EECS 140 **Solution HW12**

① ⓐ $G_m \cong \sqrt{50\mu \cdot 100\mu \cdot 12.5} = 250\mu S$

$r_{o8} = \frac{1}{0.1 \cdot 25\mu} = 400k\Omega$

$g_{m6} = \sqrt{50\mu \cdot 200\mu \cdot 40} = 632\mu S$

$r_{o6} = \frac{1}{0.02 \cdot 25\mu} = 2M\Omega$

$r_{o4} = \frac{1}{0.05 \cdot 50\mu} = 400k\Omega$

$\Rightarrow A_{dmo} = 250\mu S \cdot 400k \,||\, \underbrace{632\mu S \cdot 2M\Omega \cdot 400k}_{505 M\Omega}$

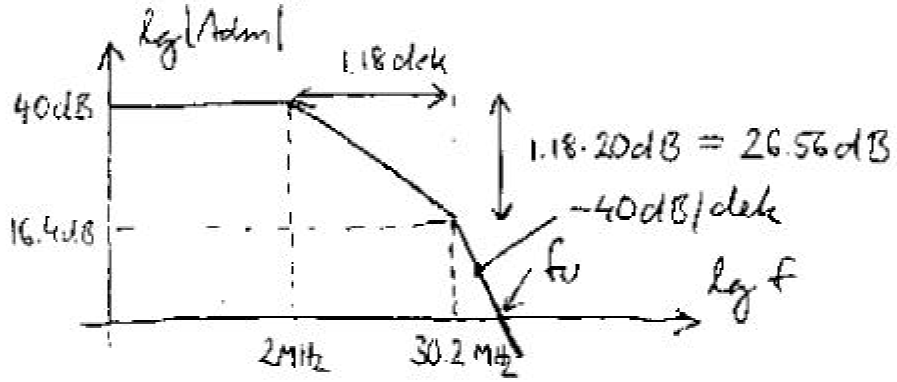
$A_{dmo} = 100$

$A_{dmo} \triangleq 40dB$

$f_{p1} = \frac{1}{2\pi C_L r_{o8}} = \frac{1}{2\pi\ 0.2p \cdot 400k} = 2MHz$

$f_{p2} = \frac{g_{m5}}{2\pi C_{gs5}} = \boxed{30.2MHz}$

$C_{gs5} = \frac{2}{3} 1000 \cdot 5fF = 3.33pF$



$f_u \cong \underbrace{10^{\wedge}\left(\frac{16.4}{40}\right)}_{2.57} \cdot 30.2MHz = \boxed{77.6MHz}$

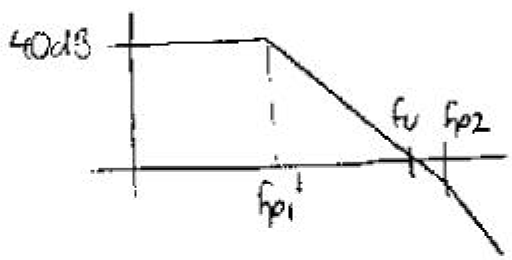
① b) phase shift from $p_1 \cong -90°$

phase shift from p_2: $\arctan\left(\frac{f_U}{f_{p2}}\right) = -\arctan\left(\frac{77.6\,MHz}{32\,MHz}\right) = -67.6°$

$\Rightarrow \varphi_m = 180° - 90° - 67.7° = \underline{\underline{22.3°}}$ POOR!

c) For $\varphi_m = 60°$:

$f_U \overset{!}{=} \frac{1}{2} f_{p2}$ and f_U caused by dominant pole f_{p1}'



$f_{p1}' = \frac{1}{2} \cdot \frac{1}{100} \cdot 30.2\,MHz$

$f_{p1}' = 151.1\,KHz$

$\Rightarrow C_L' = \frac{1}{2\pi f_{p1}' \cdot r_{o8}} = \frac{1}{2\pi \cdot 151K \cdot 400K} = \underline{\underline{2.64\,pF}}$

d) $G_m \sim I_0 \Rightarrow f_U \sim I_0$; $g_{m5} \sim I_0 \Rightarrow f_{p2} \sim I_0$ $\Big\}$ $\frac{f_{p2}}{f_U} = \text{const.}$!

$\Rightarrow$ THE PHASE MARGIN DOES NOT CHANGE WHEN I_0 IS CUT IN HALF!

e) $W_{1,2} \uparrow 2x \Rightarrow G_m \uparrow \sqrt{2} \Rightarrow f_U \uparrow \sqrt{2}$

and $f_{p2} = \text{const.} \Rightarrow \frac{f_{p2}}{f_U} \downarrow \times 1/\sqrt{2}$

