CHAPTER 7

7.1

(a) Transistor parameters are

$$r_\pi = \frac{\beta_o}{g_m} = 200 \times 52 = 10.4\,k\Omega$$

$$\tau_T = \frac{1}{2\pi f_T} = 318\,ps$$

$$C_\pi + C_\mu = g_m \tau_T = \frac{1}{52} \times 318 = 6.12\,pF$$

$$\therefore C_\pi = 6.1 - 0.3 = 5.8\,pF$$

$$C_M = (1 + g_m R_L) C_\mu$$

$$= (1 + \frac{3000}{52}) \times 0.3 = 17.6\,pF$$

In (7.12) and (7.9)

$$f_{-3dB} = \frac{1}{2\pi} \frac{5000+300+10400}{(5000+300)\times 10400} \frac{10^{12}}{5.8+17.6}\ Hz$$

$$= 1.94\,MHz$$

(b) From (7.27)

$$P_2 = -\left(\frac{1}{R_L C_\mu} + \frac{1}{R C_\pi} + \frac{1}{R_L C_\pi} + \omega_T\right)$$

$$R = (R_S + r_b) \,//\, r_\pi$$

$$= 5300 \,||\, 10400 = 3511\,\Omega$$

$$\therefore P_2 = -\left(\frac{10^{12}}{3000\times 0.3} + \frac{10^{12}}{3511\times 5.8} + \frac{10^{12}}{3000\times 5.8} + 2\pi \times 500 \times 10^6\right)$$

