

Homework Assignment No. 2 - Solutions**Problem 1 - (10 points)** (Problem 5.20 of Gray, Hurst, Lewis and Meyer)

(a). Device Currents

	Hand Calculations	SPICE Simulations
I_{C1}	420 μ A	473 μ A
I_{C2}	340 μ A	390 μ A
I_{C3}	420 μ A	415 μ A
I_{C5}	100 μ A	100 μ A
I_{C6}	500 μ A	504 μ A
I_{D1}	80 μ A	83.9 μ A
I_{D2}	80 μ A	83.9 μ A
I_{D3}	30 μ A	28.4 μ A

(b). $V_{o(max)} = \underline{3.95V}$ $V_{o(min)} = \underline{-4.00V}$

$P_{max} = \underline{8.3 \text{ mW}}$

(c). SPICE Results

- A plot of the DC transfer characteristic and mark on your results where clipping begins to occur.
- Plots of i_{C1} , i_{C2} , and i_{D2} for $v_o = 2V$ peak and $v_o = 4V$ peak. Assume a signal frequency of 10 KHz. (Note: you will have to apply the appropriate dc bias and signal amplitude to achieve the desired output conditions.)
- Also use SPICE to compute the THD of the output voltage for both the 2V and 4 V conditions.

	Hand Calculations	SPICE Simulations
Clipping		
max	3.95V	4.0V
min	-3.975V	-4.0V
THD of v_o		
2V peak	NA	0.4875%
4V peak	NA	0.3678%

(For the remainder of the problems, see plots on following pages.)

$$K_p := 26 \cdot 10^{-6} \quad V_T := 0.7 \quad V_t := .026 \quad \beta_P := 20 \quad \beta_N := 80$$

$$I_o := 100 \cdot 10^{-6} \quad S_1 := 500 \quad S_2 := 500 \quad S_3 := 1$$

$$R_1 := 10 \cdot 10^3 \quad R_2 := 10 \cdot 10^3 \quad R_3 := 500 \quad R_4 := 100 \quad R_L := 200$$

$$V_{BE} := .8 \quad V_{CEsat} := .2 \quad V_{CC} = 5 \quad V_{EE} := 5$$

$$I_{C5} = I_o \quad I_{C6} = 5 \cdot I_o$$

$$I_{D3} := \frac{I_{C5} + I_{C6}}{\beta_P} \quad I_{D1} := \frac{V_{BE}}{R_1} \quad I_{D2} := \frac{V_{BE}}{R_2}$$

$$I_{C3} = I_{C6} - I_{D1}$$

Note: $V_{GS1} + V_{BE3} = V_{GS2} + V_{BE}$. Therefore, $V_{GS1} = V_{GS2}$, so that.

$$I_{C1} = I_{C3} \quad I_{C2} = I_{C1} - I_{D2}$$

Summary

$$I_{C1} = 4.2 \cdot 10^{-4} \quad I_{D1} = 8 \cdot 10^{-5}$$

$$I_{C2} = 3.4 \cdot 10^{-4} \quad I_{D2} = 8 \cdot 10^{-5}$$

$$I_{C3} = 4.2 \cdot 10^{-4} \quad I_{D3} = 3 \cdot 10^{-5}$$

$$I_{C5} = 1 \cdot 10^{-4}$$

$$I_{C6} = 5 \cdot 10^{-4}$$

(b)

$$V_{omax} := V_{CC} - V_{BE} - V_{CEsat} - I_{C6} \cdot R_4$$

$$V_{omax} = 3.95$$

For V_{omin} , the limit will be M2 entering the active region where $V_{DS} = V_{GS} - V_T$. M2 will carry the extra base drive current to permit Q2 to sink about 20 mA of load current. The following are seed values to set up the four simultaneous equations for solution.

$$V_{omin} := -4 \quad I_{C2} = 20 \cdot 10^{-3} \quad I_{B2} = 250 \cdot 10^{-6} \quad V_{GS1} := 1$$

Given

$$- \frac{V_{omin}}{R_L} = I_{C1} = I_{D2} + I_{C2}$$

$$I_{C2} = \beta_N \cdot I_{B2}$$

$$I_{D2} = \frac{V_{BE}}{R_2} + I_{B2}$$

$$V_{omin} - (V_{EE} + V_{BE}) = \sqrt{\frac{2 \cdot I_{D2}}{K_p \cdot S_2}}$$

$$\begin{bmatrix} V_{omin} \\ I_{C2} \\ I_{B2} \\ I_{D2} \end{bmatrix} := \text{Find}(V_{omin}, I_{C2}, I_{B2}, I_{D2})$$

$$V_{omin} = -3.975$$

$$I_{C2} = 0.01996$$

$$I_{B2} = 2.496 \cdot 10^{-4}$$

$$I_{D2} = 3.296 \cdot 10^{-4}$$

```

Prob. 5.20 from G&M - BiCMOS Output Stage
Vcc 1 0 5V
Vee 2 0 -5V
R3 1 3 500
Q5 6 4 3 PNP
M3 0 6 4 4 PMOS W=2U L=2U
Ibias 6 0 100UA
R4 1 5 100
Q6 7 4 5 PNP 5
M1 8 8 7 7 PMOS W=500U L=1U
R1 8 9 10K
Q3 7 8 9 NPN 25
Q1 1 7 10 NPN 25
M2 13 9 10 10 PMOS W=500U L=1U
R2 13 2 10K
Q2 10 13 2 NPN 25
RL 10 0 200
Vi 9 0 SIN -0.8093 2.1V 10K 0 0
.TRAN 4US 100US
.FOUR 10K V(10)
.MODEL NPN NPN RB=200 BF=80 IS=1E-18 VAF=130
.MODEL PNP PNP RB=300 BF=20 IS=1E-18 VAF=50
.MODEL PMOS PMOS KP=26U Lambda=0.0125 Vto=-0.7V LD=0
.OP
.Probe
.END

```

NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE
(1)	5.0000	(2)	-5.0000	(3)	4.9476	(4)	4.1135
(5)	4.9472	(6)	1.9712	(7)	.7909	(8)	-.0221
(9)	-.8093	(10)	981.8E-06	(13)	-4.2151		

VOLTAGE SOURCE CURRENTS

NAME	CURRENT
Vcc	-1.105E-03
Vee	4.735E-04
Vi	4.985E-04

TOTAL POWER DISSIPATION 8.30E-03 WATTS

NAME	Q5	Q6	Q3	Q1	Q2
MODEL	PNP	PNP	NPN	NPN	NPN
IB	-4.79E-06	-2.36E-05	5.15E-06	5.72E-06	4.73E-06
IC	-1.00E-04	-5.04E-04	4.15E-04	4.73E-04	3.90E-04
VBE	-8.34E-01	-8.34E-01	7.87E-01	7.90E-01	7.85E-01
VBC	2.14E+00	3.32E+00	-8.13E-01	-4.21E+00	-4.22E+00
VCE	-2.98E+00	-4.16E+00	1.60E+00	5.00E+00	5.00E+00
BETADC	2.09E+01	2.13E+01	8.05E+01	8.26E+01	8.26E+01
GM	3.86E-03	1.95E-02	1.60E-02	1.83E-02	1.51E-02
RPI	5.39E+03	1.09E+03	5.02E+03	4.52E+03	5.47E+03
RX	3.00E+02	6.00E+01	8.00E+00	8.00E+00	8.00E+00
RO	5.21E+05	1.06E+05	3.16E+05	2.84E+05	3.44E+05
BETAAC	2.08E+01	2.13E+01	8.05E+01	8.26E+01	8.26E+01
FT	6.15E+16	3.10E+17	2.55E+17	2.91E+17	2.40E+17

