000
vdsat	1.0000
beta	5.2500m
gam eff	500.0000m
gm	5.2500m
gds	5.6250m
gmb	1.6944m
cdtot	185.3549f
cgtot	483.1317f
cstot	296.5678f
cbtot	1.2090f
cgs	296.5678f
cgd	185.3549f

→ difference cgs − cgd due to different potential

(2) d) → HSPICE deck see attached

e)



↳ makes no sense to include in SPICE deck!

* these capacitors are automatically modeled through SPICE.
We added C_{OL}, C_{db} manually to complete the model.

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(3) a) $C_{OL} = C_{OL}' \cdot W = 0.5\,fF/\mu m \cdot 40\,\mu m = \underline{\underline{20\,fF}}$

$$I_D = \frac{1}{2}k'\frac{W}{L}(V_A - V_{TH})^2(1+\lambda V_{DS}) \quad ; \quad \lambda = 0.05$$

$$0.5\,mA = 2\,\frac{mA}{V^2}(V_A - 1)^2(1 + 0.15)$$

$$\Rightarrow \underline{\underline{V_A = 1.466\,V}} \quad ; \quad C_{gs} = \frac{2}{3}WLC_{ox} = \frac{2}{3}80 \cdot 5\,fF = \underline{\underline{267\,fF}}$$

b) $$g_m = \frac{2I_D}{V_{dsat}} = \frac{1\,mA}{0.466\,V} = 2.145\,mS$$

$$\left(r_o \simeq \frac{1}{\lambda I_D} = \frac{1}{0.05 \cdot 0.5\,mA}\,V = 40\,k\Omega\right. \rightarrow \text{"large error"}$$

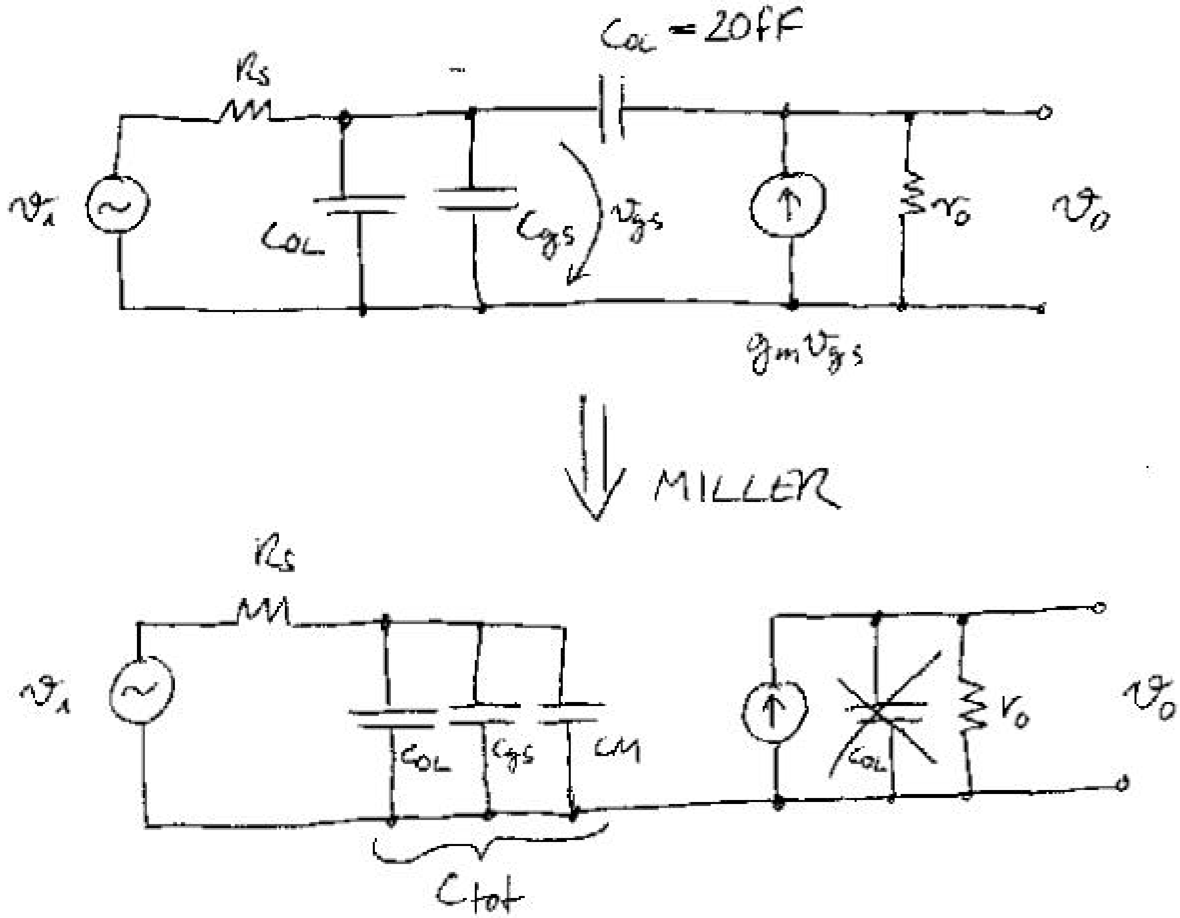
$$r_o = \frac{2}{k'\frac{W}{L}(V_{GS}-V_{TH})^2\lambda} = \underline{\underline{46\,k\Omega}} \rightarrow \text{better}$$

