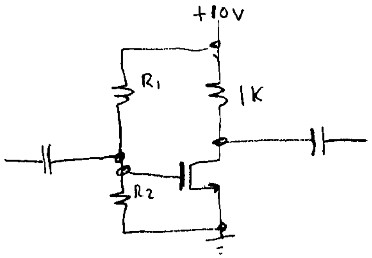
2A-1

# Example: Design using MOSFET as a resistor

Recall this amplifier: (1B-5)




$\mu = 600 \frac{cm^2}{V \cdot s} = 6 \times 10^{-2} \frac{m^2}{V \cdot s}$

$t_{ox} = .01 \mu m = 10^{-8} m$

$\Rightarrow K' = 2 \times 10^{-4}$ $\lambda = .01$

$V_{TH} = 1$ (not the same as the previous example, but that's what we will use).

$L = 1\mu$, $W = 50\mu$

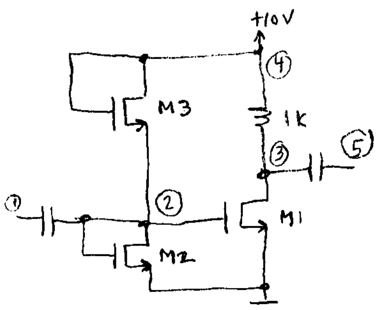
Gain $= -10$ $(-9.6)$

$V_{GS} - V_{TH} = 1 \Rightarrow V_{GS} = 2$

With resistors – $R_1 = 8$ meg, $R_2 = 2$ meg.

We want to replace $R_1$, $R_2$ with MOSFETs.

Choose a current: $1 \mu A$ (Arbitrary, keep it low). (Same as resistors).




(M2) set $\frac{W}{L}$ for $1\mu A$ with $V_{GS} = 2$

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

$10^{-6} = \left(\frac{1}{2}\right)(2 \times 10^{-4}) \frac{W}{L} (2-1)^2$

$10^{-6} = 10^{-4} \frac{W}{L}$

$\frac{W}{L} = \frac{10^{-6}}{10^{-4}} = \frac{1 \mu m}{100 \mu m}$

(M3) set $\frac{W}{L}$ for $1\mu A$ with $V_{GS} = 8$

$10^{-6} = \left(\frac{1}{2}\right)(2 \times 10^{-4}) \frac{W}{L} (8-1)^2$ ($7^2 = 49$)

$\frac{W}{L} = \frac{10^{-6}}{49 \times 10^{-4}} = \frac{1 \mu m}{4900 \mu m}$ ← very long channel. – not good.

2A-2

```
log sim-log
list
M1 ( 3 2 0 0 )  nn  l= 1.u  w= 50.u
M2 ( 2 2 0 0 )  nn  l= 100.u  w= 1.u
M3 ( 4 4 2 0 )  nn  l= 0.0049  w= 1.u
Rd ( 4 3 )  1.K
Vdd ( 4 0 )  DC  10.
Cin ( 1 2 )  1.u
Cout ( 3 5 )  1.u
Vin ( 1 0 ) GENERATOR
.model  nn  nmos  (level=1  tnom= 27.  fc= 0.5  pb= 0.8  cj= 0.  mj= 0.5  cjsw= 0.  mjsw= 0.5  i
s= 10.f  rsh= 0.  cgso= 0.  cgdo= 0.  cgbo= 0.  vto= 1.  gamma= 0.  phi= 0.6  lambda= 0.01  ld=
0.  uo= 600.  tpg=1  kp= 200.u)
*+(* cox= 0.)
print op v(nodes)
op
#          v(1)        v(2)        v(3)        v(4)        v(5)
 300.15    0.          2.0251      4.5094      10.         0.
print op id(m*)
op
#          id(M1)      id(M2)      id(M3)
 300.15    0.0054906   1.072u      1.072u
print ac v(nodes)
ac 1k
#Freq      v(1)        v(2)        v(3)        v(4)        v(5)
 1.K       1.          1.          10.178      101.78n     10.178
print ac z(vin)
ac
#Freq      z(Vin)
 1.K       413.31K   <- why so low?
print op region(m*)
op
#          region(M1)  region(M2)  region(M3)
 300.15    7.          7.          7.
print op gds(m*)
op
#          gds(M1)     gds(M2)     gds(M3)
 300.15    52.537u     10.507n     9.9285n
build                     ^-----------^----- R ≈ 100 meg
m3 4 4 2 2 nn w=1u l=4900u

list
M1 ( 3 2 0 0 )  nn  l= 1.u  w= 50.u
M2 ( 2 2 0 0 )  nn  l= 100.u  w= 1.u
M3 ( 4 4 2 2 )  nn  l= 0.0049  w= 1.u
Rd ( 4 3 )  1.K
Vdd ( 4 0 )  DC  10.
Cin ( 1 2 )  1.u
Cout ( 3 5 )  1.u
Vin ( 1 0 ) GENERATOR
.model  nn  nmos  (level=1  tnom= 27.  fc= 0.5  pb= 0.8  cj= 0.  mj= 0.5  cjsw= 0.  mjsw= 0.5  i
s= 10.f  rsh= 0.  cgso= 0.  cgdo= 0.  cgbo= 0.  vto= 1.  gamma= 0.  phi= 0.6  lambda= 0.01  ld=
0.  uo= 600.  tpg=1  kp= 200.u)
*+(* cox= 0.)
print op v(nodes)
op
#          v(1)        v(2)        v(3)        v(4)        v(5)
 300.15    0.          2.0251      4.5093      10.         0.
save amp2a1.ckt
```

