Figure 1: An op-amp model suitable for calculating the maximum capacitive load for the op-amp.

1 Warm Up Problem

Maximum capacitive load is a common specification on op-amp datasheets. When the capacitive load of an op-amp is too high, the op-amp can become unstable. In this figure, C_l is the load capacitance, r_{out} is the op-amp's output impedance and $a_{ol} = a_{dc}/(\tau s + 1)$ is the op-amp's open loop gain. Find an expression for the maximum capacitive load of the op-amp. Assume $R_1 + R_2 \gg r_{out}$ and $r_{out} C_l \ll \tau$. Express your solution in terms of a_{dc}, τ, r_{out} and the desired feedback factor $f = R_2/(R_1 + R_2)$.

2   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 how many analog subcircuits can come together into a more complex analog system.

- Appreciate the power of op-amp compensation.

3   Build Your Op-Amp

Build a complete operational amplifier, either by designing a gain stage that can be DC coupled to the output of your differential amplifier and the input of your output stage or by designing/adjusting all three amplifier stages. If you are designing a gain stage to work with the differential amplifier and output stage, then be sure to be mindful of loading effects and to check whether a PNP stage will be easier to DC couple than an NPN stage. Your op-amp needs to meet the following specifications:

- Open loop gain of 50 or higher

- Able to operate with DC input voltages

- Uses one 12V supply rail.

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, 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!

Test your gain stage on its own and make sure it is working with a DC coupled input voltages. After that, complete your op-amp by connecting one of the outputs from your differential amplifier to the input of your gain stage and connecting the output of the gain stage to the class AB output stage. Add a 10nF compensation capacitor to the gain stage.

4   Assess Your Stability

Conduct tests to answer the gather the following data:

1. Is the amplifier open-loop stable? If not, improve your bypassing, biasing and compensation. Is it stable without the compensation capacitor?

2. Measure a Bode plot of your open loop gain. You may need to attenuate (and/or capacitively couple) your test input to do so.

3. Configure your op-amp for unity gain feedback. Is it 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.

4. Measure a step respones 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?

5. 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?

Required Data: Gain stage design, Gain stage proof of functionality (eg: input/output scope trace), scope traces showing open loop stability/instability, Bode plot of open loop gain, proof of stabilty 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, maximum capacitive load and proof of stability or instability under that load, analytical transfer functions and analytical comparisons for every extracted number.