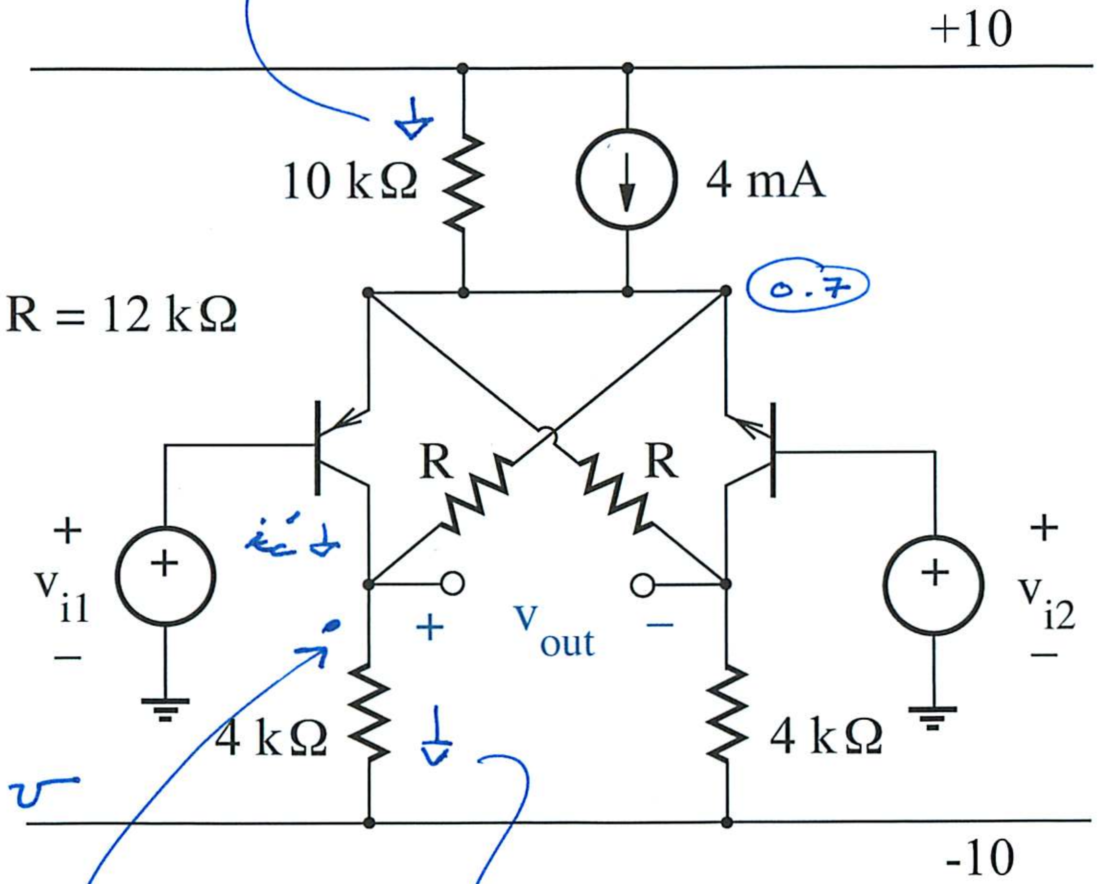
9.4

Biasing calculation for $v_{i1} = v_{i2} = 0$

$\frac{9.3}{10} = 0.93\ mA$



$g_m = \frac{2.4\ mA}{25.9\ mV}$

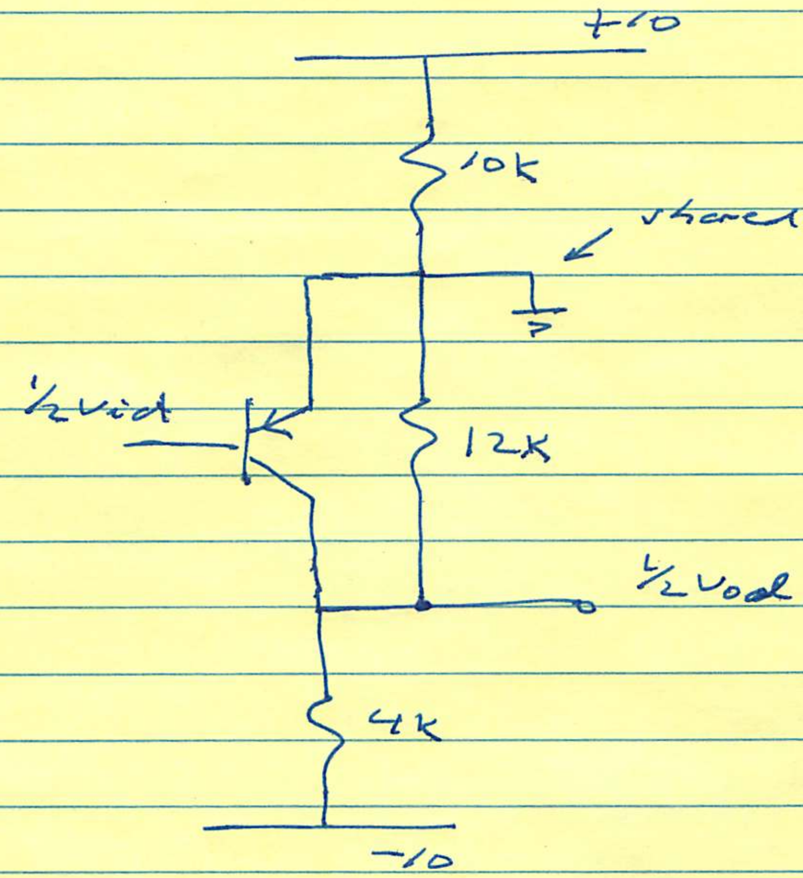
$= 92.7 \times 10^{-3}\ \mho$

$\frac{1}{2}(4.93\ mA) = 2.47\ mA$

