University of California
Department of Electrical Engineering and Computer Sciences
EE128, Fall 2005, Prof. Hsu modified by A. Aswani

Lab 2: Simple Feedback Circuit

Prelab:
Read through the lab manual below and, **in your own words,** summarize the lab procedure and "Introduction to Step Responses". This is worth 5 points. Simply copying the lab manual or just changing a few of the words will result in no credit for this part of the prelab.

Next, make a sketch of the traces of a proto-board (some people refer to these as bread-boards, even though they are different things). There are many resources in books and on the web for you to refer to, if you have forgotten how a proto-board is arranged. Also, make another sketch of how you will place and connect the components of the circuit seen in figure 1. Be sure your sketch includes the placement of the components on the proto-board. The sketch does not have to be perfect, but should be a reasonable attempt. This is just to get you thinking about how you will arrange the circuit on the proto-board. This is also worth 5 points.

Lastly, sketch a block diagram in which each stage of the circuit in Figure 4 is represented by a transfer function block (the first stage is a summing junction). Determine the transfer function between Vi and Vo1, between Vi and Vo2, and between Vi and Vo3. This part of the prelab is worth 5 points for completing it, but all of your work must be shown.

Introduction to Step Responses:
A standard way of characterizing the performance of a linear feedback system is through its step response. The step response is simply the output of a feedback system that is given a unit-step input. If the system is stable, this output will be a step function with decreasing fluctuations. Some important characteristics of the step-response are:

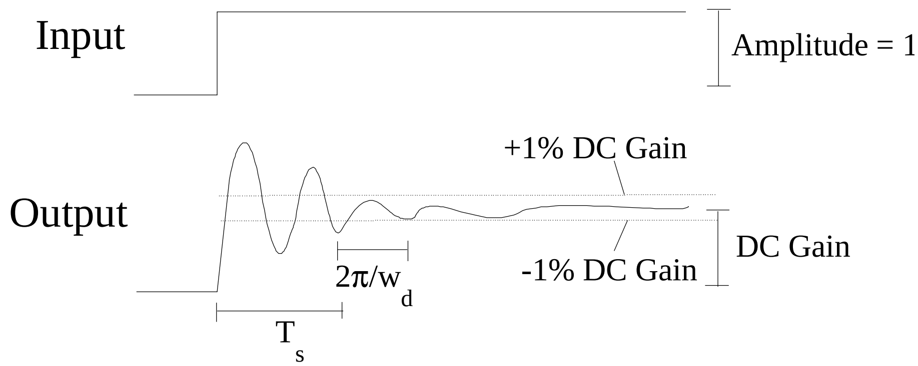
DC gain – the final, steady-state value of the output to the unit-step input

Damping ratio – this tells how fast the amplitude of the fluctuations of the step response dies off; its variable is ζ

Natural frequency – this tells the frequency of the fluctuations of the step response, assuming that there was no damping; its variable is $\omega_0 = \omega_n$

Settling time – this is the time the step response takes to get to within 1% of it's final, steady-state value; its variable is T_s

The following figure shows these characteristics:



and to estimate the damping ratio and natural frequency, use the equations:

$$T_s = 4.6/(\omega_0 \zeta) \text{ and } w_d = \omega_0 * \text{sqrt}(1 - \zeta\text{^}2)$$

These quantities are related to the transfer function of the system by the following equation for the denominator of the transfer function (characteristic equation):

$$d(s) = s\text{^}2 + 2\zeta\omega_0 s + \omega_0\text{ ^}2$$

The equation above is one of the more important equations in linear feedback systems. It allows you to relate the system performance to the poles of the system, and so it is very useful in designing controllers to meet certain specifications. Refer to Section 3.3 of the textbook for more information about step responses and the impact of pole locations on system response.

Part 1:
Figure 1 shows a simple unity gain amplifier with a push-pull (Class B) amplifier stage that is often used in the output stages of stereos and servo amplifiers. Due to the V_{BE} of the silicon transistors, this circuit has a dead-band between about -0.6v and +0.6v. This 'cross-over' distortion can be nearly eliminated by closing the feedback loop around the push-pull stage as the circuit shown in Figure 2.

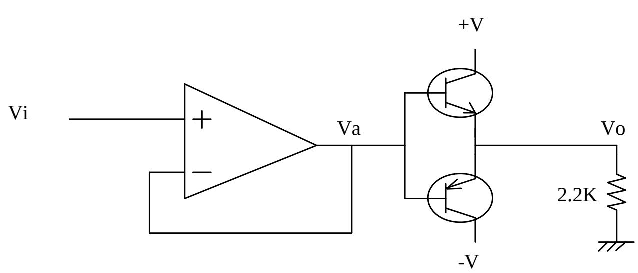


Figure 1

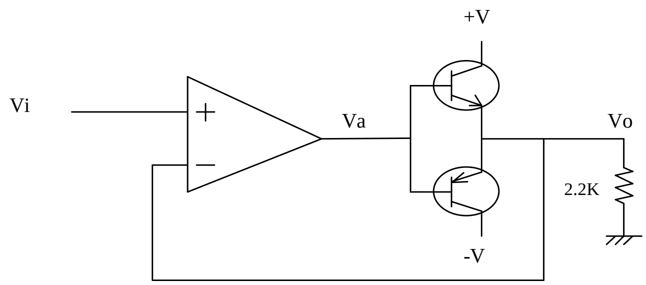


Figure 2

Construct the circuit shown in Figure 1 using a LM741 op-amp and 2N3904 (NPN) and 2N3906 (PNP) transistor. The node with the arrow is the emitter (E), and the top transistor in Figures 1 and 2 is the NPN transistor. Their pin-outs are shown in Figure 3. Note the positions of the notches and shapes of the elements.