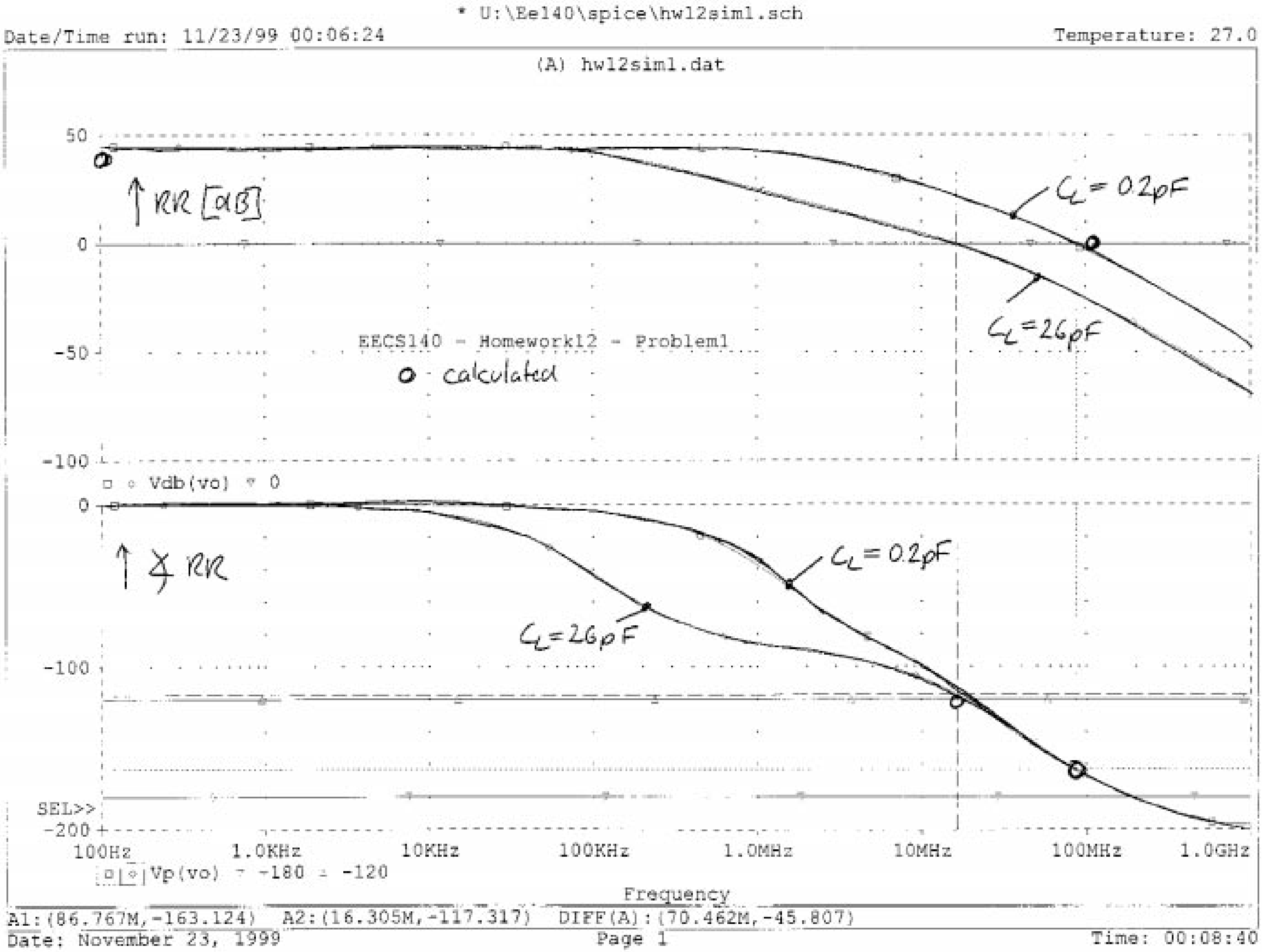
$\rightarrow$ THE PHASE MARGIN WILL DECREASE IN THIS CASE, BY

$\arctan 2 - \arctan\left(\frac{2}{\sqrt{2}}\right) = \underline{\underline{8.7°}}$

① f) see attached plot

	CALC	SIM	ERR
φ_m ($C_L = 0.2p$)	22.3°	16.8°	30%
φ_m ($C_L = 2.6p$)	≅ 60°	63°	4.7%

→ good agreement


* U:\Ee140\spice\hwl2siml.sch
Date/Time run: 11/23/99 00:06:24
Temperature: 27.0
(A) hwl2siml.dat
50
0
-50
-100
↑ RR [dB]
$C_L = 0.2pF$
$C_L = 26pF$
EECS140 - Homework12 - Problem1
o calculated
Vdb(vo) 0
0
-100
-200
↑ ∡ RR
$C_L = 0.2pF$
$C_L = 26pF$
SEL>>
100Hz
1.0KHz
10KHz
100KHz
1.0MHz
10MHz
100MHz
1.0GHz
Vp(vo) -180 -120
Frequency
A1:(86.767M,-163.124) A2:(16.305M,-117.317) DIFF(A):(70.462M,-45.807)
Date: November 23, 1999
Page 1
Time: 00:08:40

② a) $g_{m8} = \sqrt{2 I_D k' \frac{W}{L}} = \sqrt{200\mu \cdot 200\mu \cdot 25} = 1mS$

$R_Z = \frac{1}{g_{m8}} = \underline{\underline{1k\Omega}}$

b) $\omega_U \cong \frac{g_{m1}}{C_L}$ $\quad g_{m1} = \sqrt{100\mu \cdot 100\mu \cdot 50} = 707\mu S$

$f_U \cong \frac{1}{2\pi} \frac{707\mu S}{5pF} = \underline{\underline{22.5 MHz}}$

$f_{P2} \cong \frac{1}{2\pi} \frac{g_{m8}}{C_L} \geq 2 \cdot f_U$ for 60° phase margin

$\Rightarrow C_{Lmax} = \frac{g_{m8}}{2 \cdot 2\pi f_U} = \frac{1mS}{2 \cdot 2\pi \cdot 22.5MHz} = \underline{\underline{3.5pF}}$

c) $W_{1,2} \uparrow 2x \Rightarrow g_{m1} \uparrow \sqrt{2}$

$W_5 \uparrow 2x \Rightarrow I_{D1} \uparrow 2x \Rightarrow g_{m1} \uparrow \sqrt{2}$ } $g_{m1} \uparrow 2x$

$\Rightarrow \omega_U \uparrow 2x \rightarrow \omega_U' = \underline{\underline{44.5 MHz}} = f_{P2}$

$\Rightarrow$ since $\omega_U = f_{P2} \Rightarrow \varphi_m' = \underline{\underline{45°}}$

d) $I_{D8} \uparrow 2x$, $W_8 \uparrow 2x$ } $\Rightarrow g_{m8} \uparrow 2x$ $\quad g_{m8}' = 2mS$

$(R_Z' = 500\Omega)$

$\rightarrow$ unity gain frequency does not change! $(f_U = 22.5MHz)$

f_{P2} doubles $\Rightarrow f_{P2} = 4 f_U$

$\Rightarrow \varphi_m = \arctan 4 = \underline{\underline{76°}}$

e)

$g_{m1} \uparrow \sqrt{2}$
$g_{m8} \uparrow \sqrt{2}$ $\Big\}$ $\varphi_m = \text{const}$

$f_u' - \sqrt{2} f_u = \underline{\underline{31.8\,MHz}}$

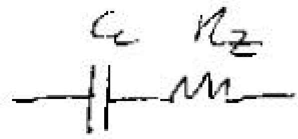
$\underline{\underline{\varphi_m \cong 60^\circ}}$

f) $f_{p2} = 45\,MHz$

from class: $a_{(s)} = \frac{v_o(s)}{v_i(s)} = \frac{N(s)}{D(s)}$

$N_{(s)} = 0 = g_{m8} - sC_c$

replace sC_c with $\frac{1}{\frac{1}{sC_c} + R_Z}$



$$= \frac{sC_c}{1 + sR_Z C_c}$$

$$0 = \frac{g_{m8} + s g_{m8} R_Z C_c - sC_c}{1 + sR_Z C_c}$$

$$0 = g_{m8} + sC_c\left(g_{m8} R_Z - 1\right)$$

$$0 = 1 + sC_c\left(R_Z - \frac{1}{g_{m8}}\right) \quad \underline{\text{zero}}: \ z = -\frac{1}{C_c\left(R_Z - \frac{1}{g_{m8}}\right)}$$

$$z \overset{!}{=} p_2 = -2\pi \cdot 45\,MHz = -\frac{1}{C_c\left(R_Z - \frac{1}{g_{m8}}\right)}$$

$$R_Z = \frac{1}{\omega_{p2} C_c} + \frac{1}{g_{m8}} = \frac{1}{2\pi \cdot 45\,MHz \cdot 2\,pF} + \frac{1}{1\,mS} = \underline{\underline{2.768k}}$$