EECS140 HW2 - Problem 2d

```
***** circuit description
m1 vd vg 0 0 nmos2 w=50um l=2um

***** the above line for M1 automatically takes care of the intrinsic caps,
***** the following lines are for the extrincsic caps:

COL1 vg 0  25fF
COL2 vg vd 25fF
CDB  vd 0  18.9fF

***** sources
vi  1  vg  ac 1
vg  1  0   dc 1.5
vd  vd 0   dc 3

***** analyses
.ac dec 10 1k 10k

***** model
.model nmos2 nmos level=1 vto=1 tox=6.9n kp=200u lambda=0.05 gamma=0.5 phi=0.6

.options brief
.end
```

(3) b) ctd. $|a_{vo}| = g_m r_o = 2.145\,\text{mS} \cdot 46\,\text{k}\Omega = \underline{\underline{98.67}}$

small-signal circuit:



$$C_M = (1 + |a_{vo}|)\, C_{OL} = 1.97\,\text{pF} \;! \;\Rightarrow C_{TOT} = \underline{\underline{2.25\,\text{pF}}}$$

$$\Rightarrow f_{p1} = \frac{1}{2\pi R_S C_{tot}} = \frac{1}{2\pi \cdot 500k \cdot 2.25pF} = 141\,\text{kHz}$$

