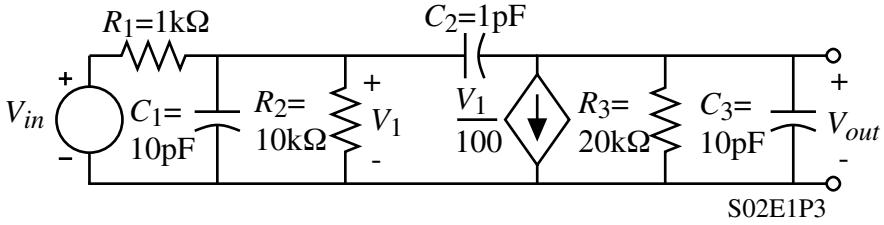
Homework Assignment No. 4 - Solutions

Problem 1

Find the midband voltage gain and the –3dB frequency in Hertz for the circuit shown.



Solution

The midband gain is given as,

$$\frac{V_{out}}{V_{in}} = -\left(\frac{20\text{k}\Omega}{100}\right)\left(\frac{10\text{k}\Omega}{11\text{k}\Omega}\right) = \underline{\underline{-181.82\text{V/V}}}$$

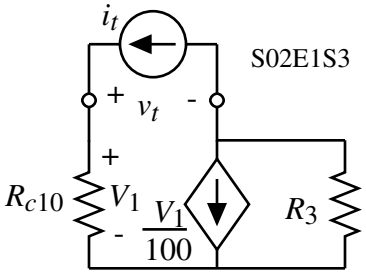
To find the –3dB frequency requires finding the 3 open-circuit time constants.

R_{C10}:

$R_{C10} = 1\text{k}\Omega \| 10\text{k}\Omega = 0.9091\text{k}\Omega \quad \rightarrow \quad R_{C10}C = 0.9091\text{x}10\text{ns} = 9.09\text{ns}$

R_{C20}:

$$v_t = i_t R_{C10} + R_3(i_t + 0.01V_1)$$
$$= i_t(R_{C10} + R_3 + 0.01R_{C10}R_3)$$
$$\therefore R_{C20} = R_{C10} + R_3 + 0.01R_{C10}R_3$$
$$= 0.9091 + 20\text{x}(1+0.01\cdot 909.1)\text{k}\Omega = 202.72\text{k}\Omega$$



$$R_{C20}C_2 = 202.72\text{x}1\text{ns} = 202.72\text{ns}$$

R_{C30}:

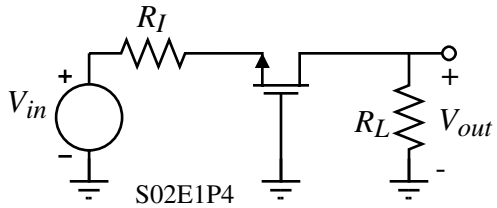
$$R_{C30} = 20\text{k}\Omega \quad \rightarrow \quad R_{C30}C_3 = 20\text{x}10\text{ns} = 200\text{ns}$$

$$\Sigma T_0 = (9.091 + 202.72 + 200)\text{ns} = 411.82\text{n} \quad \rightarrow \quad \omega_{\text{-3dB}} = \frac{1}{\Sigma T_0} = 2.43\text{x}10^6 \text{ rad/s}$$

$$f_{\text{-3dB}} = \frac{2.43\text{x}10^6}{2\pi} = \underline{\underline{754.6\text{kHz}}}$$

Problem 2 – (10 points)

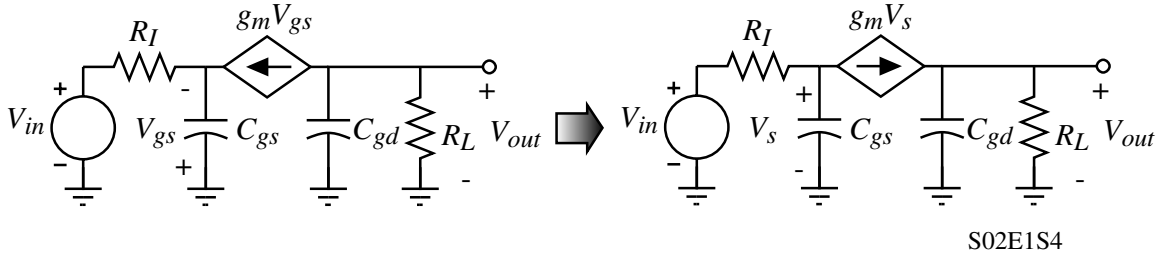
Find the midband voltage gain and the exact value of the two poles of the voltage transfer function for the circuit shown. Assume that R_I = 1kΩ, R_L = 10KΩ, g_m = 1mS, C_{gs} = 5pF and C_{gd} = 1pF. Ignore r_{ds}.



Solution

The best approach to this problem is a direct analysis.

Small-signal model:



$V_{out} = g_m Z_L V_s$ where $Z_L = \frac{1}{sR_LC_{gd}+1}$ and $\frac{V_{in}-V_s}{R_I} = g_mV_s + sC_{gs}V_s$

Solving for V_s from the second equation gives,

$$V_s = \frac{V_{in}}{1+g_mR_I+sC_{gs}R_I}$$

Substituting V_s in the first equation gives,

$$V_{out} = g_mZ_L\frac{V_{in}}{1+g_mR_I+sC_{gs}R_I} \rightarrow \frac{V_{out}}{V_{in}} = g_m\left(\frac{1}{sR_LC_{gd}+1}\right)\left(\frac{1}{1+g_mR_I+sC_{gs}R_I}\right)$$

