

# ECE-205 Lab 8

## Feedback Control Systems

### Overview

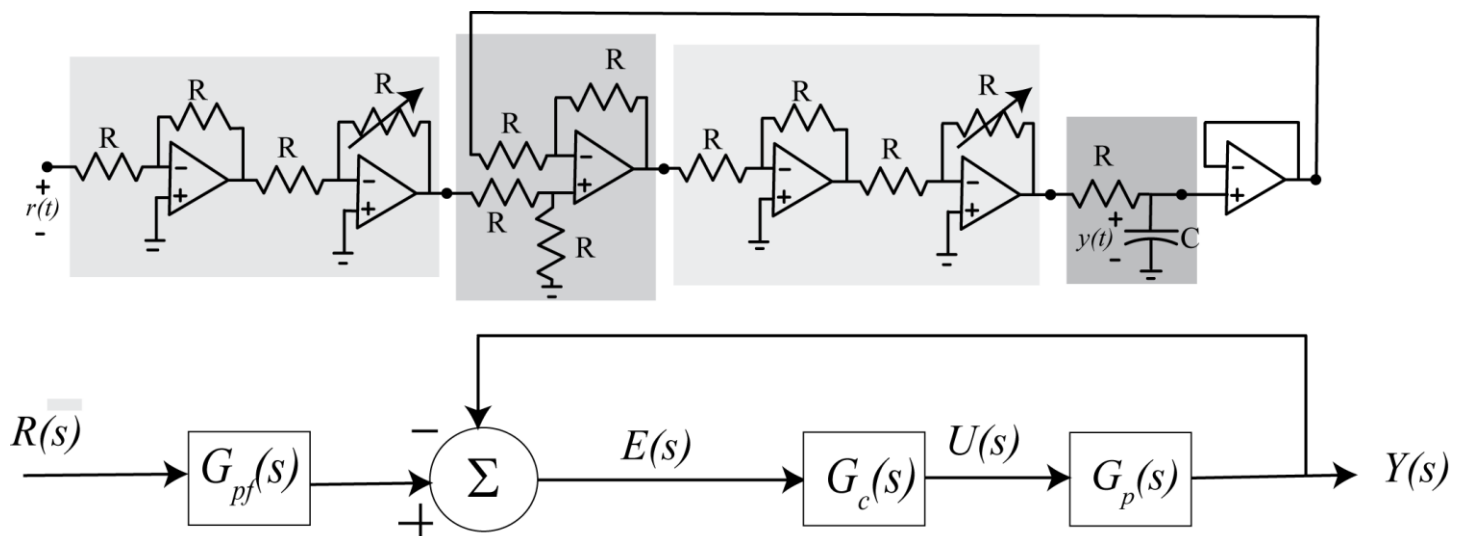
In this lab you will build a simple feedback control system using both a proportional and proportional plus integral controller. The systems you will be controlling are simple first and second order systems. We will also be utilizing a prefilter to adjust the gain so the output follows the input. Be careful to build and test the circuit subsystems individually before you connect them together. (See Figure 12 for an approximate size of the total system when it is put together.)

### PART I : Proportional Control for a First Order System

Our proportional controller has five parts, shown in the different shaded regions in Figure 1. The equivalent block diagram is shown below the circuit, so you can match elements of the block diagram with the circuit subsystems. As with most of the circuits in this class, this design has not been optimized and is a bit inefficient, but should be fairly easy to build. All of the resistors are either 1 kΩ resistors, or are variable resistors. The capacitors are 1 μf capacitor. (We will later use a 0.01 μf capacitor and a 33 mH inductor, just as we did in Lab 2.) We will be utilizing TL072 chips, which include two op amps on each chip. We will build and debug this circuit in stages, so do not start building yet!

The first shaded part is the prefilter, which changes the gain of the system so the steady state value of the output matches the steady state value of the input. The next stage is the differential amplifier, or the feedback element. The third stage is the proportional gain controller (another gain stage). The fourth stage is the plant or system we want to control. The final stage is a simple isolation amplifier to avoid loading effects. Note that the output is the voltage across the capacitor.

**It is a good idea to disconnect the power from your circuit while you are building it. Note that it may take some time for the screen to update when you change the variable resistor values. Be patient, and you will be rewarded. If you are impatient you will have to go back and redo parts of the lab!**



**Figure 1.** Proportional controller for the first order circuit.

1) The first thing we want to do is set the ground and the two power rails, just as we did for the previous labs. First connect one of the grounds (a down arrow) to the blue “rail” and then use another wire to connect the top and bottom blue rails together. It is better to do this somewhere away from the board where the USB and power connectors are. Next connect a wire from VP+ to the top red rail (this will be our  $V_{CC}$ ) and connect a wire from VP- to the bottom red rail (this will be our  $-V_{CC}$ ). Both  $V_{CC}$  and  $-V_{CC}$  are just to provide the necessary voltages to our op amp, *they are not the input signals*. Note that we want as much room on our breadboard as possible for this circuit.

2) Next start Waveforms (the Digilent software), select the voltage icon, then set Positive Supply VP+ to 9 volts and Negative Supply VP- to -9 volts. Set the maximum currents for the power supplies to 100 and -100 mA. Do not turn the power on until you have constructed the circuit each part of the circuit, then turn the power on.

3) Build the prefilter, shown in Figure 2. We have included a load resistor for measuring the output. The input to this circuit should be the signal generator, and the output should be the voltage across the load resistor. Set the input to a 50 Hz square wave with a peak to peak value of 2.0 volts and 1.0 volt offset. Start the oscilloscope and connect channels DC1 and DC2 as shown in Figure 2. Set the voltage scale to 2 volts/div and the time scale to 10 ms/div. Turn the power to the circuit on. (If you get a small negative voltage connect the load resistor to the other active pin on the variable resistor.) As the variable resistor is changed, you should be able to get an amplitude from 0 to approximately 6 volts. Before you go on, set the scope channels both to 1 volt/div and adjust the variable resistor so the output is that same as the input. Once this is working, disconnect the load resistor and function generator and disconnect the power to the circuit.