$\Rightarrow \underline{\underline{\varphi_m = 90^\circ}}$

g) → see attached plot

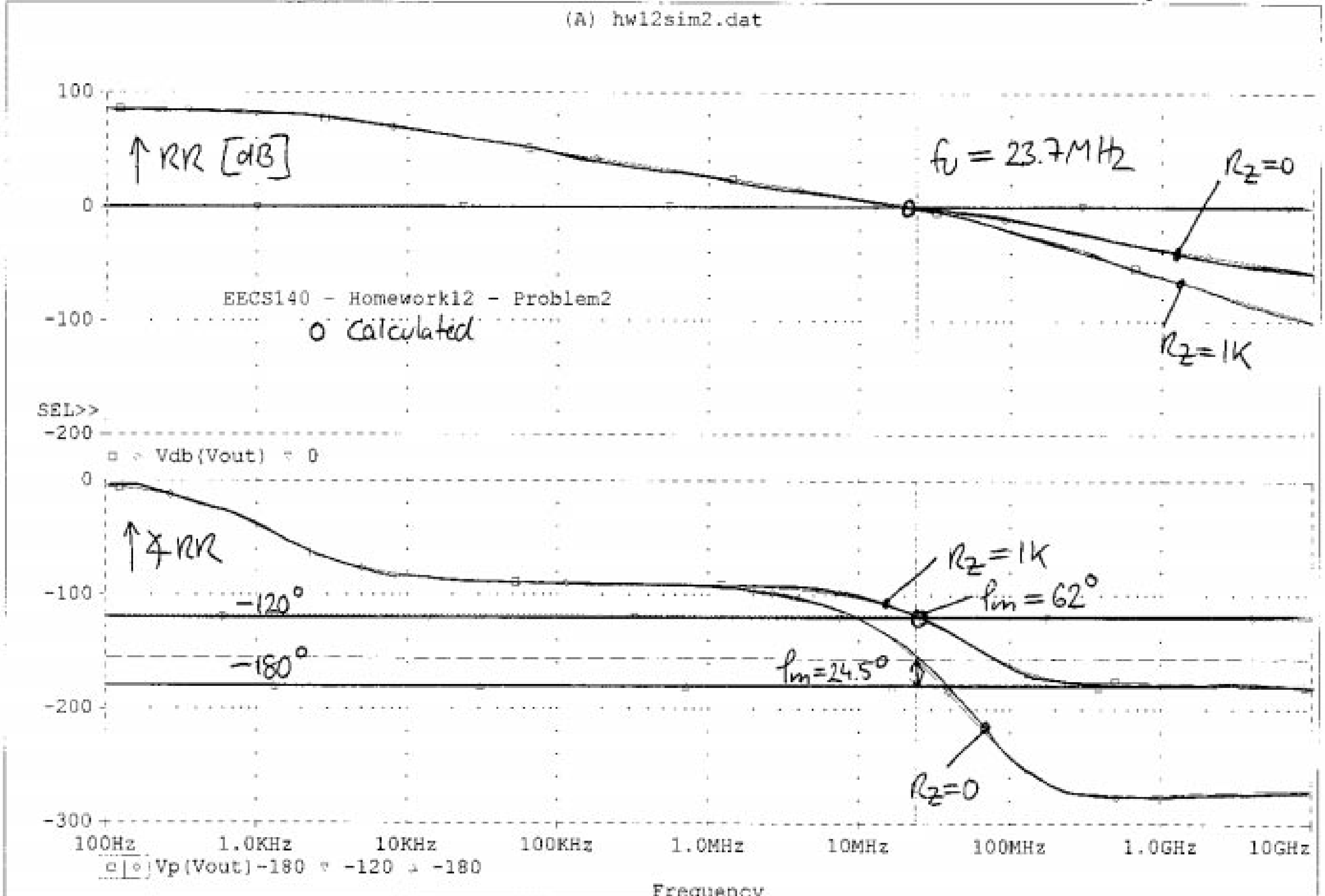
	CALC	SIM	ERR
f_U	22.5 MHz	23.7 MHz	4 %
$\phi_m (R_z = 1K)$	$\cong 60^0$	62^0	3%
$\phi_m (R_z = 0)$	—	24.5^0	—

↓ (24.5^0) due to additional phase shift from RHP zero!

* U:\Ee140\spice\hw12sim2.sch

Date/Time run: 11/23/99 13:57:00 Temperature: 27.0

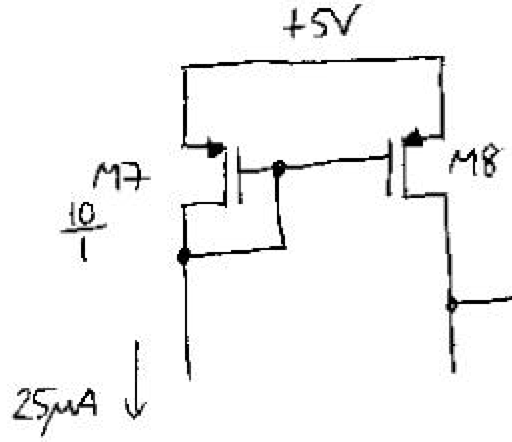
(A) hw12sim2.dat



A1:(23.714M,-118.090) A2:(23.714M,-155.589) DIFF(A):(0.000,37.500)

Date: November 23, 1999 Page 1 Time: 13:59:05

③ ⓐ



$V_o|_{Q\text{-point}} = 5V - V_{GS7}$

$$V_{dsat_7} = \sqrt{\frac{2I_D}{k'\frac{W}{L}}} = \sqrt{\frac{50\mu}{100\mu \cdot 10}} = 223\,mV$$

$\Rightarrow V_{OQ} = 5V - 1.223V = \underline{\underline{3.77V}}$

$\rightarrow$ for $V_0 \overset{!}{=} 0$ need $V_{OS} = V_{id}|_{V_0=0} = \frac{V_{OQ}}{A_{dm}}$