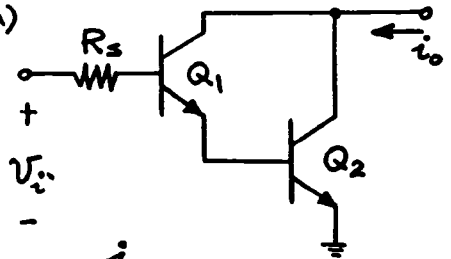
$$= \left(\frac{g_mR_L}{1+g_mR_I}\right)\left(\frac{1}{sR_LC_{gd}+1}\right)\left(\frac{1}{\frac{sC_{gd}R_I}{1+g_mR_I}+1}\right) = \text{MBG}\left(\frac{1}{1-\frac{s}{p_1}}\right)\left(\frac{1}{1-\frac{s}{p_2}}\right)$$

$$\therefore \text{ MBG} = \left(\frac{g_mR_L}{1+g_mR_I}\right) = \left(\frac{1\cdot 10}{1+1\cdot 1}\right) = \underline{\underline{5\text{V/V}}}$$

$$p_1 = -\frac{1}{R_LC_{gd}} = -\frac{1}{10\cdot 1\text{ns}} = \underline{\underline{-10^8\text{ rad/s}}} \text{ and } p_2 = -\frac{1+g_mR_I}{R_IC_{gs}} = -\frac{1+1}{1\cdot 5\text{ns}} = \underline{\underline{-4\text{x}10^8\text{ rad/s}}}$$

7.21

(a)



$G_m = \frac{i_o}{v_i} \simeq \frac{1}{2} g_{m2} = \frac{1}{2} \frac{1}{26}$

$= \frac{1}{52}$ A/V —both circuits

$R_i \simeq r_{\pi 1}(1 + g_{m1} r_{\pi 2}) = 2 r_{\pi 1} = 2 \frac{\beta}{g_{m1}}$

$= 2 \times 100 \times 2.6k = 520k\Omega$

—both Circuits

$\therefore \frac{v_o}{v_i} = -\frac{R_i}{R_i + R_s} G_m R_L$

$= -\frac{520}{620} \times \frac{1}{52} \times 3000$

$= -48.4$ —both circuits

(b) Darlington

$R_{CS0} = R_L = 3k\Omega$ for Q_1 and Q_2

$\therefore R_{CS0}(C_{CS1} + C_{CS2}) = 3 \times 2 = 6$ ns

$R_{\pi 01} = r_{\pi 1} \| \frac{R_s + R_E}{1 + g_{m1} R_E} = r_{\pi 1} \| \frac{R_s + r_{\pi 2}}{1 + g_{m1} r_{\pi 2}}$

$= 260k \| \frac{102.6k}{2} = 42.9k\Omega$

$C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{1}{26} \frac{1}{2\pi \times 500 \times 10^6}$

$= 12.2$ pF at $I_C = 1$mA

$\therefore C_\pi = 11.8$ pF at $I_C = 1$mA

$C_b = 9.8$ pF

$\therefore C_{b1} = 0.1$ pF, $\therefore C_{\pi 1} = 2.1$ pF

$\therefore C_{\pi 1} R_{\pi 01} = 2.1 \times 42.9 = 90.1$ ns

$R_{\mu 01} = R_x + R_L + G_m R_x R_L$

$R_x = R_i \| R_s = 520k \| 100k = 83.9k\Omega$

$\therefore R_{\mu 01} = 83.9 + 3 + \frac{1}{52} \times 3000 \times 83.9$

$= 4.93\ M\Omega$

$\therefore C_{\mu 1} R_{\mu 01} = 0.4 \times 4.93 \times 10^3 = 1972$ ns

$C_{\pi 2} = 11.8$ pF

$R_{\pi 02} = r_{\pi 2} \| (\frac{1}{g_{m1}} + \frac{R_s}{\beta_1})$

$= 2.6k \| (2.6k + \frac{100k}{100})$

$= 2.6k \| 3.6k = 1.51\ k\Omega$

$\therefore C_{\pi 2} R_{\pi 02} = 17.8$ ns

$R_{\mu 0} = R_{\pi 02} + R_L + g_{m2} R_L R_{\pi 02}$

$= 1.51 + 3 + \frac{3000}{26} \times 1.51$

$= 179\ k\Omega$

$\therefore C_{\mu 2} R_{\mu 02} = 0.4 \times 179 = 71$ ns

$\therefore \Sigma T_o = 6 + 90 + 1972 + 18 + 71$

$= 2157$ ns

$\therefore f_{-3dB} = \frac{1}{2\pi \Sigma T_o} = 73.8$ kHz

Common-collector-Common emitter

$R_{CS0} C_{CS2} = 3$ ns

$R_{CS0} C_{CS1} = 0$

$C_{\pi 1} R_{\pi 01} = 90.1$ ns

$C_{\pi 2} R_{\pi 02} = 17.8$ ns

$C_{\mu 2} R_{\mu 02} = 71$ ns

$R_{\mu 01} = R_i \| R_s = 83.9\ k\Omega$

$\therefore C_{\mu 1} R_{\mu 01} = 0.4 \times 83.9 = 33.6$ ns

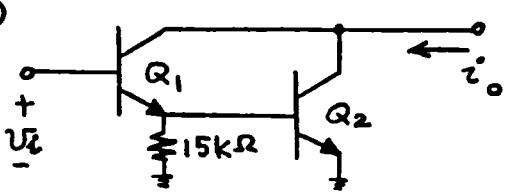
$\therefore \Sigma T_o = 3 + 90.1 + 17.8 + 71 + 33.6$

$= 215.5$ ns

$\therefore f_{-3dB} = \frac{1}{2\pi \Sigma T_o} = 738$ kHz

7.22

(a)



Effective value of $r_{\pi 2} = 15k \| 2.6k = 2.2\,k\Omega$

$$G_m = \frac{i_o}{v_i} \simeq \frac{g_{m1} R_E}{g_{m1} R_E + 1} \times g_{m2}$$

$R_E = 2.2\,k\Omega$

$$\therefore G_m = \frac{\frac{0.05}{26} \times 2200}{1 + \frac{0.05}{26} \times 2200} \times \frac{1}{26}$$