HW
4.2
p.361: 19, 20, 21, 22
p.362: 32, 33
4.3 all exercises

2A 3

```
get amp2a1.ckt
'
print op v(nodes)
op
#           v(1)       v(2)       v(3)       v(4)       v(5)
 300.15     0.         2.0251     4.5093     10.        0.
print op gm(m*)
op
#           gm(M1)     gm(M2)     gm(M3)
 300.15     0.010713   2.0916u    307.4n
list
M1 ( 3 2 0 0 )  nn  l= 1.u  w= 50.u
M2 ( 2 2 0 0 )  nn  l= 100.u  w= 1.u
M3 ( 4 4 2 2 )  nn  l= 0.0049  w= 1.u
Rd ( 4 3 )  1.K
Vdd ( 4 0 )  DC  10.
Cin ( 1 2 )  1.u
Cout ( 3 5 )  1.u
Vin ( 1 0 ) GENERATOR
.model  nn  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= 0.  cgdo= 0.  cgbo= 0.  vto= 1.  gamma= 0.  ph
i= 0.6  lambda= 0.01  ld= 0.  uo= 600.  tpg=1  kp= 200.u)
*+(* cox= 0.)
del m2
build
i3 2 0 dc 1u

op
#           gm(M1)     gm(M3)
 300.15     0.012808   296.57n
print op v(nodes)
op
#           v(1)       v(2)       v(3)       v(4)       v(5)
 300.15     0.         2.2563     1.9547     10.        0.
build
build

list
M1 ( 3 2 0 0 )  nn  l= 1.u  w= 50.u
M3 ( 4 4 2 2 )  nn  l= 0.0049  w= 1.u
Rd ( 4 3 )  1.K
Vdd ( 4 0 )  DC  10.
Cin ( 1 2 )  1.u
Cout ( 3 5 )  1.u
Vin ( 1 0 ) GENERATOR
.model  nn  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= 0.  cgdo= 0.  cgbo= 0.  vto= 1.  gamma= 0.  ph
i= 0.6  lambda= 0.01  ld= 0.  uo= 600.  tpg=1  kp= 200.u)
*+(* cox= 0.)
I3 ( 2 0 )  DC  1.u
build
i3 2 0 dc 1.1u

op
#           v(1)       v(2)       v(3)       v(4)       v(5)
 300.15     0.         1.9376     5.369      10.        0.
print ac v(nodes) z(vin)
ac 1k
#Freq       v(1)       v(2)       v(3)       v(4)       v(5)       z(Vin)
 1.K        1.         1.         9.463      94.627n    9.463      3.1086Meg
print op gm(m3) gds(m3)
op
#           gm(M3)     gds(M3)
 300.15     311.5n     10.179n
get amp2a1.ckt
'
print op v(nodes)
op
#           v(1)       v(2)       v(3)       v(4)       v(5)
```

2A 4

```
 300.15     0.         2.0251     4.5093     10.        0.
print ac v(nodes) z(vin)
ac 1k
#Freq       v(1)       v(2)       v(3)       v(4)       v(5)       z(Vin)
 1.K        1.         1.         10.178     101.78n    10.178     413.31K
del m3
build
i3 4 2 dc 1u

op
#           v(1)       v(2)       v(3)       v(4)       v(5)
 300.15     0.         1.9902     4.8594     10.        0.
ac
#Freq       v(1)       v(2)       v(3)       v(4)       v(5)       z(Vin)
 1.K        1.         1.         9.8979     98.979n    9.8979     492.71K
```

