TABLE 1. Design Summary

Parameter	Specification	Calculated	Simulated
V_A	NA	4.0	4.0
V_B	NA	3.7	3.7
$\|Av\|$	> 77.5 dB	135.2 dB	78.3 dB
f_{3dB}	> 100 KHz	103.7 KHz	123 KHz
f_{unity}	> 40 MHz	73.3 Mhz	41.7 MHz
Output Voltage Swing	> 3 V	3.7 V	3.2 V
Power Dissipation	< 100 uW	8.84 uW ?	95.9 uW

88.4?

W/L ? −2

~~Report should~~

Chapter 2

Engineering Decisions

2.1 Drain Current Id

Considering the maximum power dissipation was 100uW and the Vdd was 5 volts, we immediately knew that the maximum drain current was 20uA. Id can be controlled in two ways.

- Increasing the width effectively increases the current.
- Decreasing the voltage (Va and Vb) increases the current.

There was a tradeoff involved, however. Increasing the current will increase the second-pole breakpoint frequency f3db, but will decrease the gain. We want the gain to be as high as possible.

2.2 Choice of Va and Vb

It was clear from the start that the choice of Va and Vb were crucial because they would have major implications as far as current, power, and frequency are concerned. The constraints, coupled with some trial-and-error, helped us find the optimal choice. The process behind choosing Va and Vb is outlined below.

- As discussed in the previous section, the power constraint makes the maximum drain current 20 uA. We begain by assuming that Id1 (stage 1) and Id2 (stage 2) were each 10 uA, yielding a total drain current of 20 uA.
- We assumed the minimum length (1.5 um) and minimum width (6 um) to begin with and using a saturation current of 10 uA, calculated that Va and Vb both are 4.7 Volts. Using this as a starting point, we kept lowering the voltages (keeping them equal) until Va = Vb = 4 Volts. At this point, we noticed that the gain specification was met (well over 7500) but the 3 dB frequency was ~~too~~ too low (by 50 percent).
- In order to raise the 3 dB frequency, we had to adjust the open-circuit time constants associated with the Miller Approximation. As shown in the Miller equivalent circuit following the report, f3db is dependent on the capacitances Ca, Cb and Cc, which in turn are dependent on the gain (Av1 and Av2).

- In this configuration, Cc was *significantly* higher (by 3 orders of magnitude) than Ca and Cb. Clearly, the time constant associated with Capacitor C was the dominant term. Since w(3dB) is the inverse of the sum of the individual open-circuit time constants, decreasing the capacitance of C would effectively increase the 3 dB frequency. Thus, as illustrated by the calculations accompanying the Miller Approximation circuit, Av2 must decrease, thereby resulting in a decrease in Vb. Vb was set at 3.7 Volts. Keeping Va at 4 Volts was sufficient.

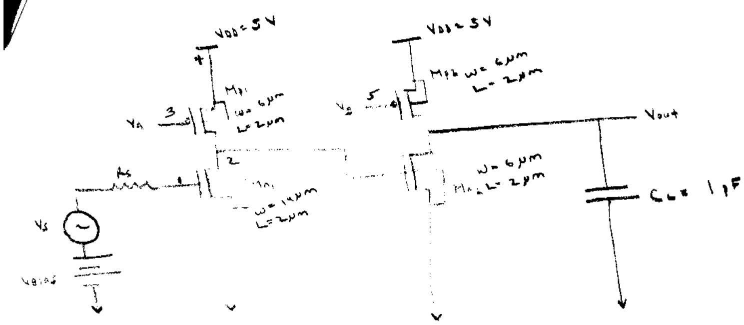
2.3 Lengths and Widths

The final adjustments involved the lengths and the widths of the 4 MOSFETS. For the PMOS transistors, keeping the dimensions close to the minumum configurations seemed optimal. The widths were kept at their minimum (6 um) and the length was chosen in such a way that there was a ratio of 3:1.

