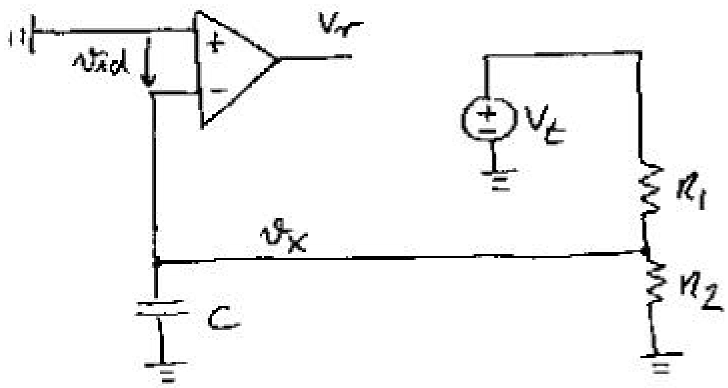
EECS 140 — Solution HW 11

① a)



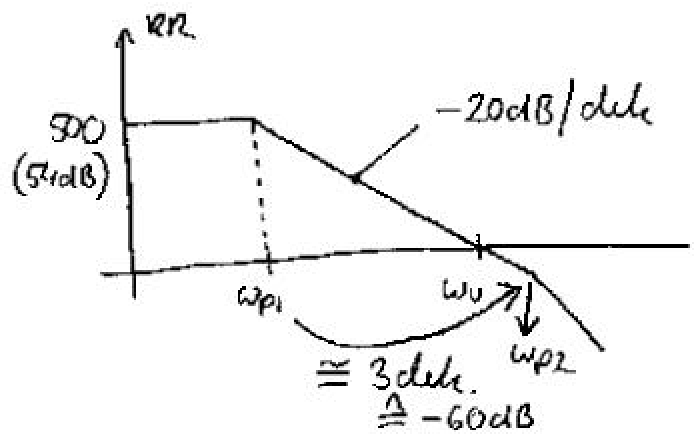
$$v_x = \frac{R_2}{R_1+R_2}\,\frac{1}{1+s/p_2}\cdot v_t \qquad p_2 = -\frac{1}{(R_1 \| R_2)C}$$

$$v_r = -v_x\,\frac{a_0}{1+s/p_1}$$

$$RR = -\frac{v_r}{v_t} = \frac{a_0 R_2}{R_1+R_2}\cdot\frac{1}{1+s/p_1}\cdot\frac{1}{1+s/p_2} \quad //$$

b)

$$1 = \underbrace{\frac{1000\cdot 30k}{60k}}_{500 = RR_0}\cdot\left|\frac{1}{1+s/p_1}\right|\cdot\left|\frac{1}{1+s/p_2}\right| \qquad p_2 = -2\pi\cdot 1.06\,\text{MHz} \quad p_1 = -2\pi\cdot 1\,\text{kHz}$$



⇒ P_1 is a dominant pole that ≅ sets the f_u of RR

b) ctd.

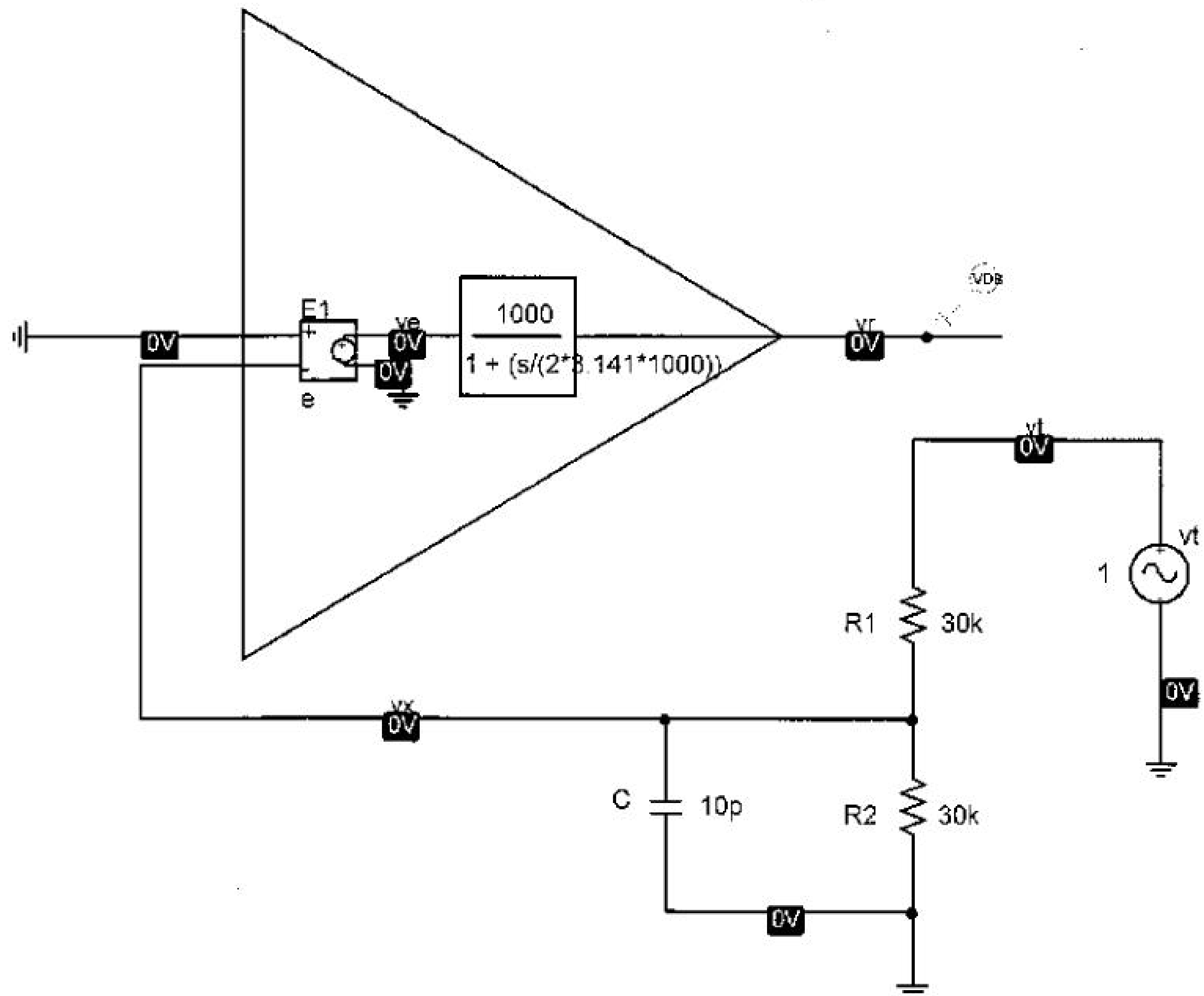
$$\Rightarrow \frac{f_u}{f_{p1}} \cong \frac{500}{1} \Rightarrow f_u \cong 500\,\text{KHz}$$