**** MOSFETS

NAME	M3	M1	M2
MODEL	PMOS	PMOS	PMOS
ID	-2.84E-05	-8.39E-05	-8.32E-05
VGS	-2.14E+00	-8.13E-01	-8.10E-01
VDS	-4.11E+00	-8.13E-01	-4.22E+00
VBS	0.00E+00	0.00E+00	0.00E+00
VTH	-7.00E-01	-7.00E-01	-7.00E-01
VDSAT	-1.44E+00	-1.13E-01	-1.10E-01
GM	3.94E-05	1.48E-03	1.51E-03
GDS	3.38E-07	1.04E-06	9.88E-07

Prob. 5.20 from G&M - BiCMOS Output Stage

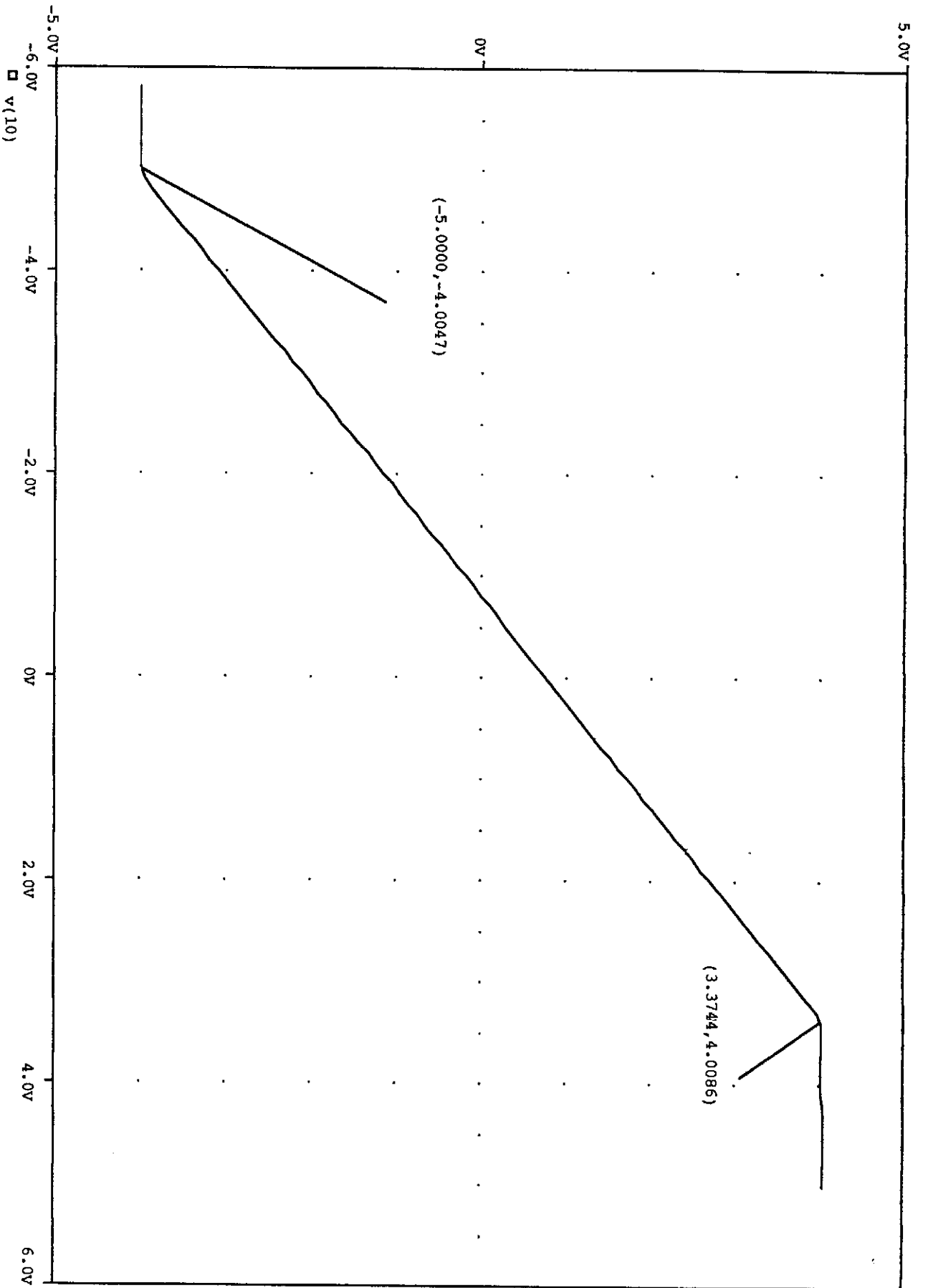
**** FOURIER ANALYSIS TEMPERATURE = 27.000 DEG C

FOURIER COMPONENTS OF TRANSIENT RESPONSE V(10)