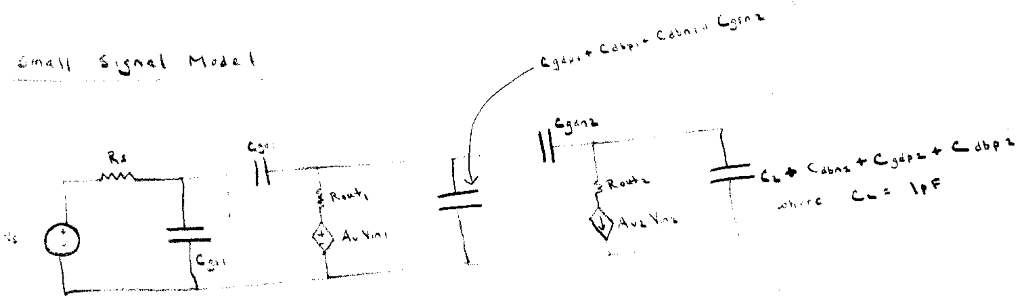
For the NMOS transistors, on the other hand, there was greater flexibility. We found that increasing the width further increased the 3 dB frequency as well as the overall gain because increasing the width increases Ca. As Ca increases, the time constants are closer in value, increasing ω(3dB).

Again a good report! – a bit long though.