$-10 + 4(2.47) = -0.12\ V$

$i_c'|_Q = 2.47\ mA - \frac{0.7 - (-0.12)}{12} = \underline{2.4\ mA}$

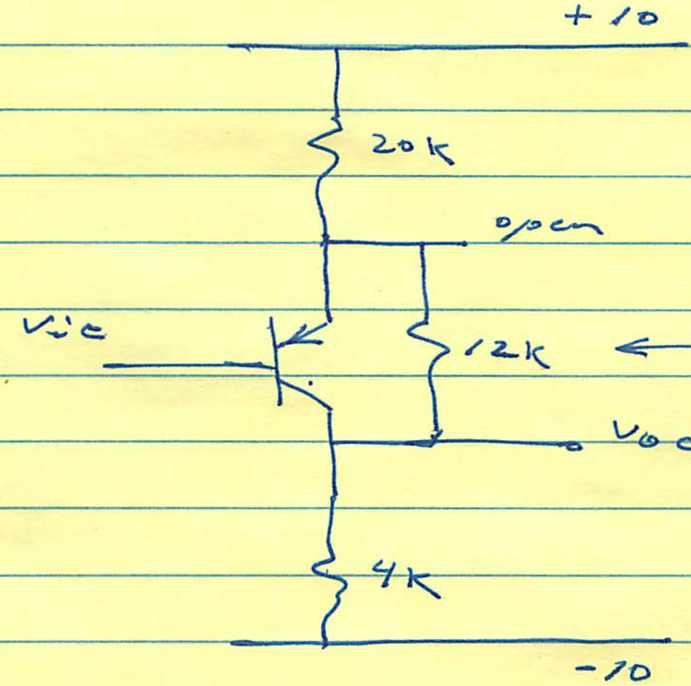
differential mode ac half circuit



$$\frac{\tfrac{1}{2} v_{od}}{\tfrac{1}{2} v_{id}} = A_{dd} = -g_m\,(\underbrace{12K \parallel 4K}_{3K})$$

