1 Design Project Introduction

In this project you will finalize the design of your operational amplifier and explore the stability of the amplifier.

The learning goals are listed below:

- See many analog subcircuits coming together into a more complex analog system.
- Appreciate the power of op-amp compensation.

Your op-amp needs to meet the following specifications:

- Open loop gain of 50 or higher
- Able to operate with DC input voltages
- Uses at most one 6V supply rail, one -6V supply rail and one ground rail.
- Open-loop stable.

As usual in design projects, it is expected that simulated, measured and analytical estimates of amplifier properties agree.

2 Build Your Gain Stage

Design a gain stage that can be DC coupled to the output of your differential amplifier and the input of your output stage. You are free to modify your differential and output stages, and many students find this project easier if they do so. Be sure to be mindful of loading effects, and check whether a PNP stage will be easier to DC couple than an NPN stage.

Design the gain stage so your op-amp meets the specifications above. Characterize this gain stage to prove that it operates.

Required Data: Gain stage design, Gain stage proof of functionality (eg: input/output scope trace), design of any level shifts.

3 Build Your Op-Amp and Measure Open-Loop Behavior

Connect your gain stage between your input and output stages. Add a compensation cap of 100 pF.

Conduct the following open-loop tests of your amplifier:

1. Is the amplifier open-loop stable? If not, improve your bypassing, biasing, compensation and layout.
2. Can you make your amplifier unstable by removing the compensation capacitor?
3. Measure a transfer characteristic of your op-amp to verify its input common mode range, output swing and gain.
4. Measure a Bode plot of your open loop gain. You may need to attenuate (and/or capacitively couple) your test input to do so.

Required Data: Scope traces showing open loop stability/instability and design of any changes you made to the initial compensation capacitor, transfer characteristic, Bode plot of open loop gain, analytical transfer functions and analytical comparisons, especially of dominant pole location and input common mode range.

4 Make a Closed-Loop Op-Amp and Assess Your Stability

Configure your op-amp for unity gain feedback.

Conduct tests to answer the gather the following data:

1. Is your op-amp stable? Does this match your Bode plot? If it is not unity gain stable, then configure it for non-inverting gain and increase the attenuation of the feedback factor until it becomes stable.
2. Measure a closed-loop transfer characteristic of your op-amp.
3. Measure a Bode plot of your closed-loop gain.
4. Measure a step responses for your closed-loop op-amp both with small input amplitude (so you get a linear response) and large input amplitude (so you observe slewing). What is your settling time constant, slew rate and steady state error? Do these agree with analytical predictions?

Required Data: Proof of stability and functionality in feedback (specifying whether it's unity gain or with some other feedback factor), large and small input step responses from closed loop amplifier, measured time constant, slew rate and steady state error, analytical transfer functions and analytical comparisons for every extracted number.

5 Extra Credit Options

- You may add one "special feature" of your choice to the op-amp for a few (up to 5) bonus points. For example, you might use a mirror-load on your differential stage, bias your gain stage with a current mirror, design a rail-to-rail input stage, operate on a single rail, or use more aggressive compensation methods. I'm open to a wide variety of possible modifications, so talk to me about what you're trying to do!
- Find the maximum capacitive load of your op-amp. Does your maximum capacitive load make sense when you compare it to your Bode plot and to the design of your output stage?