$= 31.2\ mA/V$ — for both circuits

$R_i = r_{\pi 1}(1 + g_{m1} R_E)$

$= \frac{100 \times 26}{0.05}\left(1 + \frac{0.05}{26} \times 2200\right) = 274 K\Omega$

$$\therefore \frac{v_o}{v_i} = -\frac{R_i}{R_i + R_s} G_m R_L$$

$$= -\frac{274}{274+100} \times 31.2 \times 10^{-3} \times 3000$$

$= -68.6$ — for both circuits

(b) $I_{C1} = 50\mu A \quad \therefore C_{b1} = 0.5\,pF$

$C_{\pi 1} = 2.5\,pF$

Darlington

$R_{CS0} = R_L = 3\,k\Omega$

$\therefore R_{CS0}(C_{CS1} + C_{CS2}) = 3 \times 2 = 6\,ns$

$$R_{\pi 01} = r_{\pi 1} \| \frac{R_s + R_E}{1 + g_{m1} R_E}$$

$$= 52k \| \frac{102.2K}{1 + 4.27} = 14.1\,K\Omega$$

$\therefore C_{\pi 1} R_{\pi 01} = 2.5 \times 14.1 = 35.3\,ns$

$R_{\mu 01} = R_x + R_L + G_m R_x R_L$

$R_x = R_i \| R_s = 274 \| 100 = 73.3\,K\Omega$

$\therefore R_{\mu 01} = 73.3 + 3 + 31.2 \times 73.3 \times 3$

$= 6.94\,M\Omega$

$\therefore C_{\mu 1} R_{\mu 01} = 0.4 \times 6940 = 2776\,ns$

$$R_{\pi 02} = r_{\pi 2} \| \left(\frac{1}{g_{m1}} + \frac{R_s}{\beta_1}\right)$$

$$= 2.6k \| (520 + \frac{100k}{100})$$

$= 2.6k \| 1.52k = 959\,\Omega$

$\therefore C_{\pi 2} R_{\pi 02} = 11.8 \times 0.959 = 11.3\,ns$

$R_{\mu 02} = R_{\pi 02} + R_L + g_{m2} R_L R_{\pi 02}$

$= 0.959 + 3 + \frac{3000}{26} \times 0.959$

$= 114.6\,K\Omega$

$\therefore C_{\mu 2} R_{\mu 02} = 0.4 \times 114.6 = 45.8\,ns$

$\therefore \Sigma T_o = 6 + 35.3 + 2776 + 11.3 + 45.8$

$= 2874\,ns$

$$\therefore f_{-3dB} = \frac{1}{2\pi \Sigma T_o} = 55.4\,KHz$$

Common-collector - common emitter

$R_{CS0} C_{CS2} = 3\,ns$

$R_{CS0} C_{CS1} = 0$

$C_{\pi 1} R_{\pi 01} = 35.3\,ns$

$C_{\pi 2} R_{\pi 02} = 11.3\,ns$

$C_{\mu 2} R_{\mu 02} = 45.8\,ns$

$R_{\mu 01} = R_i \| R_s = 274 \| 100 = 73.3\,K\Omega$

$\therefore C_{\mu 1} R_{\mu 01} = 0.4 \times 73.3 = 29.3\,ns$

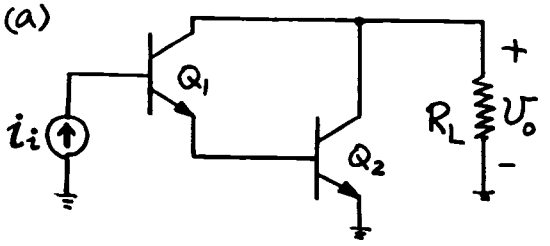
$\therefore \Sigma T_o = 3 + 35.3 + 11.3 + 45.8 + 29.3$

$= 124.7\,ns$

$$\therefore f_{-3dB} = \frac{1}{2\pi \Sigma T_o} = 1.28\,MHz$$

7.23

(a)



In both cases

$$\frac{v_o}{i_i} \simeq -\beta_1 \beta_2 R_L = -100 \times 100 \times 3K = -30M\Omega$$

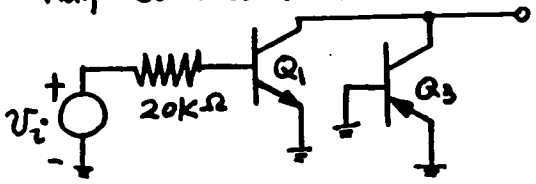
$R_i = r_{\pi 1}(1 + g_{m1} r_{\pi 2}) = 520\,K\Omega$

(b) Darlington

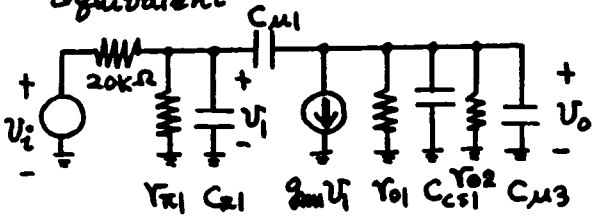
$R_{CS0}(C_{CS1} + C_{CS2}) = 6\,ns$

7.27

Half-circuits (ac)



Equivalent



$I_{C6} = \frac{9.4}{20} = 470\,\mu A$

$I_{C5} = \frac{V_T}{R_E} \ln \frac{I_{C6}}{I_{C5}} = 2.6 \ln \frac{470}{I_{C5}}\,\mu A$

$= 10\,\mu A$

$\therefore I_{C1} = I_{C3} = I_{C5}/2 = 5\,\mu A$

Q_1

$r_{o1} = \frac{V_A}{I_{C1}} = \frac{120}{5} = 24\,M\Omega$

$r_{\pi 1} = \frac{\beta}{g_{m1}} = 200 \times \frac{26}{0.005} = 1.04\,M\Omega$

$C_{\mu 1} = \frac{0.7}{\sqrt{1 + \frac{3}{0.55}}} = 0.22\,pF$

$C_{cs1} = \frac{2}{\sqrt{1 + \frac{15}{0.55}}} = 0.38\,pF$

$C_{\pi 1} + C_{\mu 1} = \frac{g_m}{2\pi f_T} = \frac{1}{2\pi \times 26 \times 500 \times 10^6}$

$= 12.2pF$ at $1mA$

$\therefore C_{\pi 1} = 12\,pF$ at $1mA$

$C_{b1} = 9\,pF$ at $1mA$

$\simeq 0$ at $5\,\mu A$

$\therefore C_{\pi 1} = 3\,pF$ at $5\,\mu A$

Q_3

$r_{o3} = \frac{50}{5} = 10M\Omega$

$C_{\mu 3} = \frac{1}{\sqrt{1 + \frac{4.4}{0.55}}} = 0.33\,pF$

$\frac{v_o}{v_i} = -\frac{r_{\pi 1}}{r_{\pi 1} + R_S} g_{m1} r_o$

$r_o = r_{o1} \| r_{o3} = 24 \| 10 = 7.06\,M\Omega$

$\frac{v_o}{v_i} = -\frac{1.04}{1.06} \times \frac{0.005}{26} \times 7.06 \times 10^6$