$\Rightarrow V_{OS} = \frac{-3.86V}{100} = \underline{\underline{-37.7\,mV}}$

ⓑ $\varepsilon_s = \frac{1}{T_0} = \frac{1}{a_0} = \frac{1}{100} = \underline{\underline{1\%}}$

ⓒ $SR = \frac{2I_0}{C_L} = \frac{50\mu A}{10pF} = \underline{\underline{5V/\mu s}}$

$\tau = \frac{1}{\omega_u(MR)} = \frac{C_L}{g_{m1}} = \frac{10pF}{250\mu S} = \underline{\underline{40ns}}$

ⓓ (i) double $\left(\frac{W}{L}\right)_9 \Rightarrow I_0 \uparrow 2x \Rightarrow SR \uparrow 2x$ $\left(\left(\frac{W}{L}\right)_9 \overset{!}{=} \frac{100}{2}\right)$

(ii) $\tau \sim \frac{1}{g_{m1}} \rightarrow$ e.g. double g_{m1} by increasing $\left(\frac{W}{L}\right)_{1,2}$ by a factor of 2 and $I_{D1} \uparrow 2x$

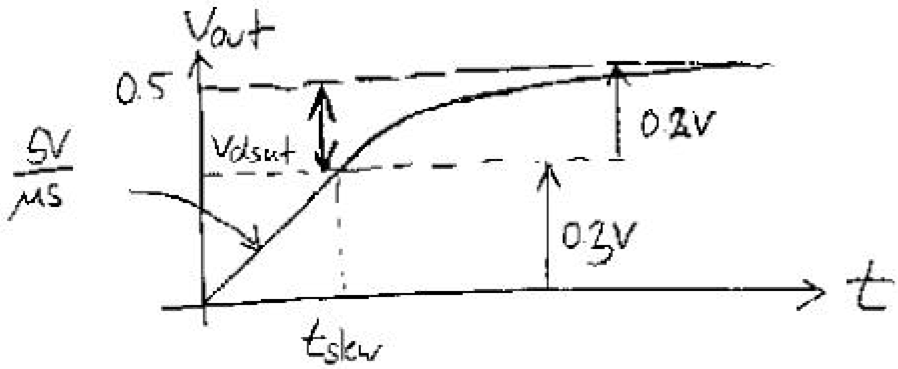
$\rightarrow \left(\frac{W}{L}\right)_{1,2} \overset{!}{=} \frac{50}{2}$, $\left(\frac{W}{L}\right)_9 \overset{!}{=} \frac{100}{2}$

(e) $V_{dsat1} = \sqrt{\frac{50\mu}{100\mu \cdot 12.5}} = 200mV$

$\Delta V_i = 50mV < 200mV \Rightarrow$ LINEAR SETTLING

$t_s \cong 6.9\,\tau = 4.6 \cdot 40ns = \underline{\underline{276ns}}$

(f) $\Delta V_1 = 500mV > 200mV$



– $t_{SLEW} = \frac{V_{dsat}}{SR} = \frac{0.2}{5}\mu s = 60ns$

– exponential needs to settle within 0.1 % of 0.5V
$= 0.5mV$

$\Rightarrow \left(200mV - 0.5mV\right) = 200mV\left(1 - e^{-t/\tau}\right)$

$t_{lin} = -\tau \cdot \ln\left(1 - \frac{200-0.5}{200}\right)$

$t_{lin} = -40ns\,\ln\left(0.16667\%\right)$

$t_{lin} = 239\,ns$

$\Rightarrow t_s = t_{lin} + t_{slew} = 60ns + 239\,ns = \underline{\underline{299\,ns}}$

g) i) see attached plot

$V_{OS} = -19.715 mV$ (calculated $-38.6 mV$ → discrepancy due to underestimated A_{dm})

ii) see attached plot

<u>settling voltages:</u> (after cancelling V_{OS})

V_i	V_o
−25mV	−24.931mV
+25mV	+24.906mV
−250mV	−249.218mV
+250mV	+249.142mV

iii) see attached plot

iv) see attached plot

DISCREPANCIES (COMPARED TO HAND ANALYSIS) ARE DUE TO:

— LARGE V_{DS}'s ⇒ large λV_{DS} → difference in I_D, g_m, r_o, etc.

— LARGE SIGNAL EFFECTS SHOW UP IN NEG. TRANSIENT OF −500mV STEP (SEE P.17)

→ TO BE EXAMINED !!

→ LOOK AT $V_{I,f}$ DURING NEG. SLEWING

M7 IS OFF ⇒ IMPEDANCE LOOKING INTO SOURCE OF M5 IS LARGE → LOW FREQUENCY f_{p2} ⇒ INSTABILITY EFFECTS ...

(CAN BE FIXED BY SIZING M_{5-6} TO $\frac{40}{1}$)