$$= -(11.1 + 0.49 + 0.57 + 31.4) \times 10^8\ rad/sec$$

$$= -43.6 \times 10^8\ rad/sec$$

$$= -693\,MHz$$

```
COMMON EMITTER GAIN STAGE
VCC 1 0 5V
RL 1 2 3K
Q1 2 3 0 NPN
RS 4 3 5K
VI 4 0 0.7696 AC
.TF V(2) VI
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 10 100K 1GIG
.MODEL NPN NPN IS=1E-16A BF=200
+ RB=300 CJC=0.3PF CJS=0 TF=302PS
* ASSUME CJE SMALL COMPARED TO CB
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END
```

```
 ******  OPERATING POINT INFORMATION       TNOM=  27.000 TEMP=  27.000

+0:1       = 5.000E+00 0:2       = 3.497E+00 0:3       = 7.571E-01
+0:4       = 7.696E-01

**** BIPOLAR JUNCTION TRANSISTORS

ELEMENT  0:Q1
MODEL    0:NPN
 IB       2.504E-06
 IC       5.009E-04
 VBE      7.571E-01
 VCE      3.497E+00
 VBC     -2.740E+00
 VS      -3.497E+00
 POWER    1.754E-03
 BETAD    2.000E+02
 GM       1.937E-02
 RPI      1.032E+04
 RX       3.000E+02
 RO       2.741E+16
 CPI      5.849E-12
 CMU      1.806E-13
 CBX      0.
 CCS      0.
 BETAAC   2.000E+02
 FT       5.112E+08

****     SMALL-SIGNAL TRANSFER CHARACTERISTICS

     V(2)/VI                                 = -3.839E+01
     INPUT RESISTANCE AT         VI          =  1.562E+04
     OUTPUT RESISTANCE AT V(2)               =  3.000E+03
```

```
******  AC ANALYSIS                       TNOM=  27.000 TEMP=  27.000

     FREQ       VDB(2)
(A       )   -4.000E+01   -2.000E+01       0.        2.000E+01   4.000E+01
             +            +            +            +            +
1.000E+05  3.16E+01 +------+------+------+------+------+------+A-----+
1.258E+05  3.16E+01 +      +      +      +      +      +      +A     +
1.584E+05  3.16E+01 +      +      +      +      +      +      +A     +
1.995E+05  3.16E+01 +      +      +      +      +      +      +A     +
2.511E+05  3.16E+01 +      +      +      +      +      +      +A     +
3.162E+05  3.16E+01 +      +      +      +      +      +      +A     +
3.981E+05  3.15E+01 +      +      +      +      +      +      +A     +
5.011E+05  3.15E+01 +      +      +      +      +      +      +A     +
6.309E+05  3.14E+01 +      +      +      +      +      +      +A     +
7.943E+05  3.13E+01 +      +      +      +      +      +      +A     +
1.000E+06  3.11E+01 +------+------+------+------+------+------+A-----+
1.258E+06  3.08E+01 +      +      +      +      +      +      +A     +
1.584E+06  3.04E+01 +      +      +      +      +      +      A      +
1.995E+06  2.98E+01 +      +      +      +      +      +      A      +
2.511E+06  2.90E+01 +      +      +      +      +      +     A+      +
3.162E+06  2.80E+01 +      +      +      +      +      +     A+      +
3.981E+06  2.67E+01 +      +      +      +      +      +    A +      +
5.011E+06  2.52E+01 +      +      +      +      +      +   A  +      +
6.309E+06  2.36E+01 +      +      +      +      +      +  A   +      +
7.943E+06  2.19E+01 +      +      +      +      +     +A    +      +
1.000E+07  2.01E+01 +------+------+------+------+------A------+------+
1.258E+07  1.82E+01 +      +      +      +      +     A+     +      +
1.584E+07  1.62E+01 +      +      +      +      +    A +     +      +
1.995E+07  1.43E+01 +      +      +      +      +   A  +     +      +
2.511E+07  1.23E+01 +      +      +      +      +  A   +     +      +
3.162E+07  1.03E+01 +      +      +      +      + A    +     +      +
3.981E+07  8.39E+00 +      +      +      +     A+     +     +      +
5.011E+07  6.39E+00 +      +      +      +    A  +     +     +      +
6.309E+07  4.38E+00 +      +      +      +   A   +     +     +      +
7.943E+07  2.37E+00 +      +      +      +  A    +     +     +      +
1.000E+08  3.56E-01 +------+------+------+-A----+------+------+------+
1.258E+08 -1.67E+00 +      +      +     A+     +     +     +      +
1.584E+08 -3.73E+00 +      +      +    A +     +     +     +      +
1.995E+08 -5.82E+00 +      +      +   A  +     +     +     +      +
2.511E+08 -7.95E+00 +      +      +  A   +     +     +     +      +
3.162E+08 -1.01E+01 +      +      + A    +     +     +     +      +
3.981E+08 -1.24E+01 +      +      +A     +     +     +     +      +
5.011E+08 -1.49E+01 +      +     A +     +     +     +     +      +
6.309E+08 -1.75E+01 +      +    A   +     +     +     +     +      +
7.943E+08 -2.03E+01 +      +   A    +     +     +     +     +      +
1.000E+09 -2.34E+01 +------+--A---+------+------+------+------+------+
             +            +            +            +            +
```

```
     FREQ       VP(2)
(A       )       0.        5.000E+01   1.000E+02   1.500E+02   2.000E+02
             +            +            +            +            +
1.000E+05  1.77E+02 +------+------+------+------+------+------+A-----+
1.258E+05  1.77E+02 +      +      +      +      +      +      +A     +
1.584E+05  1.76E+02 +      +      +      +      +      +      A      +
1.995E+05  1.75E+02 +      +      +      +      +      +      A      +
2.511E+05  1.74E+02 +      +      +      +      +      +      A      +
3.162E+05  1.73E+02 +      +      +      +      +      +      A      +
3.981E+05  1.71E+02 +      +      +      +      +      +     A+      +
5.011E+05  1.69E+02 +      +      +      +      +      +    A +      +
6.309E+05  1.67E+02 +      +      +      +      +      +    A +      +
7.943E+05  1.63E+02 +      +      +      +      +      +   A  +      +
1.000E+06  1.59E+02 +------+------+------+------+------+---A--+------+
1.258E+06  1.55E+02 +      +      +      +      +      +  -A   +      +
1.584E+06  1.49E+02 +      +      +      +      +      +  A    +      +
1.995E+06  1.43E+02 +      +      +      +      +      + A +   +      +
2.511E+06  1.37E+02 +      +      +      +      +     A  +   +      +
3.162E+06  1.30E+02 +      +      +      +      +    A   +   +      +
3.981E+06  1.24E+02 +      +      +      +      +   A    +   +      +
5.011E+06  1.18E+02 +      +      +      +     A +       +   +      +
6.309E+06  1.13E+02 +      +      +      +    A   +      +   +      +
7.943E+06  1.08E+02 +      +      +      +   A    +      +   +      +
1.000E+07  1.04E+02 +------+------+------+--A---+------+------+------+
1.258E+07  1.01E+02 +      +      +      +  A    +      +   +      +
1.584E+07  9.86E+01 +      +      +      +  A    +      +   +      +
1.995E+07  9.63E+01 +      +      +      +A     +      +   +      +
2.511E+07  9.44E+01 +      +      +      + A    +      +   +      +
3.162E+07  9.26E+01 +      +      +      + A    +      +   +      +
3.981E+07  9.10E+01 +      +      +      +  A   +      +   +      +
5.011E+07  8.95E+01 +      +      +      +  A   +      +   +      +
6.309E+07  8.79E+01 +      +      +      +   A  +      +   +      +
7.943E+07  8.62E+01 +      +      +      +   A  +      +   +      +
1.000E+08  8.44E+01 +------+------+------+---A--+------+------+------+
1.258E+08  8.22E+01 +      +      +      +    A +      +   +      +
1.584E+08  7.97E+01 +      +      +      +   -A +      +   +      +
1.995E+08  7.66E+01 +      +      +      +   A  +      +   +      +
2.511E+08  7.30E+01 +      +      +      +  A-  +      +   +      +
3.162E+08  6.86E+01 +      +      +      + A   +      +   +      +
3.981E+08  6.35E+01 +      +      +      + A   +      +   +      +
5.011E+08  5.76E+01 +      +      +      +A    +      +   +      +
6.309E+08  5.12E+01 +      +      +      A     +      +   +      +
7.943E+08  4.39E+01 +      +      +      +     +      +   +      +
1.000E+09  3.66E+01 +------+---A--+------+------+------+------+------+
             +            +            +            +            +
```

7.2

$$g_m = \sqrt{2k_n' \frac{W}{L} I_D} = \sqrt{2 \times 60 \times 10^{-6} \times \frac{100}{2-2\times0.2-0} \times 500 \times 10^{-6}}$$

$$= 1.9 \times 10^{-3}\ A/V$$

$$A_v = -g_m R_L = -1.9 \times 10^{-3} \times 5 \times 10^3 = -9.5$$

$$C_{gs} = \frac{2}{3} WL_{eff} C_{ox} + WL_d C_{ox}$$

$$= \frac{2}{3} 100 \times 1.6 \times 0.7 + 100 \times 0.2 \times 0.7$$

$$= 89\,fF$$

$$C_{gd} = WL_d C_{ox} = 100 \times 0.2 \times 0.7 = 14\,fF$$

(a) Use the Miller effect.

$$|P_1| = \frac{1}{R_S[C_{gs} + C_{gd}(1 - A_v)]}$$

$$= \frac{1}{10k[89 + 14(1 + 9.5)] \times 10^{-15}}$$

$$= \frac{1}{2.4 \times 10^{-9}} = 4.2 \times 10^8\ rad/s$$

$$f_{-3dB} = \frac{|P_1|}{2\pi} = 67\,MHz$$

(b) Do not use the Miller effect to calculate the second pole.