$= -1332$

$R_{\pi o1} = r_{\pi 1} \| R_S = 1M \| 20k = 19.6k\Omega$

$\therefore C_{\pi 1} R_{\pi o1} = 3 \times 19.6 = 59\,ns$

$R_{\mu o1} = R_{\pi o1} + r_o + g_{m1} R_{\pi o1} r_o$

$R_{\mu o1} = 19.6k + 7.06M + \frac{0.005}{26} \times 19600 \times 7.06M$

$= 33.7M\Omega$

$\therefore C_{\mu 1} R_{\mu o1} = 0.22 \times 33.7 = 7.41\,\mu s$

$(C_{cs1} + C_{\mu 3}) r_o = 0.71 \times 7.06 = 5.0\,\mu s$

$\therefore \Sigma T_o = 0.06 + 7.41 + 5 = 12.47\,\mu s$

$\therefore f_{-3dB} = \frac{1}{2\pi \Sigma T_o} = 12.8\,kHz$

7.37 (a)

$V_o = 2.5\,V$ dc

$V_{GS_2} = 2.5\,V$

$V_{t_2} = V_{to} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$

$= 0.7 + 0.4\left(\sqrt{0.6+2.5} - \sqrt{0.6}\right)$

$= 1.09\,V$

$I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)_2 (V_{GS_2} - V_{t_2})^2$

$= \frac{60\mu}{2}\frac{4}{1}(2.5-1.09)^2$

$= 237\,\mu A$

$\frac{V_o}{V_i} = \frac{-g_{m_1}}{g_{m_2} + g_{mb_2}} = \frac{-1.69m}{337\mu + 38.3\mu}$

$= -4.5$

$g_{m_1} = \sqrt{2 I_D \mu C_{ox} \frac{W}{L}}$

$= \sqrt{2(237\mu)(60\mu)(100)}$

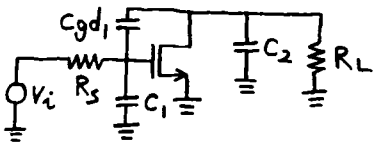
$= 1.69\,mA/V$

$g_{m_2} = \sqrt{2(237\mu)(60\mu)(4)}$

$= 337\,\mu A/V$

$g_{mb_2} = \frac{g_{m_2}\gamma}{2\sqrt{2\phi_f + V_{SB}}} = \frac{g_{m_2}\,0.4}{2\sqrt{0.6+2.5}}$

$= 38.3\,\mu A/V$



$C_{ox} = 1.73\,\frac{fF}{\mu^2}$

$C_{gs_1} = \frac{2}{3}WL\,C_{ox} + C_{ol}W$

$= 115\,fF + 30fF = 145fF$

$C_{gs_2} = \frac{2}{3}WL\,C_{ox} + C_{ol}W$

$= 4.61\,fF + 1.2\,fF$

$= 5.8\,fF$

$C_{db_1} = \frac{0.8\,(100)}{\sqrt{1+\frac{2.5}{0.6}}} = 35.2\,fF$

$C_{gd_1} = C_{ol}W = 30fF$

$C_{sb_2} = \frac{0.8\,(4)}{\sqrt{1+\frac{2.5}{0.6}}} = 1.41\,fF$

$C_1 = C_{gs_1} = 145\,fF$

$C_2 = C_{db_1} + C_{sb_2} + C_{gs_2} + C_L$

$= 142\,fF$

$C_1 R_S = 145\,ps$

$C_2 R_L = 142fF\,(2665\,\Omega)$

$= 378\,ps$

$C_{gd_1}(R_S + R_L + g_m R_S R_L)$

$= 30(1k + 2665 + 1.69m\,(1k)(2665))\,f$

$= 245\,ps$

$f_{-3dB} = \frac{1}{2\pi}\frac{10^{12}}{145+378+245}$

$= 207\,MHz$

(b)