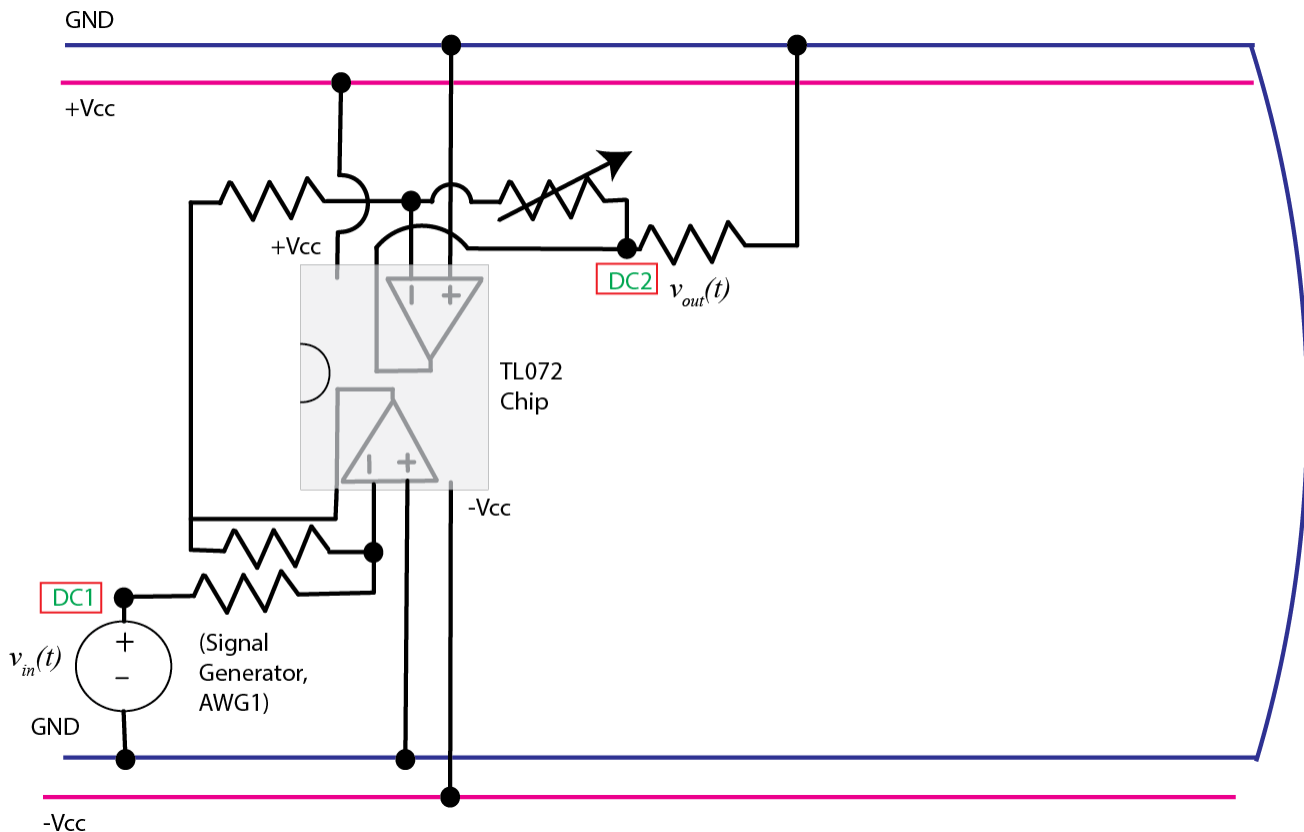


Figure 2. Prefilter (gain) circuit.

4) Build the differential amplifier, shown in Figure 3. Note that at this point we have connected the feedback input to ground. We have also offset it a bit so we will be able to get a feedback wire to it (it would seem easier to go directly to ground from the negative terminal, but that will cause problems later.) Again, we have included a load resistor to measure the output for debugging purposes. You should use a single chip for this (and waste an op amp) so your circuit will be easier to debug. Do not connect this to the prefilter circuit yet, but you should put this close to your prefilter so you will have room on your board for the rest of the circuit. Connect the signal generator to the input of this circuit and measure the output. They should be equal, if they are not you need to check your wiring.

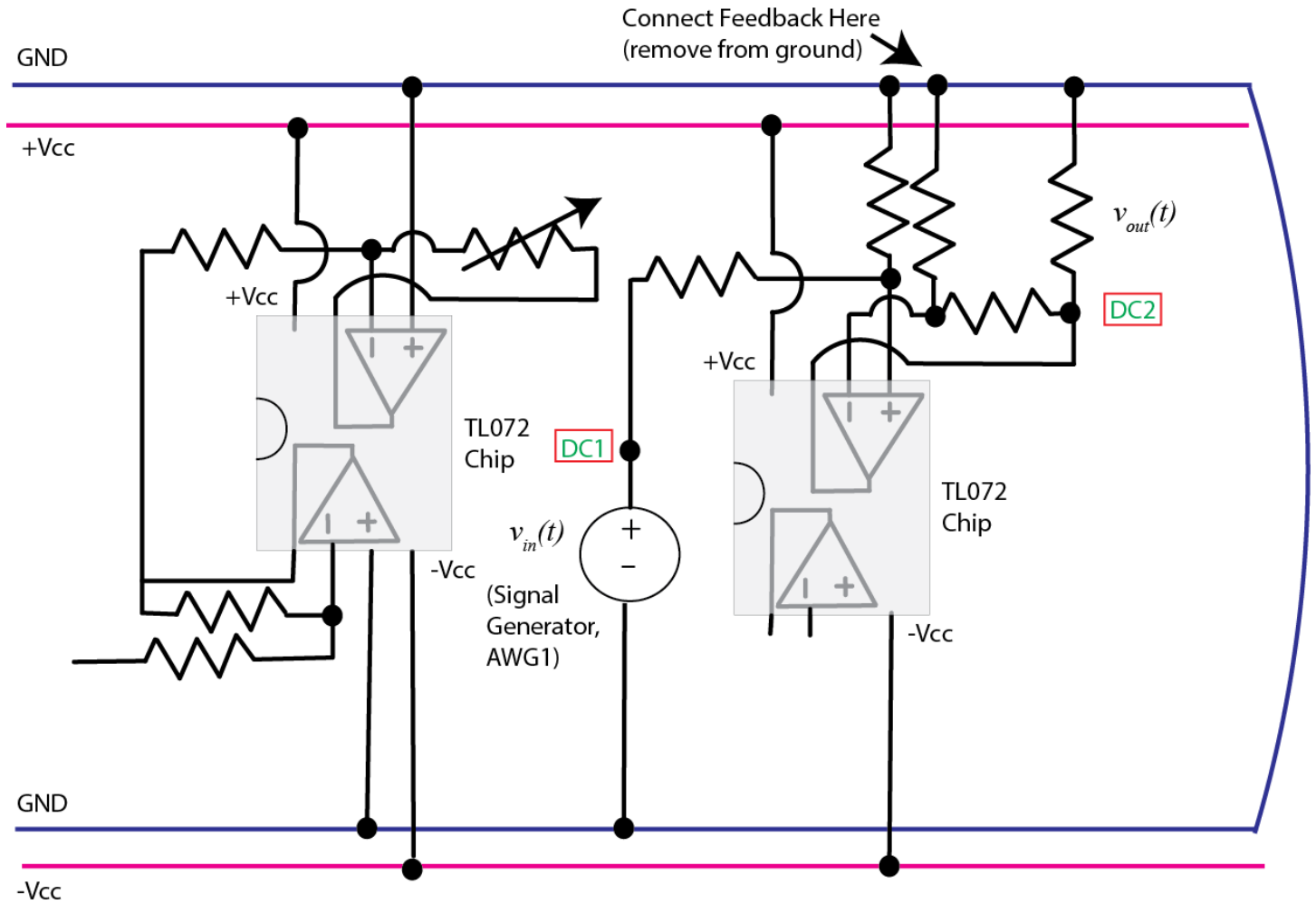


Figure 3. Differential amplifier circuit.

5) Now connect the first two parts of your circuit, the prefilter and the differential amplifier, as shown in Figure 4. The output of this combined circuit should match the input. If it is a little off, modify the variable resistor so they match (though they should be close). Do not go on if the input and output do not match.