From Eq. (7.26),

$$|P_2| = \frac{1}{|P_1|} \frac{1}{R_L R_S C_{gd} C_{gs}}$$

$$= \frac{1}{4.2 \times 10^8} \frac{1}{5k \times 10k \times 14f \times 89f}$$

$$= 3.8 \times 10^{10}\ rad/s$$

It is equivalent to 6.1 GHz.

```
COMMON SOURCE AMPLIFIER
VDD 1 0 5
VI 2 0 DC 1.216 AC 1
RS 2 3 10K
RL 1 4 5K
M1 4 3 0 0 CMOSN  W=100U  L=2U
* COX'=0.7FF/UM**2=EOX/TOX => TOX=500 ANGSTROMS
.MODEL CMOSN NMOS LEVEL=1 LAMBDA=0 VTO=0.7 KP=60U LD=0.2U TOX=500E-10
.OPTIONS NOMOD
.AC DEC 10 1MEG 10G
.PLOT AC VM(4)
.WIDTH OUT=80
.OPTIONS SPICE
.END

 ******  OPERATING POINT INFORMATION      TNOM=  27.000 TEMP=  27.000

+0:1       = 5.000E+00 0:2       = 1.216E+00 0:3       = 1.216E+00
+0:4       = 2.503E+00

**** MOSFETS

SUBCKT
ELEMENT  0:M1
MODEL    0:CMOSN
 ID        4.992E-04
 IBS       0.
 IBD      -2.504E-14
 VGS       1.216E+00
 VDS       2.503E+00
 VBS       0.
 VTH       7.000E-01
 VDSAT     5.160E-01
 BETA      3.750E-03
 GAM EFF   0.
 GM        1.935E-03
 GDS       0.
 GMB       0.
 CDTOT     1.418E-14
 CGTOT     1.050E-13
 CSTOT     8.748E-14
 CBTOT     3.349E-15
 CGS       8.748E-14
 CGD       1.418E-14

 ******  AC ANALYSIS                      TNOM=  27.000 TEMP=  27.000

    FREQ      VM(4)
(A      )  1.000E-02    1.000E-01    1.000E+00    9.999E+00    9.999E+01
           +            +            +            +            +
1.000E+06  9.67E+00+------+------+------+------+------A------+------+-
1.258E+06  9.67E+00 +      +      +      +      +      A      +      +
1.584E+06  9.67E+00 +      +      +      +      +      A      +      +
1.995E+06  9.67E+00 +      +      +      +      +      A      +      +
2.511E+06  9.66E+00 +      +      +      +      +      A      +      +
3.162E+06  9.66E+00 +      +      +      +      +      A      +      +
3.981E+06  9.65E+00 +      +      +      +      +      A      +      +
5.011E+06  9.64E+00 +      +      +      +      +      A      +      +
6.309E+06  9.62E+00 +      +      +      +      +      A      +      +
7.943E+06  9.60E+00 +      +      +      +      +      A      +      +
1.000E+07  9.56E+00-+------+------+------+------+------A------+------+-
1.258E+07  9.49E+00 +      +      +      +      +      A      +      +
1.584E+07  9.39E+00 +      +      +      +      +      A      +      +
1.995E+07  9.24E+00 +      +      +      +      +      A      +      +
2.511E+07  9.01E+00 +      +      +      +      +      A+     +      +
3.162E+07  8.68E+00 +      +      +      +      +      A+     +      +
3.981E+07  8.23E+00 +      +      +      +      +      A+     +      +
5.011E+07  7.64E+00 +      +      +      +      +      A +    +      +
6.309E+07  6.91E+00 +      +      +      +      +      A +    +      +
7.943E+07  6.09E+00 +      +      +      +      +    A +      +      +
1.000E+08  5.24E+00-+------+------+------+------+----A-+------+------+-
1.258E+08  4.41E+00 +      +      +      +      + A    +      +      +
1.584E+08  3.64E+00 +      +      +      +      +A     +      +      +
1.995E+08  2.97E+00 +      +      +      +      A      +      +      +
2.511E+08  2.40E+00 +      +      +      +    A +      +      +      +
3.162E+08  1.93E+00 +      +      +      +  A   +      +      +      +
3.981E+08  1.54E+00 +      +      +      + A    +      +      +      +
5.011E+08  1.23E+00 +      +      +      +A     +      +      +      +
6.309E+08  9.79E-01 +      +      +      A      +      +      +      +
7.943E+08  7.77E-01 +      +      +    A +      +      +      +      +
1.000E+09  6.15E-01-+------+------+----A-+------+------+------+------+-
1.258E+09  4.86E-01 +      +      +  A   +      +      +      +      +
1.584E+09  3.82E-01 +      +      +A     +      +      +      +      +
1.995E+09  2.98E-01 +      +      A      +      +      +      +      +
2.511E+09  2.31E-01 +      +    A +      +      +      +      +      +
3.162E+09  1.77E-01 +      +  A   +      +      +      +      +      +
3.981E+09  1.33E-01 +      +A     +      +      +      +      +      +
5.011E+09  9.87E-02 +      A      +      +      +      +      +      +
6.309E+09  7.16E-02 +    A +      +      +      +      +      +      +
7.943E+09  5.09E-02 +  A   +      +      +      +      +      +      +
1.000E+10  3.58E-02-+--A---+------+------+------+------+------+------+-
           +            +            +            +            +
```

