EECS 140

Solution HW2

① a) $I_{OUT} = \frac{V_{BE}}{R} = I_S e^{V_{BE}/V_t}$

→ need numerical solver, since I_{OUT} appears inside & outside exp

$$0 = \frac{V_{BE}}{R} - I_S e^{V_{BE}/V_t} = \frac{V_{BE}}{10^3} - 10^{-15} e^{V_{BE}/26 \cdot 10^{-3}}$$

⇒ using MATLAB function "fzero" ⇒ $V_{BE}\big|_{T=T_0} = 647.2mV = V_{BE0}$

T	$V_{BE} = V_{BE0} - \Delta T \cdot 1.8mV/°C$	$R = R_0 + \Delta T \cdot 15\Omega/°C$	$I_{OUT} = \frac{V_{BE}}{R}$ //
27°C	647.2mV	10kΩ	64.72μA
0°C	695.8mV	9.595 kΩ	72.52μA
100°C	515.8mV	11.095 kΩ	46.49μA

b) plot I_{OUT} vs. TEMP → see attached
PSPICE input file → see attached
Comparison hand analysis vs. simulation:

T	I_{OUT} calculated	I_{OUT} simulated	error = $\frac{sim - calc}{sim} \cdot 100\%$
27°C	64.72μA	64.4μA	−0.5%
0°C	72.52μA	72.4μA	−0.2%
100°C	46.49μA	44.9μA	−3.5% *

* this relatively large error results from an assumption we made in ⓐ. In the hand analysis, we are assuming a constant TC of −1.8mV/°C. However, since I_{OUT} is decreasing, V_{BE} also changes due to this decrease in current, which results in a slighty larger overall temperature dependence!

ⓒ Max. deviation occurs at 100°C: $\frac{64.4 - 44.9}{64.4} = \underline{\underline{30.3\%}}$
(simulated data)

②

ⓐ $V_{OUT} = V_{BE1} + 2I \cdot R_1 = V_{BE1} + \frac{R_1}{R_2} \cdot 2V_t \ln 10$

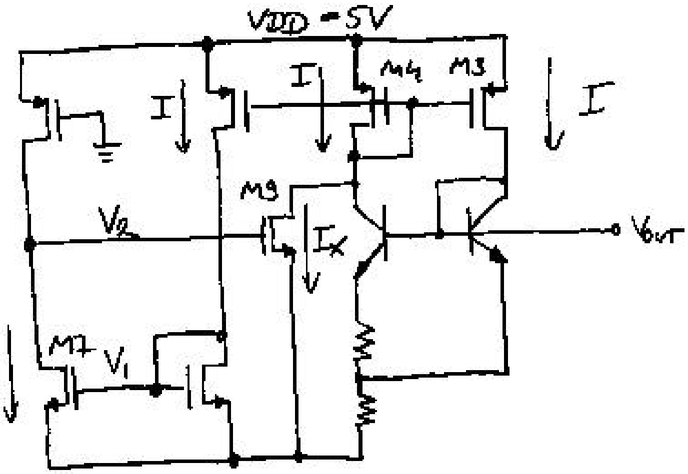
$$\frac{dV_{OUT}}{dT} = \frac{dV_{BE}}{dT} + \frac{R_1}{R_2} \cdot 2 \frac{k}{q} \ln 10 \overset{!}{=} 0$$

$$\Rightarrow \frac{R_1}{R_2} = -\frac{dV_{BE}}{dT} \cdot \frac{q}{2k \ln 10} = +1.8 \frac{mV}{°C} \cdot \frac{1.6 \cdot 10^{-19} As}{2 \cdot 1.38 \cdot 10^{-23} J/°C \ln 10}$$

$$\Rightarrow \frac{R_1}{R_2} = \underline{\underline{4.53}}$$

ⓑ $I = \frac{V_t}{R_2} \ln 10 \Rightarrow R_2 = \frac{V_t}{I} \ln 10 = \frac{26mV}{10\mu A} \cdot \ln 10 = \underline{\underline{5.99 k\Omega}}$

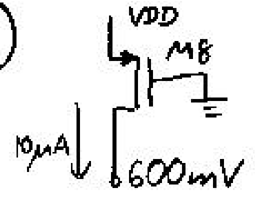
ⓒ



	I	V_1	V_2	I_x
Before Startup:	0	0	VDD	$\neq 0$
After Startup:	10µA	$V_{THN} + V_{OD}$	<0.6V	0

In the possible bias point where $I=0$, $V_2 = VDD$, which turns on M9. M9 then forces a current through M3/M4 which starts up the circuit. After startup, M9 turns off again, since M7 pulls down the gate of M9 to a voltage $< V_{TH}$.