$$\varphi_m = \arctan\left(\frac{f_{p2}}{f_u}\right) = \arctan\left(\frac{1060}{500}\right) = 64^\circ$$

c) → see attached schematic, SPICE deck and Plot. Results:

	SIM	CALC	ERROR
f_u	462 KHz	500 kHz	7.6 %
φ_m	66.7°	64°	4 %

→ errors due to dominant pole approximation (note that you can only make this assumption when the poles are "far enough" apart s.t. a dominant pole basically sets the ω_0 of the RR)



Return-Ratio Simulation for Problem 1

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* EECS140 - HW11 - Problem1
```
(RR Simulation)

```
* Schematics Netlist *

R_R1         vx vt   30k
R_R2         0 vx   30k
V_vt         vt 0 DC 0V AC 1
E_E1         ve 0 0 vx 1
C_C          0 vx   10p

E_LAPLACE1   vr 0 LAPLACE {V(ve)}
+ {(1000)/(1 + (s/(2*3.141*1000)))}

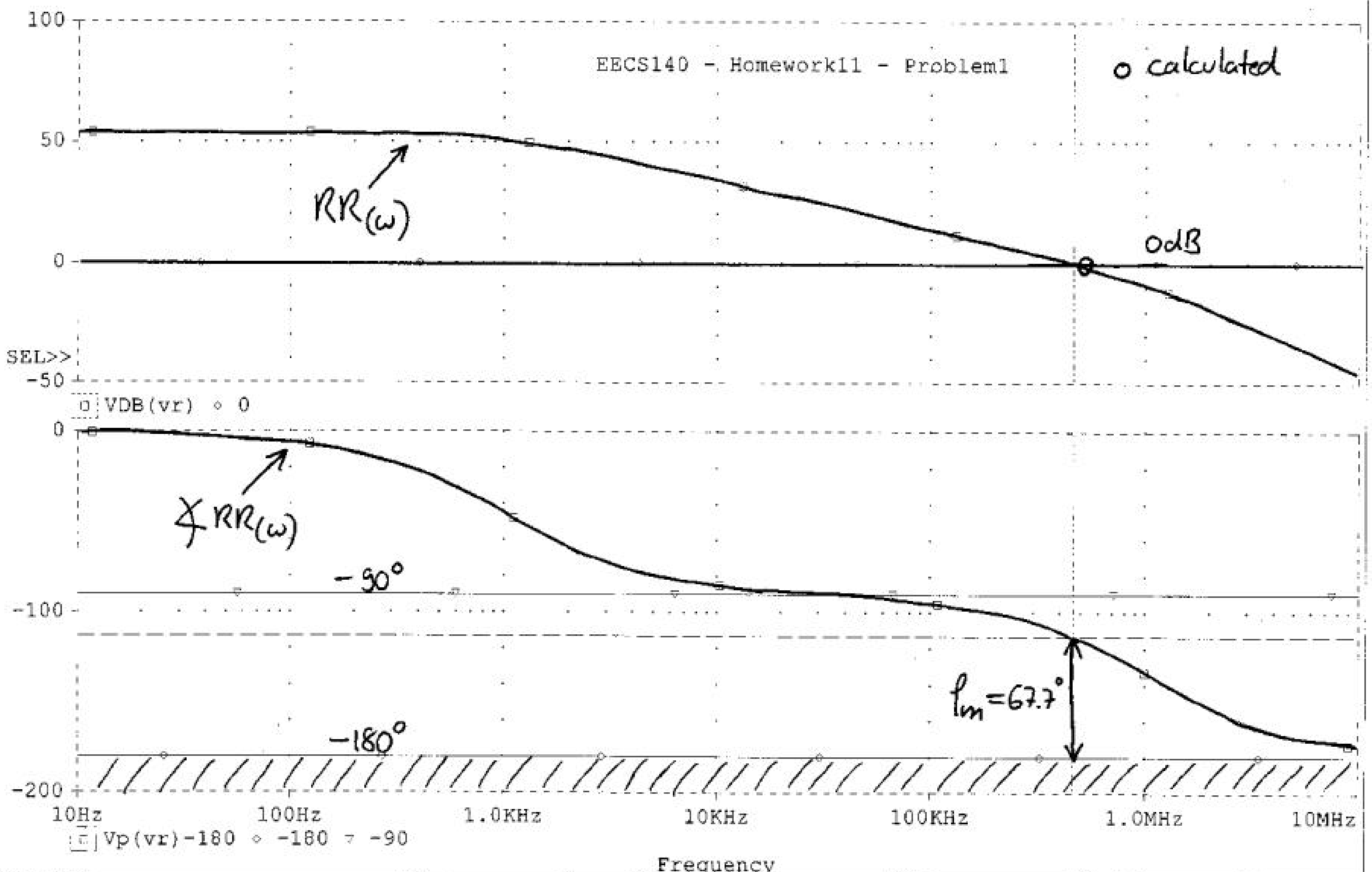
.ac 101 10 10meg
.probe
.END
```

← LAPLACE EXPRESSION

* U:\Ee140\spice\hw11sim1.sch

Date/Time run: 11/16/99 13:57:02 Temperature: 27.0

(A) hw11sim1.dat



