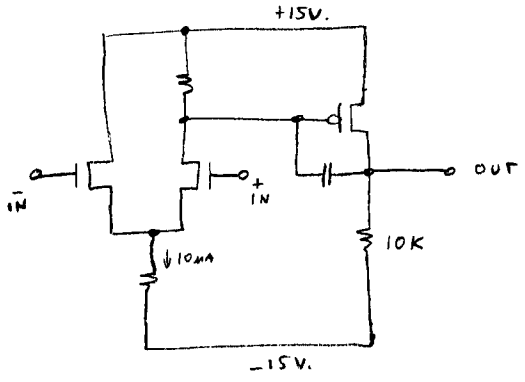


①

Stage 2 – design for 40 dB gain.

$\text{Gain} = -g_m R_L \Rightarrow \frac{1}{g_m} = \frac{R_L}{\text{gain}} = \frac{10K}{100} = 100$ $\qquad I_{DQ} = \frac{15V}{10K\Omega} = 1.5mA.$

$g_m = .01$

$g_m = \sqrt{2K'\frac{W}{L} I_{DQ}}$

$.01 = \sqrt{2(5\times10^{-6})(\frac{W}{L})(1.5\times10^{-3})}$

$10^{-4} = 2(5\times10^{-6})(\frac{W}{L})(1.5\times10^{-3})$

$\frac{W}{L} = 6667$ $\qquad L = 1\mu m$, $W = 6666\mu m$

check: $\sqrt{2(5\times10^{-6})(6667)(1.5\times10^{-3})} = .01$ ✓

Bias: $V_{GS} = ?$

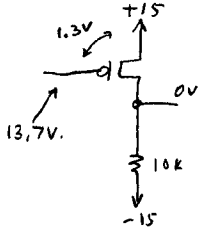
$I_D = \frac{1}{2}K'\frac{W}{L}(V_{GS}-V_{TH})^2$

$1.5\times10^{-3} = \frac{1}{2}(5\times10^{-6})(6667)(V_{GS}-V_{TH})^2$

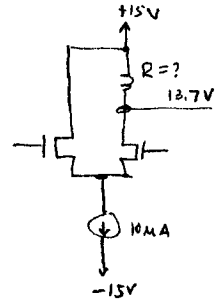
$(V_{GS}-V_{TH})^2 = 9\times10^{-2}$

$V_{GS}-V_{TH} = .3 \Rightarrow V_{GS} = 1.3$

$V_G = 15 - 1.3 = 13.7$



Stage 1: design for 40 dB gain



②

$I_D = 5\mu A \qquad V_{R_D} = 1.3$

$R = \frac{V}{I} = \frac{1.3}{5\times10^{-6}} = 260K$

$\text{gain} = g_m R_L \qquad g_m = \frac{\text{gain}}{R_L} = \frac{100}{260K}$

$g_m = 3.85\times10^{-4} = \frac{1}{2600}$

$g_m = \sqrt{2K'\frac{W}{L} I_{DQ}}$

$3.85\times10^{-4} = \sqrt{2(20\times10^{-6})\frac{W}{L}(5\times10^{-6})}$

$1.48\times10^{-5} = 2(20\times10^{-6})\frac{W}{L}(5\times10^{-6})$

$\frac{W}{L} = 740$ $\qquad L = 1\mu m$, $W = 740\mu m$

check: $\sqrt{2(20\times10^{-6})(74000)(5\times10^{-6})} = 3.85\times10^{-4}$ ✓

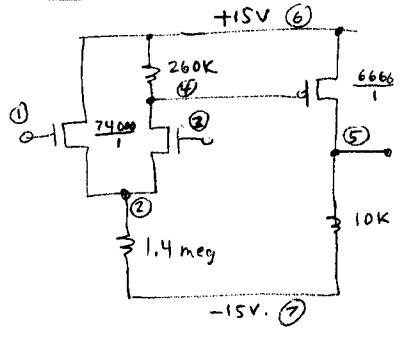
Bias: $I_D = \frac{1}{2}K'\frac{W}{L}(V_{GS}-V_{TH})^2$