ⓓ



$\rightarrow$ M8 is in <u>SAT</u> since $V_{DS} = (V_{DD} - 0.6V) > (V_{GS} - V_T) = V_{DD} - 1V$

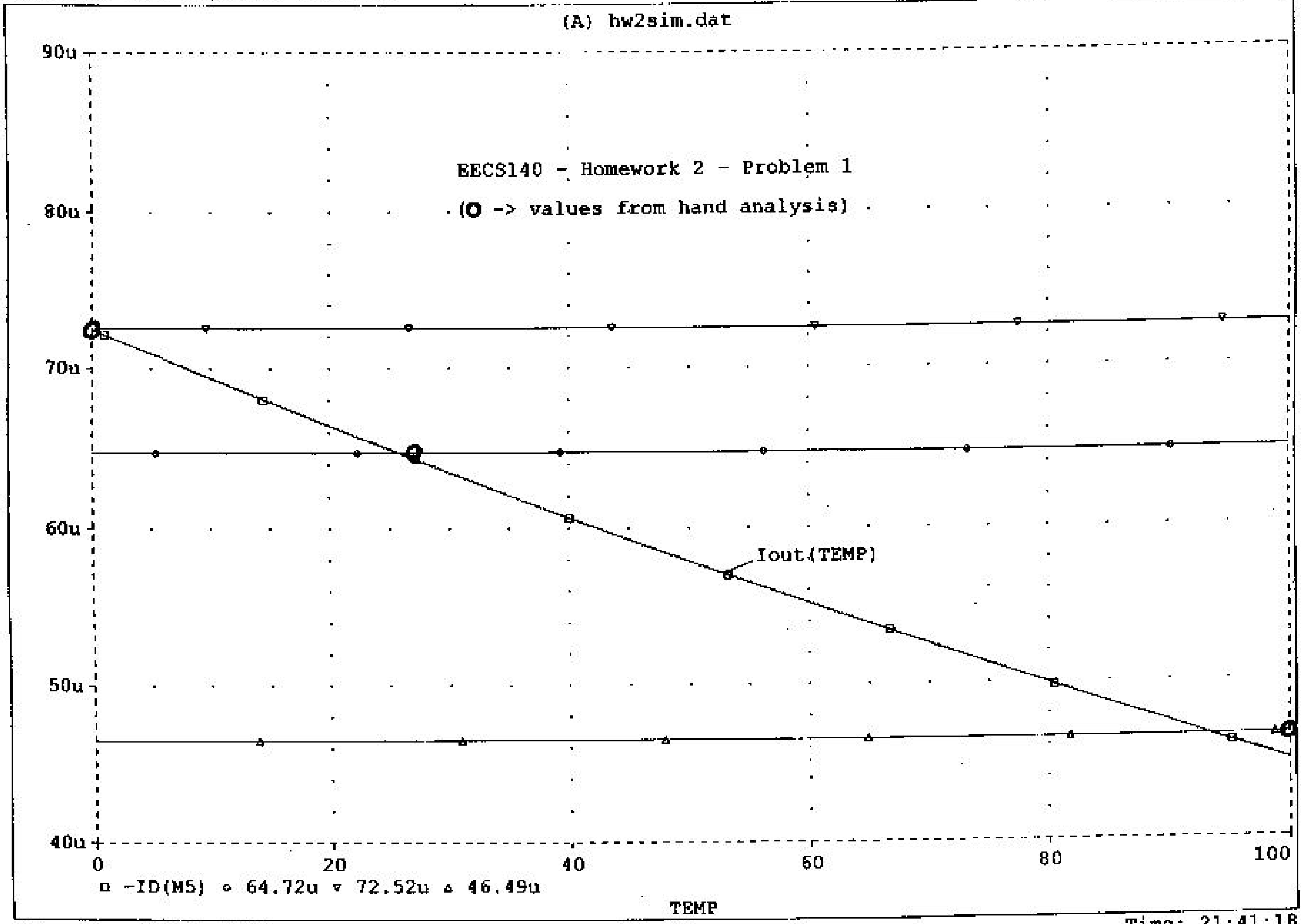
$$\Rightarrow I = \frac{1}{2} k_p' \frac{W}{L} (V_{DD} - V_{TH})^2$$

$$\frac{W}{L} \leq \frac{2I}{k_p' (V_{DD} - V_{TH})^2} = \frac{2 \cdot 10 \mu A}{100 \frac{\mu A}{V^2} \cdot (5-1)^2 V^2} = \underline{\underline{\frac{1}{80}}}$$

So $\left(\frac{W}{L}\right)_8$ needs to be less than $\frac{1}{80}$. //

Date/Time run: 08/29/99 21:21:36

Temperature: 0.0



Date: August 29, 1999

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Time: 21:41:18

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*** EECS140 - Homework 2 - Problem 1
*** Example Spice Deck for PSPICE, looks quite similar for HSpice...
*** Boris Murmann, FALL '99


** Analysis setup **

.DC LIN TEMP 0 100 0.1
.options stepgmin
.probe


** Schematics Netlist **

V_VDD       vdd 0 10
Q_Q1       1 vb 0 NPNi
M_M3       1 vbp vdd vdd PMOSi
+ L=2u
+ W=50u
M_M4       vbp vbp vdd vdd PMOSi
+ L=2u
+ W=50u
M_M5       0 vbp vdd vdd PMOSi
+ L=2u
+ W=50u
M_M2       vbp 1 vb vb NMOSi
+ L=2u
+ W=50u
R_R5       0 vb  10k TC1=1.5m


** (idealized) Models **

.model npni npn is=1f bf=1E6 va=1000 tf=20p
.model nmosi nmos vto=1 tox=6.9n kp=200u lambda=0 gamma=0.5 phi=0.6
.model pmosi pmos vto=-1 tox=6.9n kp=100u lambda=0 gamma=0.5 phi=0.6
```