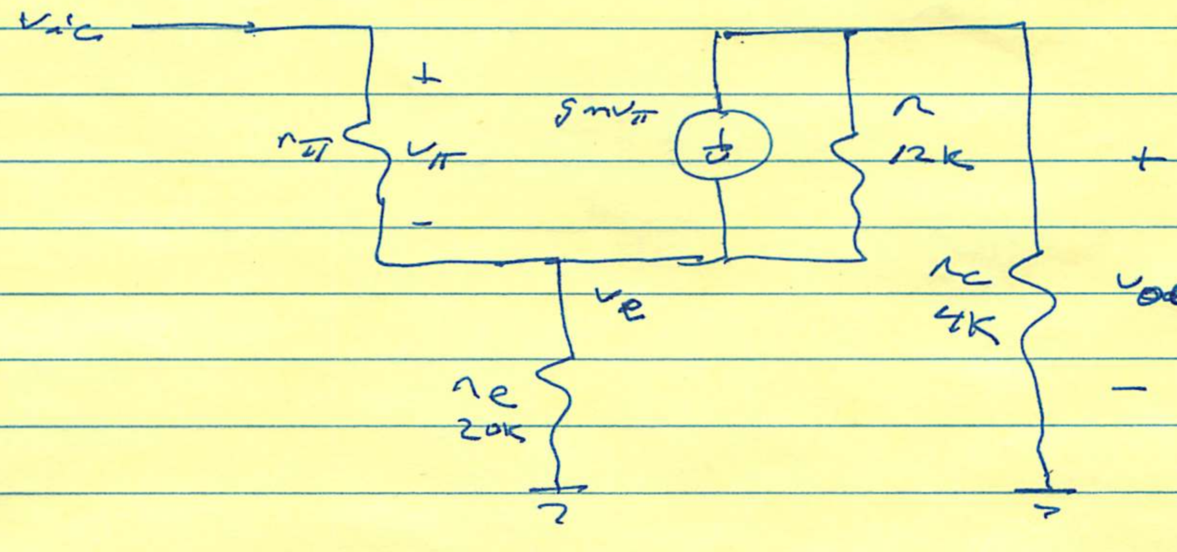
$$A_{dd} = -\,92.7 \times 10^{-3}\,\mho \times 3 \times 10^{3}\,\Omega = \underline{-278}$$

Common mode ac half circuit



This invalidates the simple gain expression in the ~~[illegible]~~ formula sheet.

small-signal circuit



$$r_\pi = \frac{\beta_0}{g_m} = \frac{100}{g_m} = 1.08\text{K}$$

$$\frac{1}{R}$$

$$g_\pi (v_{ic} - v_e) + g_m (v_{ic} - v_e) + G (v_{oc} - v_e)$$

$$= G_e v_e$$

$$g_m (v_{ic} - v_e) + G (v_{oc} - v_e) + G_c v_{oc} = 0$$

$$\begin{pmatrix} G_e + g_m + g_\pi + G & -G \\ -g_m - G & G + G_c \end{pmatrix} \begin{pmatrix} v_e \\ v_{oc} \end{pmatrix} = \begin{pmatrix} g_m + g_\pi \\ -g_m \end{pmatrix} v_{ic}$$

$$v_{oc} = v_{ic} \frac{\det \begin{pmatrix} G_e + g_m + g_\pi + G & g_m + g_\pi \\ -g_m - G & -g_m \end{pmatrix}}{\det \begin{pmatrix} G_e + g_m + g_\pi + G & -G \\ -g_m - G & G + G_c \end{pmatrix}}$$

$$\frac{v_{oc}}{v_{ic}} = A_{cc} = \frac{-g_m G_e + G g_\pi}{G_e G + g_\pi G + G_c G_e + G_c g_m + G_c g_\pi + G_e G}$$

$$= \frac{-\beta_0 R R_c + R_e R_c}{r_\pi R_c + R_e R_c + r_\pi R + \beta_0 R_e R + R_e R + R_e r_\pi}$$

$$= \frac{-\beta_0 R_c + \frac{R_e R_c}{R}}{r_\pi + (1+\beta_0) R_e + \frac{r_\pi R_c + R_e R_c + R_e r_\pi}{R}}$$