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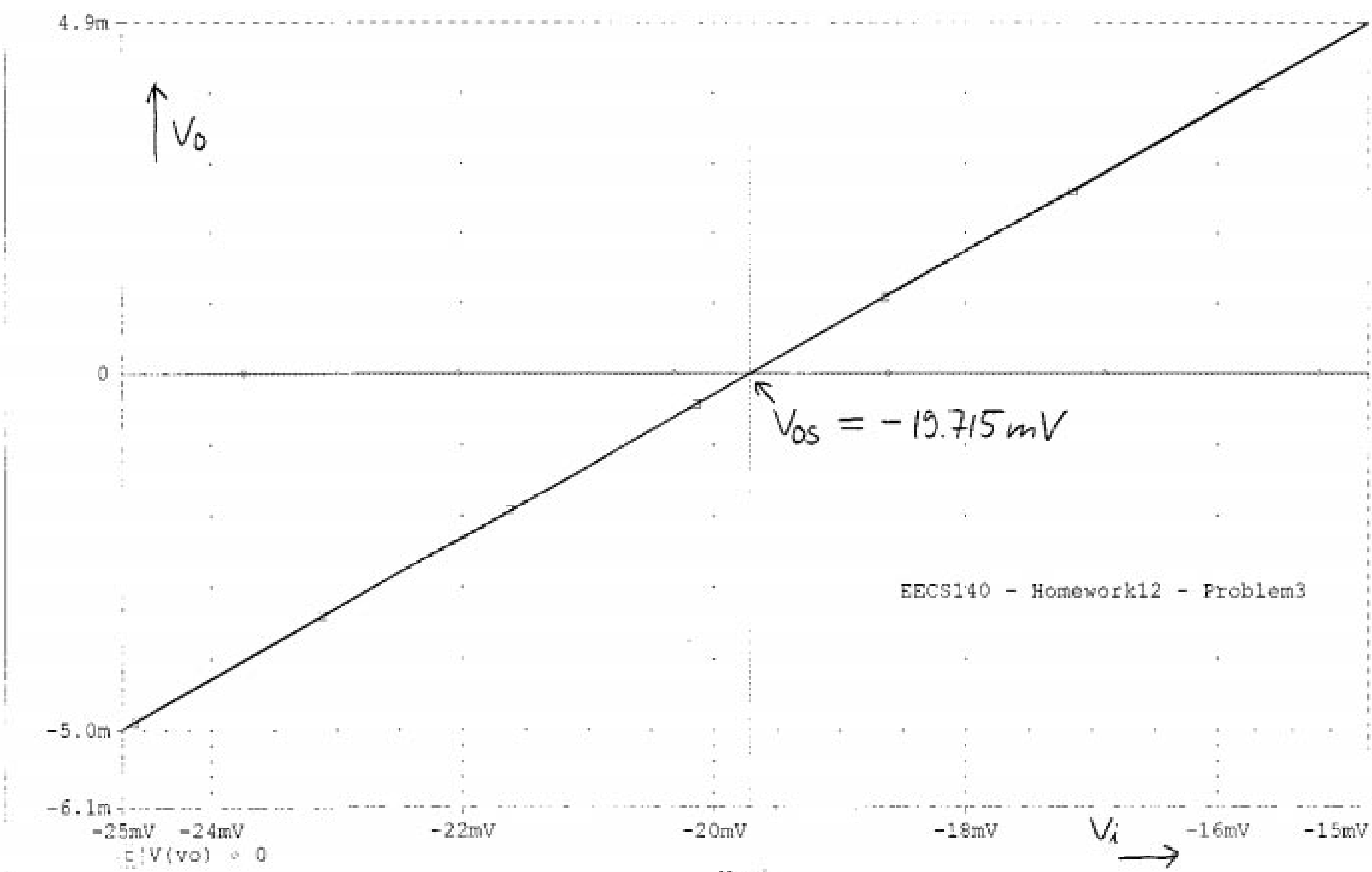
Date/Time run: 11/23/99 17:44:20 Temperature: 27.0

(A) hw12sim3.dat



A1:(-19.715m,-12.636u) A2:(-50.000m,-30.198m) DIFF(A):(30.285m,30.186m)

Date: November 23, 1999 Page 1 Time: 17:46:51

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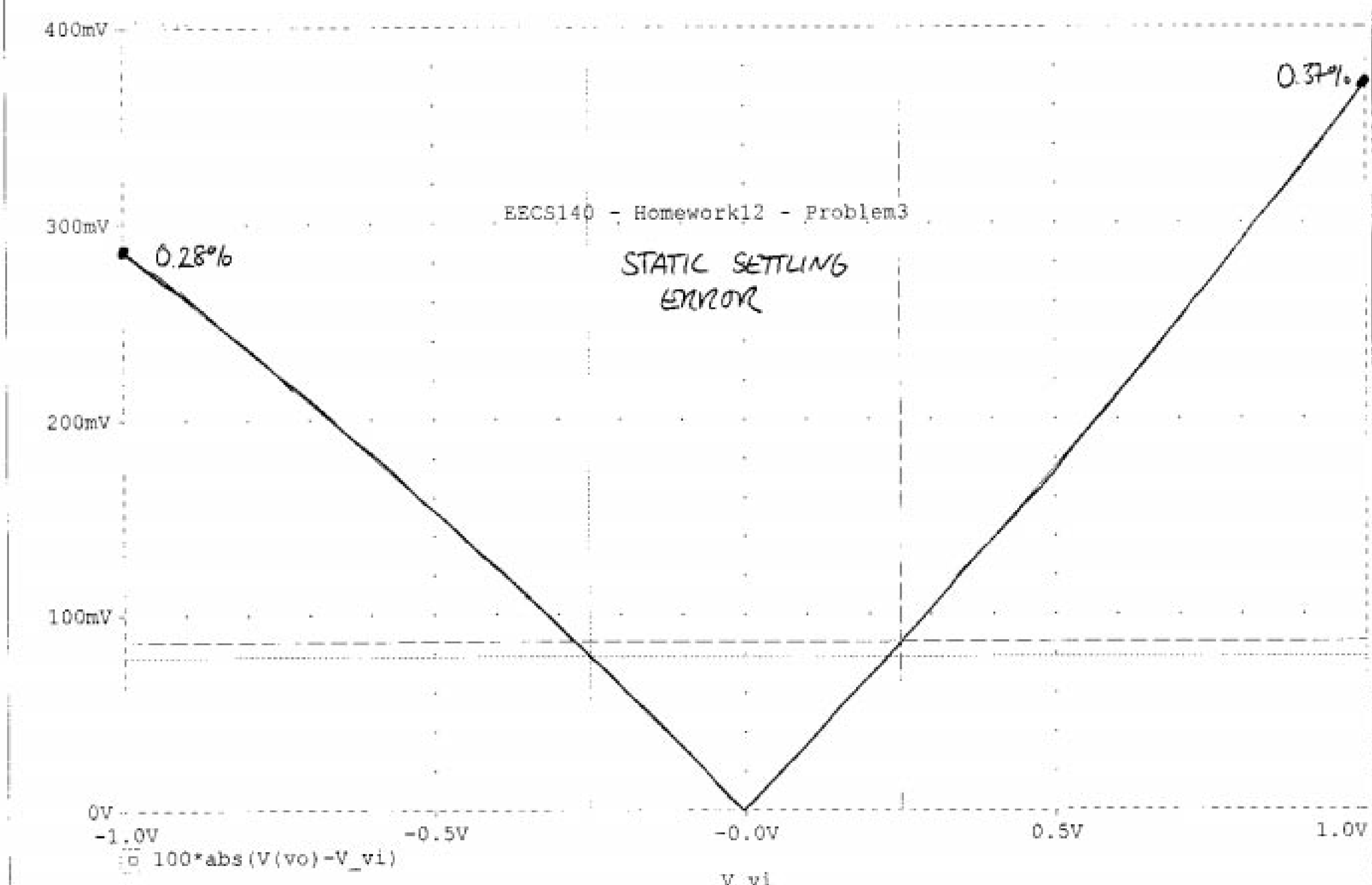
Date/Time run: 11/23/99 17:54:05 Temperature: 27.0