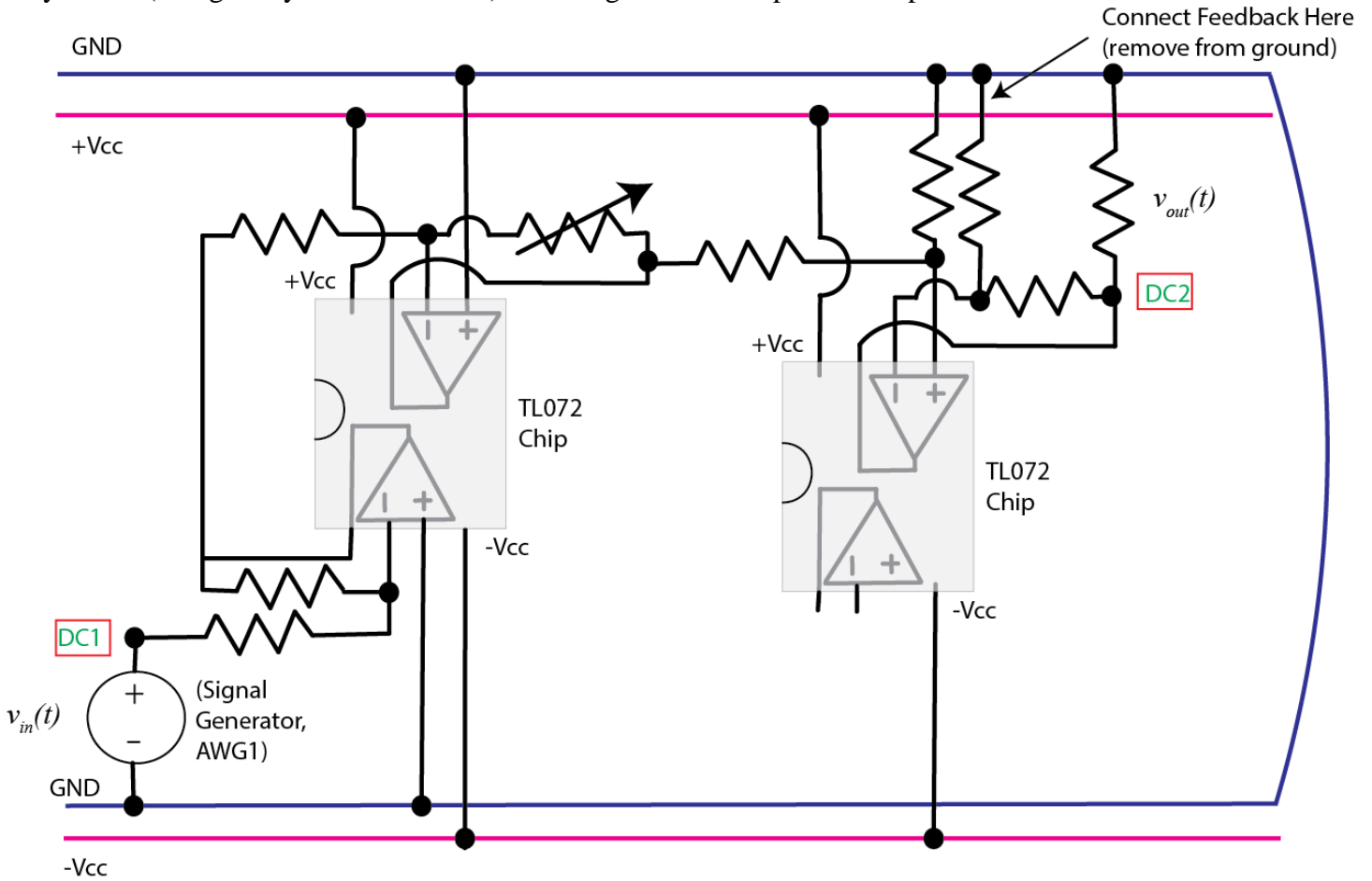
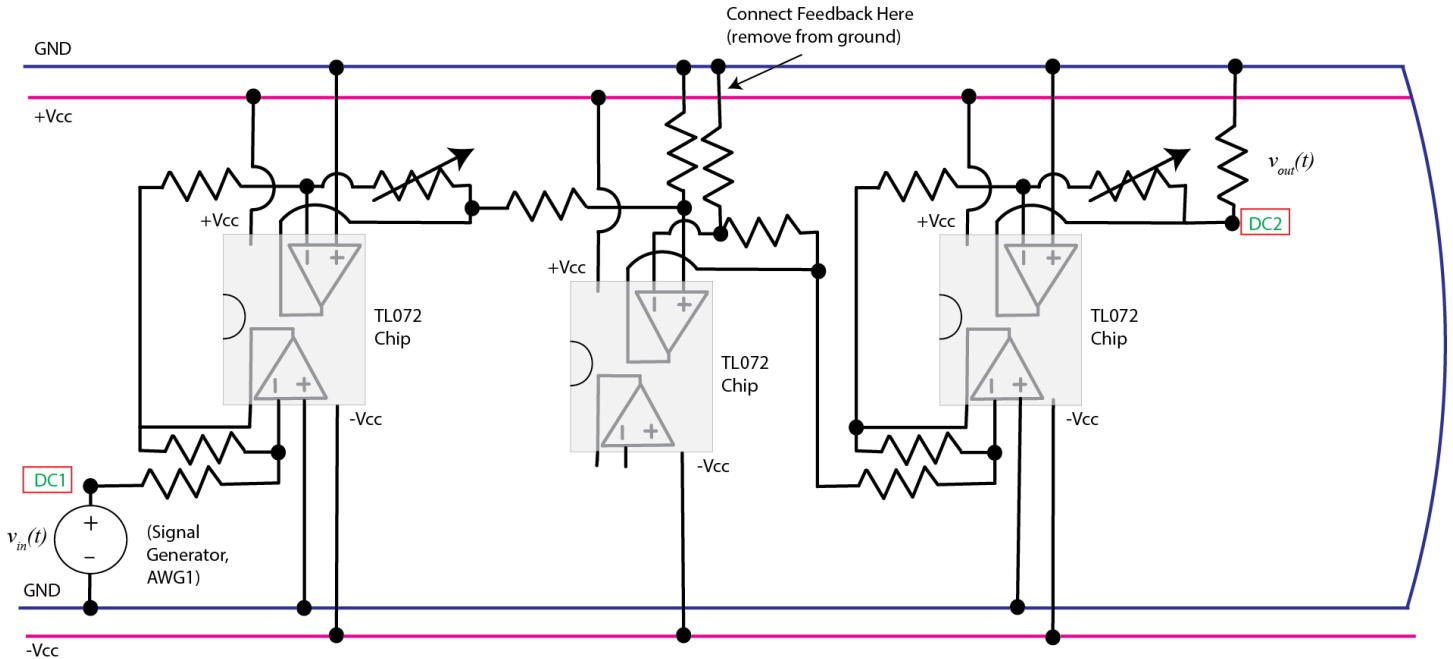


Figure 4. Prefilter and differential amplifier.

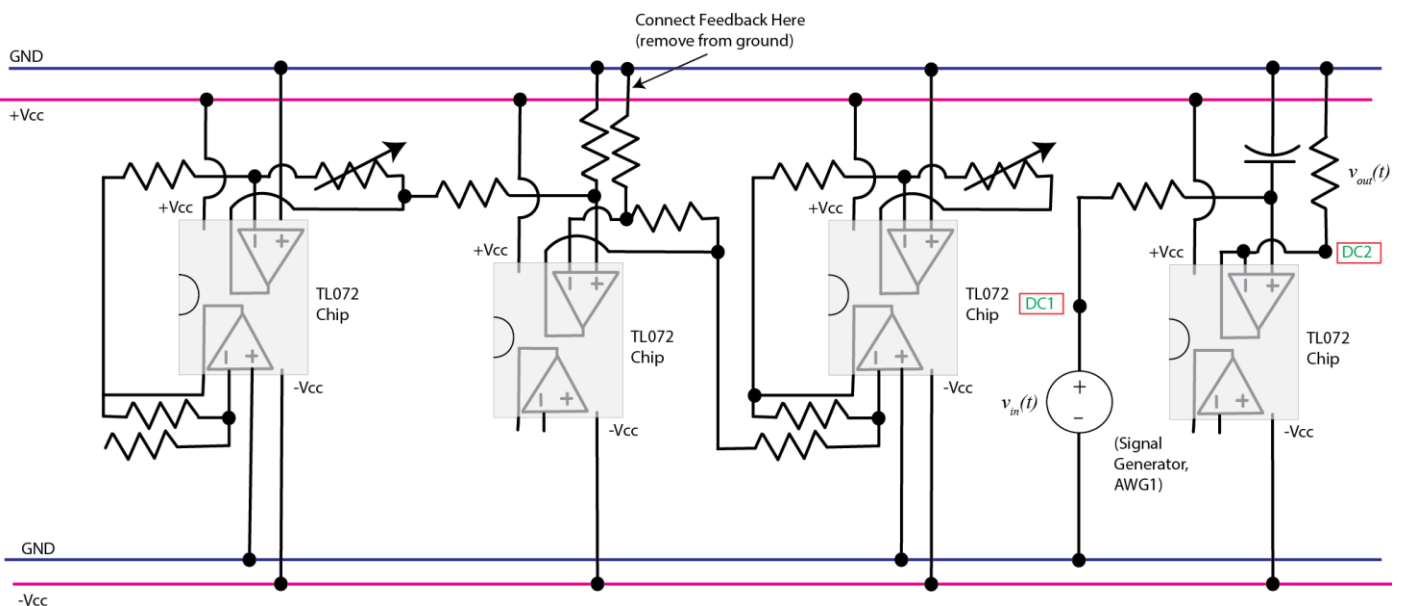
6) Build the proportional controller (a simple gain amplifier). Follow the same steps as in the prefilter (Step 1, Figure 2). Test this in the same way as you tested the prefilter. Before you go on, set the variable resistor so the output is the same as the input.