7.8

$$\frac{v_o}{v_i} = \frac{g_m R_E + \frac{R_E}{r_\pi}}{1 + g_m R_E + \frac{R_b + R_E}{r_\pi}} \frac{1 - \frac{s}{z_1}}{1 - \frac{s}{p_1}}$$

$$= \frac{\frac{0.3}{26}\times 4000 + \frac{4000}{50}\frac{0.3}{26}}{1 + \frac{0.3}{26}\times 4000 + \frac{4450}{50}\frac{0.3}{26}} \frac{1 - \frac{j\omega}{z_1}}{1 - \frac{j\omega}{p_1}}$$

$$= 0.977 \frac{1 - j\frac{\omega}{z_1}}{1 - j\frac{\omega}{p_1}}$$

$$z_1 = -\frac{g_m}{C_\pi} = -\omega_T = -2\pi \times 4\times 10^6$$

$$= -25.1\times 10^6 \text{ rad/sec}$$

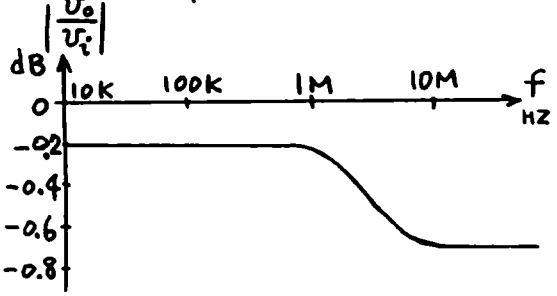
$$p_1 = -\frac{1}{C_\pi R_1}$$

$$R_1 = r_\pi \| \frac{R_b + R_E}{1 + g_m R_E} = \frac{50\times 26}{0.3} \Big\| \frac{450 + 4000}{1 + \frac{0.3\times 4000}{26}}$$

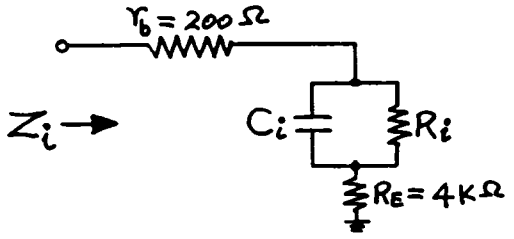
$$= 4333 \| 94.4 = 92.4\ \Omega$$

$$C_\pi = \frac{g_m}{\omega_T} = \frac{0.3}{26}\frac{1}{2\pi\times 4\times 10^6} = 459 \text{ pF}$$

$$\therefore p_1 = -\frac{10^{12}}{459\times 92.4} = -23.6\times 10^6 \text{ rad/sec}$$



7.9

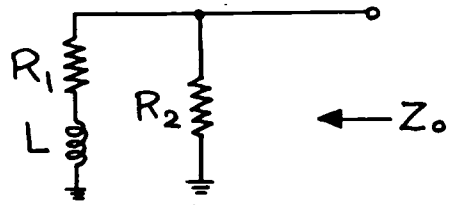


$$C_i = \frac{C_\pi}{1 + g_m R_E} = \frac{459}{1 + \frac{0.3\times 4000}{26}} = 9.73 \text{ pF}$$

$$R_i = (1 + g_m R_E) r_\pi = \left(1 + \frac{0.3\times 4000}{26}\right)\times \frac{50\times 26}{0.3}$$

$$= 204\ K\Omega$$

$$Z_i = 4.2k\Omega + 204K\Omega \| \frac{1}{j\omega C_i}$$

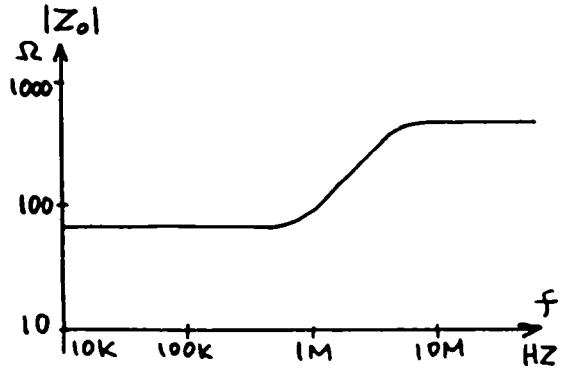


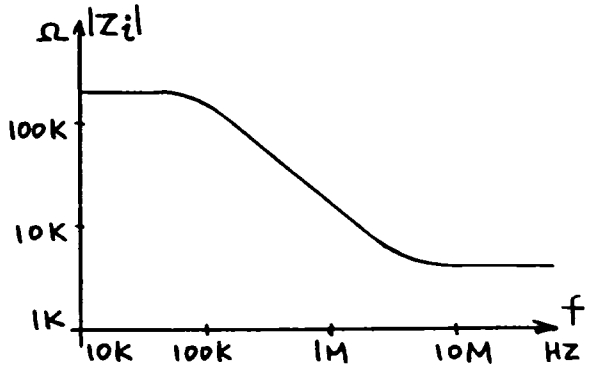
$$R_1 = \frac{1}{g_m} + \frac{R_b}{\beta_o} = \frac{26}{0.3} + \frac{450}{50} = 95.7\ \Omega$$

$$R_2 = R_b = 450\ \Omega$$

$$L = C_\pi r_\pi \frac{R_b}{\beta_o} = 459\times \frac{50\times 26}{0.3}\times \frac{450}{50}\times 10^{-12}$$

$$= 17.9\ \mu H$$





```
PNP EMITTER FOLLOWER, REISTIVE LOAD
* DC VO=0V, 300UA*4K=1.2V=VCC
VCC 1 0 1.2V
VEE 2 0 -1.2V
RE 1 5 4K
Q1 2 4 5 PNP
RS 3 4 250
RLOAD 5 0 1K
VBIAS 3 6 -0.745V AC
VPULSE 6 0 PULSE 0V 1MV 1NS 0NS 0NS 100NS
.TRAN 0.25NS 10NS
.PLOT TRAN V(5)
.MODEL PNP PNP IS=1E-16A BF=50
+ RB=200 CJE=0 CJC=0 CJS=0 TF=39.8NS
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END
```