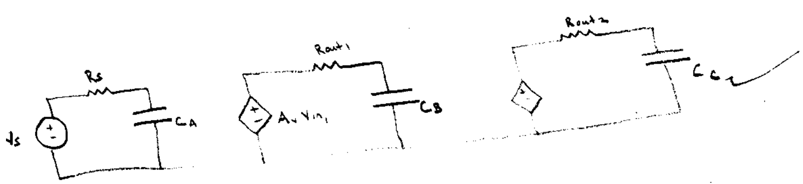
Final Circuit



Small Signal Model



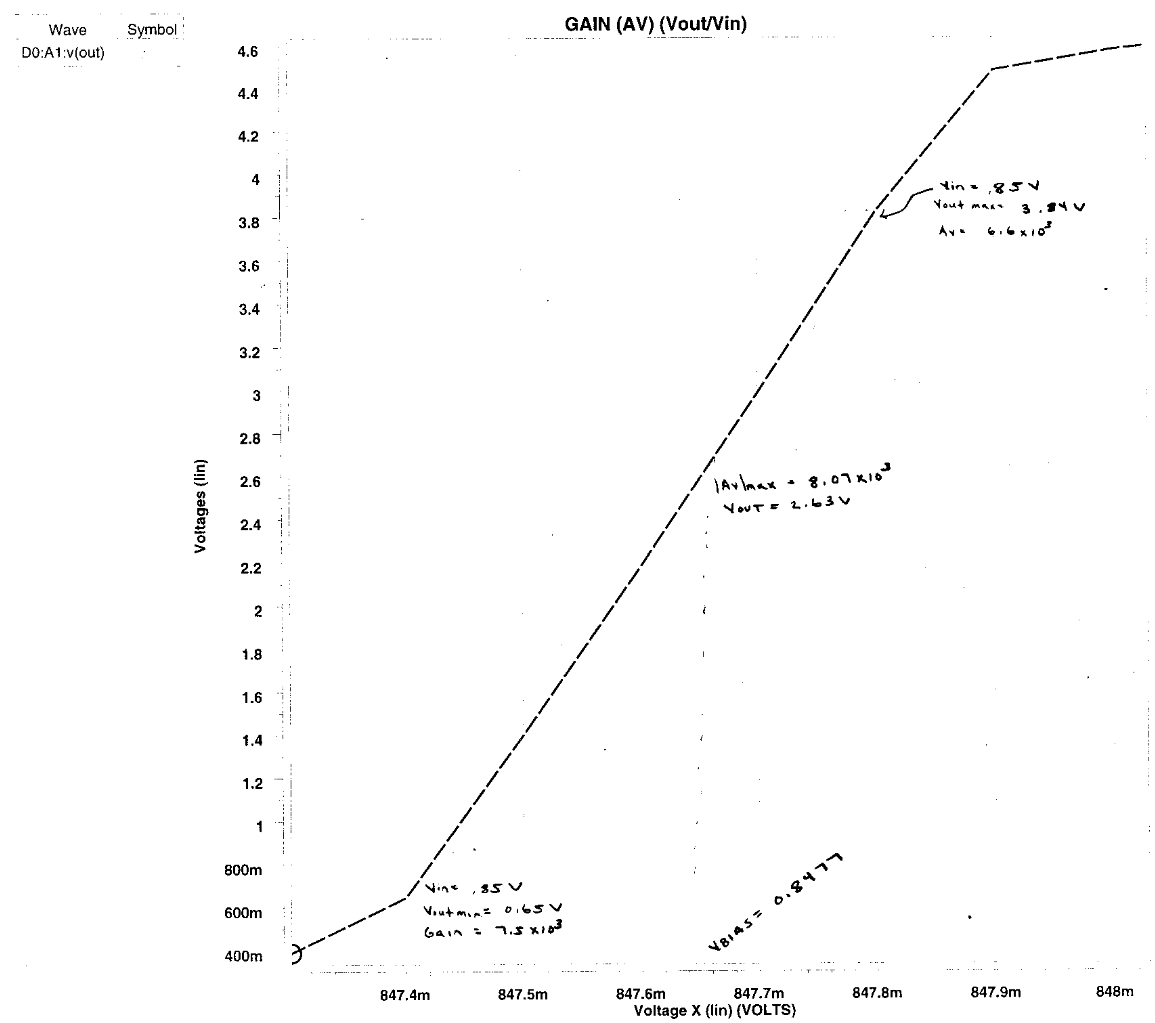
Miller Approximation



$$C_A = C_{gsn1} + C_{gdn1}(1 - A_{v1})$$