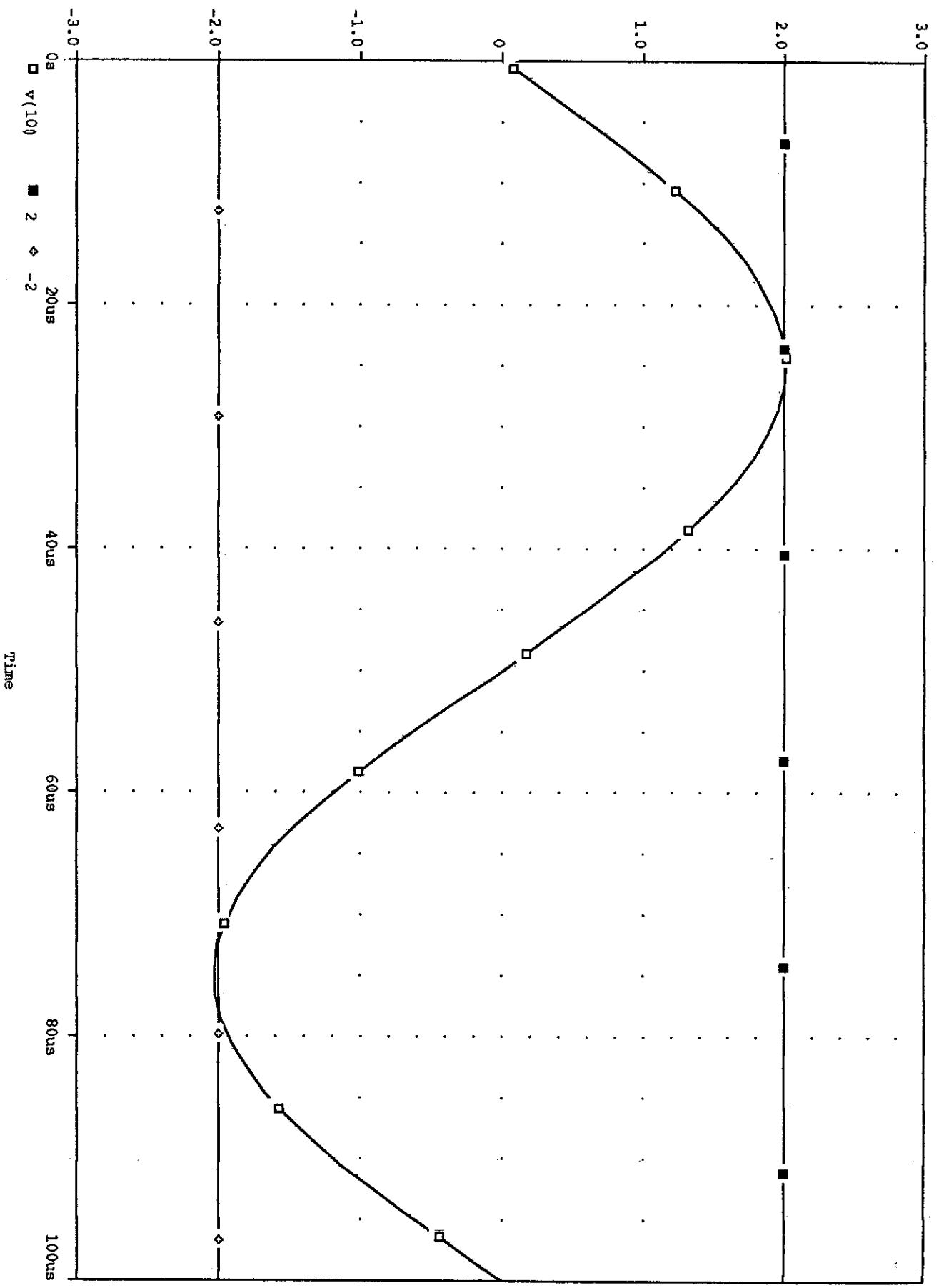
DC COMPONENT = -1.100053E-02

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	1.000E+04	2.012E+00	1.000E+00	2.390E-03	0.000E+00
2	2.000E+04	1.323E-03	6.576E-04	8.992E+01	8.991E+01
3	3.000E+04	8.405E-03	4.178E-03	1.794E+02	1.794E+02
4	4.000E+04	2.628E-03	1.306E-03	8.991E+01	8.991E+01
5	5.000E+04	3.001E-03	1.492E-03	1.783E+02	1.783E+02
6	6.000E+04	1.954E-03	9.714E-04	8.979E+01	8.979E+01
7	7.000E+04	1.316E-03	6.541E-04	1.761E+02	1.761E+02
8	8.000E+04	1.393E-03	6.926E-04	8.955E+01	8.955E+01
9	9.000E+04	6.102E-04	3.033E-04	1.715E+02	1.715E+02

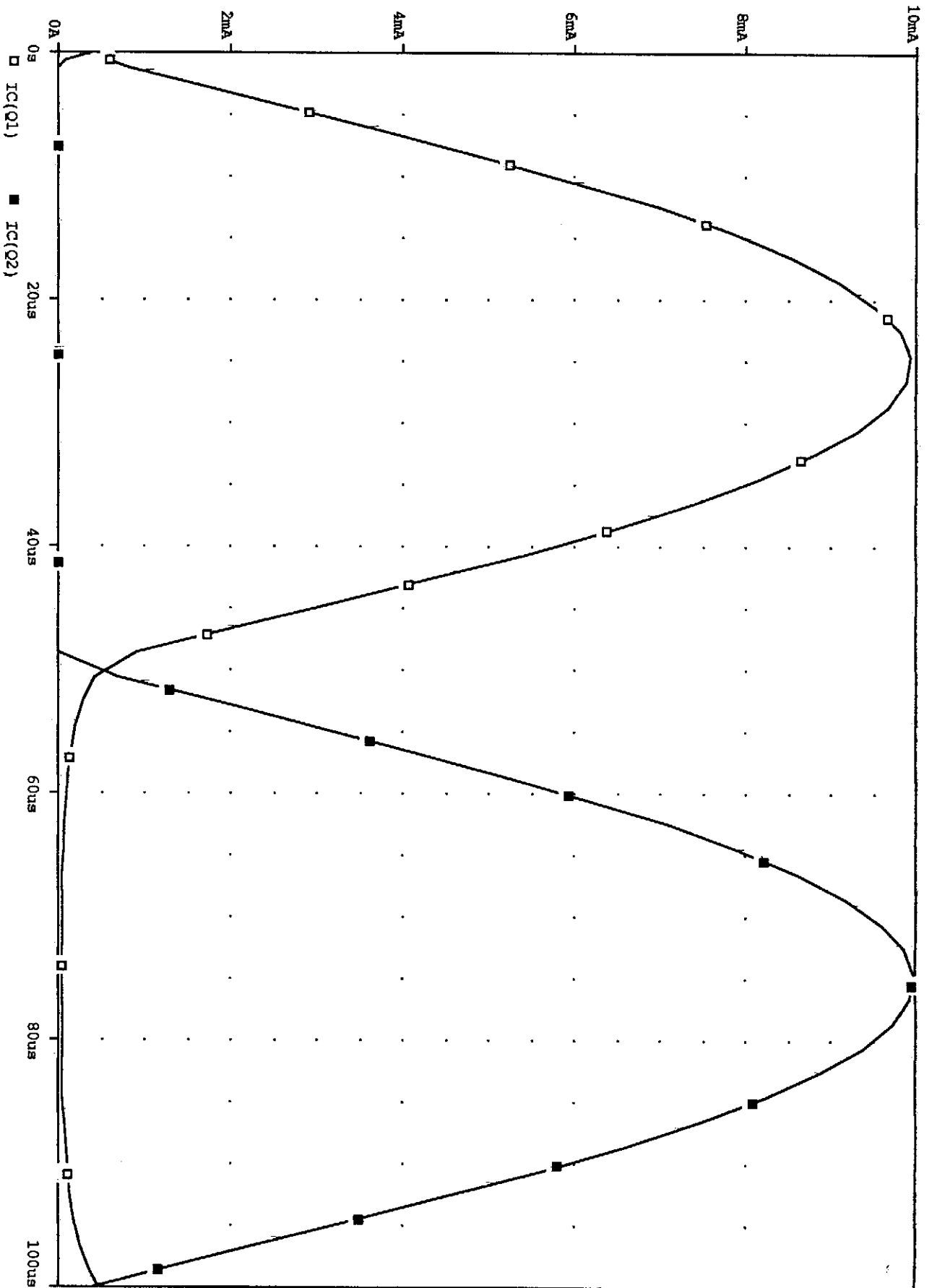
TOTAL HARMONIC DISTORTION = 4.874744E-01 PERCENT



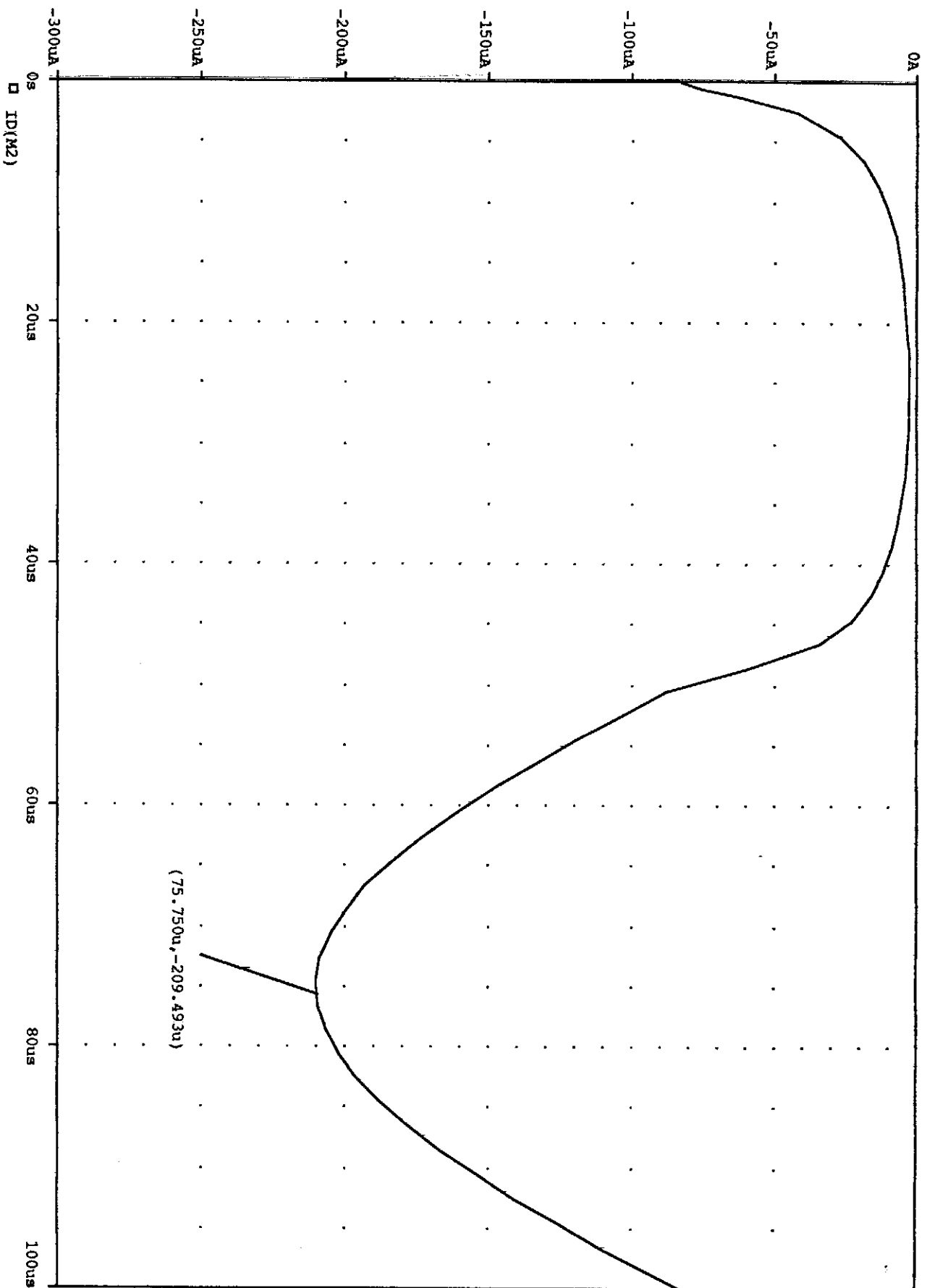
"Prob. 5.10 from G&M - BiCMOS Output Stage" 04/09/100 20:55:47 27.0°
 Evaluation Probe 5.3 © 1993 MicroSim Corp.