A1:(461.725K,-39.520m) A2:(461.725K,-113.344) DIFF(A):(0.000,113.304)

Date: November 16, 1999 Page 1 Time: 14:00:15

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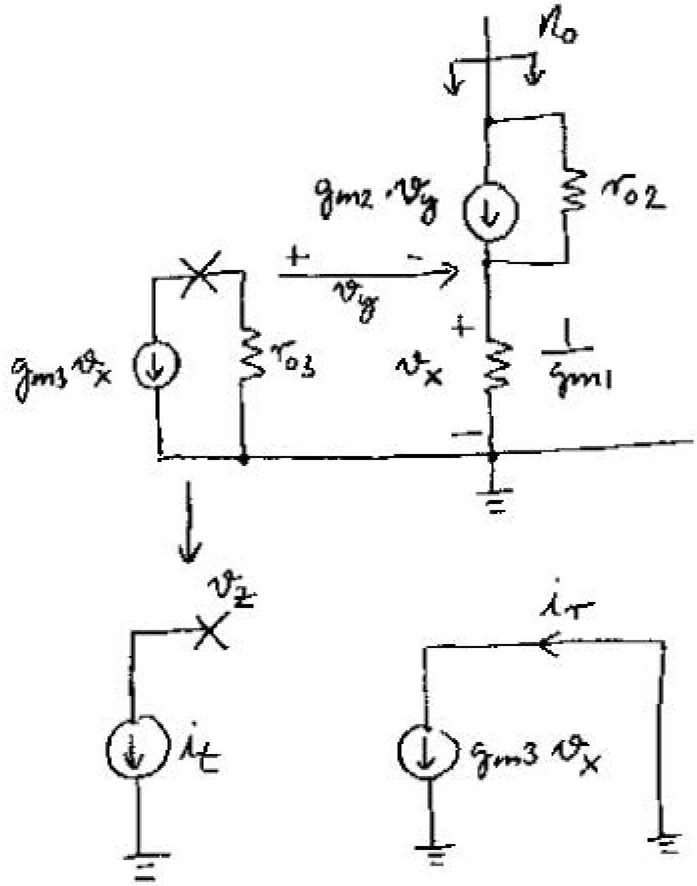
(2) Bias point: all $I_D = I_{ref}$

$g_m = \sqrt{200\mu \cdot 200\mu \cdot 50}$

$g_m = 1.41\,mS$

$r_o = \frac{1}{0.05 \cdot 100\mu} = 200k\Omega$



see also EX. in text. (p. 8T.68)

(i) find $R_o(h=0) = R_o(g_{m3}=0)$

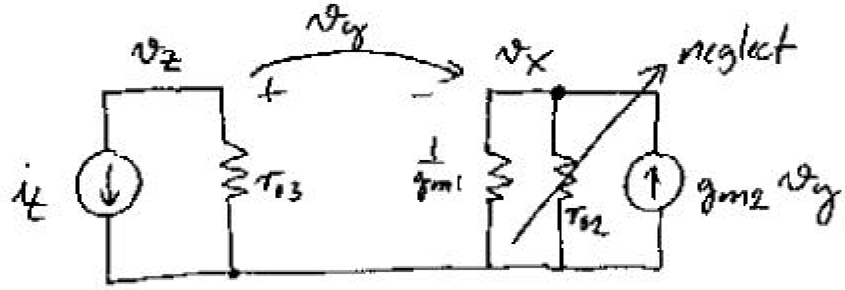
$$R_o(h=0) = r_{o2} + \frac{1}{g_{m1}} \cong \underline{\underline{r_{o2}}} = 200k\Omega$$

(ii) find RR (open port)

→ for an open output port, g_{m2} can only supply current to $r_{o2} \Rightarrow v_x = 0$

$i_r = g_{m3} v_x \Rightarrow RR = \underline{\underline{0}}$ (open port)

iii) find RR (shorted port)



$i_r = g_{m3} v_x$

$$v_x = \frac{g_{m2}}{g_{m1}} v_y \quad ; \quad v_y = v_z - v_x$$

$$v_z = -i_t r_{o3}$$

$$\Rightarrow v_x = \frac{g_{m2}}{g_{m1}} v_z - \frac{g_{m2}}{g_{m1}} v_x$$