****** OPERATING POINT INFORMATION TNOM= 27.000 TEMP= 27.000

```
+0:1      = 1.200E+00 0:2      =-1.200E+00 0:3      =-7.450E-01
+0:4      =-7.435E-01 0:5      = 1.819E-04 0:6      =  0.
```

**** BIPOLAR JUNCTION TRANSISTORS

ELEMENT	0:Q1
MODEL	0:PNP
IB	-5.878E-06
IC	-2.939E-04
VBE	-7.437E-01
VCE	-1.200E+00
VBC	4.565E-01
VS	7.424E-01
POWER	3.571E-04
BETAD	5.000E+01
GM	1.136E-02
RPI	4.400E+03
RX	2.000E+02
RO	4.576E+15
CPI	4.522E-10
CMU	0.
CBX	0.
CCS	0.
BETAAC	5.000E+01
FT	3.998E+06

****** TRANSIENT ANALYSIS TNOM= 27.000 TEMP= 27.000

```
   TIME      V(5)
(A      )   -5.000E-04      0.         5.000E-04     1.000E-03     1.500E-03
            +            +            +             +             +
  0.      1.82E-04+------+------+---A--+------+------+------+------+------+-
2.500E-10 1.82E-04 +      +      +   A +      +      +      +      +      +
5.000E-10 1.82E-04 +      +      +   A +      +      +      +      +      +
7.500E-10 1.82E-04 +      +      +   A +      +      +      +      +      +
1.000E-09 1.82E-04 +      +      +   A +      +      +      +      +      +
1.250E-09 8.23E-04 +      +      +     +      +    + A    +      +      +
1.500E-09 8.24E-04 +      +      +     +      +    + A    +      +      +
1.750E-09 8.25E-04 +      +      +     +      +    + A    +      +      +
2.000E-09 8.26E-04 +      +      +     +      +    + A    +      +      +
2.250E-09 8.27E-04 +      +      +     +      +    + A    +      +      +
2.500E-09 8.28E-04+------+------+------+------+------+-A----+------+------+-
2.750E-09 8.29E-04 +      +      +     +      +    + A    +      +      +
3.000E-09 8.31E-04 +      +      +     +      +    + A    +      +      +
3.250E-09 8.32E-04 +      +      +     +      +    + A    +      +      +
3.500E-09 8.33E-04 +      +      +     +      +    + A    +      +      +
3.750E-09 8.34E-04 +      +      +     +      +    + A    +      +      +
4.000E-09 8.35E-04 +      +      +     +      +    + A    +      +      +
4.250E-09 8.36E-04 +      +      +     +      +    + A    +      +      +
4.500E-09 8.37E-04 +      +      +     +      +    + A    +      +      +
4.750E-09 8.38E-04 +      +      +     +      +    + A    +      +      +
5.000E-09 8.39E-04+------+------+------+------+------+-A----+------+------+-
5.250E-09 8.40E-04 +      +      +     +      +    + A    +      +      +
5.500E-09 8.42E-04 +      +      +     +      +    + A    +      +      +
5.750E-09 8.43E-04 +      +      +     +      +    + A    +      +      +
6.000E-09 8.44E-04 +      +      +     +      +    + A    +      +      +
6.250E-09 8.45E-04 +      +      +     +      +    + A    +      +      +
6.500E-09 8.46E-04 +      +      +     +      +    + A    +      +      +
6.750E-09 8.47E-04 +      +      +     +      +    + A    +      +      +
7.000E-09 8.48E-04 +      +      +     +      +    + A    +      +      +
7.250E-09 8.49E-04 +      +      +     +      +    + A    +      +      +
7.500E-09 8.50E-04+------+------+------+------+------+-A----+------+------+-
7.750E-09 8.51E-04 +      +      +     +      +    + A    +      +      +
            +            +            +             +             +
```

*****

```
PNP EMITTER FOLLOWER, CAPACITIVE LOAD
VCC 1 0 1.2V
VEE 2 0 -1.2V
IEE 1 5 300UA
Q1 2 4 5 PNP
RS 3 4 250
CLOAD 5 0 400PF
VBIAS 3 6 -0.745V AC
VPULSE 6 0 PULSE 0V 1MV 1NS 0NS 0NS 1300NS
.TRAN 20NS 800NS
.PLOT TRAN V(5)
.MODEL PNP PNP IS=1E-16A BF=50
+ RB=200 CJE=0 CJC=0 CJS=0 TF=39.8NS
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END
```

**** BIPOLAR JUNCTION TRANSISTORS

ELEMENT	0:Q1
MODEL	0:PNP
IB	-5.882E-06
IC	-2.941E-04
VBE	-7.437E-01
VCE	-1.200E+00
VBC	4.565E-01
VS	7.424E-01
POWER	3.574E-04
BETAD	5.000E+01
GM	1.137E-02
RPI	4.396E+03
RX	2.000E+02
RO	4.576E+15
CPI	4.526E-10
CMU	0.
CBX	0.
CCS	0.
BETAAC	5.000E+01
FT	3.998E+06