(A) hw12sim3.dat



A1:(-250.900m,78.507m) A2:(251.000m,86.127m) DIFF(A):(-501.900m,-7.6205m)

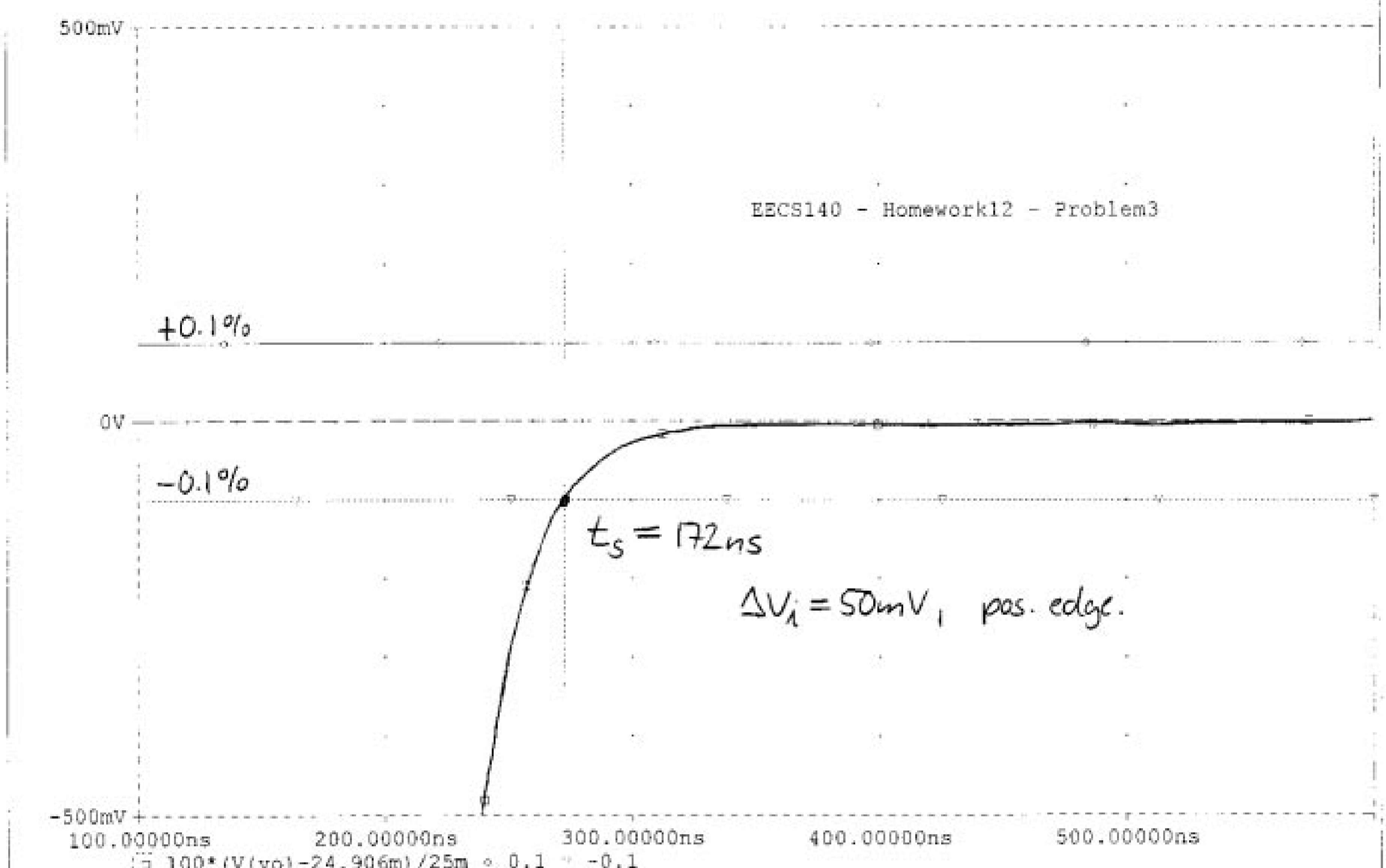
Date: November 23, 1999 Page 1 Time: 17:57:42

13/

* U:\Ee140\spice\hw12sim3.sch

Date/Time run: 11/23/99 18:45:46 Temperature: 27.0

(A) hw12sim3.dat



A1:(272.727n,-99.810m) A2:(600.505n,481.392u) DIFF(A):(-327.778n,-100.291m)