$R_{SX} = \frac{1}{\varepsilon_c \mu C_{ox} W}$

$m1\;R_{SX} = \frac{1}{1.5M\;\;60\mu\;\;100\mu}$

$= 111\,\Omega$

$$m2\ R_{SX} = \frac{1}{1.5M\ 60\mu\ 4\mu}$$

$$= 2.78\,k$$

$$R_L' = R_{SX2} + \frac{1}{g_{m2} + g_{mb2}}$$

$$= 2.78\,k + 2.66\,k$$

$$= 5.44\,k$$

$$g_{m1}' = \frac{g_{m1}}{1 + g_{m1} R_{SX1}}$$

$$= 1.42\,m\frac{A}{V}$$

$$\frac{V_o}{V_i} = -g_{m1}' R_L' = -7.74$$

$C_1 R_S = 145\,ps$ unchanged

$$C_2 R_L' = C_2 R_L \frac{R_L'}{R_L}$$

$$= 378\,ps\,(2.04)$$

$$= 772\,ps$$

$$C_{gd1}(R_S + R_L' + g_{m1}' R_L' R_S)$$

$$= 30f(1k + 5.44k + 1.42m(5.44k)(1k))$$

$$= 425\,ps$$

$$f_{-3dB} = \frac{1}{2\pi} \frac{10^{12}}{145 + 772 + 425}$$

$$= 119\,MHz$$

```
NMOS AMP
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 0.981V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.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       = 2.500E+00 0:3       = 9.810E-01
+0:4       = 9.810E-01
**** MOSFETS
ELEMENT  0:M2       0:M1
MODEL    0:NMOS2    0:NMOS
 ID       2.369E-04  2.369E-04
 IBS     -2.501E-14  0.
 IBD     -5.000E-14 -2.501E-14
 VGS      2.499E+00  9.810E-01
 VDS      2.499E+00  2.500E+00
 VBS     -2.500E+00  0.
 VTH      1.094E+00  7.000E-01
 VDSAT    1.405E+00  2.810E-01
 BETA     2.400E-04  6.000E-03
 GAM EFF  4.000E-01  4.000E-01
 GM       3.372E-04  1.686E-03
 GMB      3.830E-05  4.353E-04
 CDTOT    2.411E-15  6.996E-14
 CGTOT    7.037E-15  1.780E-13
 CSTOT    7.380E-15  2.251E-13
 CBTOT    2.774E-15  1.217E-13
 CGS      5.804E-15  1.451E-13
 CGD      1.223E-15  3.058E-14
 ******  AC ANALYSIS                TNOM=  27.000 TEMP=  27.000
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```
   FREQ       VDB(2)
(A       )  -2.000E+01   -1.000E+01       0.        1.000E+01   2.000E+01
1.000E+06  1.30E+01+------+------+------+------+------+------+---A--+------+-
1.165E+06  1.30E+01 +      +      +      +      +      +      + A +      +
1.359E+06  1.30E+01 +      +      +      +      +      +      + A +      +
1.584E+06  1.30E+01 +      +      +      +      +      +      + A +      +
1.847E+06  1.30E+01 +      +      +      +      +      +      + A +      +
2.154E+06  1.30E+01 +      +      +      +      +      +      + A +      +
2.511E+06  1.30E+01 +      +      +      +      +      +      + A +      +
2.928E+06  1.30E+01 +      +      +      +      +      +      + A +      +
3.414E+06  1.30E+01 +      +      +      +      +      +      + A +      +
3.981E+06  1.30E+01 +      +      +      +      +      +      + A +      +
4.641E+06  1.30E+01+------+------+------+------+------+------+---A--+------+-
5.411E+06  1.30E+01 +      +      +      +      +      +      + A +      +
6.309E+06  1.30E+01 +      +      +      +      +      +      + A +      +
7.356E+06  1.30E+01 +      +      +      +      +      +      + A +      +
8.577E+06  1.30E+01 +      +      +      +      +      +      + A +      +
1.000E+07  1.30E+01 +      +      +      +      +      +      + A +      +
1.165E+07  1.30E+01 +      +      +      +      +      +      + A +      +
1.359E+07  1.30E+01 +      +      +      +      +      +      + A +      +
1.584E+07  1.30E+01 +      +      +      +      +      +      + A +      +
1.847E+07  1.30E+01 +      +      +      +      +      +      + A +      +
2.154E+07  1.30E+01+------+------+------+------+------+------+---A--+------+-
2.511E+07  1.30E+01 +      +      +      +      +      +      + A +      +
2.928E+07  1.29E+01 +      +      +      +      +      +      + A +      +
3.414E+07  1.29E+01 +      +      +      +      +      +      + A +      +
3.981E+07  1.29E+01 +      +      +      +      +      +      + A +      +
4.641E+07  1.28E+01 +      +      +      +      +      +      + A +      +
5.411E+07  1.28E+01 +      +      +      +      +      +      + A +      +
6.309E+07  1.27E+01 +      +      +      +      +      +      + A +      +
7.356E+07  1.26E+01 +      +      +      +      +      +      + A +      +
8.577E+07  1.25E+01 +      +      +      +      +      +      + A +      +
1.000E+08  1.23E+01+------+------+------+------+------+------+---A--+------+-
1.165E+08  1.20E+01 +      +      +      +      +      -      + A +      +
1.359E+08  1.17E+01 +      +      +      +      +      +      +A  +      +
1.584E+08  1.14E+01 +      +      +      +      +      +      +A  +      +
1.847E+08  1.09E+01 +      +      +      +      +      +      +A  +      +
2.154E+08  1.03E+01 +      +      +      +      +      +      A  +      +
2.511E+08  9.66E+00 +      +      +      +      +      +      A  +      +
2.928E+08  8.86E+00 +      +      +      +      +      +   A  +      +      +
3.414E+08  7.93E+00 +      +      +      +      +      +  A +      +      +
3.981E+08  6.90E+00 +      +      +      +      +      + A  +      +      +
4.641E+08  5.75E+00+------+------+------+------+------+---A--+------+------+-
5.411E+08  4.50E+00 +      +      +      +      +     A+      +      +      +
6.309E+08  3.14E+00 +      +      +      +      +  A  +      +      +      +
7.356E+08  1.67E+00 +      +      +      +     A+     +      +      +      +
8.577E+08  9.97E-02 +      +      +      +     A      +      +      +      +
1.000E+09 -1.55E+00 +      +      +      +  A  +      +      +      +      +
1.165E+09 -3.38E+00 +      +      +     A+     +      +      +      +      +
1.359E+09 -5.28E+00 +      +      +    A       +      +      +      +      +
1.584E+09 -7.30E+00 +      +      +  A  +      +      +      +      +      +
1.847E+09 -9.40E+00 +      +     +A     +      +      +      +      +      +
2.154E+09 -1.15E+01+------+------A------+------+------+------+------+------+-
```

```
   FREQ       VP(2)
(A       )     0.        5.000E+01    1.000E+02    1.500E+02    2.000E+02
                +            +            +            +            +
1.000E+06  1.79E+02+------+------+------+------+------+------+------+A-----+-
1.165E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
1.359E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
1.584E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
1.847E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