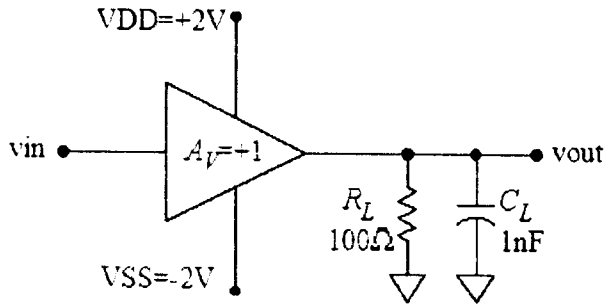
****** TRANSIENT ANALYSIS TNOM= 27.000 TEMP= 27.000

```
   TIME      V(5)
(A      )     0.         5.000E-04     1.000E-03     1.500E-03     2.000E-03
            +            +             +             +             +
  0.      2.03E-04+------A+------+------+------+------+------+------+------+-
2.000E-08 2.59E-04 +      A      +      +      +      +      +      +      +
4.000E-08 3.94E-04 +      +  A   +      +      +      +      +      +      +
6.000E-08 5.42E-04 +      +      +A     +      +      +      +      +      +
8.000E-08 6.95E-04 +      +      +   A  +      +      +      +      +      +
1.000E-07 8.44E-04 +      +      +     + A    +      +      +      +      +
1.200E-07 9.81E-04 +      +      +     +    A+      +      +      +      +
1.400E-07 1.10E-03 +      +      +     +      + A    +      +      +      +
1.600E-07 1.21E-03 +      +      +     +      +    A+      +      +      +
1.800E-07 1.29E-03 +      +      +     +      +     +A     +      +      +
2.000E-07 1.35E-03-+------+------+------+------+------+-A----+------+------+-
2.200E-07 1.39E-03 +      +      +     +      +      +  A   +      +      +
2.400E-07 1.42E-03 +      +      +     +      +      +   A  +      +      +
2.600E-07 1.43E-03 +      +      +     +      +      +    A +      +      +
2.800E-07 1.42E-03 +      +      +     +      +      +    A +      +      +
3.000E-07 1.41E-03 +      +      +     +      +      +   A  +      +      +
3.200E-07 1.39E-03 +      +      +     -      +      +   A  +      +      +
3.400E-07 1.36E-03 +      +      +     +      +      +  A   +      +      +
3.600E-07 1.33E-03 +      +      +     +      +      + A    +      +      +
3.800E-07 1.30E-03 +      +      +     +      +      +A     +      +      +
4.000E-07 1.27E-03-+------+------+------+------+------+A-----+------+------+-
4.200E-07 1.24E-03 +      +      +     -      +      A      +      +      +
4.400E-07 1.22E-03 +      +      +     -      +     A+      +      -      +
4.600E-07 1.20E-03 +      +      +     +      +     A-      +      +      +
4.800E-07 1.18E-03 +      +      +     +      +     A +     -      +      +
5.000E-07 1.17E-03 +      +      +     -      +     A +     +      +      -
5.200E-07 1.16E-03 +      +      +     -      +     A +     +      +      -
5.400E-07 1.16E-03 +      +      +     +      +    A  -     +      +      +
5.600E-07 1.16E-03 +      +      +     +      +    A  +     -      +      -
5.800E-07 1.16E-03 +      +      +     +      +    A  +     +      +      +
6.000E-07 1.16E-03-+------+------+------+------+-----A+-----+------+------+-
6.200E-07 1.17E-03 +      +      +     +      +     A +     -      +      -
6.400E-07 1.17E-03 +      +      +     +      +     A +     -      +      +
6.600E-07 1.18E-03 +      +      +     +      +     A +     +      +      -
6.800E-07 1.19E-03 +      +      +     +      +     A +     +      +      -
7.000E-07 1.19E-03 +      +      +     +      +     A +     +      +      -
7.200E-07 1.20E-03 +      +      +     +      +     A-      +      +      +
7.400E-07 1.20E-03 +      +      +     +      -     A-      +      -      +
7.600E-07 1.20E-03 +      +      +     +      -     A+      +      +      +
7.800E-07 1.21E-03 +      +      +     +      -     A+      +      +      +
8.000E-07 1.21E-03-+------+------+------+------+------A+-----+------+------+-
            +            +             +             +             +
```

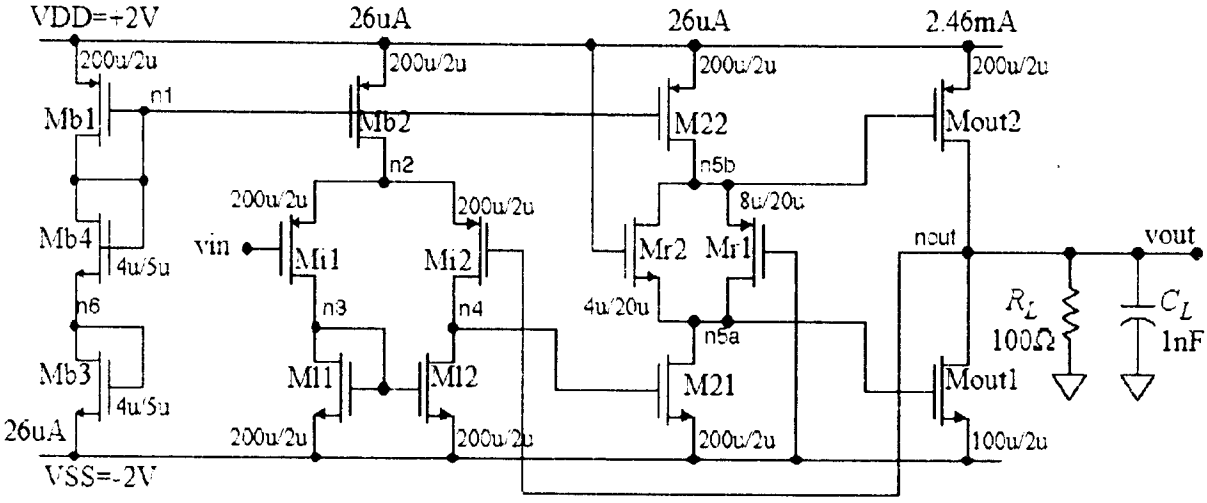
*****

CAPACITIVE LOAD RESULTS IN SOME PEAKING [V(5) JUMPS BY > 1MV]

