EE420 Lab - Week 5

3rd May 2005

1 Overview

This week we will add a second voltage gain stage. One more transistor converts the diff-amp to an op-amp. We will use a PNP. This simple op-amp can't drive much of a load, but it should work.

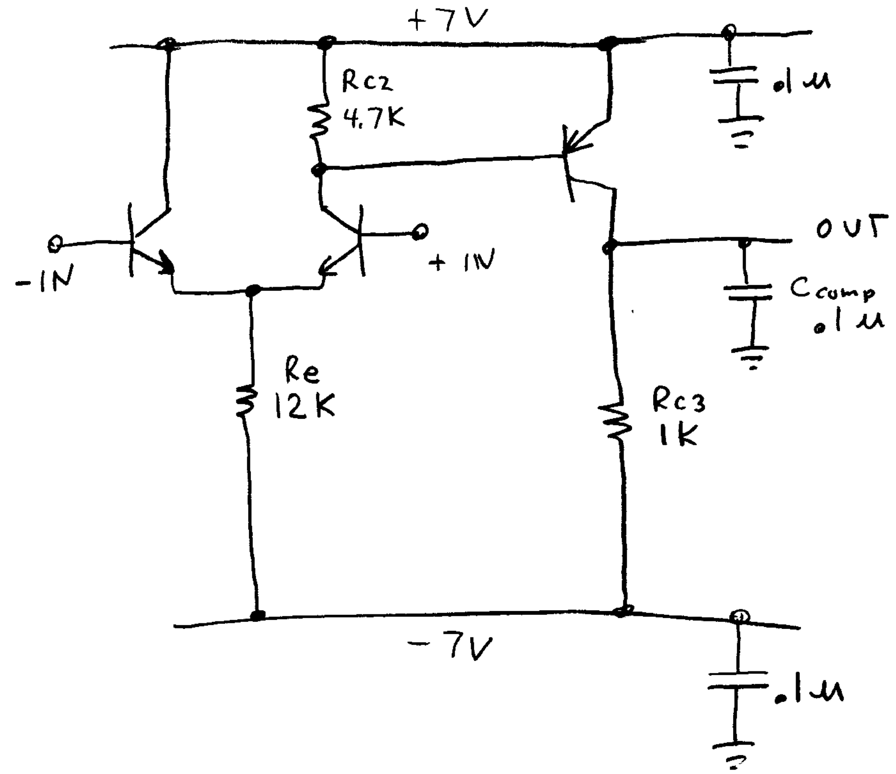
2 Objectives

1. To confirm the DC, AC, and large signal characteristics of a simple op-amp.
2. To compare to simulation and calculations.

3 Background

In this experiment, we add one transistor to our diff-amp, to convert it to a simple op-amp. To make the bias correct, we will change the current in the diff-amp so we get 0.7 volts across $R_{C1}$and R_{C2}, keeping it in balance. The gain will be high, so some measurements will be difficult.

Here is a schematic:



4 Experiment

1. Modify your circuit as shown in the schematic. If you already are using current mirrors from last week, leave them as they are. The modifications consist of:

2. Add the PNP transistor, its load resistor, and compensating capacitor.

3. Change R_e to 12k. Replace $R_{C1}$with a jumper.

4. Connect both bases to ground, apply power and measure the quiescent voltages and currents. Adjust the value of R_e so the output is centered, within 1 volt. If the output is positive, increase the value of R_e. If the output is negative, decrease R_e by putting a resistor in parallel with it. It will be difficult to center the output exactly. It is likely that it will drift.

5. Record all DC voltages.

6. Use a voltage divider in conjunction with the function generator to produce approximately 1 mV peak-to-peak triangular waveform at 10 Hz. Verify that the output looks triangular. Measure the differential gain as you did last week. Verify also that there is almost no DC offset at the output of your op-amp.

7. Change the waveform to sinusoidal, and sweep the input frequency from 10 Hz to 10 MHz. Plot the gain in dB. Also plot the phase.

8. Connect your op-amp for a nominal closed loop gain of 10, inverting, using 10k and 100k resistors. Remove the voltage divider from the input and connect the signal generator directly to the 10k resistor. Set the input to .1 volt p-p, and measure the response from 10 Hz to 10 MHz.

9. Set the frequency back to 10 Hz, triangular. Increase the level to the clip point, then back off so it is not clipping. What is the output level?

