

**LAB 5 Followers: Common Drain, Common Collector**

An ideal voltage follower has infinite input impedance, zero output impedance, and a gain of exactly one. Real voltage followers are easy to implement with the common drain and common collector topologies. Unfortunately, their performance isn't quite ideal. In this lab you'll explore the performance of several simple voltage followers.

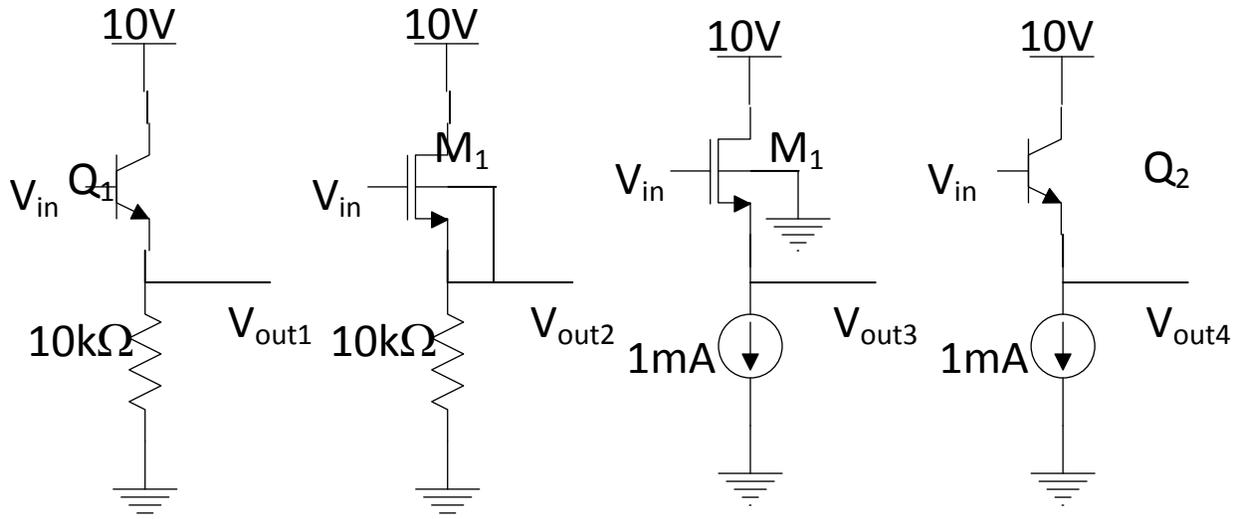


Figure 1ABCD Resistively loaded Common Collector, resistively loaded Common Drain, active load CD, active load CC.

**Part 1 Resistively loaded CC**

Build the NPN emitter follower in Figure 1A. When  $V_{out1} = 0.1, 1, \text{ and } 5V$ , what current will be flowing in the BJT,  $Q_1$ ? What  $V_{BE}$  will it need to provide that emitter current? What will the input voltage need to be to get those output voltages? Using these input/output pairs, sketch the expected input/output relationship, and estimate the error in the gain between 1 and 5 volts.

Apply a large low-frequency triangle wave to the input of the follower (0 to 10V if you can, 0 to whatever your function generator can handle if it can't get to 10V) and make sure that the output looks roughly like what you'd expect.

Keep this circuit on your board so that you can compare in part 2.

**Part 2 Resistively loaded CD**

Build the NMOS source follower in Figure 1B using the ALD1106 chip in your kit. Be careful with these chips – they are more static sensitive than BJTs. Note: in this circuit, the body of the MOSFET (pin 4) is connected to its source.

When  $V_{out2} = 0.1, 1, \text{ and } 5V$ , what current will be flowing in  $M_1$ ? What  $V_{GS}$  will it need to provide that source current (using what you learned in Lab4)? What will the input voltage need to be to get those output voltages? Using these input/output pairs, sketch the expected input/output relationship, and estimate the error in the gain between 1 and 5 volts.

Apply the same input to this follower as in part 1, and compare the outputs of the two resistively loaded followers. Measure the gain for both followers near 1V output, and near the highest output voltage that they both can reach. (Your scope has several fancy tools to help you measure the gains, so try to be accurate) The resistively loaded CD is a pretty lousy follower. Show your TA your two traces and gain estimates, and discuss briefly why the performance is so bad.

**Part 3 Active load CD**

Build the NMOS source follower in Figure 1C (you'll need to re-use M1 from part 2). The current source should be implemented using  $I_{out3}$  in the mirror shown in Figure 2. **N.b. the body of all MOSFETs is shared (pin 4), and needs to be ground in this circuit.** Calculate the proper value for resistor  $R_B$  so that the output currents  $I_{out3}$  and  $I_{out4}$  will each be 1mA. Measure the voltage drop across  $R_B$  to make sure that you got the current right. Estimate the output resistance of the current sources using what you learned in Lab 4. What is the useful output voltage range for these current sources (useful: maintains high output resistance, and doesn't violate chip specs)? When  $V_{out3} = 1, 2,$  and  $5V$ , what current will be flowing in M1? What  $V_{GS}$  will it need to provide that source current (don't forget that  $V_{SB} \neq 0$ )? What will the input voltage need to be to get those output voltages? Using these input/output pairs, sketch the expected input/output relationship, and estimate the error in the gain between 1 and 5 volts.