$$v_x\left(1 + \frac{g_{m2}}{g_{m1}}\right) = -r_{o3} \frac{g_{m2}}{g_{m1}} i_t$$

$$v_x = -\frac{\frac{g_{m2} r_{o3}}{g_{m1}}}{1 + \frac{g_{m2}}{g_{m1}}} \cdot i_t$$

$$v_x = -\frac{g_{m2} r_{o3}}{g_{m1} + g_{m2}} i_t$$

$$\Rightarrow RR = -\frac{i_r}{i_t} = \frac{g_{m2} g_{m3} r_{o3}}{g_{m1} + g_{m2}}$$

$$RR = \frac{1}{2} \cdot 1.41mS \cdot 200k = \underline{\underline{141}}$$ (shorted port

iv) R_{out} (closed loop) $= R_o(h=0)\left[\frac{1 + RR(\text{shorted})}{1 + RR(\text{open})}\right]$

$$= 200k \left[\frac{1 + 141}{1}\right] = \underline{\underline{28.4 M\Omega}}$$

③ a) $I_{D1} = 10\, I_{D2}$

$$R I_{D2} = \sqrt{\frac{2 \cdot 10 \cdot I_{D2}}{k'\left(\frac{W}{L}\right)_1}} - \sqrt{\frac{2 I_{D2}}{k'\left(\frac{W}{L}\right)_2}} \qquad \left(\frac{W}{L}\right)_2 = 10\left(\frac{W}{L}\right)_1$$

$$\sqrt{I_{D2}} = \frac{1}{R}\left(\sqrt{\frac{20}{k'\left(\frac{W}{L}\right)_1}} - \sqrt{\frac{2}{k'\left(\frac{W}{L}\right)_2}}\right)$$