Figure 3

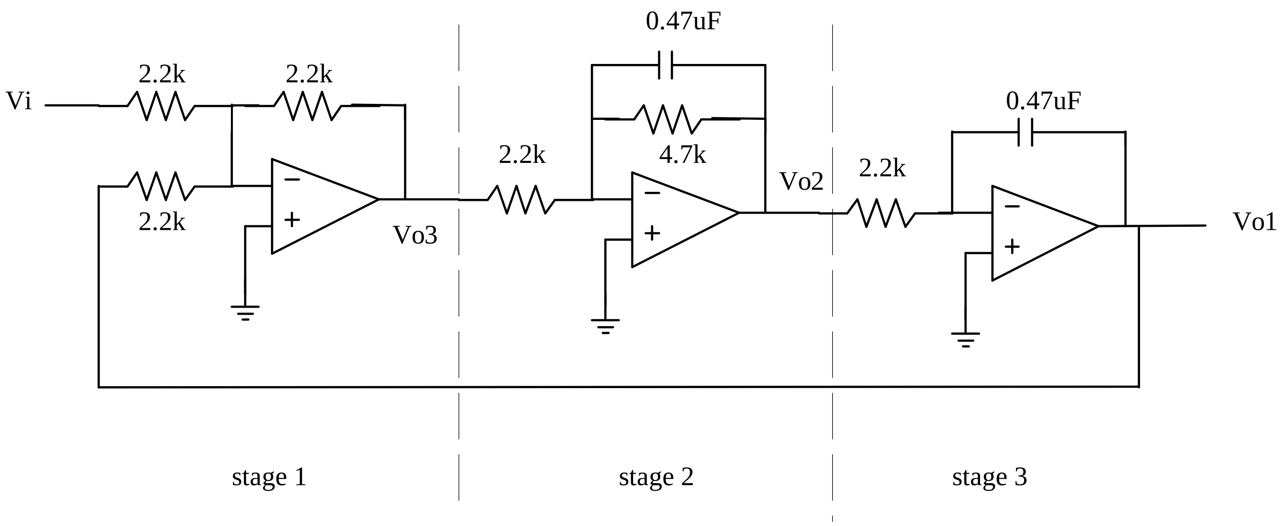
Input a ~1 kHz sinewave to the circuit and observe the waveform at Va and Vo. Include these waveforms in the report. Is this system linear from Vi to Va? Is this system linear from Vi to Vo? Remember that all linear systems have a "sine-in, sine-out" property. That is, if you put a sinusoid into a linear system, you will get a sinusoid with the same frequency out (though the amplitude and phase might be changed).

Now use the oscilloscope to X-Y plot the transfer characteristic from Vi to Va and from Vi to Vo. Use a 100 Hz sinewave input for Vi viewed on Channel 1 (X), and the other signal on Channel 2 (Y).

Modify the circuit so that the feedback loop is closed around the push-pull stage (as in Figure 2). Input a ~1 kHz sinewave to the circuit and observe the waveform at Va and Vo. Include these waveforms in the report. Is this system linear from Vi to Va? Is this system linear from Vi to Vo? Now use the oscilloscope to X-Y plot the transfer characteristic from Vi to Va and from Vi to Vo. Use a 100 Hz sinewave input for Vi viewed on Channel 1 (X), and the other signal on Channel 2 (Y).

Summarize your experimental results. In particular, explain the difference between the waveforms Vo and Va in these two circuits. Note the difference in the transfer characteristic.

Part 2: Construct the circuit shown below in Figure 4 using the LM741 op-amp.



Lab Measurements:
The input to the circuit is Vi and the output is Vo1. Experimentally determine the circuit's frequency response (both magnitude and phase over the range 10 Hz to 1 kHz), and step response (DC gain, damping ratio ζ, natural frequency ω_0, and settling time T_S).

For Vo2 as the output, experimentally determine the circuit's frequency response (both magnitude and phase over the range 10 Hz to 1 kHz), and measure the damping ratio and natural frequency.

For Vo3 as the output, measure the damping ratio and natural frequency.

Use MATLAB to plot the measured frequency response from Vi to Vo1. Also, use MATLAB to plot the theoretical step response at Vo1. The theoretical step response means the step response you would predict with the transfer function that you derived.

Theoretical Analysis:
Sketch a block diagram in which each stage of the circuit is represented by a transfer function block (the first stage is a summing junction). Determine the transfer function between Vi and Vo1, between Vi and Vo2, and between Vi and Vo3. Calculate the DC gain, damping ratio ζ, natural frequency ω_0, and settling time T_S of the transfer functions for Vo1 as the output. For Vo2 and Vo3 as the output, just calculate the damping ratio and natural frequency of the transfer function. Using MATLAB's *bode* command, make a plot of the frequency response for the transfer functions. Using *hold* in MATLAB or functions in a plotting program, plot the measured response along with the corresponding analytical response.

Discuss your lab results and explain any discrepancies between the lab results and the results from analysis.