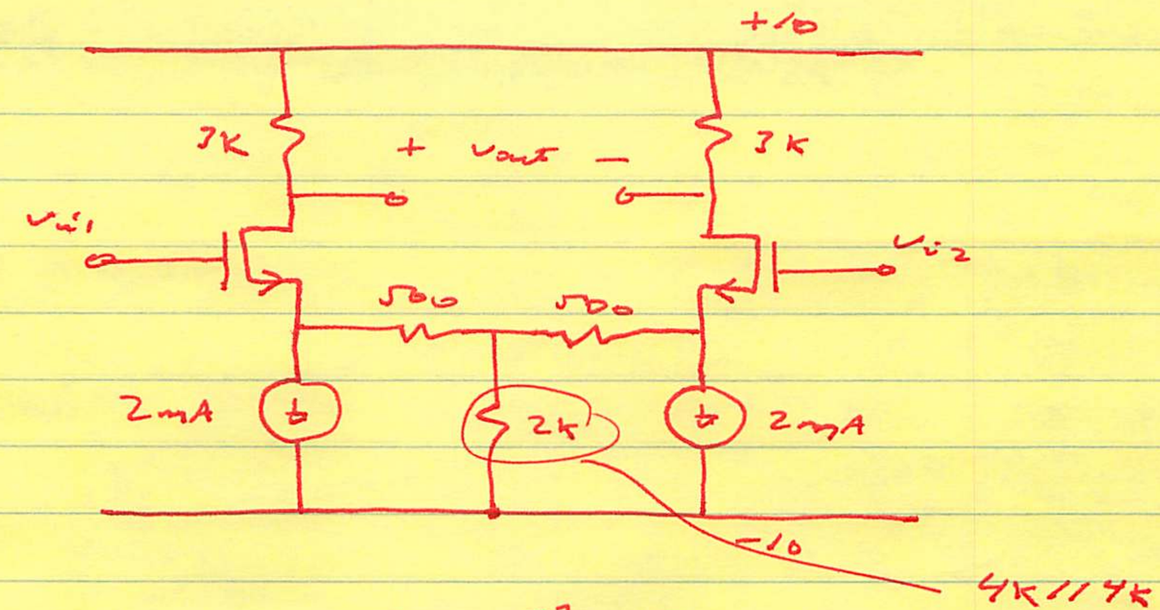
This reduces to the proper form as $R \to \infty$

$$A_{CC} = -\frac{400\text{k} - \frac{10\text{k}}{3}}{1.08\text{k} + 1010\text{k} + \frac{1.08\text{k}}{3} + 2.5\text{k} + \frac{5}{6}(1.08\text{k})}$$

$$= -0.391$$

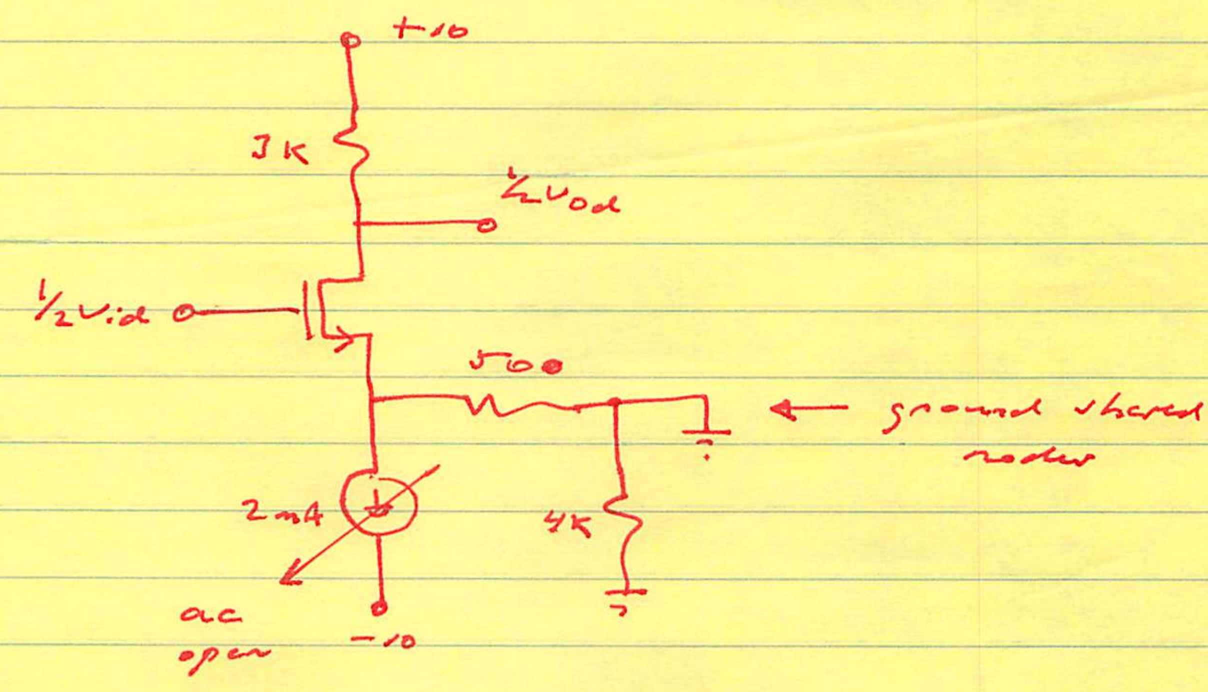
Ugh!