$$\sqrt{I_{D2}} = \frac{1}{10k}\left(\sqrt{\frac{20}{200\mu \cdot 10}} - \sqrt{\frac{2}{200\mu \cdot 100}}\right)$$

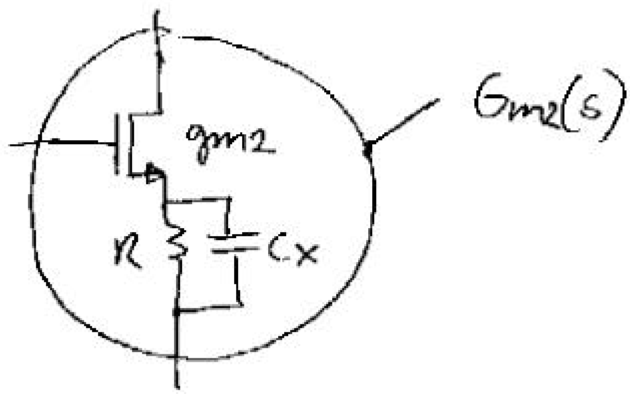
$$\underline{\underline{I_{D2} = 81\mu A}}$$

$g_{m1} = g_{m2} = 1.8mS$

$g_{m4} = 0.4mS$

$g_{m3} = 4mS$

b)



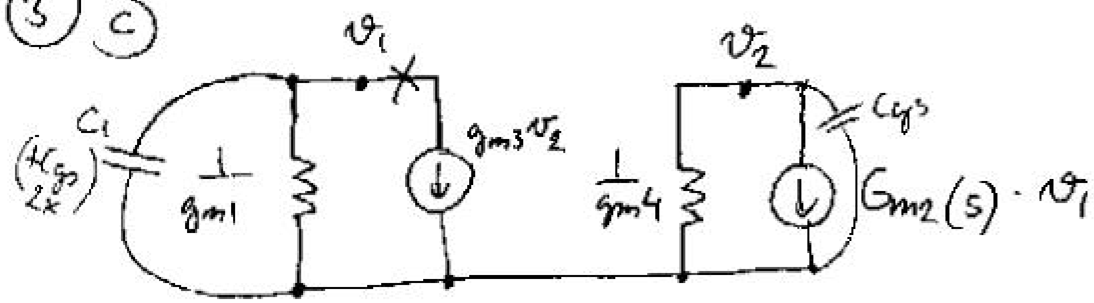
$$G_{m2(s)} = \frac{1}{\frac{1}{g_{m2}} + \left(R \,||\, \frac{1}{sC_x}\right)} = \frac{1 + sRC_x}{1 + s\frac{RC_x}{1 + g_{m2}R}} \cdot \frac{1}{\frac{1}{g_{m2}} + R}$$

__zero:__ $z_0 = -\frac{1}{RC_x}$

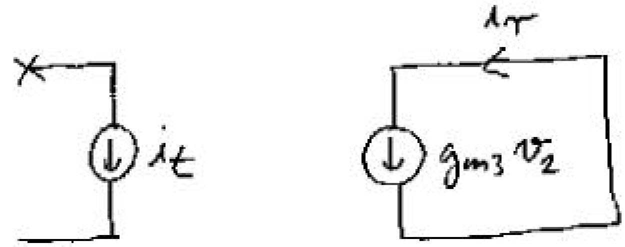
__pole:__ $p_0 = -\frac{1 + g_{m2}R}{RC_x}$ zero-pole doublet

$$p_0 = \left(1 + g_{m2}R\right) \cdot z_0$$

(3) (c)



d)



$$\Rightarrow RR = \frac{-i_R}{i_t} = -\frac{g_{m3}}{g_{m4}} \frac{G_{m2}(s)}{g_{m1}}$$

$$= -\frac{g_{m3}}{g_{m4}\, g_{m1}} \cdot \frac{1 - s/z_0}{1 - s/p_0} \cdot \frac{1}{\frac{1}{g_{m2}} + R}$$

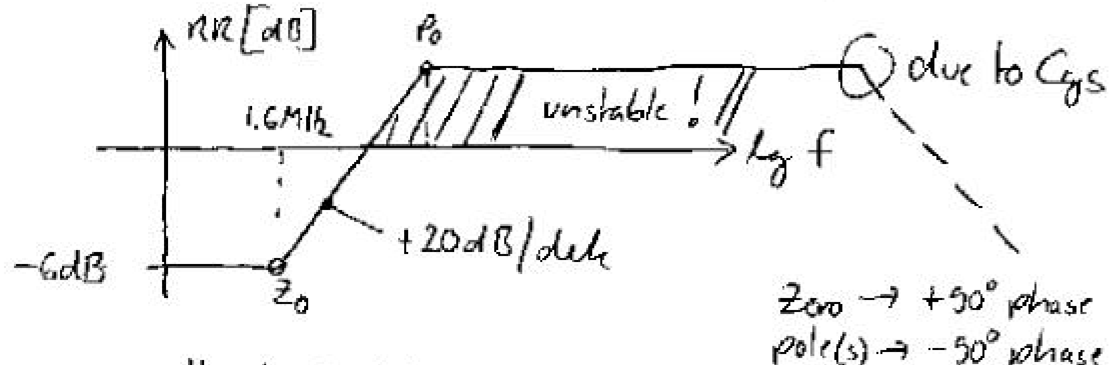
$$= 0.53 \cdot \frac{1 - s/z_0}{1 - s/p_0}$$

$\downarrow$

$\cong -6\text{dB}$