7) Connect the first three stages of your system, as shown in Figure 5. The output should match the input. If it does not, modify the variable resistor on the controller. Be sure to remove the load resistor before you go on.

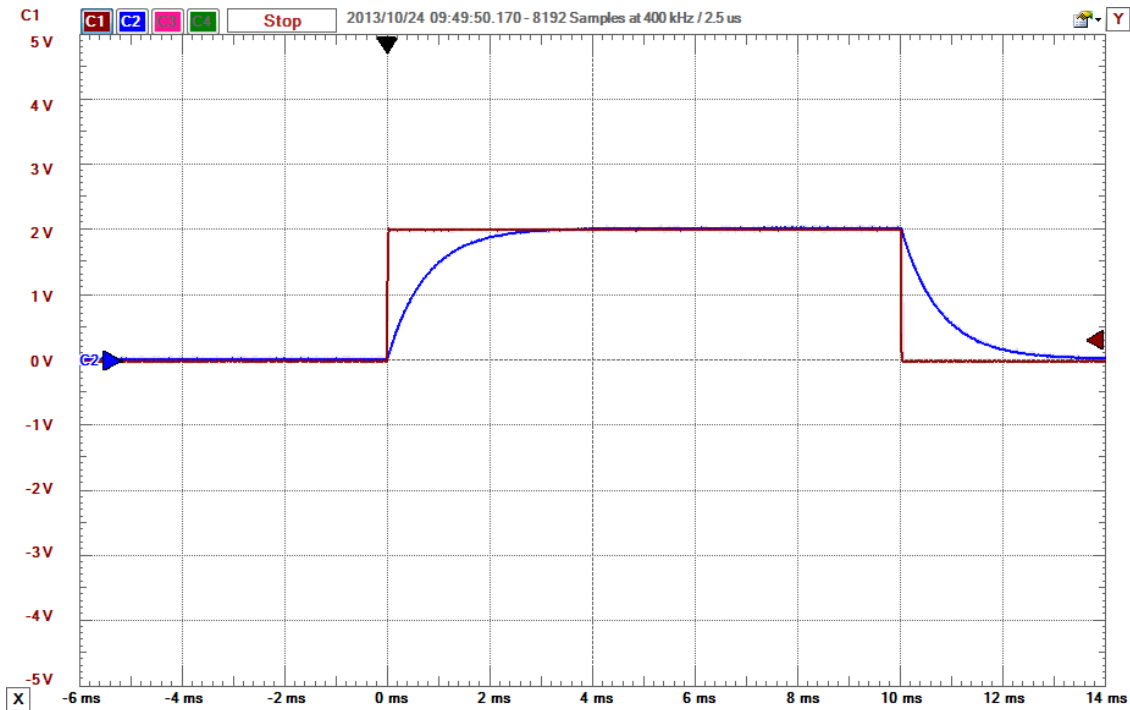


**Figure 5.** Prefilter, differential amplifier, and proportional controller.

8) Build the system, or plant, shown as the last stage in Figure 6. In this figure we have included a load resistor to measure the output of the isolation amplifier. *Note that the positive terminal is not connected directly to ground in this circuit!* Measure the output as the voltage across the load resistor. This is the response the system for an open loop configuration. You should get a response something like that shown in Figure 7. Do not disconnect the load resistor yet.

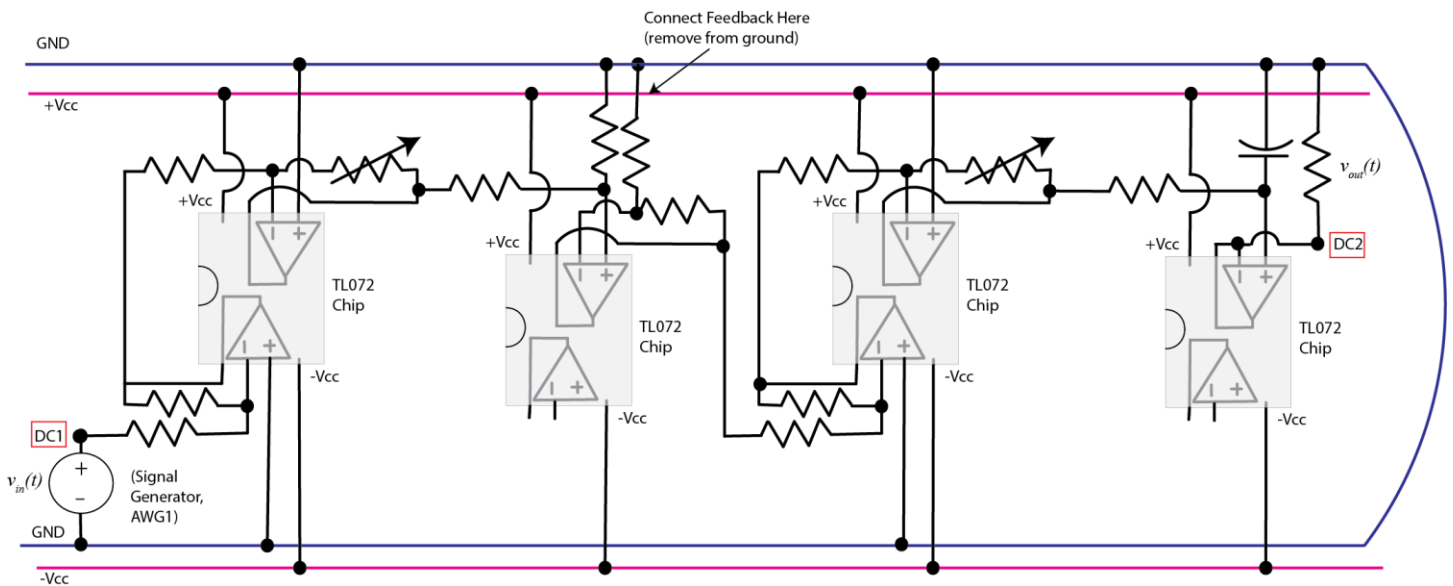


**Figure 6.** The system we are trying to control, or the plant. There is an isolating amplifier after the plant to avoid loading effects.



**Figure 7.** Open loop response of the first order plant. The output is measured across the load resistor connected to the isolating amplifier.