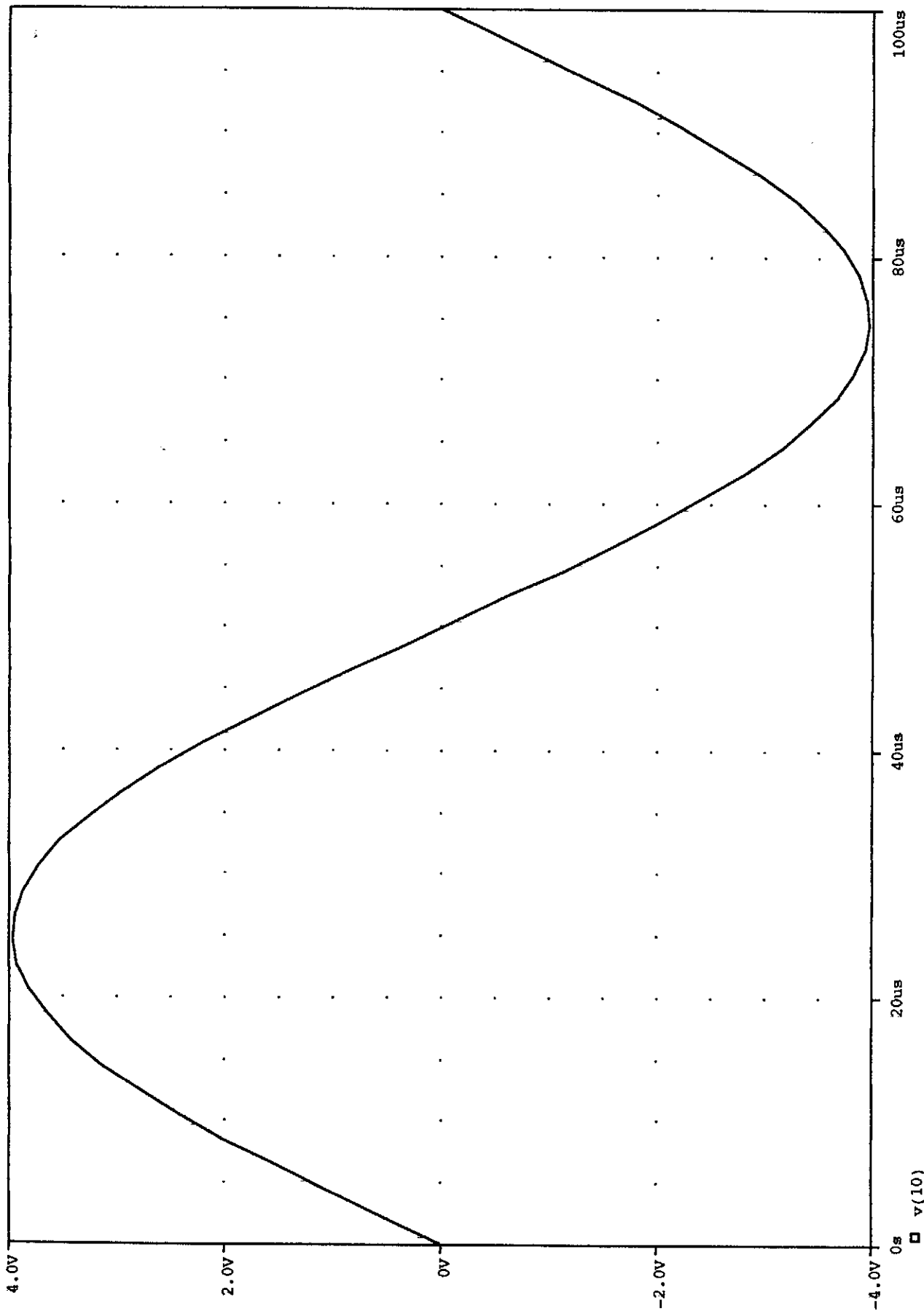
"Prob. 5.3 from G&M - BiCMOS Output Stage" 04/09/100 21:11:46 27.0°
 Evaluation Probe 5.3 © 1993 Microsim Corp.



"Prob. 5.20 from G&M - BiCMOS Output Stage" 04/09/100 21:11:46 27.0°
 Evaluation Probe 5.3 © 1993 MicroSim Corp.



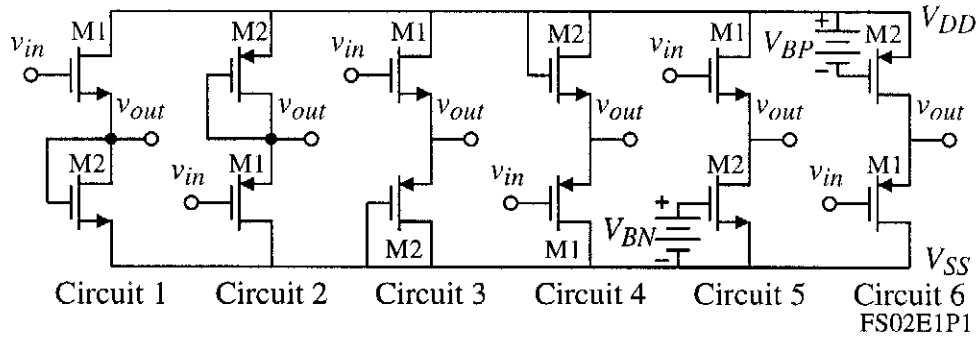
"Prob. 5.26 from G&M - BiCMOS Output Stage" 04/09/100 21:11:46 27.0°
 Evaluation Probe 5.3 © 1993 MicroSim Corp.



Time
"Prob. 5.20 from GSM - BiCMOS Output Stage" 04/09/100 21:32:33 27.0°
Evaluation Probe 5.3 © 1993 MicroSim Corp.

