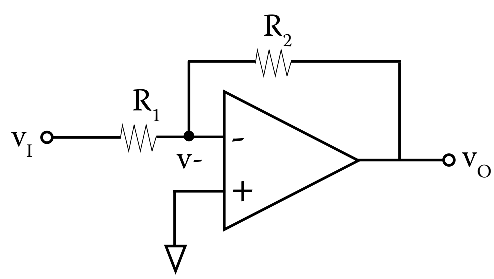
6.302 Feedback Systems

Recitation 19: Minor-Loop in an Op-Amp
Prof. Joel L. Dawson

We've given you a lot of tricks for understanding feedback systems when they are given to us as a block diagram. Sometimes, getting a feedback system from its "physical" form as a schematic diagram to block diagram form is a bit of an art. This "art" is greatly enhanced by the use of thoughtful approximations.

One such approximation you've already seen:



We can either do the math, or reason in the following way: since the gain of the op-amp is huge, the voltage at v- must be very small for ordinary values of v_O. We decide to call v- a virtual ground, and then crank merrily along.

This type of thinking helps tremendously in analyzing complicated circuits like op-amps. Let's look and see how.

CLASS EXERCISE

Consider the following two feedback circuits:

Diagram 1.

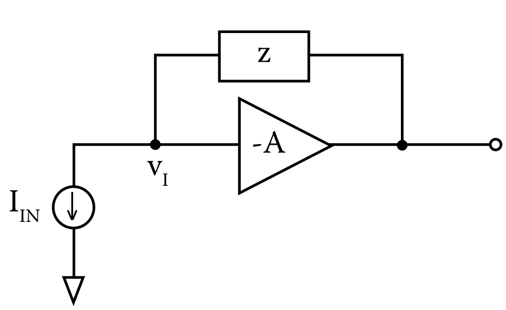
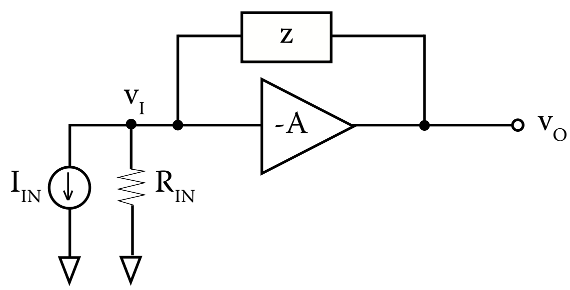


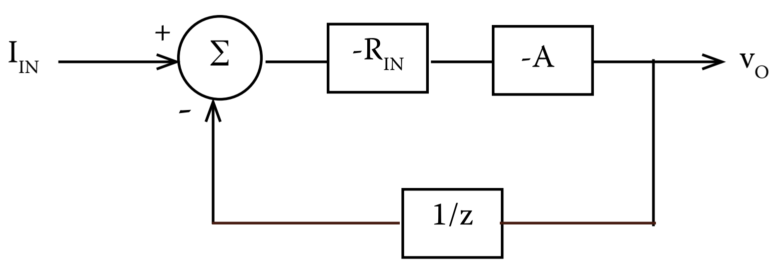
Diagram 2.



For each, determine $\frac{v_O}{I_{IN}}$ in the limit of A>>1. Also determine v_I in each case.

(Workspace below)

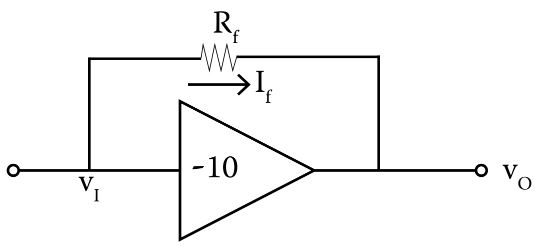
Notice that these <u>are</u> feedback systems, even though the summing junction doesn't leap out at you. A valid block diagram for circuit (2) is (in the limit of large A):



(Diagram (1) is rendered in exactly the same way. We just take the limit as $R_{IN} \rightarrow \infty$.)

Anyway, the key idea is that when the gain A is large, v_{IN} becomes a virtual ground. So how large is large enough?