Problem5 - Design Prob.#1



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

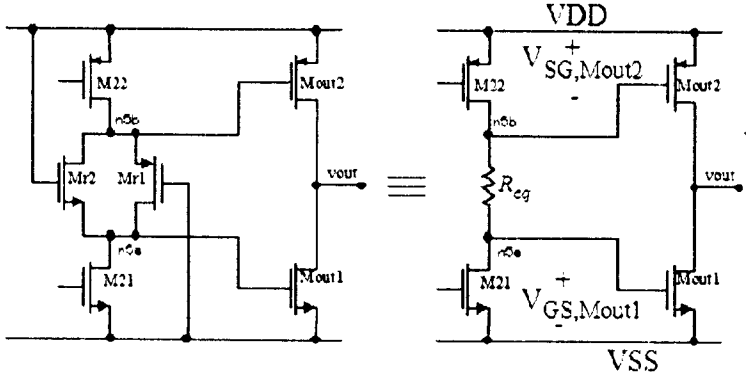


A three stage amplifier connected in unity gain configuration is used as the output buffer. The first two stages are class-A whereas the last stage is class-AB.

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

DC gain of the amplifier in unity gain configuration = $A_v/(1+A_v)$
where $A_v \propto g_m{}^3 r_{ds}{}^3$

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



VDD-VSS = $V_{GS,Mout1} + V_{SG,Mout2} + I_{d,M21}Req$

$I_{d,M21}$: quiescent drain current of M21.

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.

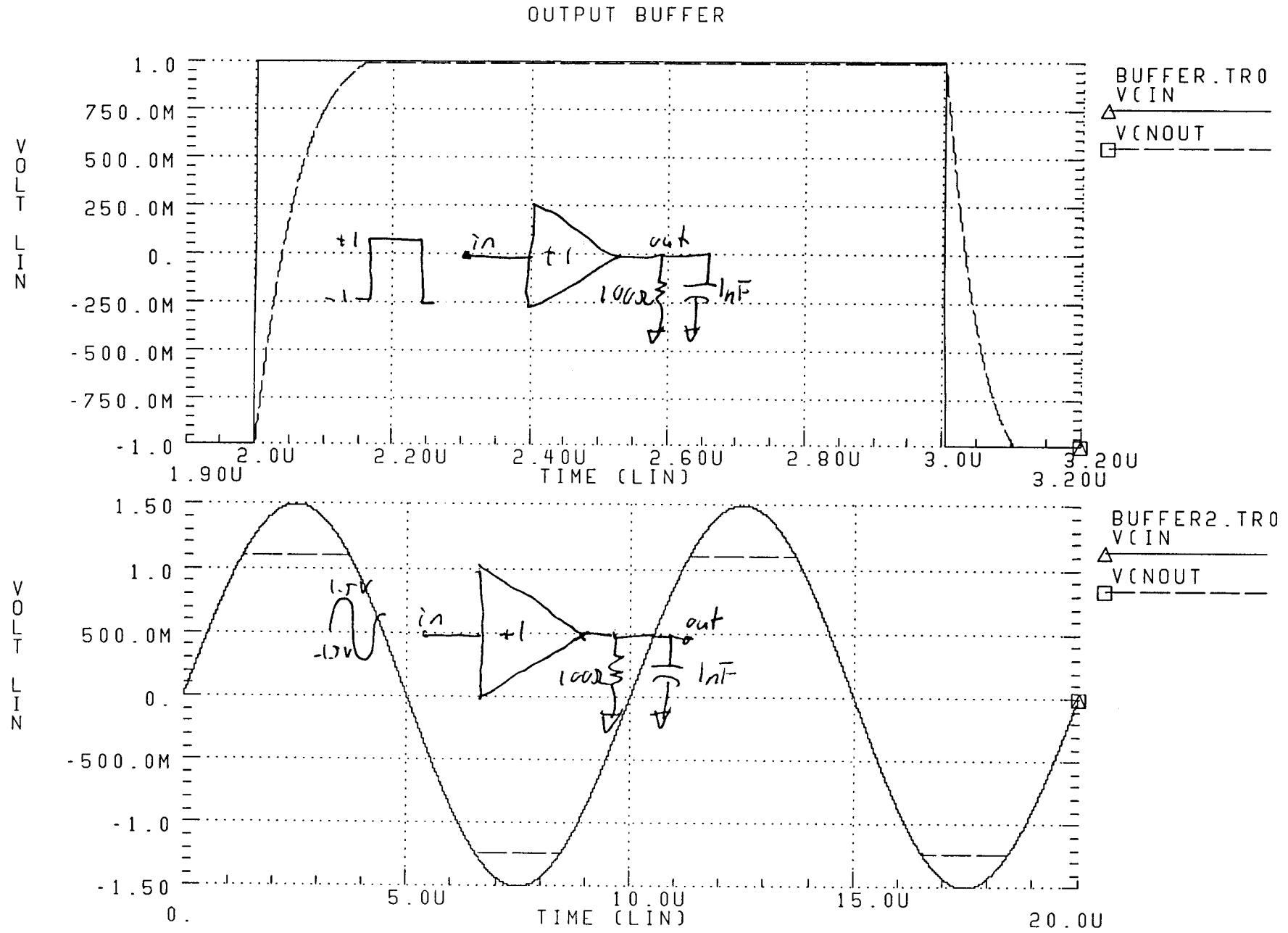
```
*output buffer
.option brief
.options
+ post
+ ingold=2
+ scale=1e-6
+ accurate
+ delmax=0.5n
+ method=gear lvltim=2
+ probe
*

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 n5a ss n5b 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
rl 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'

.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
```