Problem 2 - (10 points)

Six versions of a source follower are shown below. Assume that $K'_N = 2K'_P$, $\lambda_P = 2\lambda_N$, all W/L ratios of all devices are equal, and that all bias currents in each device are equal. Neglect bulk effects in this problem and assume no external load resistor. Identify which circuit or circuits have the following characteristics: (a.) highest small-signal voltage gain, (b.) lowest small-signal voltage gain, (c.) the highest output resistance, (d.) the lowest output resistance, (e.) the highest $v_{out(max)}$ and (f.) the lowest $v_{out(max)}$.



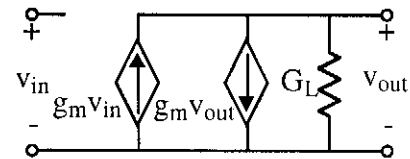
Solution

(a.) and (b.) - Voltage gain.

Small signal model:

The voltage gain is found as: $\frac{v_{out}}{v_{in}} = \frac{g_m}{g_m + G_L}$

where G_L is the load conductance. Therefore we get:



Circuit	1	2	3	4	5	6
$\frac{v_{out}}{v_{in}}$	$\frac{g_{mN}}{g_{mN} + g_{mN}}$	$\frac{g_{mP}}{g_{mP} + g_{mP}}$	$\frac{g_{mN}}{g_{mN} + g_{mP}}$	$\frac{g_{mP}}{g_{mP} + g_{mN}}$	$\frac{g_{mN}}{g_{mN} + g_{dsN} + g_{dsP}}$	$\frac{g_{mP}}{g_{mP} + g_{dsN} + g_{dsP}}$

But $g_{mN} = \sqrt{2} g_{mP}$ and $g_{dsN} = 0.5g_{dsP}$, therefore

Circuit	1	2	3	4	5	6
$\frac{v_{out}}{v_{in}}$	$\frac{1}{2}$	$\frac{1}{2}$	0.5858	0.4142	$\frac{g_{mP}}{g_{mP} + (g_{dsP} + g_{dsN})/\sqrt{2}}$	$\frac{g_{mP}}{g_{mP} + g_{dsP} + g_{dsN}}$

Thus, circuit 5 has the highest gain and circuit 4 the lowest gain

(c.) and (d.) - Output resistance.

The denominators of the first table show the following:

Ckt.6 has the highest output resistance and Ckt. 1 the lowest output resistance.

(e.) Assuming no current has to be provided by the output, circuits 2, 4, and 6 can pull the output to V_{DD} . \therefore Circuits 2, 4 and 6 have the highest output swing.

(f.) Assuming no current has to be provided by the output, circuits 1, 3, and 5 can pull the output to ground. \therefore Circuits 1, 3 and 5 have lowest output swing.

Summary

- (a.) Ckt. 5 has the highest voltage gain
- (b.) Ckt. 4 has the lowest voltage gain
- (c.) Ckt. 6 has the highest output resistance
- (d.) Ckt. 1 has the lowest output resistance
- (e.) Ckts. 2,4 and 6 have the highest output
- (f.) Ckts. 1,3 and 5 have the lowest output

Problem 3 - (10 points)

A push-pull follower is shown which uses an NPN BJT and a p-channel MOSFET. In this problem, ignore the bulk effect, the channel length modulation, and the Early voltage. The parameters for the NPN BJT are $\beta_F = 100$, $I_S = 10\text{fA}$ and $V_t = 25.9\text{mV}$. The model parameters for the PMOS are $K_P' = 50\mu\text{A}/\text{V}^2$ and $V_{TP} = -0.7\text{V}$. (a.) Find the value of the dc batteries, V_1 and V_2 , which will cause $100\mu\text{A}$ to flow in Q1 and M2 when the dc value of $v_{IN} = 0\text{VDC}$. (b.) Find the small-signal input resistance, output resistance (not including R_L) and voltage gain when the dc value of $v_{IN} = 0\text{VDC}$.

Solution

$$(a.) V_1 = V_{BE1} = V_t \ln\left(\frac{i_C}{I_S}\right) = 0.0259 \ln\left(\frac{100\mu\text{A}}{10\text{fA}}\right) = 0.5964\text{V} \quad \boxed{V_1 = 0.5964\text{V}}$$

$$V_2 = V_{SG2} = \sqrt{\frac{2I_D}{K_P'(W/L)}} + |V_{TP}| = \sqrt{\frac{2 \cdot 100}{50 \cdot 100}} + 0.7 = 0.9\text{V} \quad \boxed{V_2 = 0.9\text{V}}$$

(b.) Small-signal model (simplified):

$$g_{m1} = \frac{I_{C1}}{V_t} = \frac{100\mu\text{A}}{25.9\text{mV}} = 3.86\text{mS}$$

$$r_{\pi 1} = \frac{1 + \beta_F}{g_{m1}} = 26.159\text{k}\Omega$$

$$g_{m2} = \sqrt{\frac{2K_P'W_2I_{D2}}{L_2}} = \sqrt{2 \cdot 50 \cdot 100 \cdot 100} = 1\text{mS}$$

$$R_{in}: v_{in} = r_{\pi 1} i_{in} + (i_{in} + g_{m1} v_{\pi} + g_{m2} v_{gs2}) R_L = r_{\pi 1} i_{in} + (i_{in} + g_{m1} r_{\pi 1} i_{in} + g_{m2} r_{\pi 1} i_{in}) R_L$$

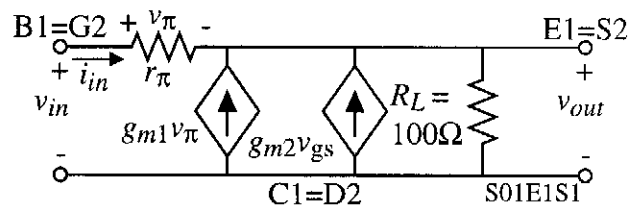
$$R_{in} = \frac{v_{in}}{i_{in}} = r_{\pi 1} + R_L + g_{m1} r_{\pi 1} R_L + g_{m2} r_{\pi 1} R_L = r_{\pi 1} + R_L(1 + \beta_F) + g_{m2} r_{\pi 1} R_L$$

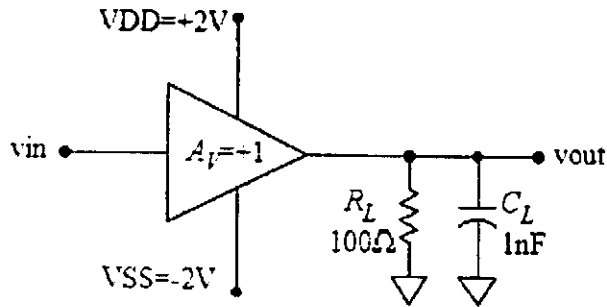
$$\therefore R_{in} = 26.159\text{k}\Omega + 101 \cdot 100\Omega + 1 \cdot 26.159\text{k}\Omega \cdot 0.1 = 38.875\text{k}\Omega \quad \boxed{R_{in} = 38.875\text{k}\Omega}$$

$$R_{out}: R_{out} = \frac{1}{g_{m1}} \parallel \frac{1}{g_{m2}} = \frac{1}{3.86\text{mS} + 1\text{mS}} = 205.8\text{k}\Omega \quad \boxed{R_{out} = 205.8\text{k}\Omega}$$