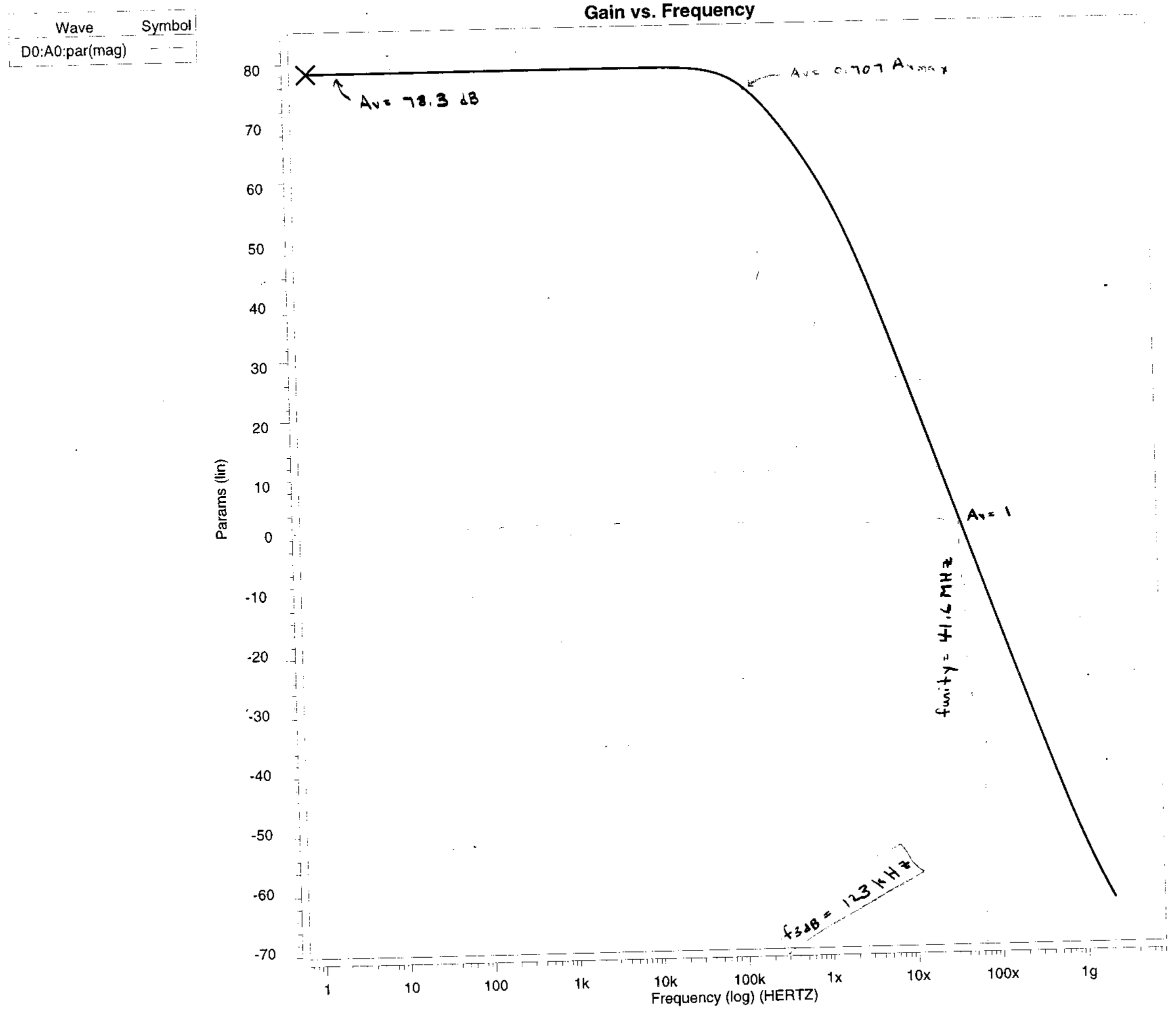
$$C_B = C_{gdp1} + C_{dbp1} + C_{dbn1} + C_{gsn2} + C_{gdn2}(1 - A_{v2}) + C_{gdn1}\left(\frac{1}{1 - A_{v1}}\right)$$