9.5



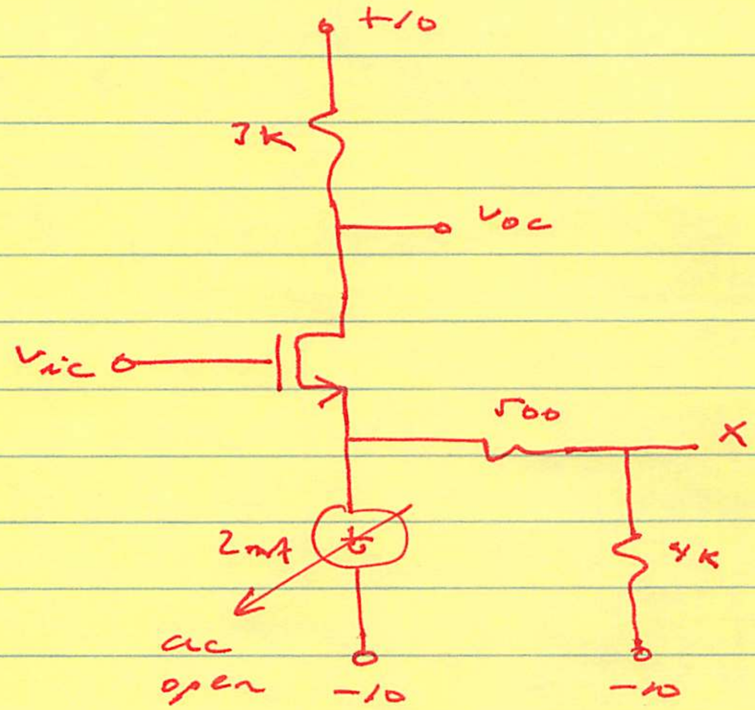
$g_{m1} = g_{m2} = 5 \times 10^{-3}$ ℧

Half circuit for Add



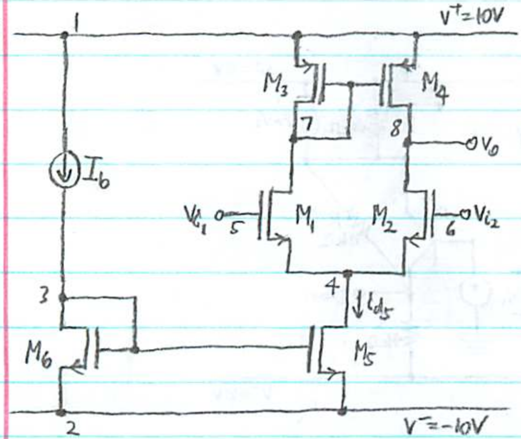
$$A_{dd} = \frac{\frac{1}{2}v_{od}}{\frac{1}{2}v_{id}} = \frac{-g_m(3k)}{1 + g_m(0.5k)} = -4.29$$

Half circuit for A_{cc}



$$A_{cc} = \frac{v_{oc}}{v_{ic}} = \frac{-g_m(3K)}{1 + g_m(4.5K)} = -0.638$$

9.57



$k_n' = 50 \frac{\mu A}{V^2}$ $\quad A_{vd} = 280$

$V_{Tn} = 0.5V$ $\quad i_{d5}|_Q = 150 \mu A$

$\lambda_n = 0.05 \frac{1}{V}$ $\quad \left(\frac{W}{L}\right)_{n_1} = ?$

$\gamma_n = 0.2 \sqrt{V}$ $\quad \left(\frac{W}{L}\right)_{n_2} = ?$

$k_p' = 50 \frac{\mu A}{V^2}$ $\quad \left(\frac{W}{L}\right)_{p_3} = ?$

$V_{Tp} = -0.5V$ $\quad \left(\frac{W}{L}\right)_{p_4} = ?$

$\lambda_p = 0.08 \frac{1}{V}$ $\quad \left(\frac{W}{L}\right)_{n_5} = ?$

$\gamma_p = 0.2 \sqrt{V}$ $\quad \left(\frac{W}{L}\right)_{n_6} = ?$

Start w/ crude estimates at 1V so quiescent M_2 source is set at $-1V$

$v_{ds_2}|_Q = |v_{ds_4}|_Q| = 5.5V$ if quiescent value for v_o partitions equal $|v_{ds}|$ voltages