2.154E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
2.511E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
2.928E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
3.414E+06  1.79E+02 +      +      +      +      +      +      +      +A     +
3.981E+06  1.78E+02 +      +      +      +      +      +      +      +A     +
4.641E+06  1.78E+02+------+------+------+------+------+------+------+------A-----+-
5.411E+06  1.78E+02 +      +      +      +      +      +      +      +A     +
6.309E+06  1.78E+02 +      +      +      +      +      +      +      +A     +
7.356E+06  1.77E+02 +      +      +      +      +      +      +      +A     +
8.577E+06  1.77E+02 +      +      +      +      +      +      +      +A     +
1.000E+07  1.77E+02 +      +      +      +      +      +      +      +A     +
1.165E+07  1.76E+02 +      +      +      +      +      +      +      A      +
1.359E+07  1.76E+02 +      +      +      +      +      +      +      A      +
1.584E+07  1.75E+02 +      +      +      +      +      +      +      A      +
1.847E+07  1.74E+02 +      +      +      +      +      +      +      A      +
2.154E+07  1.73E+02+------+------+------+------+------+------+------+------A-----+-
2.511E+07  1.72E+02 +      +      +      +      +      +      +      A+     +
2.928E+07  1.71E+02 +      +      +      +      +      +      +      A+     +
3.414E+07  1.70E+02 +      +      +      +      +      +      +      A+     +
3.981E+07  1.68E+02 +      +      +      +      +      +      +     A +     +
4.641E+07  1.66E+02 +      +      +      +      +      +      +     A +     +
5.411E+07  1.64E+02 +      +      +      +      +      +      +    A  +     +
6.309E+07  1.62E+02 +      +      +      +      +      +      +   A   +     +
7.356E+07  1.59E+02 +      +      +      +      +      +      +   A   +     +
8.577E+07  1.55E+02 +      +      +      +      +      +      +  A    +     +
1.000E+08  1.52E+02+------+------+------+------+------+------+-----A+-----+-----+-
1.165E+08  1.48E+02 +      +      +      +      +      +     A+     +     +
1.359E+08  1.43E+02 +      +      +      +      +      +    A +     +     +
1.584E+08  1.38E+02 +      +      +      +      +      +   A  +     +     +
1.847E+08  1.33E+02 +      +      +      +      +     +A   +     +     +
2.154E+08  1.27E+02 +      +      +      +      +    +A    +     +     +
2.511E+08  1.21E+02 +      +      +      +      +   A+     +     +     +
2.928E+08  1.14E+02 +      +      +      +     A +  +      +     +     +
3.414E+08  1.08E+02 +      +      +      +    A   +      +     +     +
3.981E+08  1.01E+02 +      +      +      +   A    +      +     +     +
4.641E+08  9.45E+01+------+------+------+---A--+------+------+------+-----+-
5.411E+08  8.76E+01 +      +      +     A +   +      +      +     +     +
6.309E+08  8.07E+01 +      +      +   A   +   +      +      +     +     +
7.356E+08  7.36E+01 +      +      +  A    +   +      +      +     +     +
8.577E+08  6.65E+01 +      +      + A +   +   +      +      +     +     +
1.000E+09  5.93E+01 +      +     + A  +   +   +      +      +     +     +
1.165E+09  5.20E+01 +      +    +A    +   +   +      +      +     +     +
1.359E+09  4.48E+01 +      +   A+     +   +   +      +      +     +     +
1.584E+09  3.76E+01 +      +  A +     +   +   +      +      +     +     +
1.847E+09  3.05E+01 +      + A  +     +   +   +      +      +     +     +
2.154E+09  2.35E+01+------A------+------+------+------+------+------+------+-
                +            +            +            +            +
```

```
******

NMOS AMP, EXAMINE SMALL SIGNAL BANDWIDTH AS DC VIN VARIES
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 0.5V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END

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

     FREQ       VDB(2)
(A        )  -2.000E+01   -1.800E+01   -1.600E+01   -1.400E+01   -1.200E+01
                     +            +            +            +            +
 3.981E+07 -1.50E+01 +    +       +    +       +    +       A+   +       +
 4.641E+07 -1.50E+01 +    +       +    +       +    +       A+   +       +
 5.411E+07 -1.50E+01 +    +       +    +       +    +       A+   +       +
 6.309E+07 -1.50E+01 +    +       +    +       +    +       A+   +       +
 7.356E+07 -1.50E+01 +    +       +    +       +    +       A+   +       +
 8.577E+07 -1.50E+01 +    +       +    +       +    +       A+   +       +
 1.000E+08 -1.51E+01 +----+-------+----+-------+----+-------A+---+-------+-
 1.165E+08 -1.51E+01 +    +       +    +       +    +       A+   +       +
 1.359E+08 -1.51E+01 +    +       +    +       +    +       A+   +       +
 1.584E+08 -1.51E+01 +    +       +    +       +    +       A+   +       +
 1.847E+08 -1.51E+01 +    +       +    +       +    +       A+   +       +
 2.154E+08 -1.51E+01 +    +       +    +       +    +       A+   +       +
 2.511E+08 -1.52E+01 +    +       +    +       +    +       A+   +       +
 2.928E+08 -1.52E+01 +    +       +    +       +    +      A +   +       +
 3.414E+08 -1.52E+01 +    +       +    +       +    +      A +   +       +
 3.981E+08 -1.53E+01 +    +       +    +       +    +    A   +   +       +
 4.641E+08 -1.54E+01 +----+-------+----+-------+----+---A---+---+-------+-
 5.411E+08 -1.56E+01 +    +       +    +       +    +  A    +   +       +
 6.309E+08 -1.57E+01 +    +       +    +       +    + A     +   +       +
 7.356E+08 -1.60E+01 +    +       +    +       +    A       +   +       +
 8.577E+08 -1.62E+01 +    +       +    +     A +    +       +   +       +
 1.000E+09 -1.66E+01 +    +       +    + A     +    +       +   +       +
 1.165E+09 -1.71E+01 +    +       +  A+       +    +       +   +       +
```

```
*****

NMOS AMP
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 1.5V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END

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

     FREQ       VDB(2)
(A        )  -1.500E+01   -1.000E+01   -5.000E+00        0.    5.000E+00
                     +            +            +            +            +