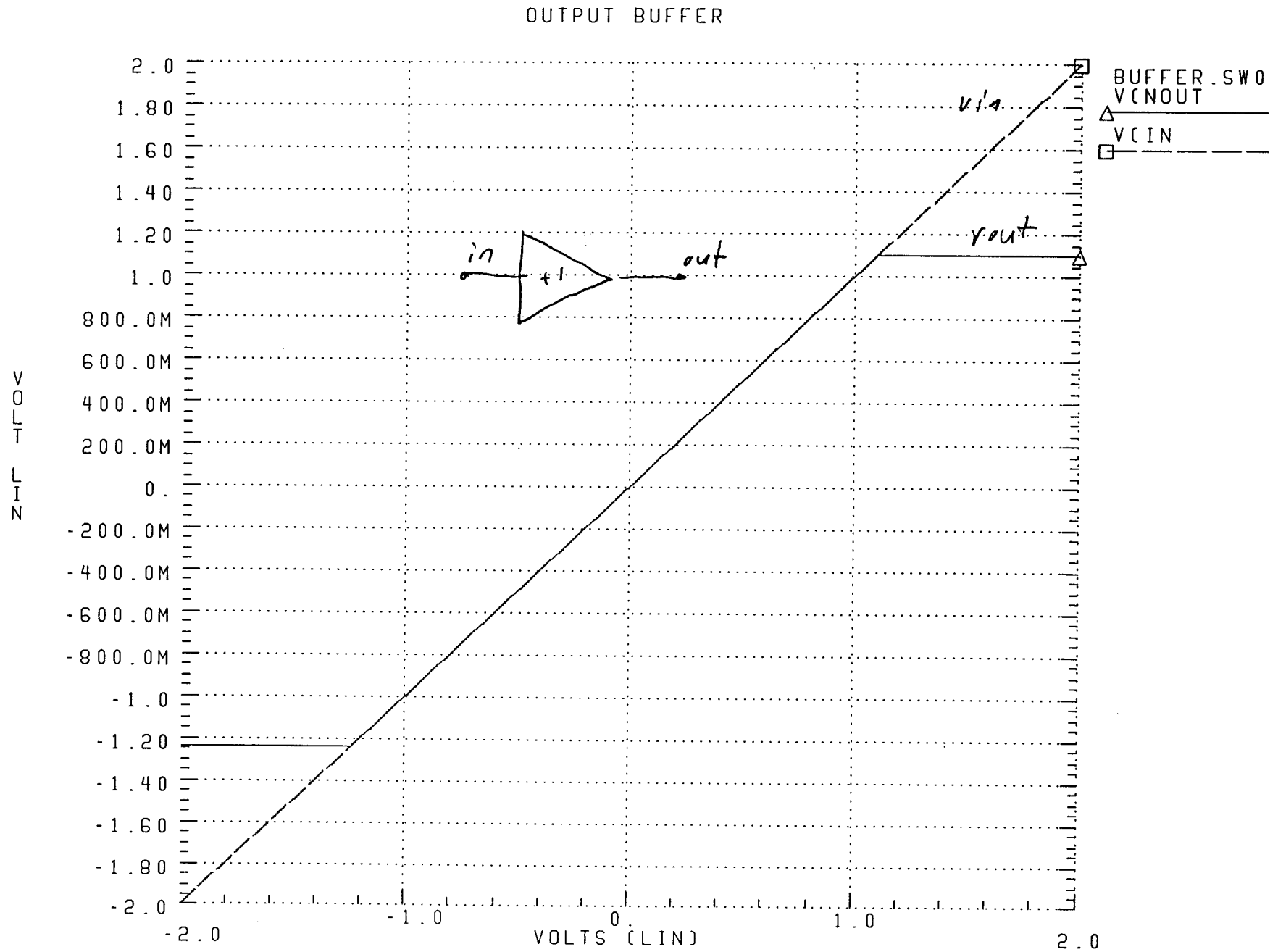
] calculates the average current drawn from Vpp. and power

```
 ******  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:mi1       0:mi2
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:ml1       0:ml2       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
VOLT LIN
1.0
750.0M
500.0M
250.0M
0.
-250.0M
-500.0M
-750.0M
-1.0
1.90U
2.0U
2.20U
2.40U
2.60U
2.80U
3.0U
3.20U
3.20U
TIME (LIN)
BUFFER.TR0
VCIN
VCNOUT
+1
-1
in
+1
out
100Ω
1nF
VOLT LIN
1.50
1.0
500.0M
0.
-500.0M
-1.0
-1.50
0.
5.0U
10.0U
15.0U
20.0U
TIME (LIN)
BUFFER2.TR0
VCIN
VCNOUT
1.5V
-1.5V
in
+1
out
100Ω
1nF


OUTPUT BUFFER
BUFFER.SWO
V(NOUT
V(IN
vin
vout
in
out
+1
2.0
1.80
1.60
1.40
1.20
1.0
800.0M
600.0M
400.0M
200.0M
0.
-200.0M
-400.0M
-600.0M
-800.0M
-1.0
-1.20
-1.40
-1.60
-1.80
-2.0
VOLT LIN
-2.0
-1.0
0
1.0
2.0
VOLTS (LIN)