6.301 Solid-State Circuits

Recitation 21: Current-Feedback, or Transimpedance, Amplifiers
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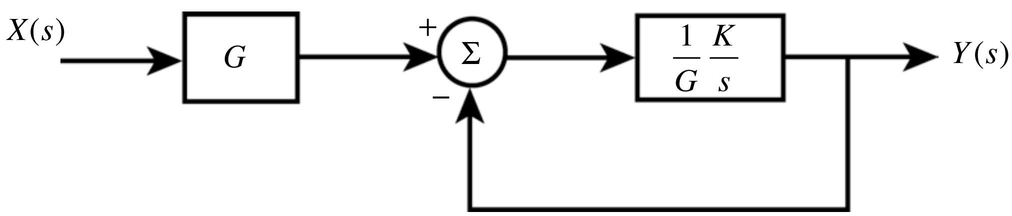
By now, you've practically grown up hearing about a "constant gain-bandwidth product." Where does that come from? And is it really a physical law?

The answer to the second question is that it is not a physical law. While it is true that you will often find it easier to get high gain for low bandwidths, this is more a consequence of the topology choices that we make than an expression of nature's laws. For instance, there is something called a "distributed amplifier," for which gain trades off with delay rather than bandwidth.

So what about the first question?

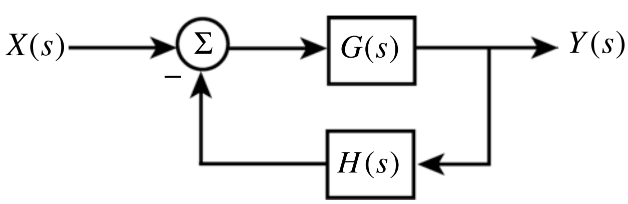
<u>CLASS EXERCISE</u>:
A simple inverting amplifier using an op-amp can be approximately modeled as follows:



Here, G is the ideal gain, and the dynamics of the op-amps are captured by $\frac{k}{s}$. Show that as the gain G is varied, this system exhibits a constant gain-bandwidth product.

(Workspace)

Hint:

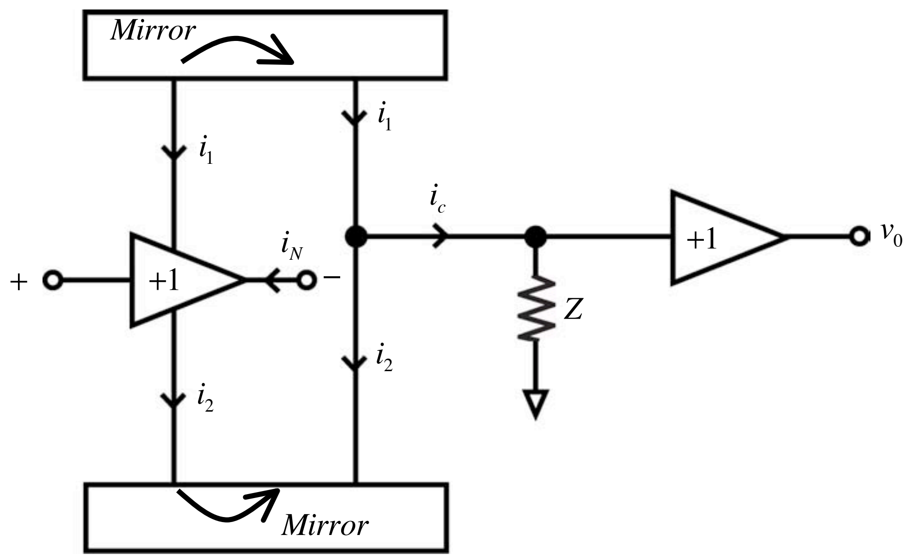


$$\Rightarrow \frac{Y(s)}{X(s)} = \frac{G}{1+GH}$$

Op-amps are often "compensated" such that their dynamics are dominated by one low-frequency pole. Op-amps are almost everywhere…hence the common belief in a fundamental gain-bandwidth product.

The current-feedback amplifier happens to be an amplifier that does not follow the constant gain-bandwidth "rule"…

<u>Current-Feedback Amplifiers</u>
Let's look at the implementation of a typical tranimpedance amplifier.