Depends on the accuracy you want, but let's try out some numbers to help clarify what we're dealing with. Suppose that A = 10, and we're calculating the current through the feedback element.



$$\left.\begin{array}{l} \text{Actual } I_f : \dfrac{-\frac{1}{10} v_O - v_O}{R_f} = \dfrac{-\frac{11}{10} v_O}{R_f} \\ \\ \text{Approximating } 10 \approx \infty : I_f = \dfrac{-v_O}{R_f} \end{array}\right\} \text{Even with the gross approx. } 10 \approx \infty, \text{ we're only off by about 10\%.}$$

These numbers should help to give you a feel for why we're not punished for making what seem like horrendous approximations.

The idea behind all of this is to help you understand the op-amp analysis that we've started in lecture.

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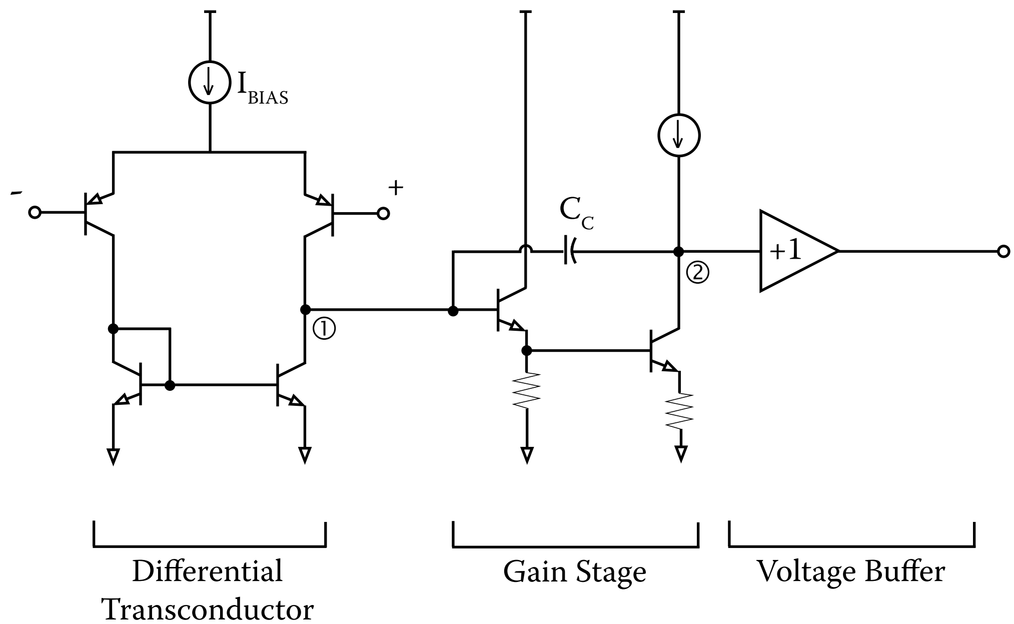
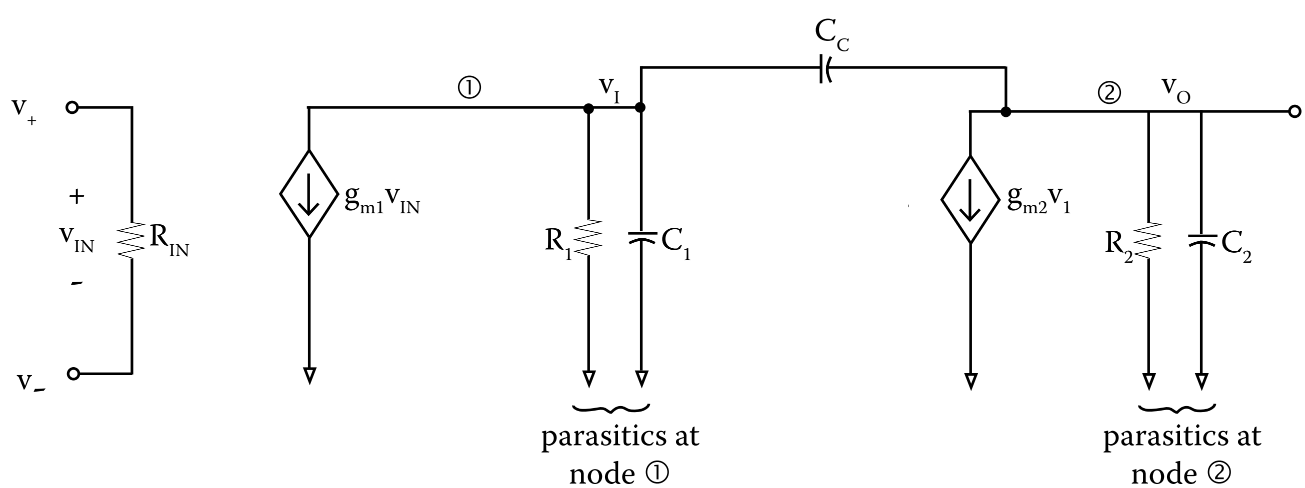
An Op-Amp example:



Writing node equations to analyze this circuit is a major, <u>major</u> pain. But with some thoughtful approximating, understanding this circuit can be made much easier.

Start by redrawing:

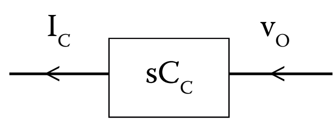


Now the gain stage provides a gain well in excess of 10. Recognizing this helps us to understand this circuit as an example of minor-loop compensation.

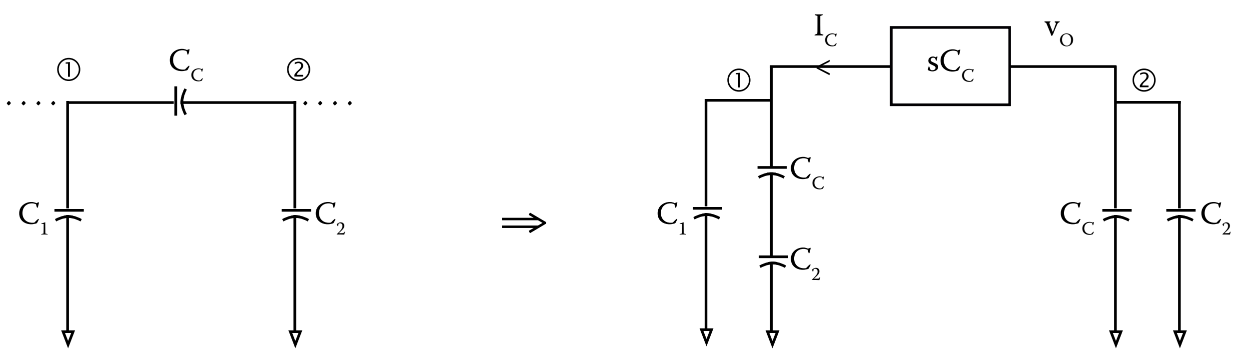
The current through C_C is just:

$$I_C = sC_C v_O$$

We can replace the capacitor C_C with the ideal block



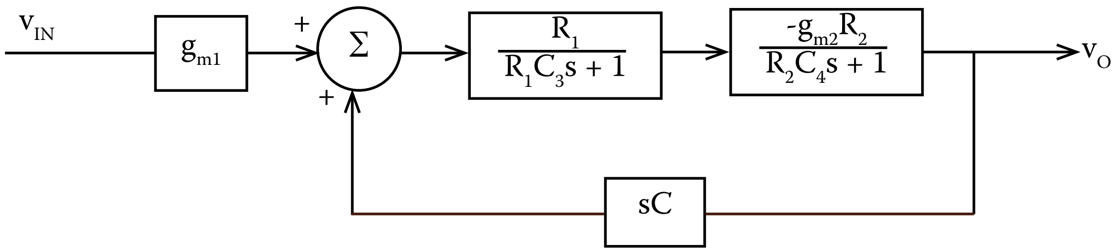
...provided we properly account for capacitive loading effects.



Define $\quad C_3 = C_1 + \dfrac{C_2 C_C}{C_2 + C_C}$

$$C_4 = C_2 + C$$

Following things through to the end, we wind up with a block diagram that looks like:



Believe it or not, a straight algebraic approach will eventually lead you here. Analyzing things this way gets you here much faster, though, and with a clearer understanding of what is going on.