$z_0 = -\frac{1}{RC_x} \Rightarrow f_{z0} = 1.6\text{MHz}$

$p_0 = 1 + g_{m2} R \Rightarrow f_{p0} = 30.4\text{MHz}$

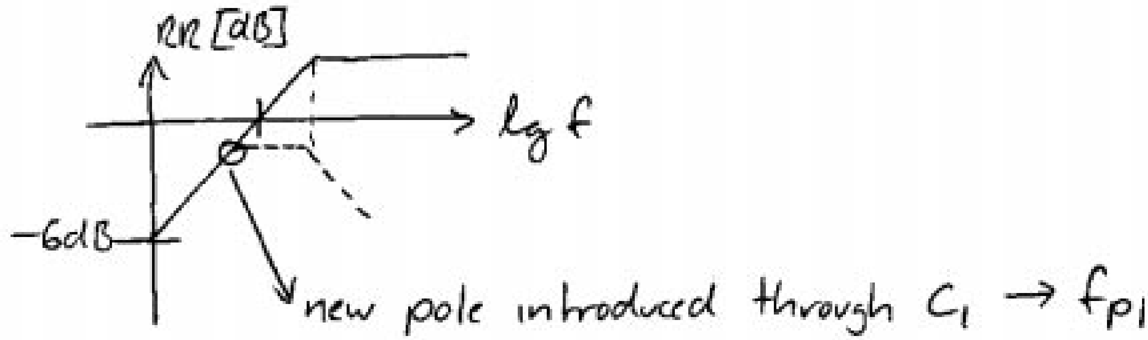


e) → see attached plot

f) → see attached plot. Note that the frequency of osc. can not be predicted from the linear analysis. This circuit acts like a "MULTIVIBRATOR". The source of M2 acts like a negative conductance seen by R, Cx.

} SEE EE142

g) → need a pole before RR reaches unity:



→ zero at 0.8 MHz, −6dB

→ slope is +6dB/octave ⇒ $f_{p1} \leq 1.6$ MHz

$$f_{p1} = \frac{1}{2\pi}\frac{g_{m1}}{C_1}$$

$$C_1 \geq \frac{g_{m1}}{2\pi f_{p1}} = \frac{1.8mS}{2\pi \cdot 3.2MHz} = \underline{\underline{179\ pF}}\ !$$

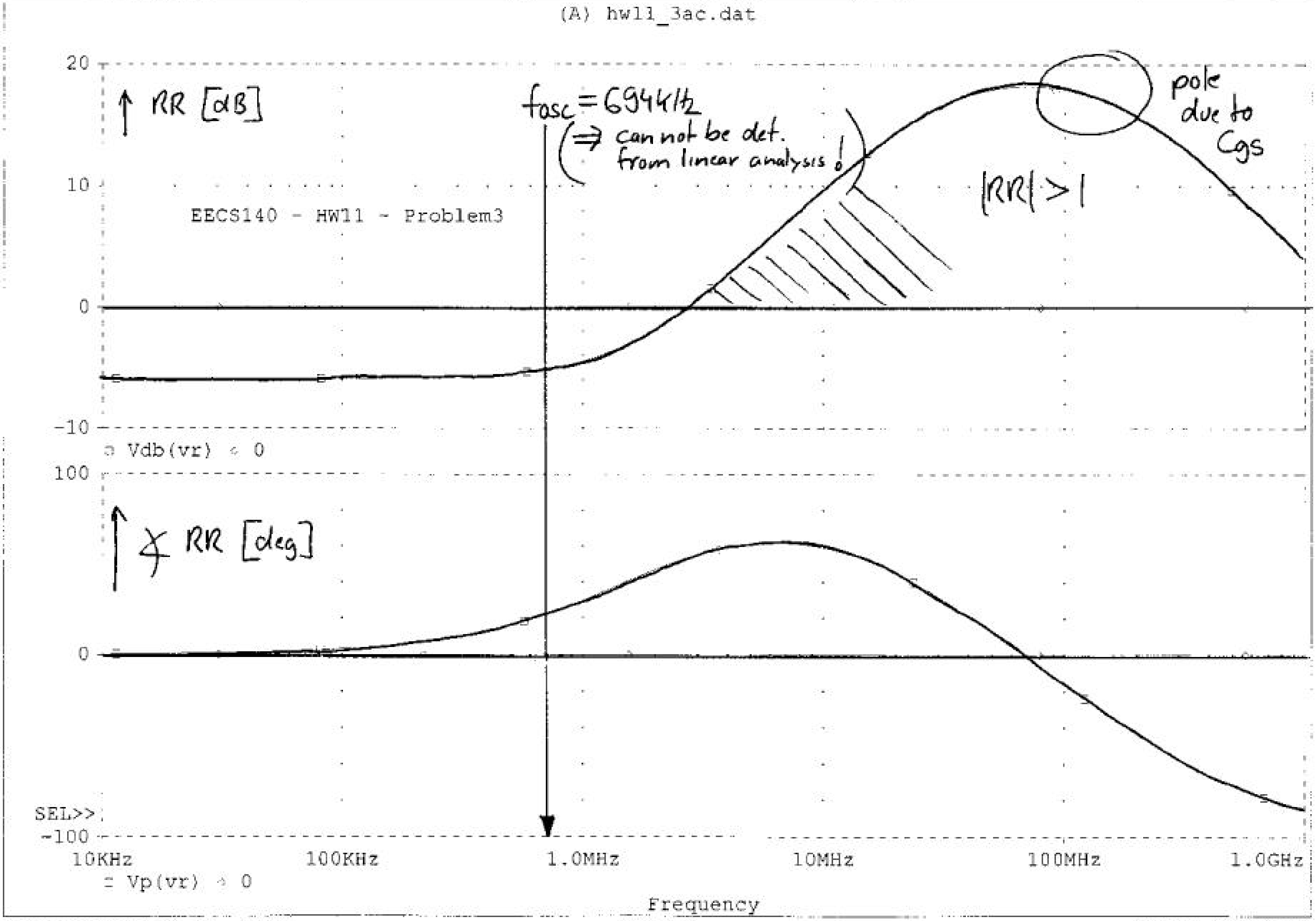
→ say $C_1 \cong 200pF$ or larger

→ not very practical... → can find other ways to compensate

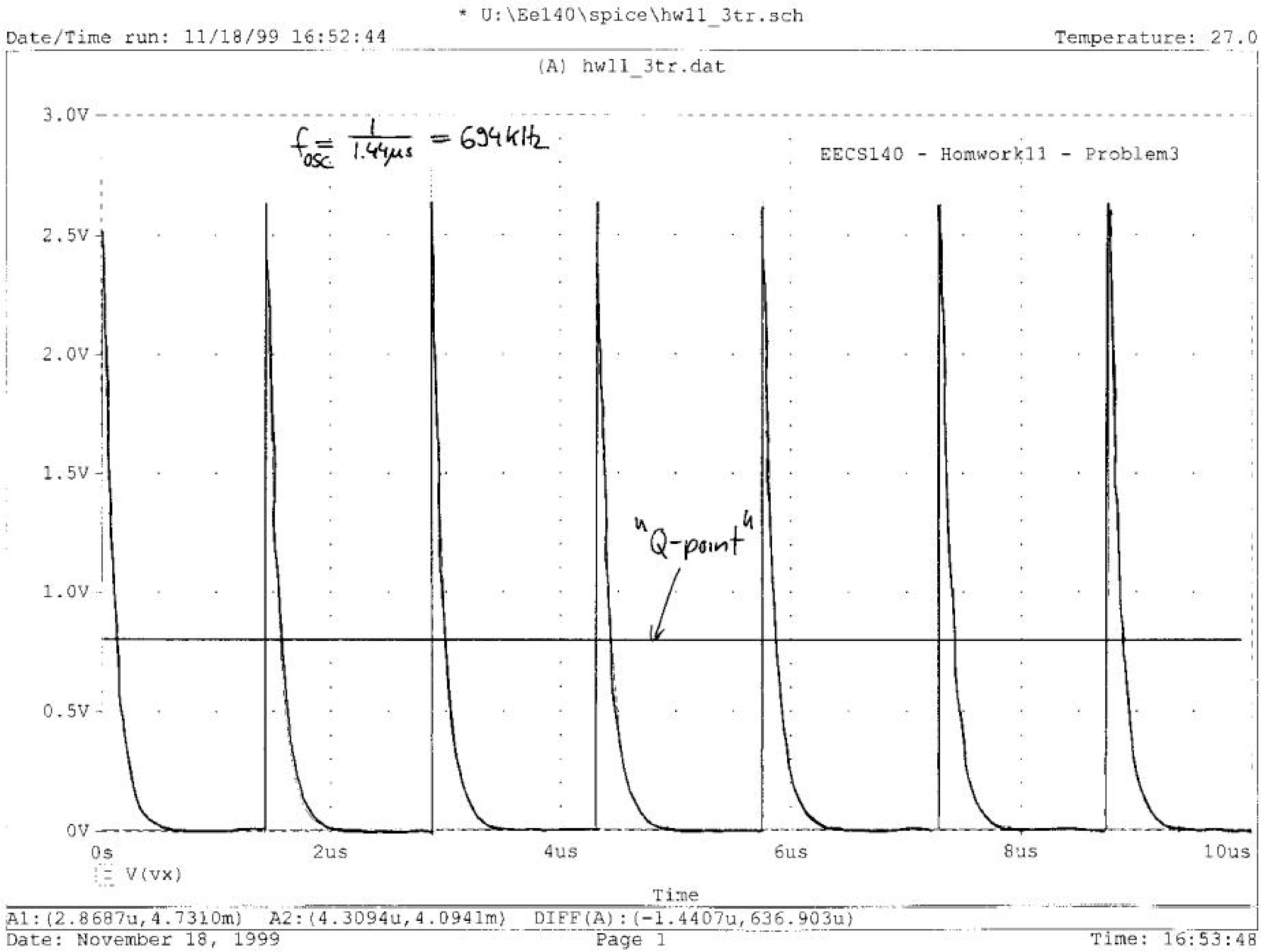
h) → see attached plots

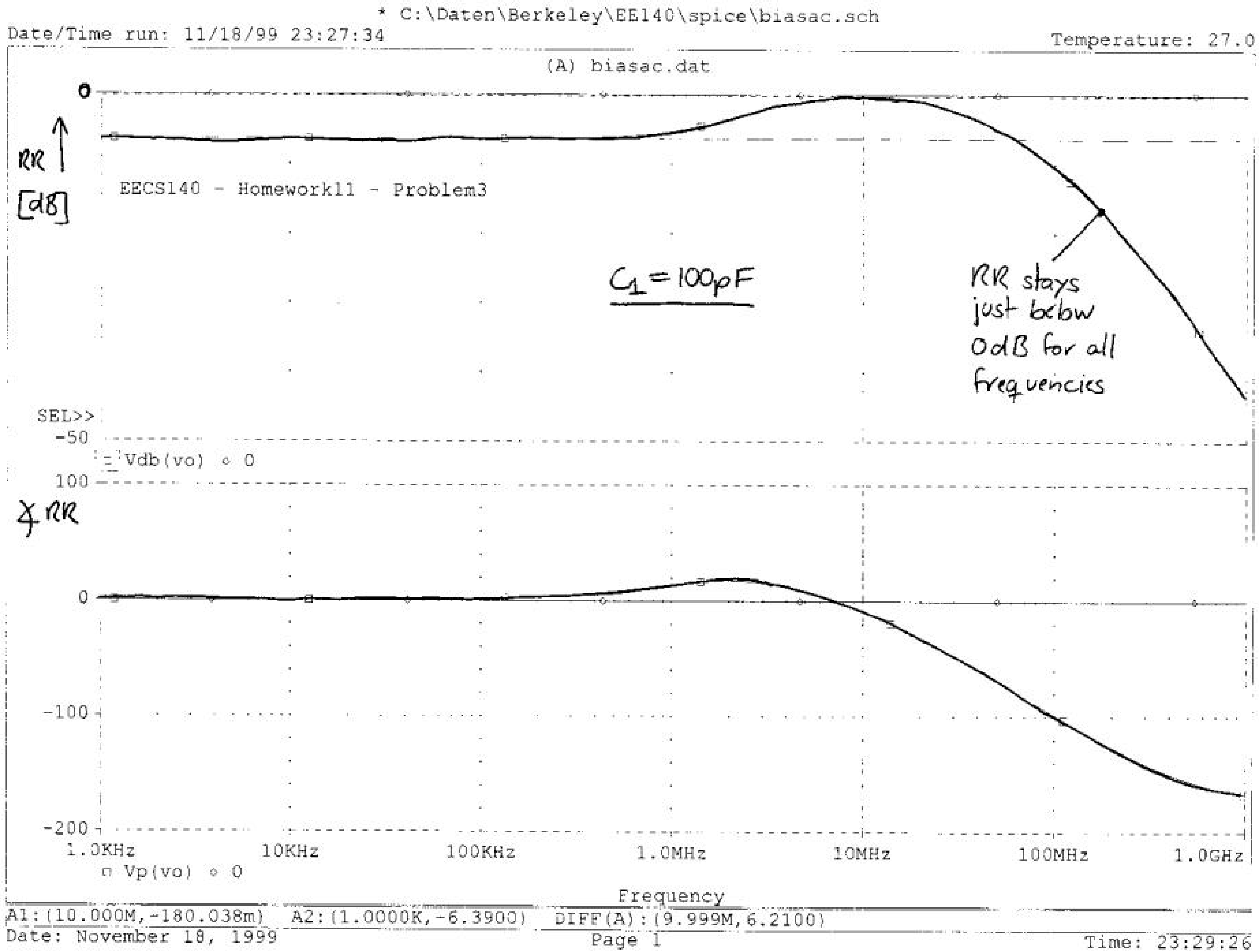
* U:\Ee140\spice\hw11_3ac.sch