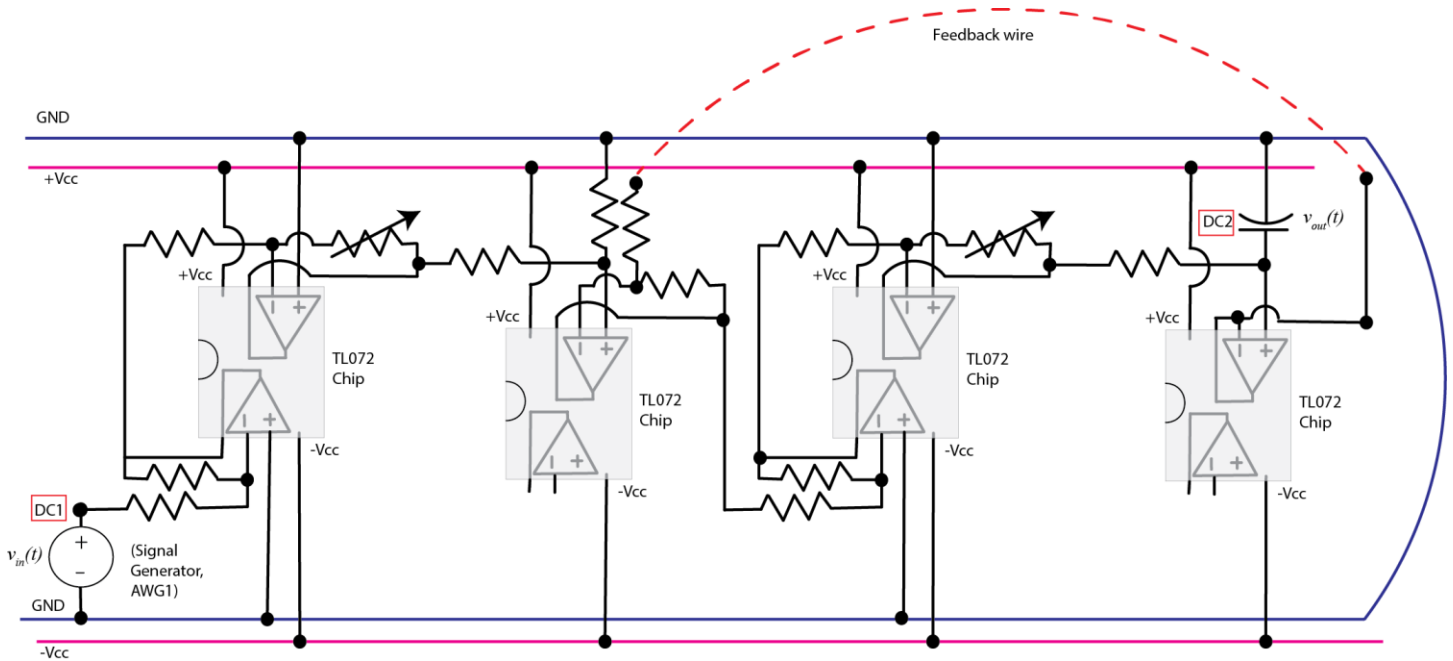
9) Connect all of the subsystems together, as shown in Figure 8, but do not connect the feedback loop. Your output should still be very nearly the same as in Figure 7.



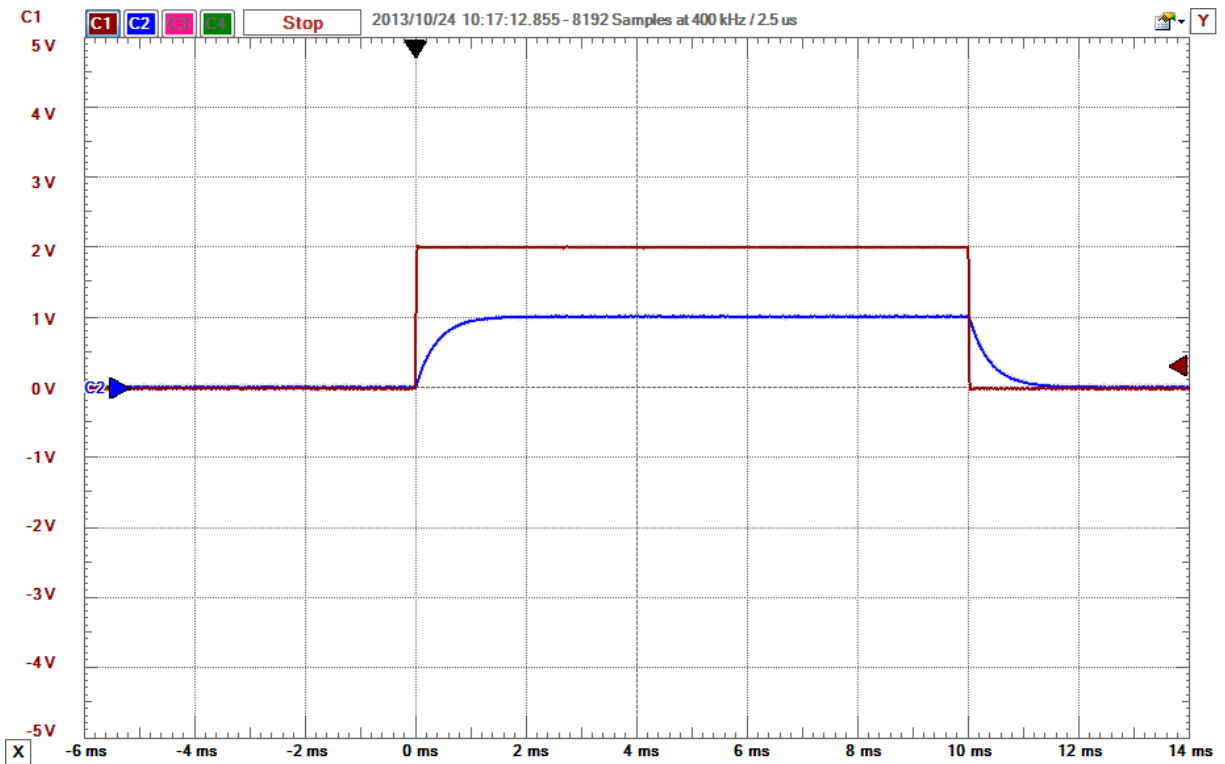
**Figure 8.** The entire system with no feedback.

10) Remove the load resistor from the isolation amplifier, and connect the feedback loop. Measure the output of the system as the voltage across the capacitor as shown in Figure 9. Do not change any of the variable resistances yet. You should get a response like that in Figure 10. Your output should be about half the amplitude of the open loop system (Figure 7) and should have a settling time about half as long (the time constant should

be one half of its previous value.) If you amplitude is the same as for the open loop response, then you probably still have an extra (load) resistor in the differential amplifier stage. Now we are ready to boogie.



**Figure 9.** Closed loop system with first order plant, proportional control, and prefilter.



**Figure 10.** Closed loop response of the first order system with all gains approximately equal to one.

11) You are now going to have to iterate a bit. Slowly change the variable resistor on the controller to speed up the response of the system. Then change the resistor on the prefilter so the output is the same amplitude as the input. *You need to include two different screen captures in your memo, both showing the system has faster response (smaller settling time) than the original and has the same amplitude output as the reference (input) signal. Here we are using the controller to speed up the response, and the prefilter to scale the output to match the input.*

## PART II: Proportional Plus Integral Control for a First Order System

We will now change our proportional controller for a proportional plus integral controller. This requires only a slight modification to your circuit. Be sure you reconnect the system so the output goes through the isolation op-amp before being fed back. A proportional controller has the form

$$G_c(s) = k_p + k_i \frac{1}{s}$$

Both variable resistors in our controller directly affect the proportional gain ( $k_p$ ), but only the second variable resistor affects the integral gain ( $k_i$ ).

1) Modify the proportional controller circuit by adding a  $1 \mu\text{f}$  capacitor and variable resistor, as shown in Figure 11. Your circuit at the end of this part should look something like that in Figure 12.