 2.928E+06  2.29E-01 +    +       +    +       +    +       +    +A      +
 3.414E+06  2.29E-01 +    +       +    +       +    +       +    +A      +
 3.981E+06  2.29E-01 +    +       +    +       +    +       +    +A      +
 4.641E+06  2.28E-01 +----+-------+----+-------+----+-------+----+A------+-
 5.411E+06  2.28E-01 +    +       +    +       +    +       +    +A      +
 6.309E+06  2.28E-01 +    +       +    +       +    +       +    +A      +
 7.356E+06  2.28E-01 +    +       +    +       +    +       +    +A      +
 8.577E+06  2.27E-01 +    +       +    +       +    +       +    +A      +
 1.000E+07  2.27E-01 +    +       +    +       +    +       +    +A      +
 1.165E+07  2.26E-01 +    +       +    +       +    +       +    +A      +
 1.359E+07  2.25E-01 +    +       +    +       +    +       +    +A      +
 1.584E+07  2.24E-01 +    +       +    +       +    +       +    +A      +
 1.847E+07  2.22E-01 +    +       +    +       +    +       +    +A      +
 2.154E+07  2.19E-01 +----+-------+----+-------+----+-------+----+A------+-
 2.511E+07  2.16E-01 +    +       +    +       +    +       +    +A      +
 2.928E+07  2.11E-01 +    +       +    +       +    +       +    +A      +
 3.414E+07  2.04E-01 +    +       +    +       +    +       +    +A      +
 3.981E+07  1.96E-01 +    +       +    +       +    +       +    +A      +
 4.641E+07  1.84E-01 +    +       +    +       +    +       +    +A      +
 5.411E+07  1.68E-01 +    +       +    +       +    +       +    A       +
 6.309E+07  1.46E-01 +    +       +    +       +    +       +    A       +
 7.356E+07  1.16E-01 +    +       +    +       +    +       +    A       +
 8.577E+07  7.64E-02 +    +       +    +       +    +       +    A       +
 1.000E+08  2.29E-02 +----+-------+----+-------+----+-------+----A------+-
 1.165E+08 -4.89E-02 +    +       +    +       +    +       +    A       +
 1.359E+08 -1.45E-01 +    +       +    +       +    +       +    A       +
 1.584E+08 -2.72E-01 +    +       +    +       +    +       +   A+       +
 1.847E+08 -4.39E-01 +    +       +    +       +    +       +   A-       +
 2.154E+08 -6.56E-01 +    +       +    +       +    +       +  A +       +
 2.511E+08 -9.36E-01 +    +       +    +       +    +       + A  +       +
 2.928E+08 -1.29E+00 +    +       +    +       +    +       +A   +       +
 3.414E+08 -1.73E+00 +    +       +    +       +    +      A+    +       +
 3.981E+08 -2.26E+00 +    +       +    +       +    +     A +    +       +
 4.641E+08 -2.91E+00 +----+-------+----+-------+----+----A--+----+-------+-
```

```
*****

NMOS AMP
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 2V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END

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

    FREQ       VDB(2)
(A      )   -2.500E+01   -2.000E+01   -1.500E+01   -1.000E+01   -5.000E+00
                 +            +            +            +            +
2.511E+07 -1.31E+01 +      +     +      +     +      A +      +     +
2.928E+07 -1.31E+01 +      +     +      +     +      A +      +     +
3.414E+07 -1.31E+01 +      +     +      +     +      A +      +     +
3.981E+07 -1.31E+01 +      +     +      +     +      A +      +     +
4.641E+07 -1.31E+01 +      +     +      +     +      A +      +     +
5.411E+07 -1.31E+01 +      +     +      +     +      A +      +     +
6.309E+07 -1.31E+01 +      +     +      +     +      A +      +     +
7.356E+07 -1.31E+01 +      +     +      +     +      A +      +     +
8.577E+07 -1.32E+01 +      +     +      +     +      A +      +     +
1.000E+08 -1.32E+01-+------+-----+------+-----+-----A-+------+------+-
1.165E+08 -1.32E+01 +      +     +      +     +      A +      +     +
1.359E+08 -1.33E+01 +      +     +      +     +      A +      +     +
1.584E+08 -1.34E+01 +      +     +      +     +     A  +      +     +
1.847E+08 -1.34E+01 +      +     +      +     +     A  +      +     +
2.154E+08 -1.36E+01 +      +     +      +     +     A  +      +     +
2.511E+08 -1.37E+01 +      +     +      +     +    A   +      +     +
2.928E+08 -1.40E+01 +      +     +      +     +    A   +      +     +
3.414E+08 -1.42E+01 +      +     +      +    +A    +      +     +
3.981E+08 -1.46E+01 +      +     +      +   +A     +      +     +
4.641E+08 -1.50E+01-+------+-----+------+---A-+------+------+------+-
5.411E+08 -1.55E+01 +      +     +      +  A  +      +      +     +
6.309E+08 -1.61E+01 +      +     +      + A   +      +      +     +
7.356E+08 -1.68E+01 +      +     +     +A     +      +      +     +
```

```
*****

NMOS AMP
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 3V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END

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

    FREQ       VDB(2)
(A      )   -3.000E+01   -2.800E+01   -2.600E+01   -2.400E+01   -2.200E+01
                 +            +            +            +            +
4.641E+07 -2.38E+01 +      +     +      +     +      +     +A     +     +
5.411E+07 -2.38E+01 +      +     +      +     +      +     +A     +     +
6.309E+07 -2.38E+01 +      +     +      +     +      +     +A     +     +
7.356E+07 -2.38E+01 +      +     +      +     +      +     +A     +     +
8.577E+07 -2.38E+01 +      +     +      +     +      +     +A     +     +
1.000E+08 -2.38E+01-+------+-----+------+-----+------+-----+A-----+------+-
1.165E+08 -2.38E+01 +      +     +      +     +      +     +A     +     +
1.359E+08 -2.39E+01 +      +     +      +     +      +     +A     +     +
1.584E+08 -2.39E+01 +      +     +      +     +      +     A      +     +
1.847E+08 -2.40E+01 +      +     +      +     +      +     A      +     +
2.154E+08 -2.41E+01 +      +     +      +     +      +    A+      +     +
2.511E+08 -2.42E+01 +      +     +      +     +      +    A +     +     +
2.928E+08 -2.43E+01 +      +     +      +     +      +   A  +     +     +
3.414E+08 -2.45E+01 +      +     +      +     +     + A   +     +     +
3.981E+08 -2.47E+01 +      +     +      +     +     + A   +     +     +
4.641E+08 -2.50E+01-+------+-----+------+-----+-----A-----+------+------+-