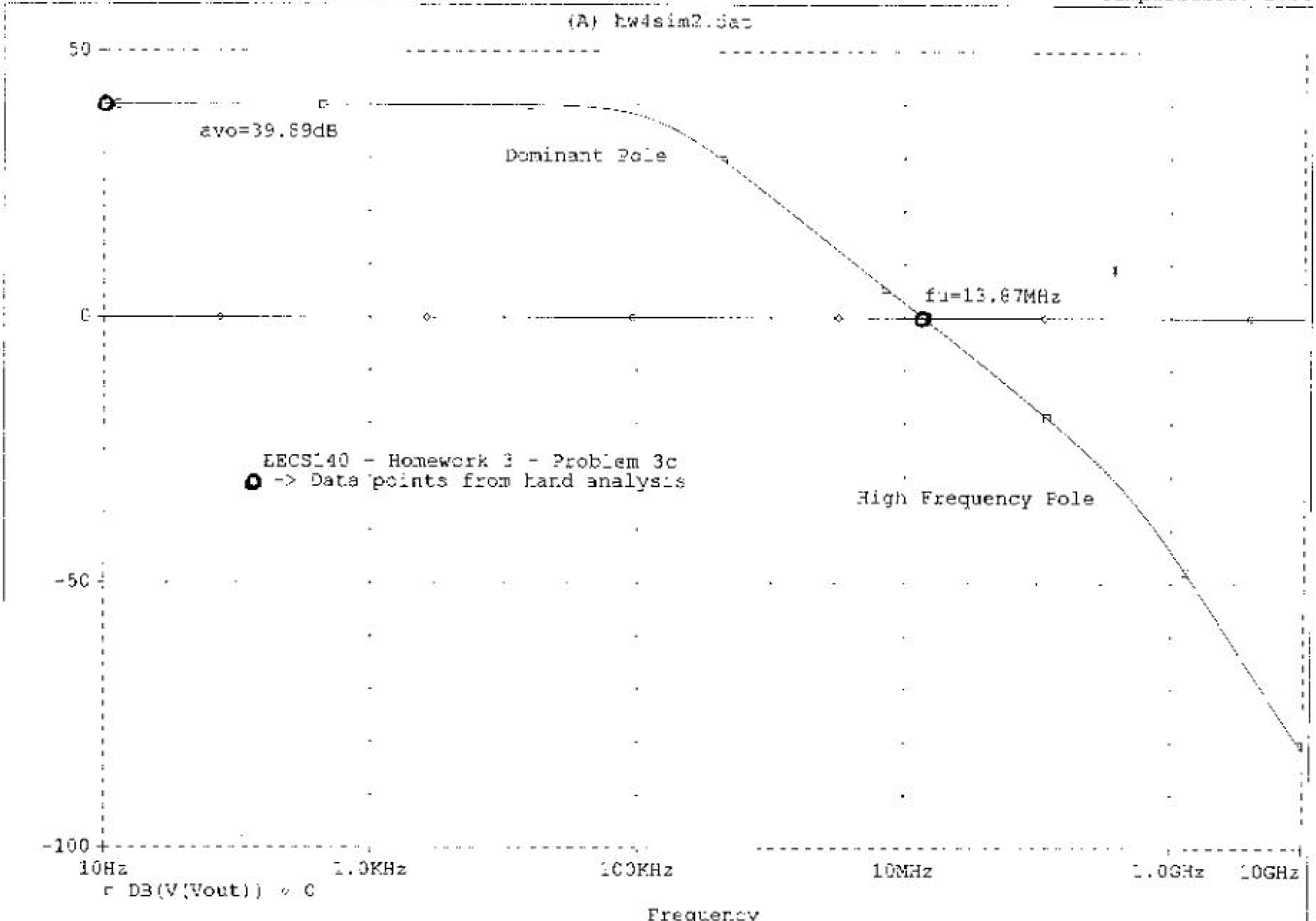
$$\Rightarrow f_u \cong f_{p1}\,|a_{vo}| = \underline{\underline{13.9\,\text{MHz}}}$$

c) Include $C_{db} = 30.23\,pF$

→ simulation plot see attached

* C:\Daten\Berkeley\EE140\spice\hw4sim2.sch

Date/Time run: 09/14/99 08:52:30 Temperature: 27.0



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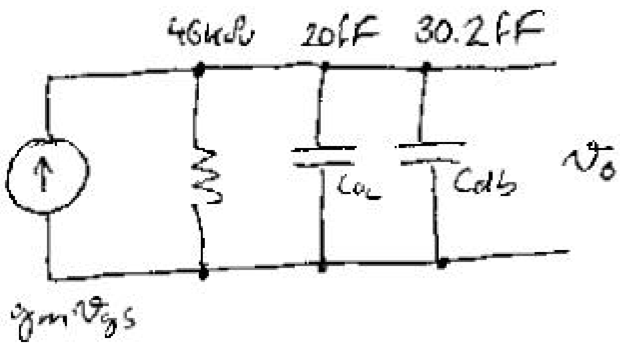
③ ⓓ

	HSPICE	hand analysis
$\lvert a_{vo} \rvert$	39.8dB $\hat{=}$ 98.7	98.7
f_H	13.87 MHz	13.9 MHz

→ exact match!

⇒ Miller approximation seems valid!

Verify pole frequency at output node:



$$f_{p2} \cong \frac{1}{2\pi \; 50fF \cdot 46k} = \underline{\underline{69\ MHz}}$$

69 MHz >>> 141 kHz = f_{p1}

→ That's why the Miller approximation works here!