$$C_C = C_L + C_{dbn2} + C_{dbp2} + C_{gdn2}\left(\frac{1}{1 - A_{v2}}\right)$$



Wave Symbol
D0:A1:v(out)
GAIN (AV) (Vout/Vin)
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
800m
600m
400m
Voltages (lin)
847.4m
847.5m
847.6m
847.7m
847.8m
847.9m
848m
Voltage X (lin) (VOLTS)
Vin = .85 V
Vout max = 3.84 V
Av = 6.6x10^3
|Av|max = 8.07x10^3
VOUT = 2.63 V
Vin = .85 V
Voutmin = 0.65 V
Gain = 7.5 x10^3
VBIAS = 0.8477

Gain vs. Frequency



```
***************************************
********** Code for Project2 **********
***************************************

.options post
.op

******  N and P MOS definitions ******

.MODEL NMOS NMOS LEVEL=1 VTO=0.7 TOX=1.7E-08 UO=250
+ LAMBDA=5E-02 GAMMA=0.6 CGSO=5E-10 CGDO=5E-10 CJ=1E-04
+ CJSW=5E-10 PB=0.95

.MODEL PMOS PMOS LEVEL=1 VTO=-0.7 TOX=1.7E-08 UO=125
+ LAMBDA=5E-02 GAMMA=0.6 CGSO=5E-10 CGDO=5E-10 CJ=3E-04
+ CJSW=3.5E-10 PB=0.9

****** initial resistor ******
Resistor 1 in 1k

****** first gate ******
Minv1 2 1 0 0 NMOS L=1.5u W=10.5u pd=26u ps=26u ad=84p as=84p
Minv2 2 3 4 4 PMOS L=1.5u W=4.5u pd=18u ps=18u ad=36p as=36p

****** second gate ******
Minv3 out 2 0 0 NMOS L=1.5u W=4.5u pd=18u ps=18u ad=36p as=3p
Minv4 out 5 4 4 PMOS L=1.5u W=4.5u pd=18u ps=18u ad=36p as=36p

****** Capacitor at end of circuit ******
Capacitor out 0 1p

****** Voltages ******

Vin in 0 ac 1 dc 1
Vdd 4 0 dc 5

Va 3 0 dc 4
Vb 5 0 dc 3.7

.ac dec 40 1 40g
.dc vin 0.5 1 0.0001

****** Measurements ******

.MEASURE AC VMAX MAX V(out)
.MEASURE AC F3DB WHEN V(out)='VMAX*.707' FALL=1
.MEASURE AC funity when v(out)='vmax/vmax' fall=1

.print  ac mag=par('20*log10(v(out))')

.end
```

```
  total voltage source power dissipation=   95.9353u        watts

******************************************
 ******  ac analysis                            tnom=  25.000 temp=  25.000
******
 vmax=  8.2192E+03     at=  1.0000E+00
              from=  1.0000E+00    to=  4.2170E+10
 f3db=  1.2320E+05
 funity=  4.1737E+07

         ***** job concluded

 ******  Star-HSPICE -- 2000.2    (20000615) 00:08:04  12/08/2000  solaris
******
******************************************
 ******  job statistics summary                 tnom=  25.000 temp=  25.000
******

         total memory used         198 kbytes

 # nodes =       8 # elements=     10
 # diodes=       0 # bjts    =      0 # jfets    =      0 # mosfets =      4

   analysis       time       # points  tot. iter  conv.iter

   op point           0.02          1        11
   dc sweep           2.03       5001     10036
   ac analysis        0.07        426       426
   readin             0.04
   errchk             0.01
   setup              0.00
   output             0.02
        total cpu time              2.20 seconds
            job started at  00:08:04  12/08/2000
            job ended   at  00:08:07  12/08/2000

 lic: Release hspice token(s)
```

Formula Sheet

These formulas were inputed to an Excel Spreadsheet, allowing for us to calculate all the parameters in parallel. The excel spreadsheet with the final values for all parameters is included.

$$\omega_{3dB} = \frac{1}{2\pi \Sigma \tau}$$

$$\tau_A = C_A R_S$$

$$\tau_B = C_B R_{OUT1}$$

$$\tau_C = C_C R_{OUT2}$$

$$R_{OUT1} = \frac{1}{(\lambda_{n1} + \lambda_{p1}) I_{D1}} = \frac{7.5}{I_{D1}}$$

$$R_{OUT2} = \frac{1}{(\lambda_{n2} + \lambda_{p2}) I_{D2}} = \frac{7.5}{I_{D2}}$$

$$R_S = 1k\Omega$$

$$C_{gsn1} = \frac{2}{3} W_{n1} L_{n1} C_{ox} + W_{n1} C_{ov}$$

$$C_{gdn1} = W_{n1} C_{ov}$$

$$C_{gdp1} = W_{p1} C_{ov}$$

$$C_{dbp1} = (W_{p1} L_{dif}) C_{jp} + (W_{p1} + 2L_{dif}) C_{jswp}$$

$$C_{dbn1} = (W_{n1} L_{dif}) C_{jn} + (W_{n1} + 2L_{dif}) C_{jswn}$$

$$C_{gsn2} = \frac{2}{3} W_{n2} L_{n2} C_{ox} + W_{n2} C_{ov}$$

$$C_{gdn2} = W_{n2} C_{ov}$$

$$C_L = 1pF$$

$$C_{dbn2} = (W_{n2} L_{dif}) C_{jn} + (W_{n2} + 2L_{dif}) C_{jswn}$$

$$C_{gdp2} = W_{p2} C_{ov}$$

$$C_{dbp2} = (W_{p2} L_{dif}) C_{jp} + (W_{p2} + 2L_{dif}) C_{jswp}$$

$$C_{gdn2} = W_{n2} C_{ov}$$

$$V_{min} = V_{GS} - V_T$$

$$= 0.838 - 0.7$$

$$= 0.138$$

$$V_{swing} = V_{max} - V_{min}$$

$$3.84 - 0.138$$

How did you find V_{max}?

−3