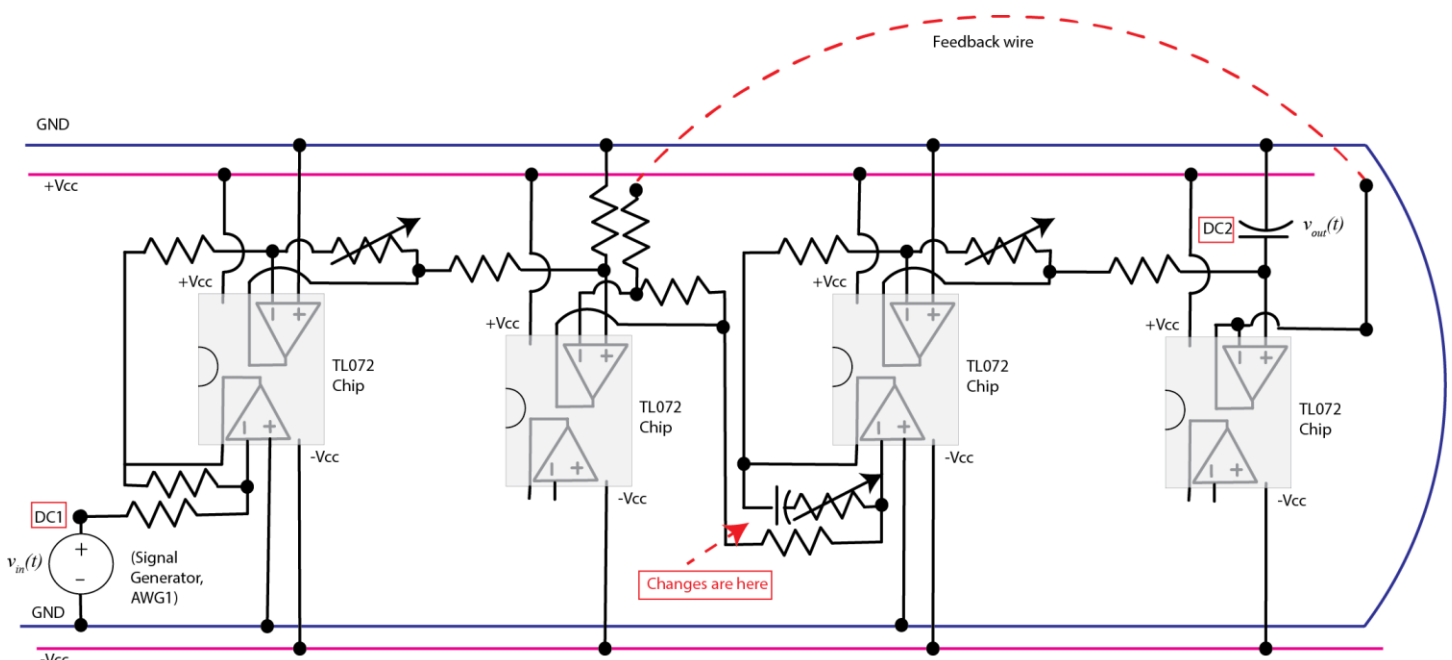
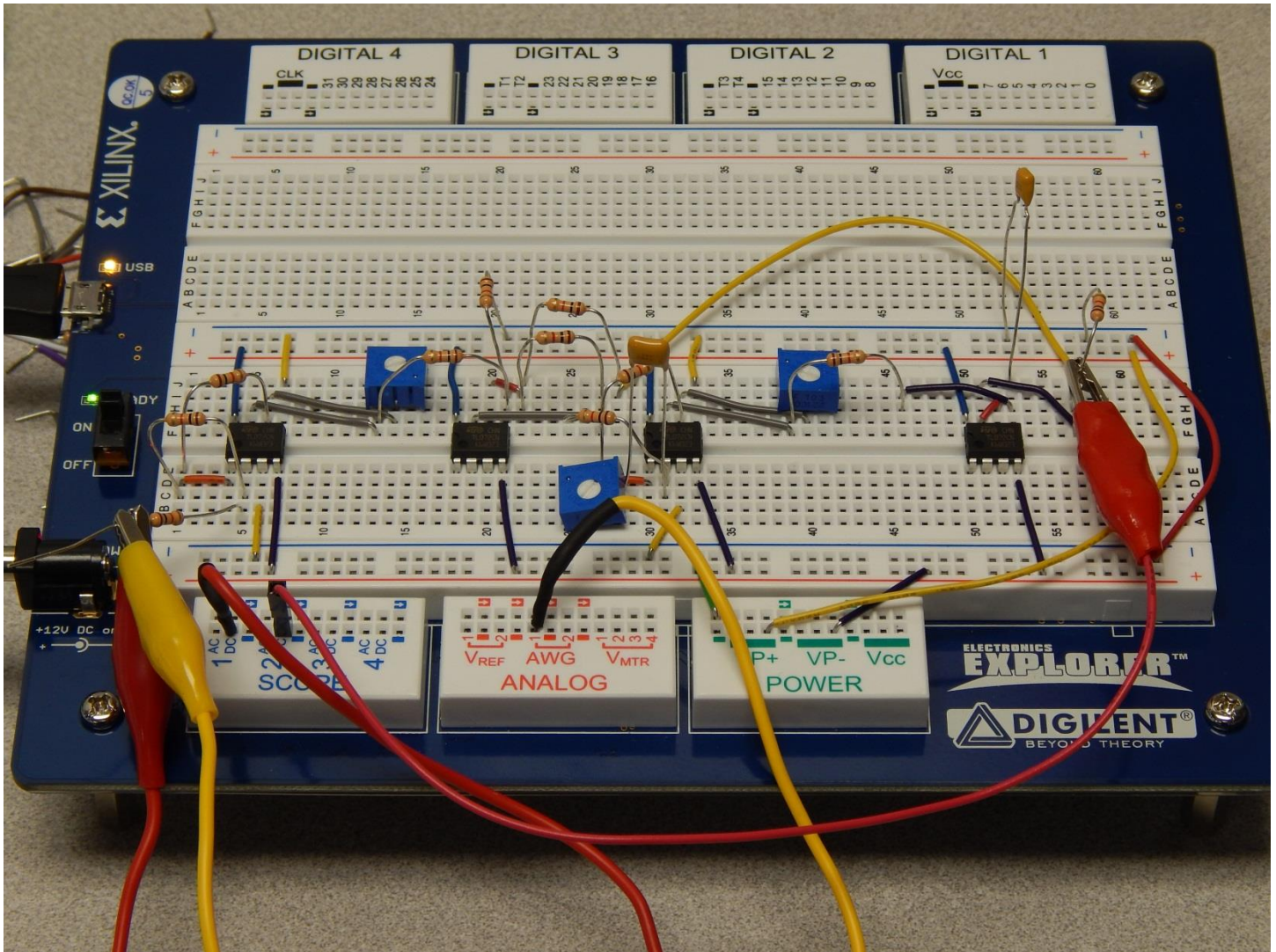


Figure 11. Proportional plus integral controller.