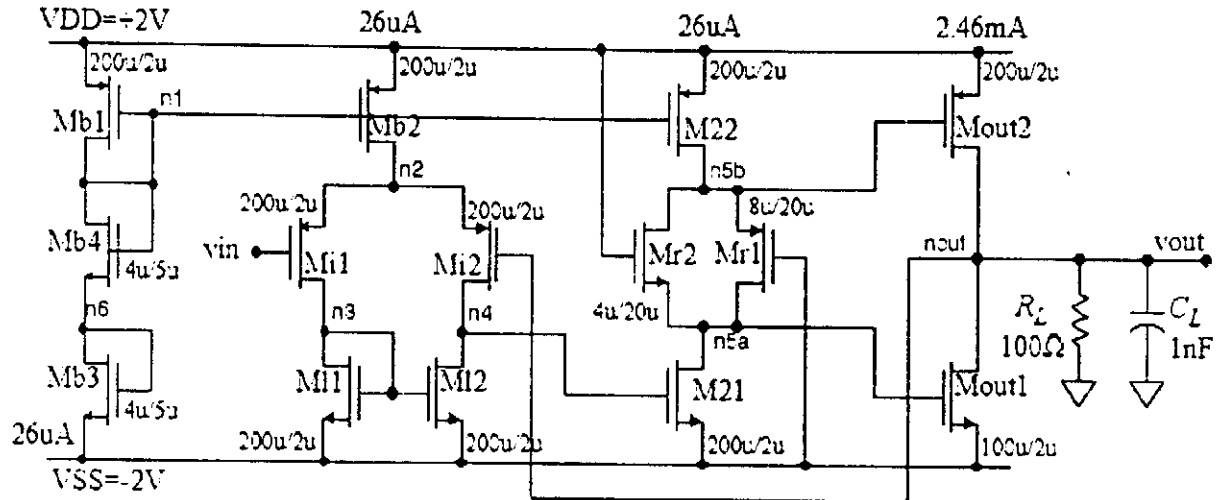
$$\frac{v_{out}}{v_{in}}: \frac{v_{out}}{v_{in}} = \frac{v_{out} i_{in}}{i_{in} v_{in}} = \frac{R_L(1 + \beta_F) + g_{m2} r_{\pi 1} R_L}{r_{\pi 1} + R_L(1 + \beta_F) + g_{m2} r_{\pi 1} R_L} = \frac{12.716}{38.875} = 0.3271$$

$$\boxed{\frac{v_{out}}{v_{in}} = 0.3271\text{V/V}}$$





Output swing = 1.25V, 1.06V
 SR > 10V/usec
 DC gain = 1
 efficiency = 30.6%
 score = 40

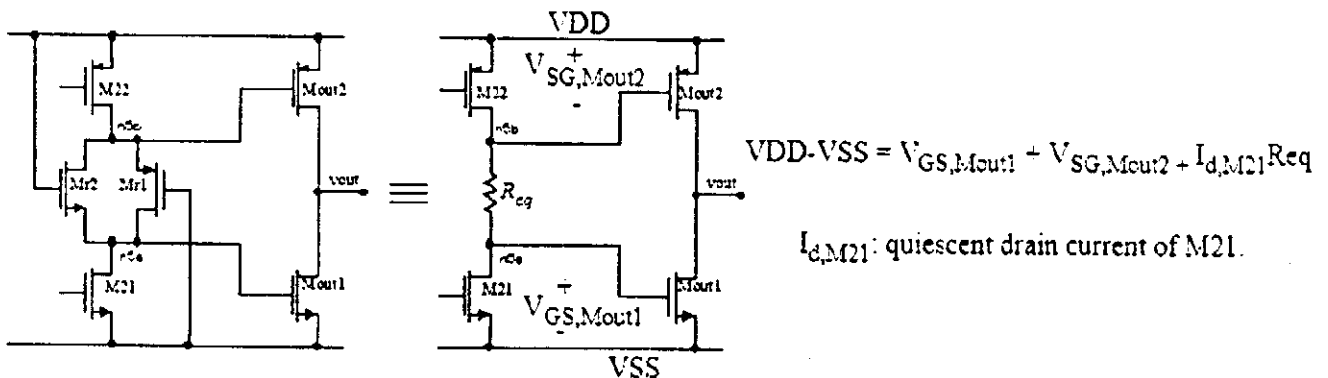


A three stage amplifier connected in unity gain configuration is used as the output buffer. The first two stages are class-A whereas the last stage is class-AB.

1nF load capacitance makes the pole present at node nout the dominant pole. Therefore, there is no need to apply additional compensation to the three stage amplifier.

DC gain of the amplifier in unity gain configuration = $A_v / (1 + A_v)$
 where $A_v \propto g_m r_{ds}$

Output impedance of the unity gain buffer = $r_{ds} / (1 + A_v)$



Mr1 and Mr2 act as a linear resistor, allowing a voltage drop between n5a and n5b. The net result is reduced quiescent current at the output stage.

```

*output buffer
.option brief
.options
+ post
+ ingold=2
+ scale=1e-6
+ accurate
+ delmax=0.5n
+ method=gear lvltim=2
+ probe
*

vdd dd 0 dc 2v
vss ss 0 dc -2v
*vin in 0 dc 0v
vin in 0 sin (0 1.5 100k 0)
*vin in 0 pulse (-1 1 2u 2n 2n 1u 2u)

mb1 n1 n1 dd dd cmosp l=2u w=200u
mb2 n2 n1 dd dd cmosp l=2u w=200u
mb3 n6 n6 ss ss cmosn l=5u w=4u
mb4 n1 n1 n6 ss cmosn l=5u w=4u
mi1 n3 in n2 n2 cmosp l=2u w=200u
mi2 n4 nout n2 n2 cmosp l=2u w=200u
ml1 n3 n3 ss ss cmosn l=2u w=200u
ml2 n4 n3 ss ss cmosn l=2u w=200u
m21 n5a n4 ss ss cmosn l=2u w=200u
m22 n5b n1 dd dd cmosp l=2u w=200u
mr1 n5b ss n5a dd cmosp l=20u w=8u
mr2 n5b dd n5a ss cmosn l=20u w=4u
mout1 nout n5a ss ss cmosn l=2u w=100u
mout2 nout n5b dd dd cmosp l=2u w=200u
r1 nout 0 100
cl nout ss 1nF
*.dc vin -2 2 1m
.meas tran current_vdd avg i(vdd) from=0 to=50u
.meas tran power_vdd param='4*current_vdd'
] calculates the average
  current drawn from VDD
  and power

.tran 1u 50u
.model cmosn nmos kp=110u vto=0.7 lambda=0.01 gamma=0.4 phi=0.7
.model cmosp pmos kp=50u vto=-0.7 lambda=0.01 gamma=0.7 phi=0.8
.probe v(in) v(n1) v(n2) v(n3) v(n4) v(n5) v(nout) v(n5a) v(n5b) i(vdd) i(vss)
.op
.end

```

***** operating point information tnom= 25.000 temp= 25.000

***** operating point status is all simulation time is 0.
node =voltage node =voltage node =voltage
+0:dd = 2.000e+00 0:in = 0. 0:n1 = 1.197e+00
+0:n2 = 7.723e-01 0:n3 = -1.250e+00 0:n4 = -1.230e+00
+0:n5a = -3.641e-01 0:n5b = 3.185e-01 0:n6 = -5.283e-01
+0:nout = -1.441e-05 0:ss = -2.000e+00

**** voltage sources

subckt
element 0:vdd 0:vss 0:vin
volts 2.000e+00 -2.000e+00 0.
current -2.537e-03 2.537e-03 0.
power 5.073e-03 5.074e-03 0.

total voltage source power dissipation= 1.015e-02 watts

**** resistors

subckt
element 0:rl
r value 1.000e+02
v drop -1.441e-05
current -1.441e-07
power 2.075e-12