10. Set the level to get 10 volts p-p at the output, or just below clipping if it won't do 10 volts p-p. Set the waveform to sinusoidal. Sweep the frequency up to the point where the level drops to 7 volts p-p. Note the frequency. What does the waveform look like?

11. Set the frequency to 10 KHz, square wave. Set the level to 10 volts p-p, or just below clipping. What is the slew rate? (both rising and falling) Is it the same both directions?

12. Set the frequency back to 100 Hz, triangle wave, and the level to 10 volts p-p. Try values for R_e that are about twice and half of the correct value. Does it matter? Why?

13. If you have time, for extra credit, repeat steps 6-12 for the non-inverting configuration.

5 Analysis

5.1 Manual analysis

Perform a DC bias point analysis and AC small signal analysis, and verify that it works as predicted.

5.2 Simulation

Using a simulator, verify the results you calculated and measured. Make all of the same measurements as you did in the lab. Compare the simulation to what you measured.

6 Report

6.1 Executive summary (on cover)

Show a schematic of your op-amp, with its measurements (gain, gain-bandwidth product, clip level, and slew rate).

6.2 More detailed summary.

Write a paragraph on what you learned, and point out any surprises. Does it match the simulation? Explain. Limit this section to one page,

6.3 Journal

Provide a journal of what you did, with enough detail that someone else can reproduce your experiment and verify your work.

6.4 Analysis

Provide your manual analysis of the circuit.