$i_{d_2}|_Q = |i_{d_4}|_Q| = 75 \mu A$

$r_{o_2} = \frac{\frac{1}{\lambda_n} + |v_{ds_2}|_Q|}{|i_{d_2}|_Q|}$ $\quad r_{o_4} = \frac{\frac{1}{\lambda_p} + |v_{ds_4}|_Q|}{|i_{d_4}|_Q|}$ $\quad r_{o_2} // r_{o_4} = \frac{1}{\frac{1}{r_{o_2}} + \frac{1}{r_{o_4}}}$ $\quad A_{vd} = g_m (r_{o_2} // r_{o_4})$ $\quad v_{ds_5}|_Q = 9V$

$r_{o_2} = 3.40 \times 10^5 \Omega$ $\quad r_{o_4} = 2.40 \times 10^5 \Omega$ $\quad r_{o_2} // r_{o_4} = 1.41 \times 10^5 \Omega$ $\quad g_m = \frac{A_{vd}}{r_{o_2} // r_{o_4}}$ $\quad v_{ds_6}|_Q = 1V$

$g_m = 1.99 \times 10^{-3} \mho$

$\left(\frac{W}{L}\right)_{n_2} = \frac{g_m^2}{2 k_n' i_{d_2}|_Q (1 + \lambda_n v_{ds_2}|_Q)}$ $\quad \left(\frac{W}{L}\right)_{p_3} = \left(\frac{W}{L}\right)_{p_4} = \left(\frac{W}{L}\right)_{n_5} = 4\mu$ $\quad \left(\frac{W}{L}\right)_{n_6} = \left(\frac{W}{L}\right)_{n_5} \left(\frac{1 + \lambda_n v_{ds_5}|_Q}{1 + \lambda_n v_{ds_6}|_Q}\right)$

$\left(\frac{W}{L}\right)_{n_2} = 414.2\mu = \left(\frac{W}{L}\right)_{n_1}$ $\quad \left(\frac{W}{L}\right)_{n_6} = 5.52\mu$

From PSpice simulation, $\left(\frac{W}{L}\right)_{n_1} = \left(\frac{W}{L}\right)_{n_2} = 466.1\mu$ w/ $A_{vd} = 280.007$ and $i_{d5}|_Q = 1.49 \times 10^{-4} A$

+.3

```
* EE-348L Homework Set 7



* Problem 9.57
V+ 1 0 10
V- 2 0 -10
Vi1 5 0 ac 1m
Vi2 0 6 ac 1m
Ib 1 3 dc 150u
M6 3 3 2 2 MOSN W = 5.5u L = 1u
M5 4 3 2 2 MOSN W = 4u L = 1u
M1 7 5 4 4 MOSN W = 466.1u L = 1u
M2 8 6 4 4 MOSN W = 466.1u L = 1u
M3 7 7 1 1 MOSP W = 4u L = 1u
M4 8 7 1 1 MOSP W = 4u L = 1u

.model MOSN NMOS(kp = 50u, VTO = 0.5, LAMBDA  = 0.05, GAMMA = 0.2)
.model MOSP PMOS(kp = 20u, VTO = -0.5, LAMBDA = 0.08, GAMMA = 0.2)

.op
.ac dec 100 1k 1G
.probe

.end
```