$5\times10^{-6} = \frac{1}{2}(20\times10^{-6})(740)(V_{GS}-V_{TH})^2$

$(V_{GS}-V_{TH})^2 = 6.76\times10^{-4}$

$V_{GS}-V_{TH} = .026$

$V_{GS} = 1.026$ V. $\qquad R_S = \frac{14V}{10mA} = 1.4$ meg.



```
Gnucap 2005.05.15 RCS 25.20
The Gnu Circuit Analysis Package
Never trust any version less than 1.0
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See the file "COPYING" for details.
gnucap> <p4.ckt echo

"project 4" simple op-amp
m1 6 1 2 7 nnn l=1u w=740u
m2 4 3 2 7 nnn l=1u w=740u
m3 5 4 6 6 ppp l=1u w=6666u
rs 2 7 1.4meg
rd 6 4 260k
rout 5 7 10k
rb1 1 0 1meg
rb2 3 0 1meg
vin 3 1 gen
vdd 6 0 dc 15
vss 7 0 dc -15
.model nnn nmos level=1 kp=20u vto=1 cgdo=2e-10 cgso=2e-10 tox=50e-9
.model ppp pmos level=1 kp=5u vto=-1 cgdo=2e-10 cgso=2e-10 tox=50e-9
.print op v(nodes)
.op
#             v(1)        v(2)        v(3)        v(4)        v(5)        v(6)        v(7)

 300.15      0.         -1.026       0.          13.702     -0.23979     15.        -15.

.print ac v(nodes)
.ac lk
#Freq         v(1)        v(2)        v(3)        v(4)        v(5)        v(6)        v(7)

 1.K         0.50549     0.02264     0.49548     48.739      4.8345K     4.8345u     4.834
5u
.ac 1 1g dec
#Freq         v(1)        v(2)        v(3)        v(4)        v(5)        v(6)        v(7)

 1.          0.5         23.233u     0.5         49.966      4.9562K     4.9562u     4.956
2u
 10.         0.5         232.11u     0.5         49.966      4.9562K     4.9562u     4.956
2u
 100.        0.50006     0.0023204   0.49995     49.953      4.955K      4.955u      4.955
u
 1.K         0.50549     0.02264     0.49548     48.739      4.8345K     4.8345u     4.834
5u
 10.K        0.58753     0.093993    0.41534     20.235      2.0072K     2.0072u     2.007
2u
 100.K       0.60229     0.10226     0.39775     2.211       219.31      219.31n     219.3
1n
 1.Meg       0.56128     0.075462    0.44315     0.22215     21.959      21.958n     21.95
8n
 10.Meg      0.5099      0.014304    0.49032     0.028886    2.1966      2.1963n     2.196
5n
 100.Meg     0.50762     0.0092518   0.49244     0.01855     0.21889     218.88p     218.8
9p
 1.G         0.4938      0.0083927   0.50626     0.016787    0.026016    26.161p     26.05
4p

gnucap> print ac v(4) vp(4)

gnucap> ac


#Freq         v(4)        vp(4)
 1.          49.966      179.99
 10.         49.966      179.87
 100.        49.953      178.71
 1.K         48.739      167.28
 10.K        20.235      113.94
 100.K       2.211       92.99
 1.Meg       0.22215     94.767
 10.Meg      0.028886    127.04
 100.Meg     0.01855     144.4
 1.G         0.016787    41.993
gnucap> b

>rgg 1 0 1

>

gnucap> op

#             v(1)        v(2)        v(3)        v(4)        v(5)        v(6)        v(7)

 300.15      0.         -1.026       0.          13.702     -0.23979     15.        -15.

gnucap> ac