Course web site:

http://www.kettering.edu/~adavis/class/ee420-electronics-2

gnucap on sun:

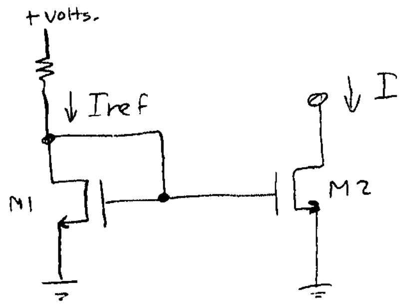
put ~adavis/public/bin in your path then "gnucap"

or -- "~adavis/public/bin/gnucap"

## Current mirror

→ How to make a current source.

You need two parts: A reference
The source




If M1 and M2 are identical, and we ignore $\lambda$ and it remains in saturation
$I = I_{ref}$.

We can make unequal currents by scaling W and L.

For 2I use 2W, etc.

Basis ---- $V_{GS}$ is the same, so I should be the same.

We can connect as many as we want:

To design: set M1 W & L for desired reference current
Size M2 to get the desired current there.

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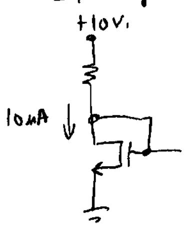
Example: $I_{ref} = 10\mu A$  $I = 100\mu A$  $V_{DD} = 10V.$
$V_{TH} = 2$  $K' = 2\times10^{-4}\ \frac{A}{V^2}$  $L_{min} = W_{min} = 1\mu m.$




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

We can choose W, L then find $V_{GS}$
or choose $V_{GS}$ then find W/L.

Let's choose W = L, then find $V_{GS}$

$10^{-5} = \frac{1}{2}(2\times10^{-4})(1)(V_{GS}-V_{TH})^2$

$(V_{GS}-V_{TH})^2 = \frac{10^{-5}}{10^{-4}} = .1$  $V_{GS}-V_{TH} = .316$  $V_{GS} = 2.316$



Now, size the mirror:

For 10× the current, use 10× the width.
W = 10 μm.

Caveats: ① It only works in saturation.
② Lambda really matters, sometimes.

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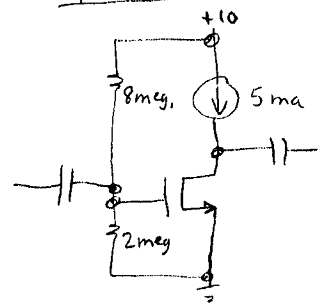
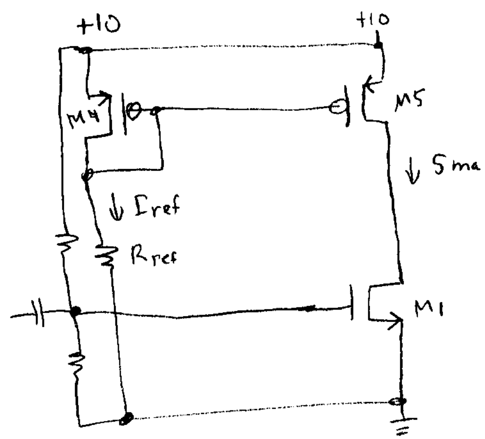
Example  Start with the example from 1B-8
same process as before.
P-channel process  $K' = 1\times10^{-4}$
otherwise the same.




Want to use a MOSFET for the current source.
Use P-channel MOSFETS.




Choose $I_{ref} = .1$ ma., W=L

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

$.1\times10^{-6} = \frac{1}{2}(10^{-4})\frac{1}{1}(V_{GS}-V_{TH})^2$

$\frac{.1\times10^{-6}}{.5\times10^{-4}} = (V_{GS}-V_{TH})^2$

$.002 = (V_{GS}-V_{TH})^2$

$.045 = V_{GS}-V_{TH}$

$V_{GS} = V_{TH}+.045 = 2.045$

$R_{ref} = \frac{8V}{.1ma} = 80K$

Then make W of $M_5 = \frac{5}{.1}\times$ width of $M_4$
$= 50\mu m.$

Use MOSFET's for the resistors too ...