**** mosfets

subckt
element 0:mb1 0:mb2 0:mb3 0:mb4 0:m11 0:m12
model 0:cmosp 0:cmosp 0:cmosn 0:cmosn 0:cmosp 0:cmosp
id -2.659e-05 -2.670e-05 2.659e-05 2.659e-05 -1.335e-05 -1.335e-05
ibs 0. 0. 0. -1.472e-14 0. 0.
ibd 8.027e-15 1.228e-14 -1.472e-14 -3.197e-14 2.023e-14 2.003e-14
vgs -8.027e-01 -8.027e-01 1.471e+00 1.725e+00 -7.723e-01 -7.724e-01
vds -8.027e-01 -1.227e+00 1.471e+00 1.725e+00 -2.023e+00 -2.003e+00
vbs 0. 0. 0. -1.471e+00 0. 0.
vth -7.000e-01 -7.000e-01 7.000e-01 9.548e-01 -7.000e-01 -7.000e-01
vdsat -1.027e-01 -1.027e-01 7.717e-01 7.708e-01 -7.235e-02 -7.236e-02
beta 5.040e-03 5.061e-03 8.930e-05 8.952e-05 5.101e-03 5.100e-03
gam eff 7.000e-01 7.000e-01 4.000e-01 4.000e-01 7.000e-01 7.000e-01
gm 5.177e-04 5.199e-04 6.891e-05 6.900e-05 3.690e-04 3.690e-04
gds 2.638e-07 2.638e-07 2.620e-07 2.614e-07 1.308e-07 1.309e-07
gmb 2.026e-04 2.034e-04 1.647e-05 9.364e-06 1.444e-04 1.444e-04
cdtot 1.478e-28 2.261e-28 0. 0. 3.726e-28 3.689e-28
cgtot 9.856e-26 9.864e-26 4.651e-27 4.641e-27 1.009e-25 1.009e-25
cstot 9.208e-26 9.208e-26 4.604e-27 4.604e-27 9.208e-26 9.208e-26
cbtot 6.331e-27 6.331e-27 0. 0. 8.414e-27 8.412e-27
cgs 9.208e-26 9.208e-26 4.604e-27 4.604e-27 9.208e-26 9.208e-26
cgd 1.478e-28 2.261e-28 0. 0. 3.726e-28 3.689e-28

subckt
element 0:m11 0:m12 0:m21 0:m22 0:mr1 0:mr2
model 0:cmosn 0:cmosn 0:cmosn 0:cmosp 0:cmosp 0:cmosn
id 1.335e-05 1.335e-05 2.682e-05 -2.682e-05 1.100e-05 1.582e-05
ibs 0. 0. 0. 0. 2.364e-14 -1.636e-14
ibd -7.491e-15 -7.693e-15 -1.636e-14 1.682e-14 1.682e-14 -2.318e-14

vgs	7.491e-01	7.491e-01	7.693e-01	-8.027e-01	-1.635e+00	2.364e+00
vds	7.491e-01	7.693e-01	1.635e+00	-1.681e+00	6.826e-01	6.826e-01
vbs	0.	0.	0.	0.	2.364e+00	-1.635e+00
vth	7.000e-01	7.000e-01	7.000e-01	-7.000e-01	-1.176e+00	9.767e-01
vdsat	4.908e-02	4.908e-02	6.927e-02	-1.027e-01	-6.826e-01	6.826e-01
beta	1.108e-02	1.108e-02	1.118e-02	5.084e-03	2.014e-05	2.215e-05
gam eff	4.000e-01	4.000e-01	4.000e-01	7.000e-01	7.000e-01	4.000e-01
gm	5.440e-04	5.441e-04	7.744e-04	5.222e-04	1.375e-05	1.512e-05
gds	1.325e-07	1.325e-07	2.639e-07	2.638e-07	9.357e-06	1.577e-05
gmb	1.300e-04	1.301e-04	1.851e-04	2.044e-04	3.054e-06	1.979e-06
cdtot	1.380e-28	1.417e-28	3.013e-28	3.097e-28	3.380e-26	1.032e-26
cgtot	9.994e-26	9.994e-26	9.836e-26	9.873e-26	5.208e-26	2.669e-26
cstot	9.208e-26	9.208e-26	9.208e-26	9.208e-26	1.810e-26	1.633e-26
cbtot	7.715e-27	7.715e-27	5.970e-27	6.331e-27	1.729e-28	0.
cgs	9.208e-26	9.208e-26	9.208e-26	9.208e-26	1.810e-26	1.633e-26
cgd	1.380e-28	1.417e-28	3.013e-28	3.097e-28	3.380e-26	1.032e-26

```

subckt
element 0:mout1 0:mout2
model 0:cmosn 0:cmosp
id 2.457e-03 -2.457e-03
ibs 0. 0.
ibd -2.000e-14 2.000e-14
vgs 1.635e+00 -1.681e+00
vds 2.000e+00 -2.000e+00
vbs 0. 0.
vth 7.000e-01 -7.000e-01
vdsat 9.359e-01 -9.815e-01
beta 5.610e-03 5.100e-03
gam eff 4.000e-01 7.000e-01
gm 5.250e-03 5.006e-03
gds 2.409e-05 2.408e-05
gmb 1.255e-03 1.959e-03
cdtot 1.842e-28 3.683e-28
cgtot 4.651e-26 9.323e-26
cstot 4.604e-26 9.208e-26
cbtot 2.788e-28 7.758e-28
cgs 4.604e-26 9.208e-26
cgd 1.842e-28 3.683e-28

```

Opening plot unit= 15
file=./buffer.tr0

```

*****
*current source
***** transient analysis tnom= 25.000 temp= 25.000
*****

```

```

current_vdd = -4.5829E-03 from= .0000E+00 to= 5.0000E-05
power_vdd = -1.8332E-02

```

average power dissipation

**** job concluded

```

***** Star-HSPICE -- 97.2.1 (970915) 14:15:30 98/06/01 pa
*****

```

```

*current source
***** job statistics summary tnom= 25.000 temp= 25.000
*****