5.411E+08 -2.53E+01 +      +     +      +     +  A  +      +     +     +
6.309E+08 -2.57E+01 +      +     +      +     + A   +      +     +     +
7.356E+08 -2.61E+01 +      +     +      +    A+     +      +     +     +
8.577E+08 -2.65E+01 +      +     +      + A   +      +      +     +     +
1.000E+09 -2.70E+01 +      +     +     A      +      +      +     +     +
```

```
*****

NMOS AMP
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 4V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END

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

    FREQ       VDB(2)
(A      )   -3.800E+01   -3.600E+01   -3.400E+01   -3.200E+01   -3.000E+01
                     +            +            +            +            +
4.641E+07 -3.00E+01 +     +      +     +      +     +      +     +      A
5.411E+07 -3.00E+01 +     +      +     +      +     +      +     +      A
6.309E+07 -3.00E+01 +     +      +     +      +     +      +     +      A
7.356E+07 -3.00E+01 +     +      +     +      +     +      +     +      A
8.577E+07 -3.00E+01 +     +      +     +      +     +      +     +      A+
1.000E+08 -3.00E+01 +-----+------+-----+------+-----+------+-----+------A+-
1.165E+08 -3.01E+01 +     +      +     +      +     +      +     +      A+
1.359E+08 -3.01E+01 +     +      +     +      +     +      +     +      A+
1.584E+08 -3.01E+01 +     +      +     +      +     +      +     +      A+
1.847E+08 -3.01E+01 +     +      +     +      +     +      +     +      A+
2.154E+08 -3.02E+01 +     +      +     +      +     +      +     +      A +
2.511E+08 -3.02E+01 +     +      +     +      +     +      +     +      A +
2.928E+08 -3.03E+01 +     +      +     +      +     +      +     +    A +
3.414E+08 -3.04E+01 +     +      +     +      +     +      +     +    A +
3.981E+08 -3.05E+01 +     +      +     +      +     +      +     +  A +
4.641E+08 -3.07E+01 +-----+------+-----+------+-----+------+-----+--A---+-
5.411E+08 -3.08E+01 +     +      +     +      +     +      +     +A     +
6.309E+08 -3.10E+01 +     +      +     +      +     +      +     A      +
7.356E+08 -3.12E+01 +     +      +     +      +     +      +   A +      +
8.577E+08 -3.14E+01 +     +      +     +      +     +      +  A  +      +
1.000E+09 -3.16E+01 +     +      +     +      +     +      + A   +      +
1.165E+09 -3.18E+01 +     +      +     +      +     +      +A    +      +
1.359E+09 -3.19E+01 +     +      +     +      +     +      A     +      +
1.584E+09 -3.21E+01 +     +      +     +      +     +     A+     +      +
1.847E+09 -3.22E+01 +     +      +     +      +     +   A +     +      +
2.154E+09 -3.23E+01 +-----+------+-----+------+-----+---A--+-----+------+-
2.511E+09 -3.24E+01 +     +      +     +      +     +  A  +     +      +
2.928E+09 -3.25E+01 +     +      +     +      +     + A   +     +      +
3.414E+09 -3.26E+01 +     +      +     +      +     +A    +     +      +
3.981E+09 -3.28E+01 +     +      +     +      +    +A     +     +      +
4.641E+09 -3.29E+01 +     +      +     +      +    A      +     +      +
5.411E+09 -3.31E+01 +     +      +     +      +   A+      +     +      +
6.309E+09 -3.33E+01 +     +      +     +      +  A  +     +     +      +
7.356E+09 -3.35E+01 +     +      +     +      + A   +     +     +      +
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NMOS AMP
VDD 1 0 5V
M2 1 1 2 0 NMOS2 W=4U L=1U
M1 2 3 0 0 NMOS W=100U L=1U
CLOAD 2 0 100FF
RS 4 3 1K
VI 4 0 5V AC
.PLOT AC VDB(2)
.PLOT AC VP(2)
.AC DEC 15 1MEG 2GIG
.MODEL NMOS NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=80FF CBS=80FF
.MODEL NMOS2 NMOS KP=60U VTO=0.7 LAMBDA=0 LD=0 GAMMA=0.4
+ TOX=20NM CGSO=300PF CGDO=300PF CBD=3.2FF CBS=3.2FF
.OPTIONS NOPAGE NOMOD
.WIDTH OUT=80
.OPTIONS SPICE
.OP
.END

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

    FREQ       VDB(2)
(A      )   -6.000E+01   -5.000E+01   -4.000E+01   -3.000E+01   -2.000E+01
                     +            +            +            +            +
3.414E+08 -3.46E+01 +     +      +     +      +     +A     +     +      +
3.981E+08 -3.46E+01 +     +      +     +      +     +A     +     +      +
4.641E+08 -3.46E+01 +-----+------+-----+------+-----+A-----+-----+------+-
5.411E+08 -3.46E+01 +     +      +     +      +     +A     +     +      +
6.309E+08 -3.46E+01 +     +      +     +      +     A      +     +      +
7.356E+08 -3.46E+01 +     +      +     +      +     A      +     +      +
8.577E+08 -3.46E+01 +     +      +     +      +     A      +     +      +
1.000E+09 -3.46E+01 +     +      +     +      +     A      +     +      +
1.165E+09 -3.47E+01 +     +      +     +      +     A      +     +      +
1.359E+09 -3.47E+01 +     +      +     +      +     A      +     +      +
1.584E+09 -3.47E+01 +     +      +     +      +     A      +     +      +
1.847E+09 -3.47E+01 +     +      +     +      +     A      +     +      +
2.154E+09 -3.47E+01 +-----+------+-----+------+-----A------+-----+------+-
2.511E+09 -3.47E+01 +     +      +     +      +     A      +     +      +
2.928E+09 -3.48E+01 +     +      +     +      +     A      +     +      +
3.414E+09 -3.48E+01 +     +      +     +      +     A      +     +      +
3.981E+09 -3.49E+01 +     +      +     +      +     A      +     +      +
4.641E+09 -3.50E+01 +     +      +     +      +     A      +     +      +
5.411E+09 -3.51E+01 +     +      +     +      +     A      +     +      +
6.309E+09 -3.52E+01 +     +      +     +      +     A      +     +      +
7.356E+09 -3.54E+01 +     +      +     +      +    A+      +     +      +
8.577E+09 -3.56E+01 +     +      +     +      +    A+      +     +      +
1.000E+10 -3.59E+01 +-----+------+-----+------+-----A+-----+-----+------+-
1.165E+10 -3.62E+01 +     +      +     +      +     A +    +     +      +
1.359E+10 -3.67E+01 +     +      +     +      +     A +    +     +      +
1.584E+10 -3.72E+01 +     +      +     +      +    A  +    +     +      +
1.847E+10 -3.79E+01 +     +      +     +      +   A   +    +     +      +
2.154E+10 -3.86E+01 +     +      +     +      +  A    +    +     +      +
2.511E+10 -3.95E+01 +     +      +     +      + A     +    +     +      +
```