Date/Time run: 11/18/99 16:41:26 Temperature: 27.0



Date: November 18, 1999 Page 1 Time: 16:43:48

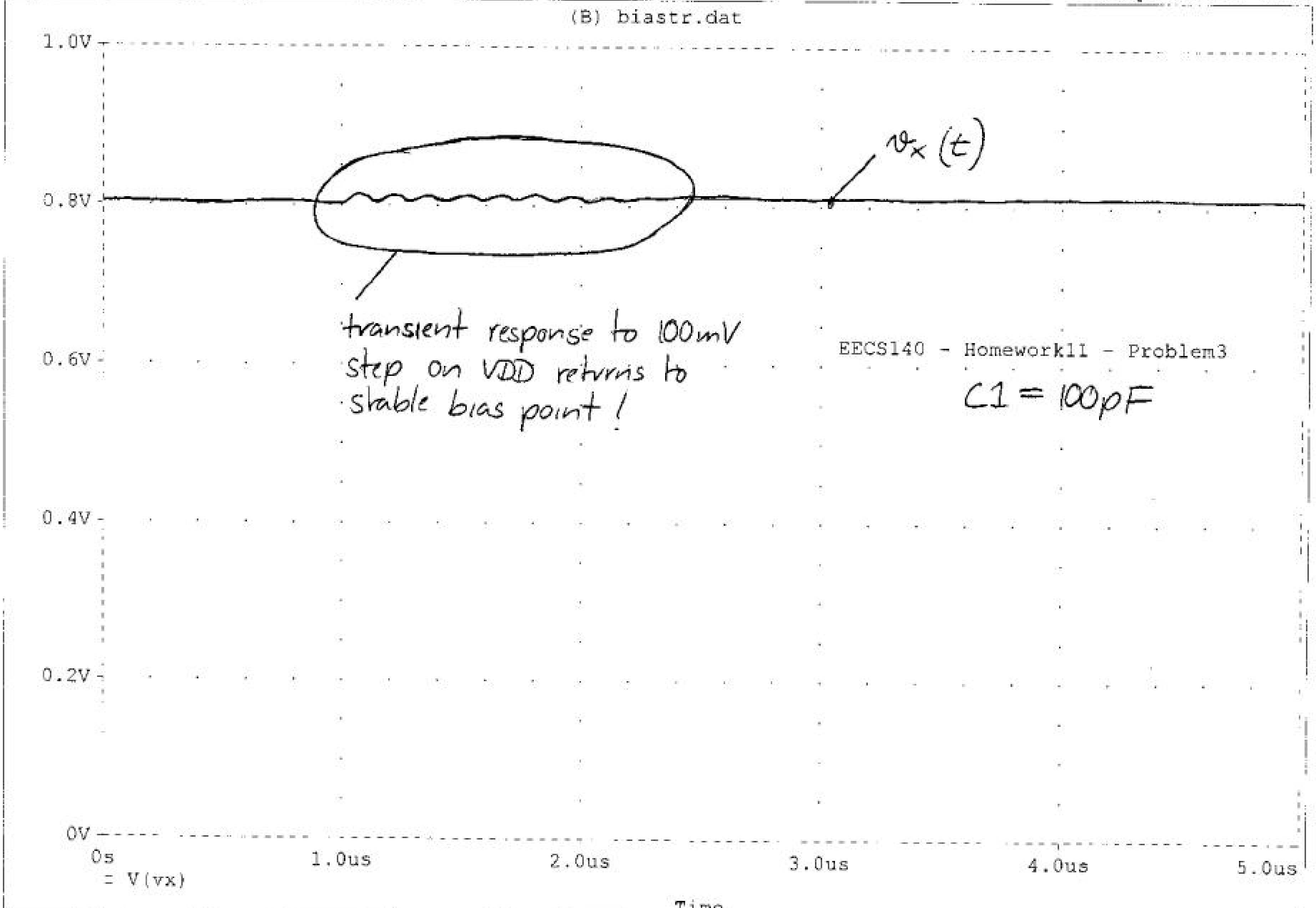

* U:\Ee140\spice\hw11_3tr.sch
Date/Time run: 11/18/99 16:52:44
Temperature: 27.0
(A) hw11_3tr.dat
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0V
0s
2us
4us
6us
8us
10us
V(vx)
Time
EECS140 - Homwork11 - Problem3
$f_{osc} = \frac{1}{1.44\mu s} = 694 kHz$
"Q-point"
A1:(2.8687u,4.7310m) A2:(4.3094u,4.0941m) DIFF(A):(-1.4407u,636.903u)
Date: November 18, 1999
Page 1
Time: 16:53:48



* C:\Daten\Berkeley\EE140\spice\biasac.sch
Date/Time run: 11/18/99 23:27:34
Temperature: 27.0
(A) biasac.dat
0
RR
[dB]
EECS140 - Homework11 - Problem3
C1 = 100pF
RR stays just below 0dB for all frequencies
SEL>>
-50
Vdb(vo) ◇ 0
100
∡ RR
0
-100
-200
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
100MHz
1.0GHz
□ Vp(vo) ◇ 0
Frequency
A1:(10.000M,-180.038m) A2:(1.0000K,-6.3900) DIFF(A):(9.999M,6.2100)
Date: November 18, 1999
Page 1
Time: 23:29:26