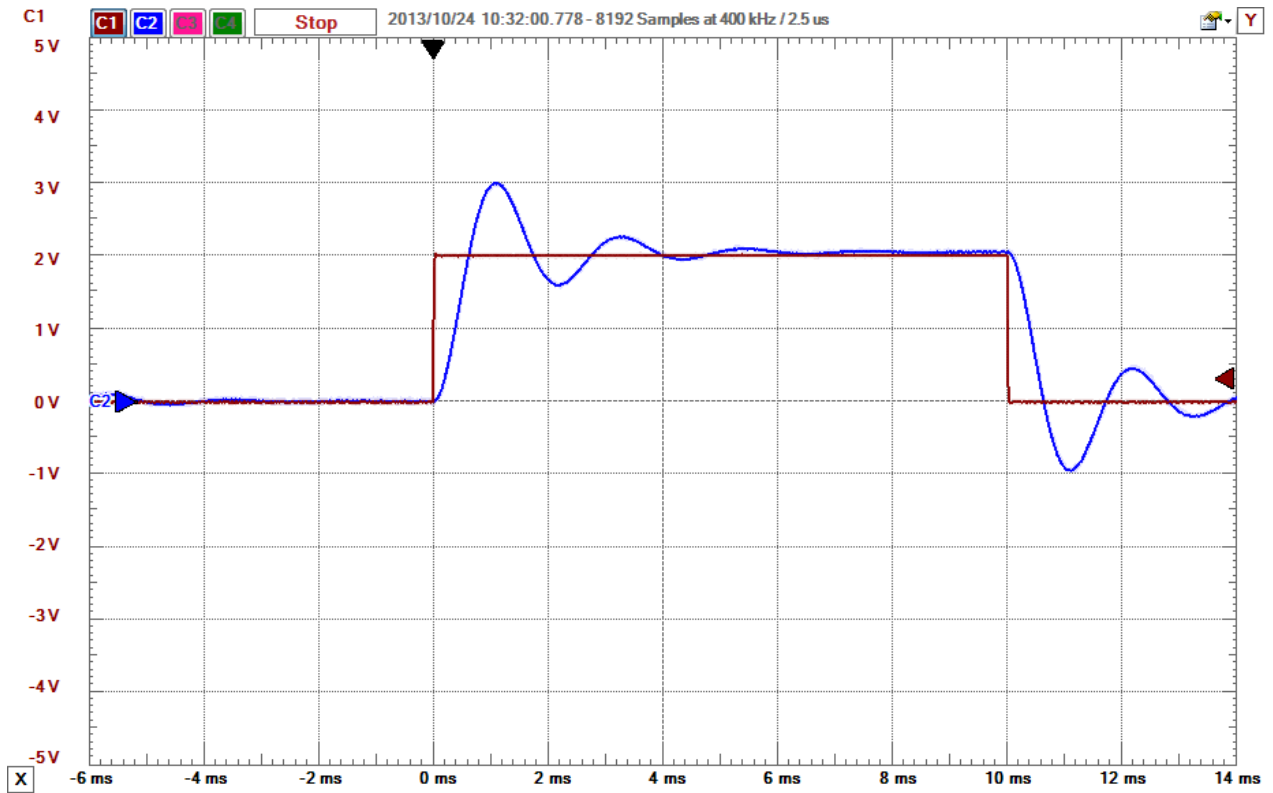
- 2) Set the variable resistors on the controller to someplace in the middle of their range, and adjust the prefilter gain so the steady state output matches the input.
- 3) Now go back and adjust the variable resistors on the controller. We can use these to change the gain of the proportional term and the gain of the integral term. You should note that as you change this resistor, the output still matches the input (as long as the system has time to reach steady state). This is the beauty of having an integral controller!
- 4) Adjust your controller so you get an output like that shown in figures 13 and 14 and *collect the two screen shots for your memo.* In particular, one screen shot (like Figure 13) should have a 50% overshoot and a settling



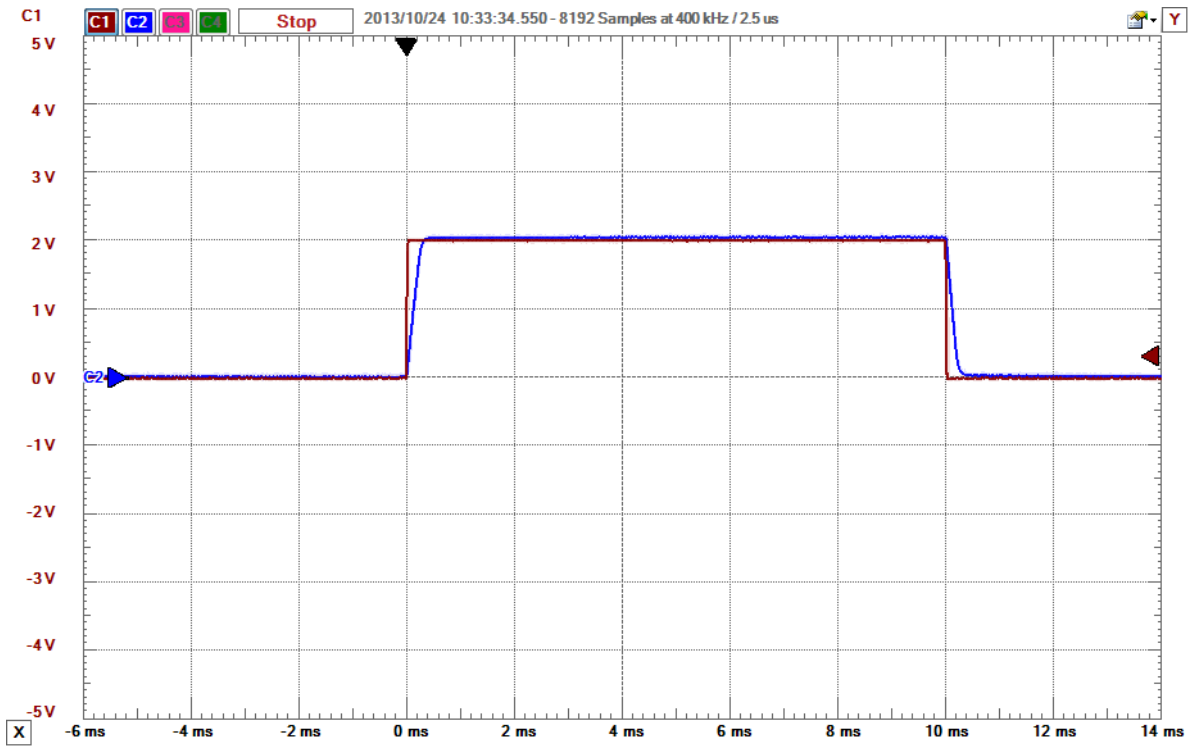
time of approximately 4-6 msec, and the other screen shot (Figure 14) should have virtually no overshoot and a settling time of approximately 0.3 ms. (You may not be able to get 50% overshoot, do the best you can!)



**Figure 12.** PI controller for a first order plant



**Figure 13.** PI control of a first order system with 50% overshoot and a settling time of approximately 4 ms.



**Figure 14.** PI control of a first order system with 0% overshoot and a settling time of approximately 0.3 ms.

### PART III: Proportional Plus Integral Control for a Second Order System

Now we are going to change the plant to a second order system and try to control it using the PI controller. This will not be as easy as the first order system, but it is typically more difficult to control a system as the system order increases.

- 1) Remove your old plant for the circuit board.
- 2) Modify your circuit so the plant and isolation amplifier is as shown in Figure 15. Again the resistor is  $1\text{ k}\Omega$ , but the capacitor is a  $0.01\ \mu\text{f}$  capacitor, and the inductor is a  $33\text{ mH}$  inductor (we've used the inductor and capacitor before in Lab 2).