6.5 Simulation

Provide a the results, including commands and netlists, of your simulation. Print it tiny, so you can fit a lot on a page. You should be able to print it "4-up" or smaller. Circle important results.

```
gnucap> width out=80

gnucap> get oa1

'
gnucap> list

Q1 ( 4 3 5 )  nn  area= 1.
Q2 ( 7 6 5 )  nn  area= 1.
Q3 ( 8 7 1 )  pp  area= 1.
Rc1 ( 1 4 )  4.7K
Rc2 ( 1 7 )  4.7K
Rc3 ( 8 2 )  1.K
Vcc ( 1 0 )  DC  7.
Vee ( 2 0 )  DC -7.
Vin1 ( 0 3 ) GENERATOR
Vin2 ( 6 0 ) GENERATOR
.model  nn  npn  (level=1  kf= 0.  af= 1.  bf= 100.  br= 1.  is= 100.E-18
+  nf= 1.  nr= 1.  isc= 0.  c4= 0.  nc= 2.  ise= 0.  c2= 0.  ne= 1.5
+  rb= 0.  rbm= 0.  re= 0.  rc= 0.  cjc= 0.  cje= 0.  cjs= 0.  fc= 0.5
+  mjc= 0.33  mje= 0.33  mjs= 0.  vjc= 0.75  vje= 0.75  vjs= 0.75
+  xcjc= 1.  itf= 0.  ptf= 0.  tf= 0.  tr= 0.  xtf= 0.  xtb= 0.
+  xti= 3.  eg= 1.11)
*+()
.model  pp  pnp  (level=1  kf= 0.  af= 1.  bf= 100.  br= 1.  is= 100.E-18
+  nf= 1.  nr= 1.  isc= 0.  c4= 0.  nc= 2.  ise= 0.  c2= 0.  ne= 1.5
+  rb= 0.  rbm= 0.  re= 0.  rc= 0.  cjc= 0.  cje= 0.  cjs= 0.  fc= 0.5
+  mjc= 0.33  mje= 0.33  mjs= 0.  vjc= 0.75  vje= 0.75  vjs= 0.75
+  xcjc= 1.  itf= 0.  ptf= 0.  tf= 0.  tr= 0.  xtf= 0.  xtb= 0.
+  xti= 3.  eg= 1.11)
*+()
Re ( 5 2 )  12.K
gnucap> print op v(nodes)
....................
gnucap> print ac v(nodes)
....................
gnucap> print op - v(1) v(2)

gnucap> op

#           v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 300.15    -25.828p     5.7861     -0.7392     -25.828p     6.1714      1.1981
gnucap> print ac - v(1) v(2)

gnucap> ac

#Freq       v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 0.         1.          46.935      40.671n     1.          2.9524      935.8
gnucap> modify rc1=1

gnucap> op

#           v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 300.15    -25.828p     6.9997     -0.7392     -25.828p     6.1714      1.1981
gnucap> ac

#Freq       v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 0.         1.          0.0099768   38.355n     1.          2.9524      935.8
gnucap> ac 1 1g dec 2

#Freq       v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 1.         1.          0.0099768   38.355n     1.          2.9524      935.8
 3.1623     1.          0.0099768   38.355n     1.          2.9524      935.8
 10.        1.          0.0099768   38.355n     1.          2.9524      935.8
 31.623     1.          0.0099768   38.355n     1.          2.9524      935.8
 100.       1.          0.0099768   38.355n     1.          2.9524      935.8
 316.23     1.          0.0099768   38.355n     1.          2.9524      935.8
 1.K        1.          0.0099768   38.355n     1.          2.9524      935.8
 3.1623K    1.          0.0099768   38.355n     1.          2.9524      935.8
 10.K       1.          0.0099768   38.355n     1.          2.9524      935.8
 31.623K    1.          0.0099768   38.355n     1.          2.9524      935.8
 100.K      1.          0.0099768   38.355n     1.          2.9524      935.8
 316.23K    1.          0.0099768   38.355n     1.          2.9524      935.8
 1.Meg      1.          0.0099768   38.355n     1.          2.9524      935.8
 3.1623Meg  1.          0.0099768   38.355n     1.          2.9524      935.8
 10.Meg     1.          0.0099768   38.355n     1.          2.9524      935.8
 31.623Meg  1.          0.0099768   38.355n     1.          2.9524      935.8
 100.Meg    1.          0.0099768   38.355n     1.          2.9524      935.8
 316.23Meg  1.          0.0099768   38.355n     1.          2.9524      935.8
 1.G        1.          0.0099768   38.355n     1.          2.9524      935.8
gnucap> build

>ccomp 8 0 .1u

>

gnucap> op

#           v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 300.15    -25.828p     6.9997     -0.7392     -25.828p     6.1714      1.1981
gnucap> ac

#Freq       v(3)        v(4)        v(5)        v(6)        v(7)        v(8)
 1.         1.          0.0099768   38.355n     1.          2.9524      935.8
 3.1623     1.          0.0099768   38.355n     1.          2.9524      935.8
 10.        1.          0.0099768   38.354n     1.          2.9524      935.78
 31.623     1.          0.0099768   38.347n     1.          2.9524      935.62
 100.       1.          0.0099768   38.279n     1.          2.9524      933.96
 316.23     1.          0.0099768   37.619n     1.          2.9524      917.86
 1.K        1.          0.0099768   32.476n     1.          2.9524      792.37
 3.1623K    1.          0.0099768   17.243n     1.          2.9524      420.7
 10.K       1.          0.0099768   6.0302n     1.          2.9524      147.09
 31.623K    1.          0.0099768   1.9334n     1.          2.9524      47.039
 100.K      1.          0.0099768   627.4p      1.          2.9524      14.892
 316.23K    1.          0.0099768   241.59p     1.          2.9524      4.7097
 1.Meg      1.          0.0099768   157.57p     1.          2.9524      1.4894
 3.1623Meg  1.          0.0099768   146.54p     1.          2.9524      0.47098
 10.Meg     1.          0.0099768   145.4p      1.          2.9524      0.14894
 31.623Meg  1.          0.0099768   145.28p     1.          2.9524      0.047098
 100.Meg    1.          0.0099768   145.27p     1.          2.9524      0.014894
 316.23Meg  1.          0.0099768   145.27p     1.          2.9524      0.0047098
 1.G        1.          0.0099768   145.27p     1.          2.9524      0.0014894
gnucap> print ac vdb(8) vp(8)

gnucap> ac

#Freq       vdb(8)      vp(8)
 1.         59.424     -0.036
 3.1623     59.424     -0.11384
 10.        59.423     -0.36
 31.623     59.422     -1.1383
 100.       59.407     -3.5953
 316.23     59.256     -11.238
 1.K        57.979     -32.142
 3.1623K    52.48      -63.284
 10.K       43.351     -80.957
 31.623K    33.449     -87.119
 100.K      23.459     -89.088
 316.23K    13.46      -89.712
 1.Meg      3.4601     -89.909
 3.1623Meg -6.5399     -89.971
 10.Meg    -16.54      -89.991
 31.623Meg -26.54      -89.997
 100.Meg   -36.54      -89.999
 316.23Meg -46.54      -90.
 1.G       -56.54      -90.
gnucap> EOF on stdin
```