```

total memory used 159 kbytes

nodes = 12 # elements= 19

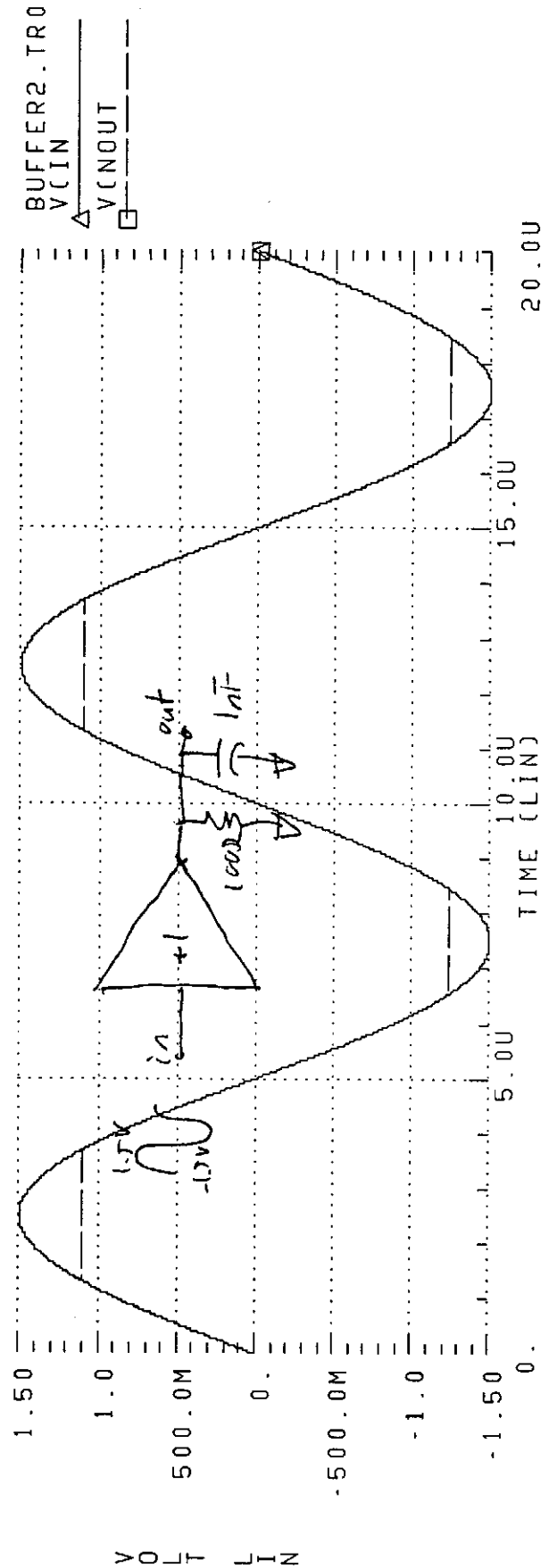
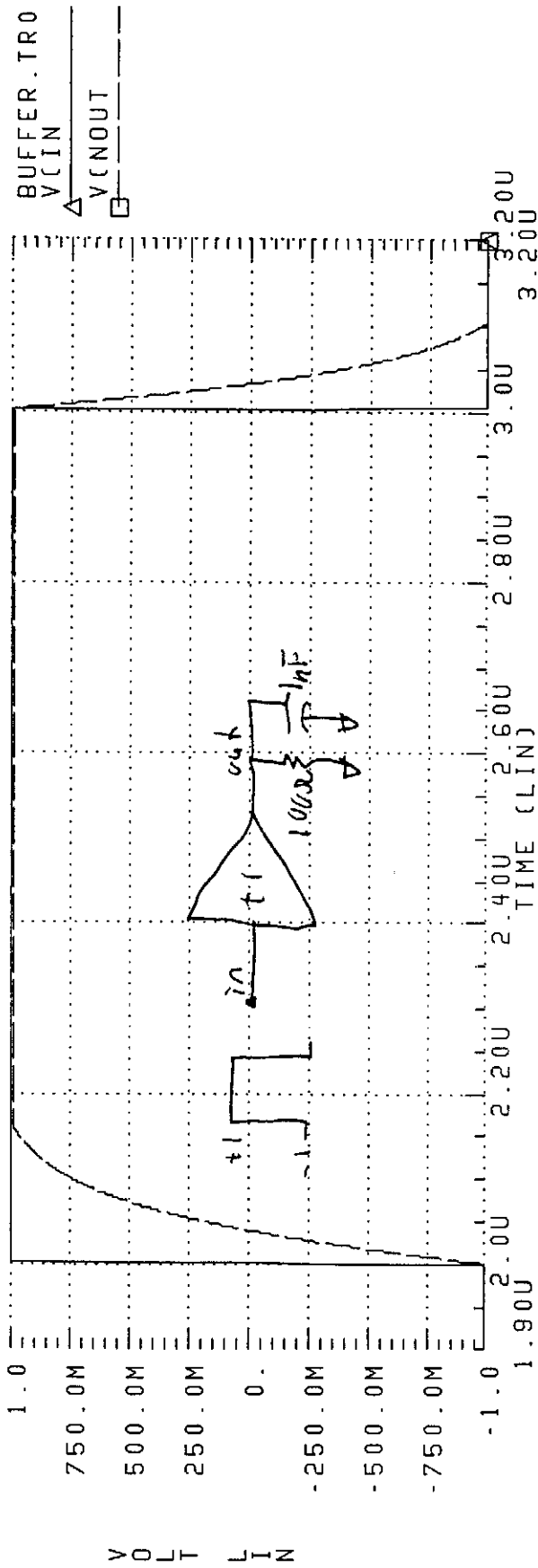
diodes= 0 # bjts = 0 # jfets = 0 # mosfets = 14

analysis	time	# points	tot. iter	conv.iter
op point	.11	1	7	
transient	214.78	51	200387	100051 rev= 27
readin	.10			
errchk	.08			
setup	.00			
output	1.55			

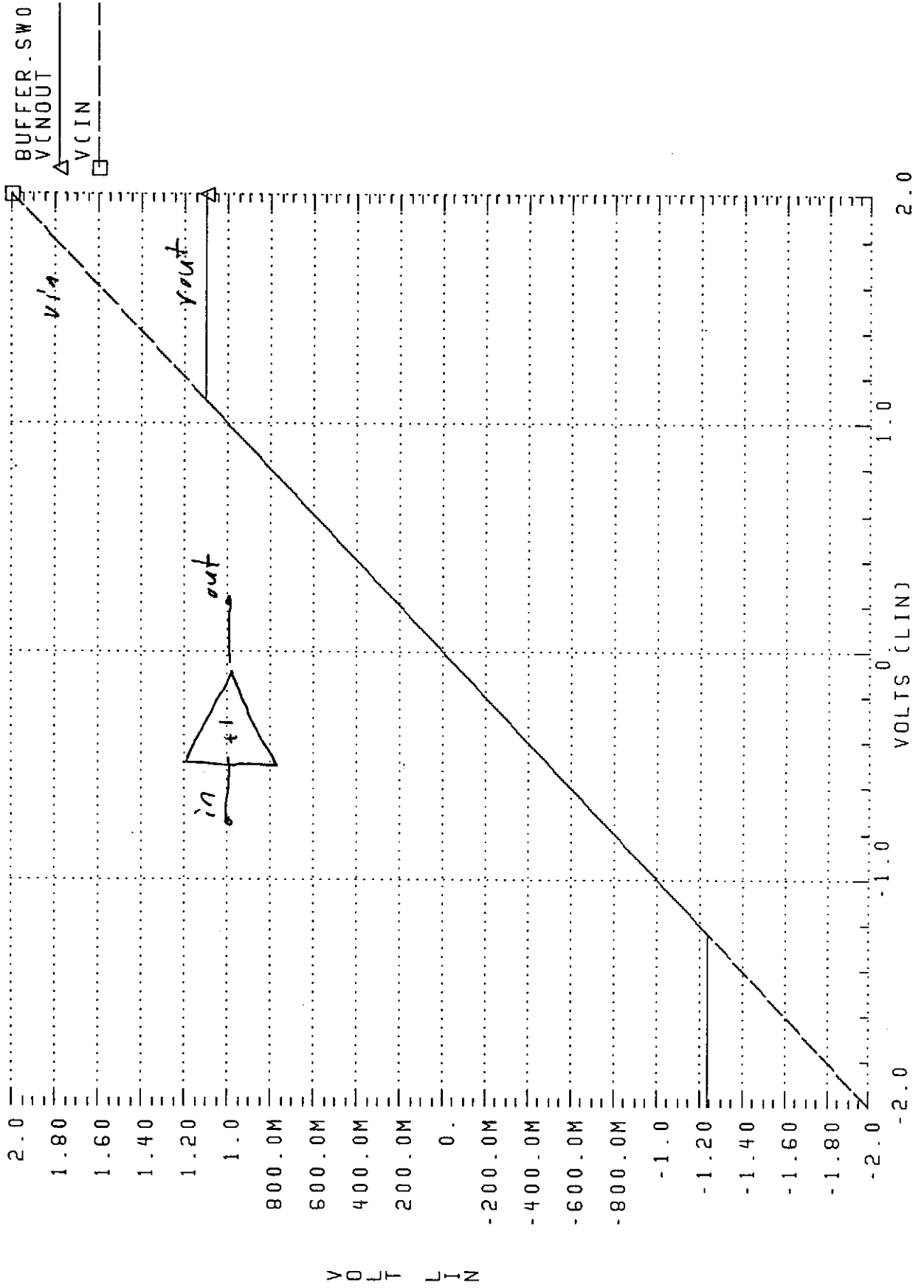
total cpu time 216.72 seconds
job started at 14:15:30 98/06/01
job ended at 14:19:15 98/06/01

lic: Release token(s)
HSPICE job buffer.sp completed.
Mon Jun 1 14:19:15 PDT 1998

OUTPUT BUFFER



OUTPUT BUFFER



BUFFER.SW0
VCNOUT
VCIN