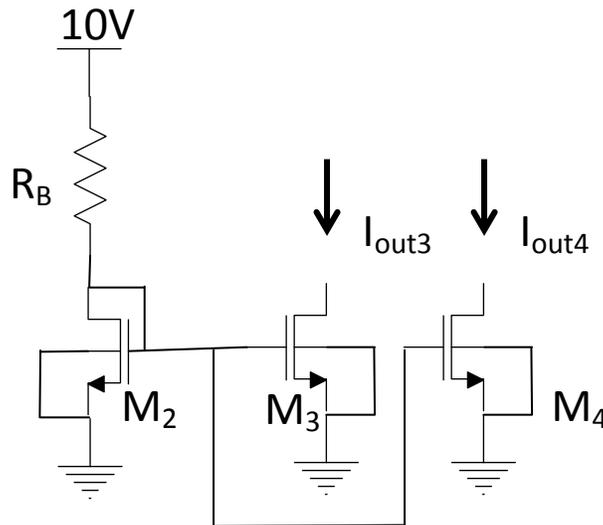
Apply the triangle wave input to this circuit, and compare the output to your circuit in part 1. Measure the gain for this follower near 1V output, and near the highest output voltage that they both can reach. This is also a pretty lousy follower. Keep this circuit on your board to show your TA after part 4.

#### Part 4 Active load CC

Build the NPN emitter follower in Figure 1D. The current source should be implemented using  $I_{out4}$  in the mirror that you already built for part 3. When  $V_{out4} = 1, 2,$  and  $5V$ , what current will be flowing in Q2? What  $V_{BE}$  will it need to provide that source current (try to get the change in  $V_{BE}$  to be accurate to 1mV)? What will the input voltage need to be to get those output voltages? Using these input/output pairs, sketch the expected input/output relationship, and estimate the error in the gain between 1 and 5 volts.

Apply the triangle wave input to this circuit, and compare the output to your circuit in part 1. Measure the gain for this follower near 1V output, and near the highest output voltage that they both can reach. This is also a pretty lousy follower.

Now show all three followers on the screen at the same time, along with the input waveform. Show your TA and discuss.



Figures 2 Active loads (current sources) for parts 3 and 4.

#### Part 5 Output Resistance

Apply a 16kHz sine wave to the follower from part 4. Use a small amplitude, <100mV if you can, and a DC offset of a few Volts. Verify that the output is a good copy of the input. Put a 1uF capacitor on the output in series with a 100 Ohm load resistor  $R_L$  as in Figure 3A. What is the magnitude of the impedance of the capacitor? Use a few different values for  $R_L$  (10, 50 Ohms) and record the gain to  $V_{out4}$  and  $V_{load}$  vs. load resistance. Estimate the output resistance of the amplifier. Comment on the magnitude and phase of the load voltage vs. the output voltage.

#### Part 6 Input Resistance

With the same 16kHz sine wave as part 5, put a 10k Ohm resistor,  $R_S$ , in series between the function generator and the base, and short the load resistor ( $R_L=0$ ) as in Figure 3B. Notice that the output waveforms don't look sinusoidal anymore. This is due to the finite discharge rate of the load capacitor

from a 1mA current source. Add in enough resistance back to  $R_L$  to get the output looking sinusoidal again (around 10 Ohms should do it). Measure the gain from the input,  $V_{in}$ , to the base voltage,  $V_B$ . Try a couple of different resistors. Remove the load (capacitor and resistor) and again measure the gain from input to base. Estimate the input resistance of your amplifier with and without the capacitive short on the output.

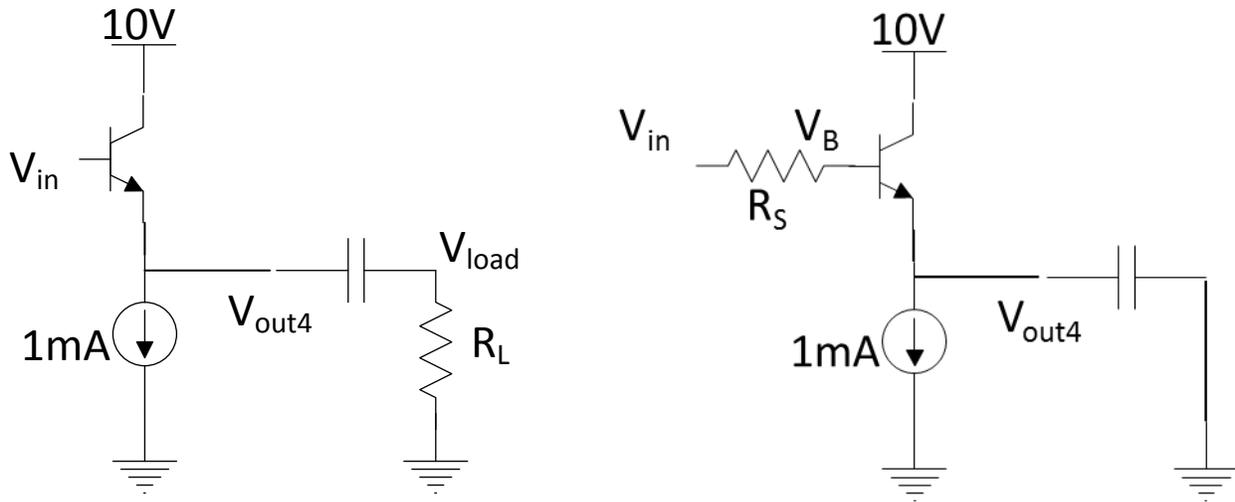


Figure 3AB Capacitively coupled output load  $R_L$ , and source resistance  $R_S$ .

### LAB 5 Followers - Report

Use the powerpoint template provided as a starting point to describe what you did, record your results, and present your conclusions. Most of your calculations and measured results should be presented in tabular form with one column for each of the different followers.

Explain the differences between your calculations and what you measured.

Explain *why* you made these measurements.

Discuss what performance you would expect for a source follower (CD) with an active load and its body tied to its source. If you work with another group you can do this experiment (for a small amount of extra credit) using 2 ALD1106s. If two groups both use the same data, make sure that you list the names of all of the people involved.