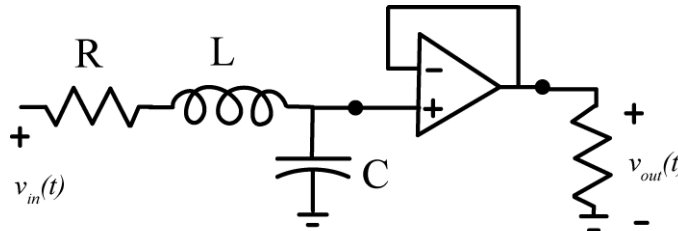


Figure 15. Our second order system

- 3) To make sure your plant (system) is correct, we will first test the plant, so you need to disconnect this system from the feedback system. Set the input to a  $1\text{ kHz}$  square wave, and the time scale to  $100\ \mu\text{s}/\text{div}$ . The output is the voltage across the capacitor, and you should get a graph like that in Figure 16. Note that this system has a settling time of approximately  $0.25\text{ ms}$  and about a  $30\%$  overshoot. *Include a screen shot of this in your memo.*
- 4) Make the voltage across the capacitor your output. The oscilloscope screen should look the same as before.
- 5) Connect your system, or plant, to the feedback network and try to adjust the system so there is no overshoot and the settling time is less than approximately  $0.4\text{ ms}$ , as shown in Figure 17. You may have to adjust the time scale and frequency of the signal generator to get a good picture. Be sure your system has reached steady state (it's flat on the top!) *Include a screen shot of this in your memo.* Note that in this case, we cannot speed up the response of the system if our goal is to reduce the overshoot.

You should remember that we are not changing our plants, or basic systems, but we are changing how they behave using feedback and an active controller to change the system characteristics.

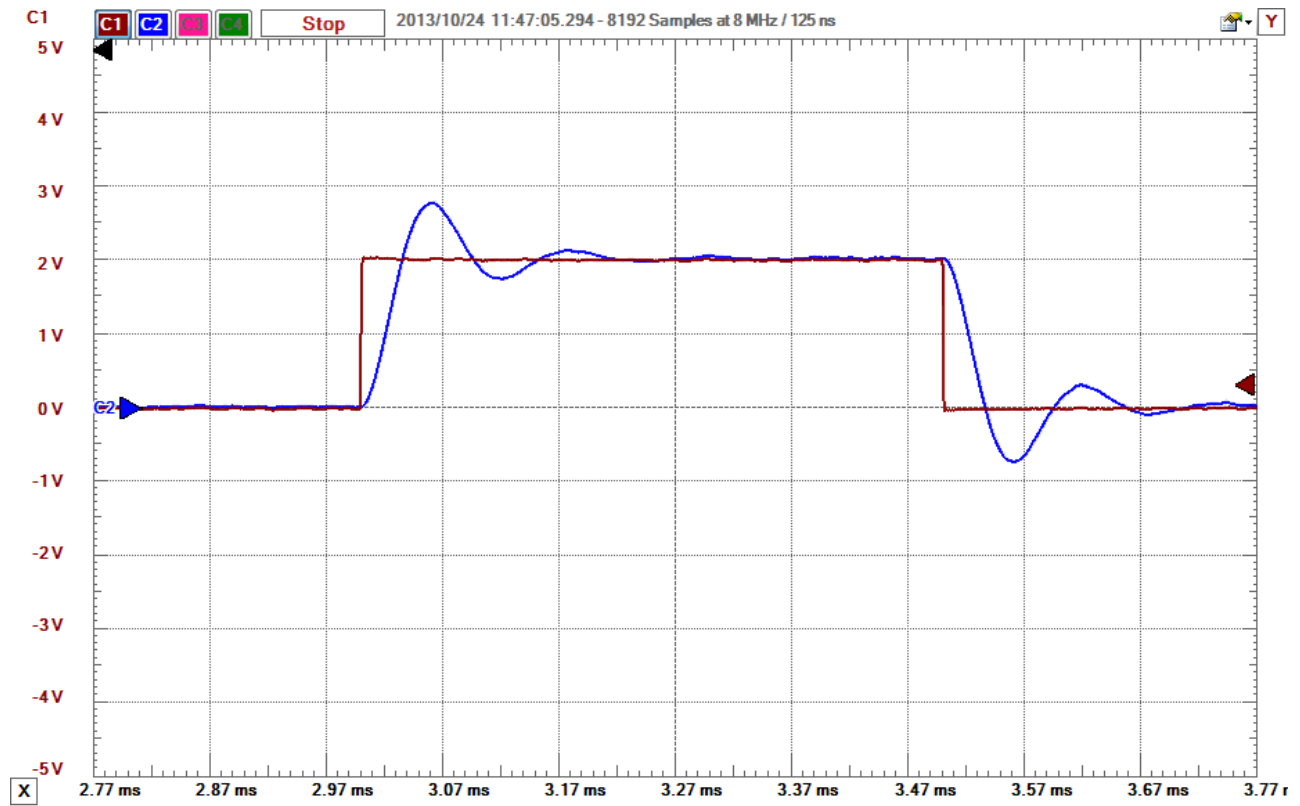


Figure 16. (Open loop) step response of our second order plant.

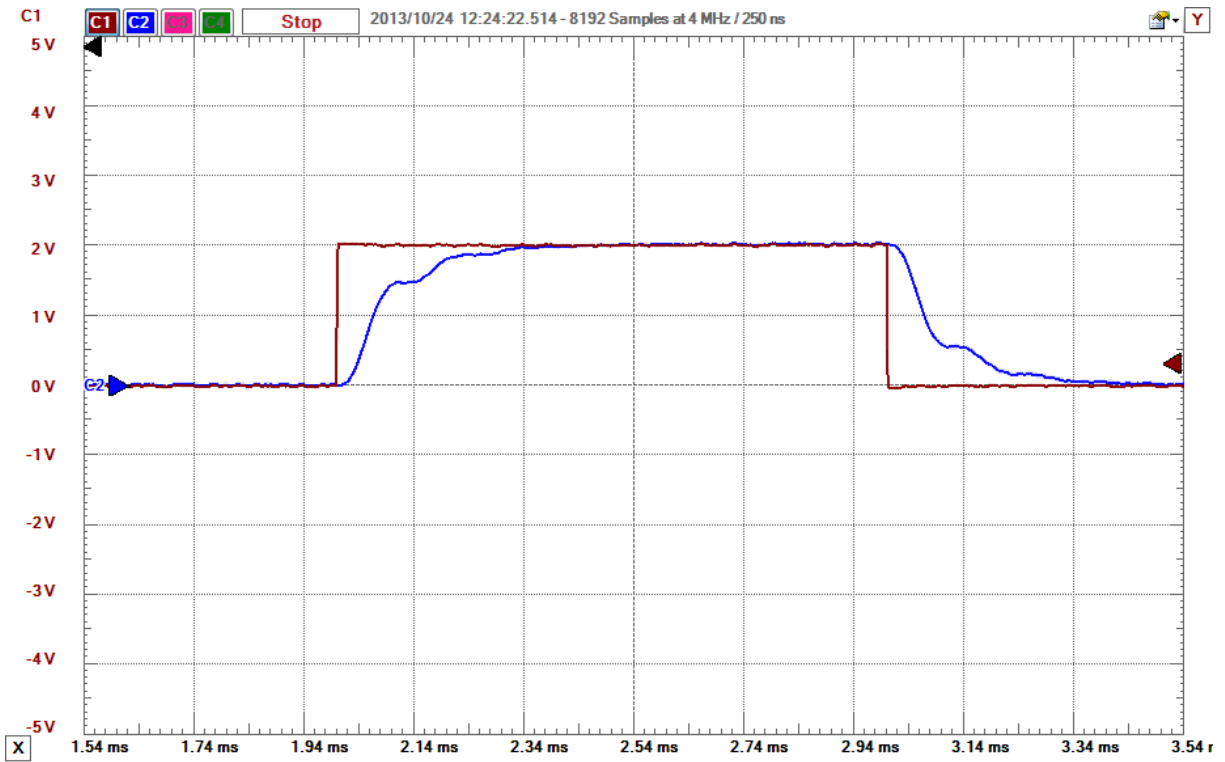


Figure 17. Closed loop step response of our second order system with no overshoot.