* EE-348L Homework Set 7

Temperature: 27.0

Date: November 16, 2015

Time: 11:46:40

```
**** 11/16/15 11:46:26 ****** PSpice Lite (October 2012) ****** ID# 10813 ****

 * EE-348L Homework Set 7


 ****     CIRCUIT DESCRIPTION


******************************************************************************




* Problem 9.57
V+ 1 0 10
V- 2 0 -10
Vi1 5 0 ac 1m
Vi2 0 6 ac 1m
Ib 1 3 dc 150u
M6 3 3 2 2 MOSN W = 5.5u L = 1u
M5 4 3 2 2 MOSN W = 4u L = 1u
M1 7 5 4 4 MOSN W = 466.1u L = 1u
M2 8 6 4 4 MOSN W = 466.1u L = 1u
M3 7 7 1 1 MOSP W = 4u L = 1u
M4 8 7 1 1 MOSP W = 4u L = 1u

.model MOSN NMOS(kp = 50u, VTO = 0.5, LAMBDA  = 0.05, GAMMA = 0.2)
.model MOSP PMOS(kp = 20u, VTO = -0.5, LAMBDA = 0.08, GAMMA = 0.2)

.op
.ac dec 100 1k 1G
.probe

.end

**** 11/16/15 11:46:26 ****** PSpice Lite (October 2012) ****** ID# 10813 ****

 * EE-348L Homework Set 7


 ****     MOSFET MODEL PARAMETERS


******************************************************************************




               MOSN              MOSP
               NMOS              PMOS
       LEVEL     1                 1
           L   100.000000E-06   100.000000E-06
           W   100.000000E-06   100.000000E-06
         VTO     .5               -.5
          KP    50.000000E-06    20.000000E-06
       GAMMA     .2                .2
         PHI     .6                .6
```

LAMBDA	.05	.08
IS	10.000000E-15	10.000000E-15
JS	0	0
PB	.8	.8
PBSW	.8	.8
CJ	0	0
CJSW	0	0
CGSO	0	0
CGDO	0	0
CGBO	0	0
TOX	0	0
XJ	0	0
UCRIT	10.000000E+03	10.000000E+03
DIOMOD	1	1
VFB	0	0
LETA	0	0
WETA	0	0
U0	0	0
TEMP	0	0
VDD	5	5
XPART	0	0

**** 11/16/15 11:46:26 ****** PSpice Lite (October 2012) ****** ID# 10813 ****

* EE-348L Homework Set 7

**** SMALL SIGNAL BIAS SOLUTION TEMPERATURE = 27.000 DEG C

****

NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE	NODE	VOLTAGE
(1)	10.0000	(2)	-10.0000	(3)	-8.4928	(4)	-.5667
(5)	0.0000	(6)	0.0000	(7)	8.2218	(8)	8.2218

VOLTAGE SOURCE CURRENTS

NAME	CURRENT
V+	-2.993E-04
V-	2.993E-04
Vi1	0.000E+00
Vi2	0.000E+00

TOTAL POWER DISSIPATION 5.99E-03 WATTS

**** 11/16/15 11:46:26 ****** PSpice Lite (October 2012) ****** ID# 10813 ****

* EE-348L Homework Set 7

**** OPERATING POINT INFORMATION TEMPERATURE = 27.000 DEG C

****

**** MOSFETS

NAME	M6	M5	M1	M2	M3
MODEL	MOSN	MOSN	MOSN	MOSN	MOSP
ID	1.50E-04	1.49E-04	7.46E-05	7.46E-05	-7.46E-05
VGS	1.51E+00	1.51E+00	5.67E-01	5.67E-01	-1.78E+00
VDS	1.51E+00	9.43E+00	8.79E+00	8.79E+00	-1.78E+00
VBS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VTH	5.00E-01	5.00E-01	5.00E-01	5.00E-01	-5.00E-01
VDSAT	1.01E+00	1.01E+00	6.67E-02	6.67E-02	-1.28E+00
Lin0/Sat1	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00
if	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00
ir	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00
TAU	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00	-1.00E+00
GM	2.98E-04	2.96E-04	2.24E-03	2.24E-03	1.17E-04
GDS	6.97E-06	5.07E-06	2.59E-06	2.59E-06	5.23E-06
GMB	3.85E-05	3.83E-05	2.89E-04	2.89E-04	1.51E-05
CBD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CBS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CGSOV	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CGDOV	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CGBOV	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CGS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CGD	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CGB	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

NAME	M4
MODEL	MOSP
ID	-7.46E-05
VGS	-1.78E+00
VDS	-1.78E+00
VBS	0.00E+00
VTH	-5.00E-01
VDSAT	-1.28E+00
Lin0/Sat1	-1.00E+00
if	-1.00E+00
ir	-1.00E+00
TAU	-1.00E+00
GM	1.17E-04
GDS	5.23E-06
GMB	1.51E-05
CBD	0.00E+00
CBS	0.00E+00
CGSOV	0.00E+00
CGDOV	0.00E+00
CGBOV	0.00E+00
CGS	0.00E+00
CGD	0.00E+00
CGB	0.00E+00