#Freq         v(4)        vp(4)
 1.          50.012      179.99
 10.         50.012      179.87
 100.        49.999      178.71
 1.K         48.785      167.28
 10.K        20.257      113.94
 100.K       2.2135      92.973
 1.Meg       0.22233     94.607
 10.Meg      0.028925    125.63
 100.Meg     0.02001     131.94
 1.G         0.031221    30.869
gnucap> print ac + vp(1) vp(3)

gnucap> ac

#Freq         v(4)        vp(4)       vp(1)       vp(3)
 1.          50.012      179.99      -180.       -2.7181n
 10.         50.012      179.87      -179.97     -27.181n
 100.        49.999      178.71      -179.73     -271.68n
 1.K         48.785      167.28      -177.44     -2.589u
 10.K        20.257      113.94      -175.82     -4.9136u
 100.K       2.2135      92.973      -175.07     -5.9561u
 1.Meg       0.22233     94.607      -141.79     -54.396u
 10.Meg      0.028925    125.63      -97.336     -543.41u
 100.Meg     0.02001     131.94      -91.542     -0.0054094
 1.G         0.031221    30.869      -91.135     -0.051855
gnucap> l

M1 ( 6 1 2 7 )  nnn  l= 1.u  w= 740.u
M2 ( 4 3 2 7 )  nnn  l= 1.u  w= 740.u
M3 ( 5 4 6 6 )  ppp  l= 1.u  w= 0.006666
Rs ( 2 7 )  1.4Meg
Rd ( 6 4 )  260.K
Rout ( 5 7 )  10.K
Rb1 ( 1 0 )  1.Meg
Rb2 ( 3 0 )  1.Meg
Vin ( 3 1 ) GENERATOR
Vdd ( 6 0 )  DC  15.
Vss ( 7 0 )  DC -15.
.model  nnn  nmos  (level=1  tnom= 27.  fc= 0.5  pb= 0.8  cj= 0.  mj= 0.5  cjsw= 0.
  mjsw= 0.5  is= 10.f  rsh= 0.  cgso= 200.p  cgdo= 200.p  cgbo= 0.  vto= 1.  gamma=
 0.  phi= 0.6  tox= 50.n  ld= 0.  uo= 600.  tpg=1  kp= 20.u)
*+(* cox= 690.6288u)
.model  ppp  pmos  (level=1  tnom= 27.  fc= 0.5  pb= 0.8  cj= 0.  mj= 0.5  cjsw= 0.
  mjsw= 0.5  is= 10.f  rsh= 0.  cgso= 200.p  cgdo= 200.p  cgbo= 0.  vto=-1.  gamma=
 0.  phi= 0.6  tox= 50.n  ld= 0.  uo= 600.  tpg=1  kp= 5.u)
*+(* cox= 690.6288u)
```

```
.print op v(nodes)
.op
.print ac v(nodes)
.ac lk
.ac 1 lg dec
Rgg ( 1 0 )  1.
gnucap> del rgg

gnucap> print ac v(5) vp(5)

gnucap> ac

#Freq       v(5)        vp(5)
 1.         10.127f     180.
 10.        1.0127p     180.
 100.       101.27p     179.97
 1.K        10.126n     179.73
 10.K       1.0115u     177.32
 100.K      91.791u     154.9
 1.Meg      0.0021447   100.41
 10.Meg     0.020571    68.419
 100.Meg    0.051191    13.373
 1.G        0.052572    1.3611
gnucap> op

#           v(1)        v(2)        v(3)        v(4)        v(5)        v(6)        v(7)

 300.15     0.          -1.026      0.          13.702      -0.23979    15.         -15.

gnucap> ac

#Freq       v(5)        vp(5)
 1.         4.9562K     -0.012936
 10.        4.9562K     -0.12936
 100.       4.955K      -1.2934
 1.K        4.8345K     -12.723
 10.K       2.0072K     -66.113
 100.K      219.31      -87.495
 1.Meg      21.959      -90.07
 10.Meg     2.1966      -93.396
 100.Meg    0.21889     -123.61
 1.G        0.026016    92.496
gnucap> EOF on stdin
```