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

Date/Time run: 11/18/99 23:32:09 Temperature: 27.0



Date: November 18, 1999 Page 1 Time: 23:37:17

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*** EECS140 Homework11 Problem3
*** This HSPICE deck shows the oscillation


** Analysis setup **
.tran 1ns 10u
.OPTIONS post brief
.OP
.model nmos1   nmos vto=1 tox=6.9n kp=200u
+ lambda=0 gamma=0.5 phi=0.6
.model pmos1   pmos vto=-1 tox=6.9n kp=100u
+ lambda=0 gamma=0.5 phi=0.6

V_VDD          1 0 5V
R_R1          0 vx  10k
M_M1          v2 v2 0 0 NMOS1
+ L=1u
+ W=10u
M_M2          v3 v2 vx vx NMOS1
+ L=1u
+ W=100u
M_M4          v3 v3 VDD VDD PMOS1
+ L=1u
+ W=10u
V_V15          VDD 1
+PWL 0 0 1u 0 1.001u 100m
M_M3          v2 v3 VDD VDD PMOS1
+ L=1u
+ W=100u

*** dummy resistor to startup the circuit...
R_R7          v2 v3  100meg
C_Cx          vx 0  10p

.END
```

HELPS SPICE TO FIND THE CORRECT OPERATING POINT

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