Date: November 23, 1999 Page 1 Time: 18:54:34

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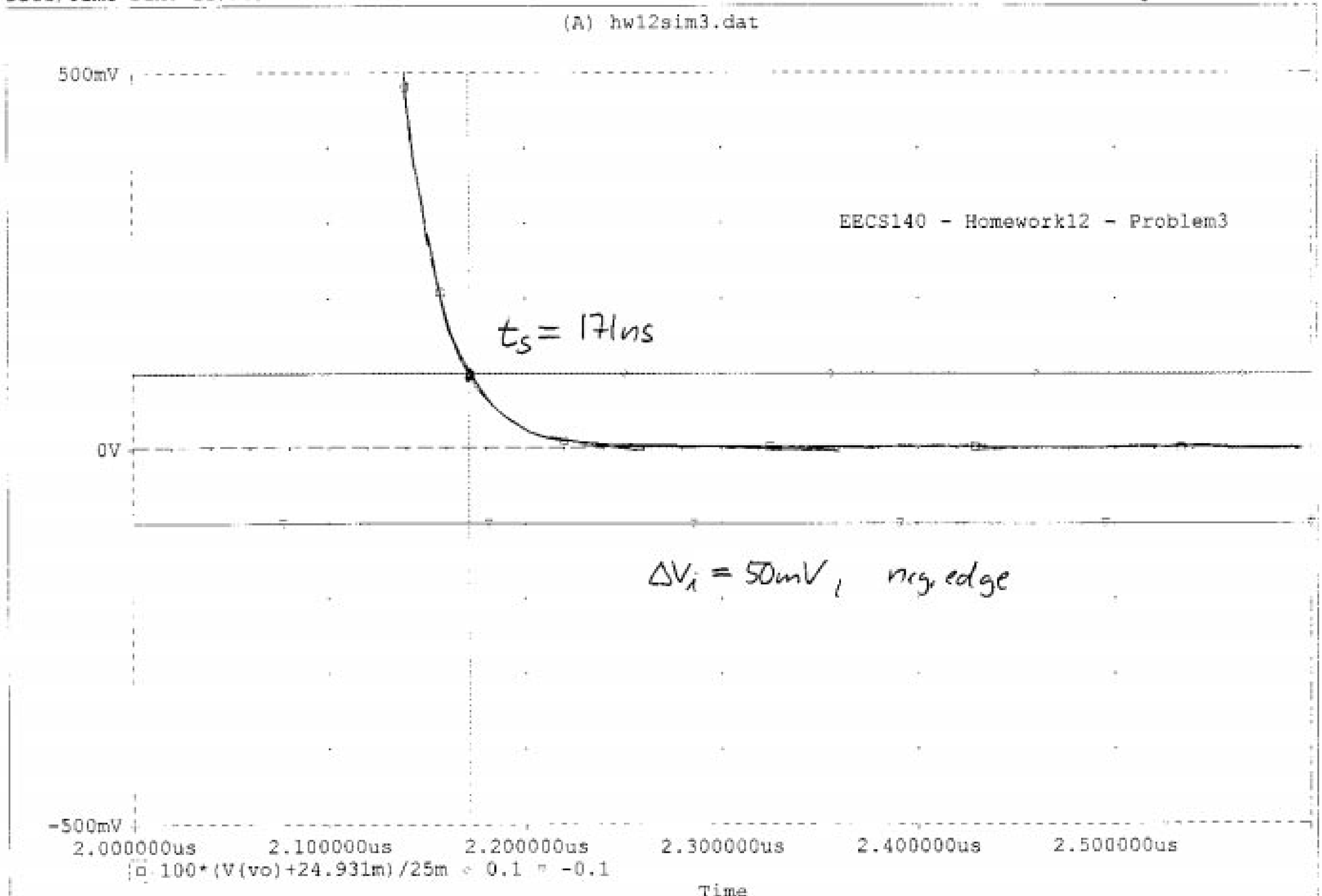
Date/Time run: 11/23/99 18:45:46 Temperature: 27.0



A1:(2.1714u,100.987m) A2:(2.6006u,2.2852m) DIFF(A):(-429.175n,98.702m)

Date: November 23, 1999 Page 1 Time: 18:57:39

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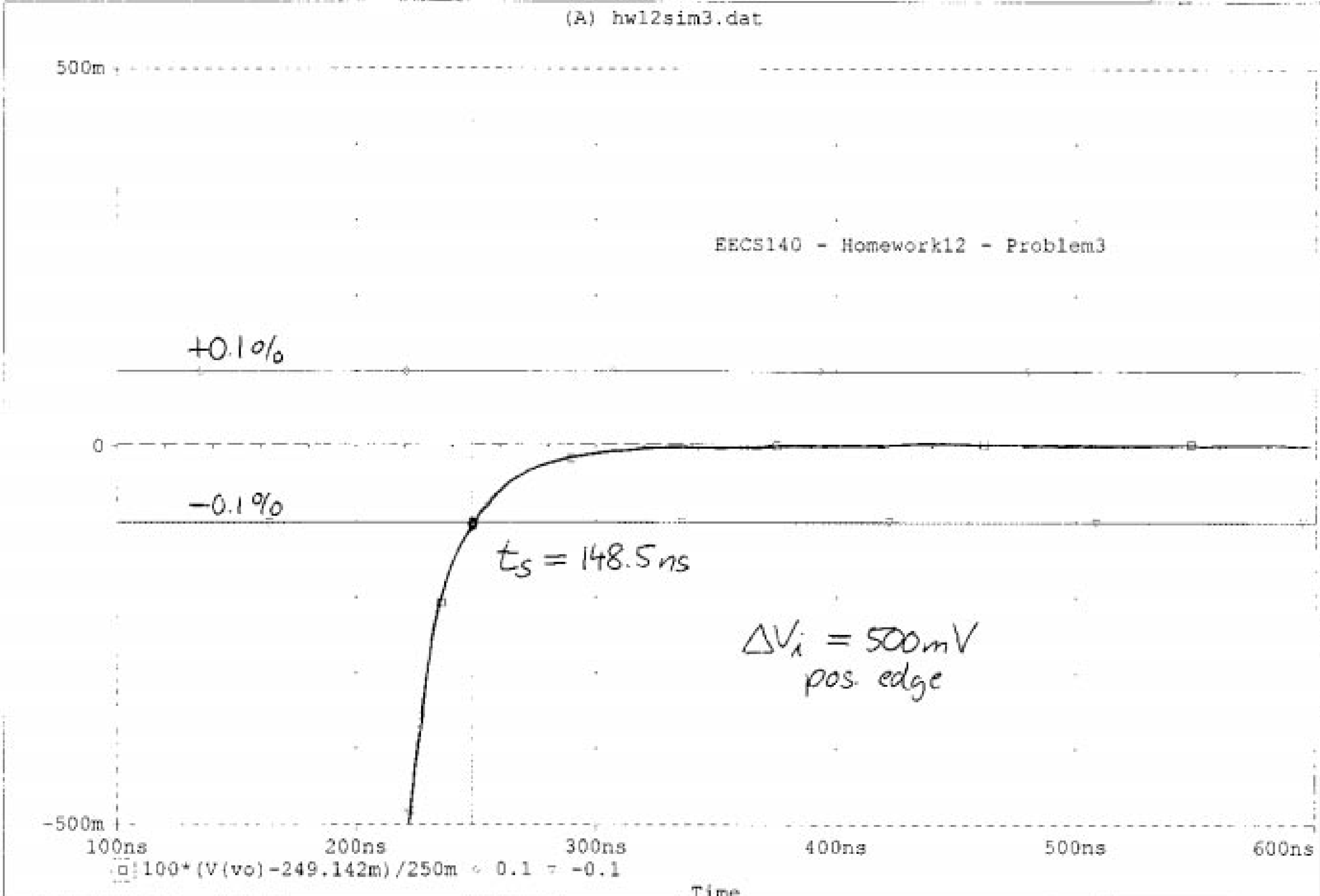
Date/Time run: 11/23/99 19:06:39 Temperature: 27.0



A1:(248.500n,-100.673m) A2:(600.000n,3.0977m) DIFF(A):(-351.500n,-103.770m)

Date: November 23, 1999 Page 1 Time: 19:07:51

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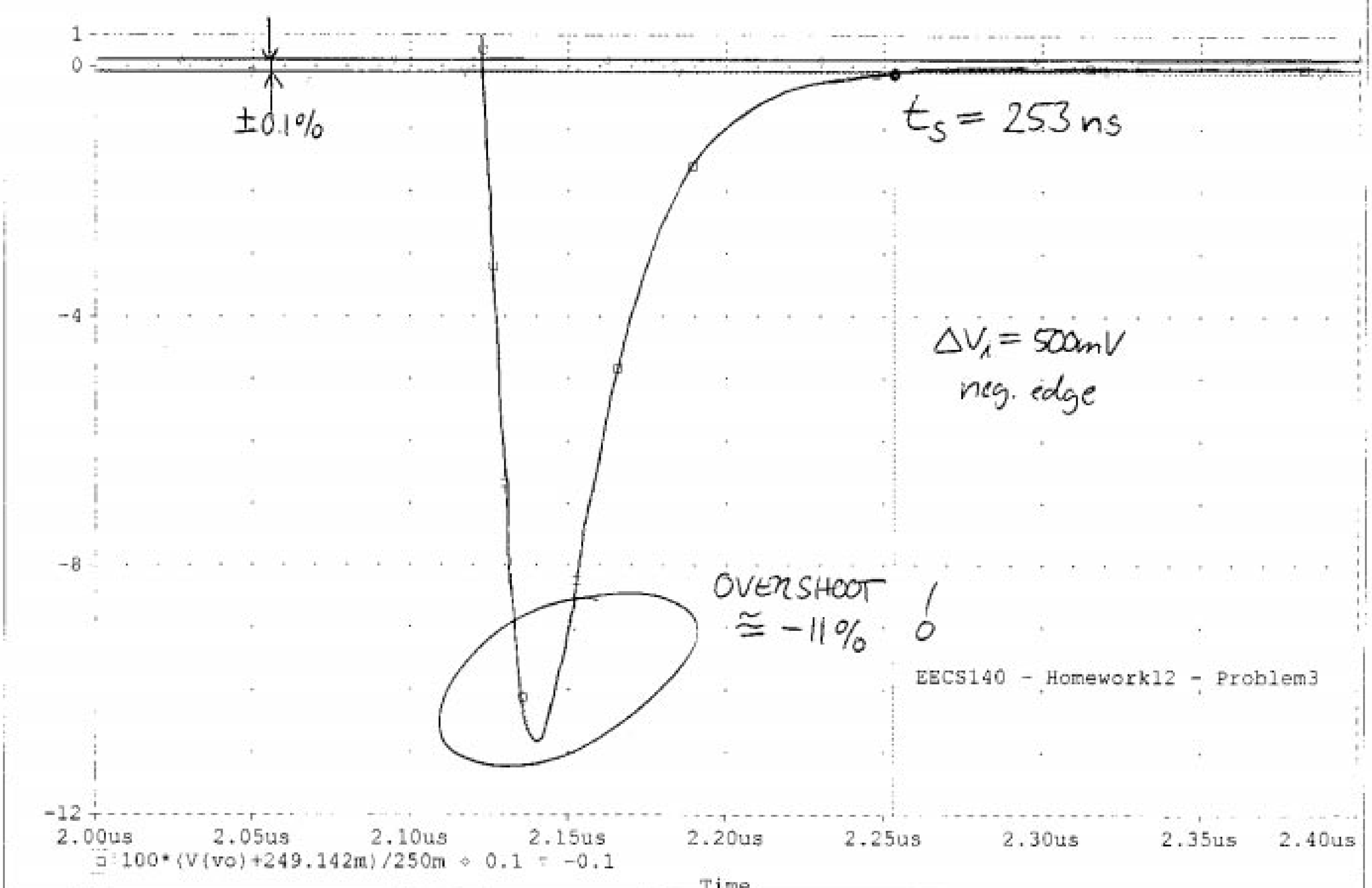
Date/Time run: 11/23/99 19:00:22 Temperature: 27.0

(A) hw12sim3.dat



A1:(2.2532u,-100.715m) A2:(2.0000u,199.316) DIFF(A):(253.150n,-199.417)

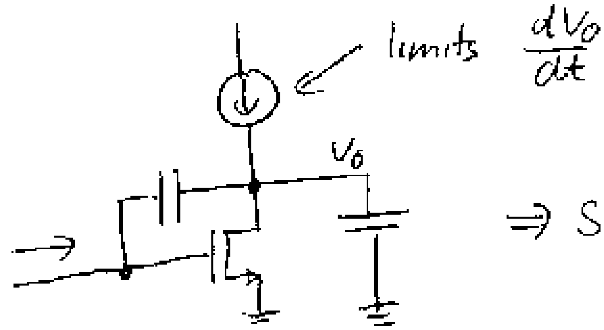
Date: November 23, 1999 Page 1 Time: 19:04:01

17/18

(4) a) $SR = \dfrac{I_{D5}}{C_c} = \dfrac{100\mu A}{5pF} = \underline{\underline{20V/\mu s}}$

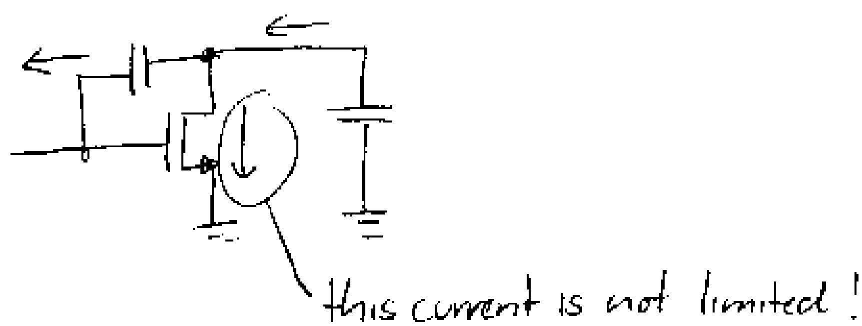
b) $SR = \dfrac{I_{D7}}{C_c + C_L} = \dfrac{100\mu A}{5pF + 15pF} = \underline{\underline{6.66\ V/\mu s}}$

c) (i) pos. slewing:



$\Rightarrow SR^+ = 6.66V/\mu s$

(ii) neg. slewing:



$\Rightarrow SR^- = \dfrac{I_{D5}}{C_c} = \underline{\underline{20V/\mu s}}$

d) $\dfrac{I_{D5}}{C_c} = \dfrac{I_{D7}}{C_c + C_L}$

$\dfrac{100\mu}{5pF} = \dfrac{100\mu}{5pF + C_L} \Rightarrow \underline{\underline{C_L = \phi}}$!