The underlying assumption is that i, i_2, and i_N together satisfy KCL. Thus,

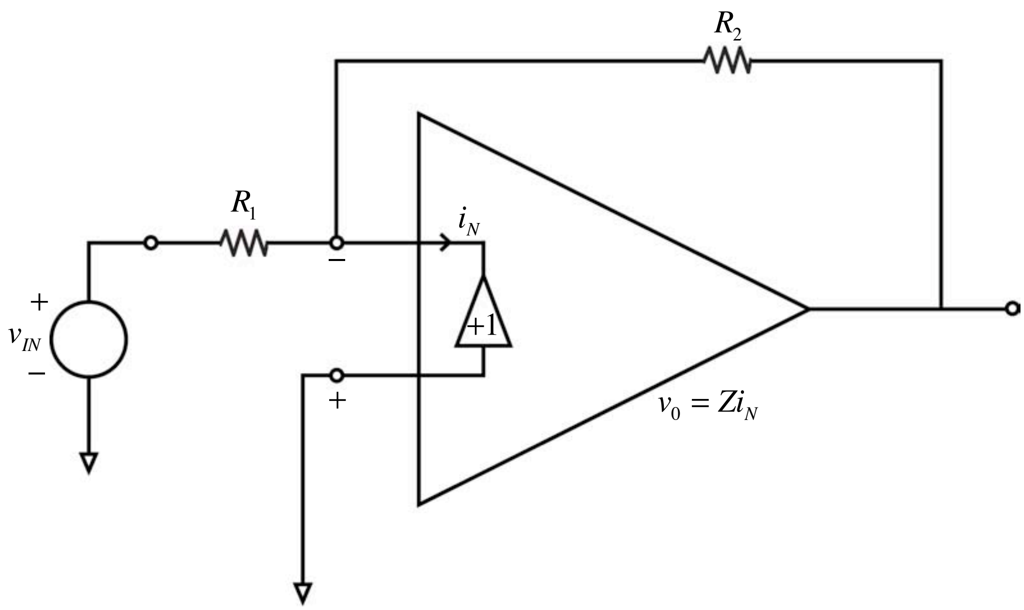
(1) $\quad i_1 + i_N = i_2$

(2) $\quad i_1 = i_2 + i_C$

(1) $\rightarrow$ (2) $\quad \cancel{i_1} = \cancel{i_1} + i_N + i_C$

$$i_C = -i_N \quad \Rightarrow \boxed{v_0 = i_C z = -Zi_N}$$

Pretty simple. It turns out that we can use this circuit in many instances just like a voltage op-amp. Let's see how.



A start to the analysis is to observe that, as in the case of the voltage op-amp, $V_+ = V_- \quad (= 0)$. The <u>reasons</u> are different, of course. For the voltage op-amp, it was negative feedback, combined with infinite gain, that forced $V_+ = V_-$. Here, $V_+ = V_-$ by construction, because we have placed a voltage buffer between them.

Very well. We write KCL at the inverting input:

$$\frac{v_{IN}}{R_1} + \frac{v_0}{R_2} = i_N$$

Recall that $v_0 = -Zi_N \Rightarrow i_N = -\frac{v_0}{Z}$

$$\frac{v_{IN}}{R_1} + \frac{v_0}{R_2} = -\frac{v_0}{Z}$$

$$\frac{v_{IN}}{R_1} + \frac{v_0}{R_2} + \frac{v_0}{Z} = 0$$

$$v_0\left(\frac{1}{Z} + \frac{1}{R_2}\right) = -\frac{v_{IN}}{R_1}$$

$$v_0\left(\frac{R_2 + Z}{ZR_2}\right) = -\frac{v_{IN}}{R_1}$$

$$v_0 = -\frac{ZR_2}{R_2 + Z}\frac{1}{R_1}v_{IN}$$

Now the idea behind a transimpedance amp is that Z, the transimpedance, is far and away the biggest impedance around.

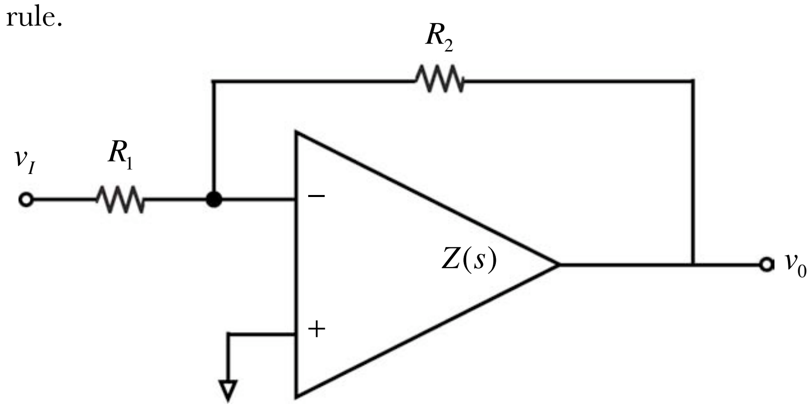
$$Z \gg R_2$$

$$v_0 = -\left(\frac{ZR_2}{R_2 + Z}\right)\frac{1}{R_1}v_{IN}$$

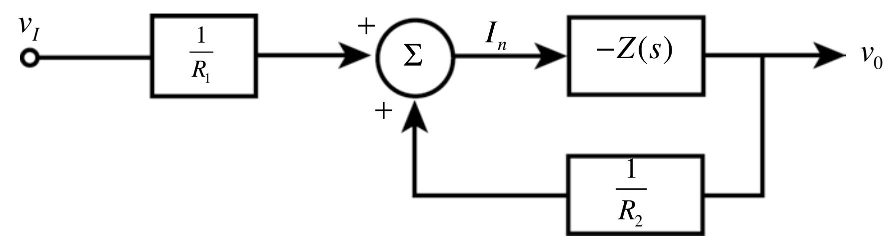
$$\boxed{v_0 \approx -\frac{R_2}{R_1}v_{IN}}$$

Just like a voltage op-amp!

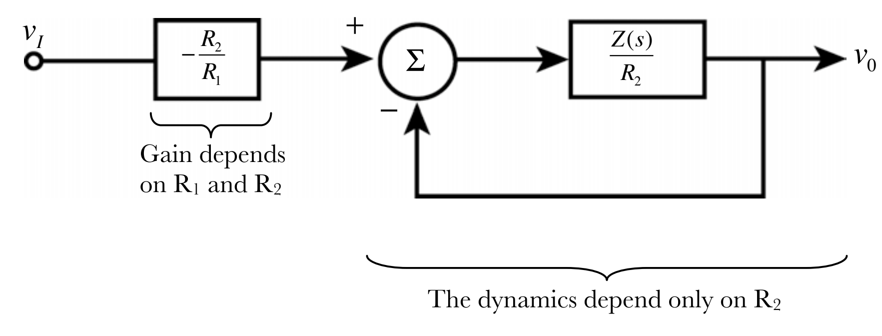
It turns out that with the transimpedance amplifier we are not subject to the constant gain-bandwidth product rule.



Block diagram:



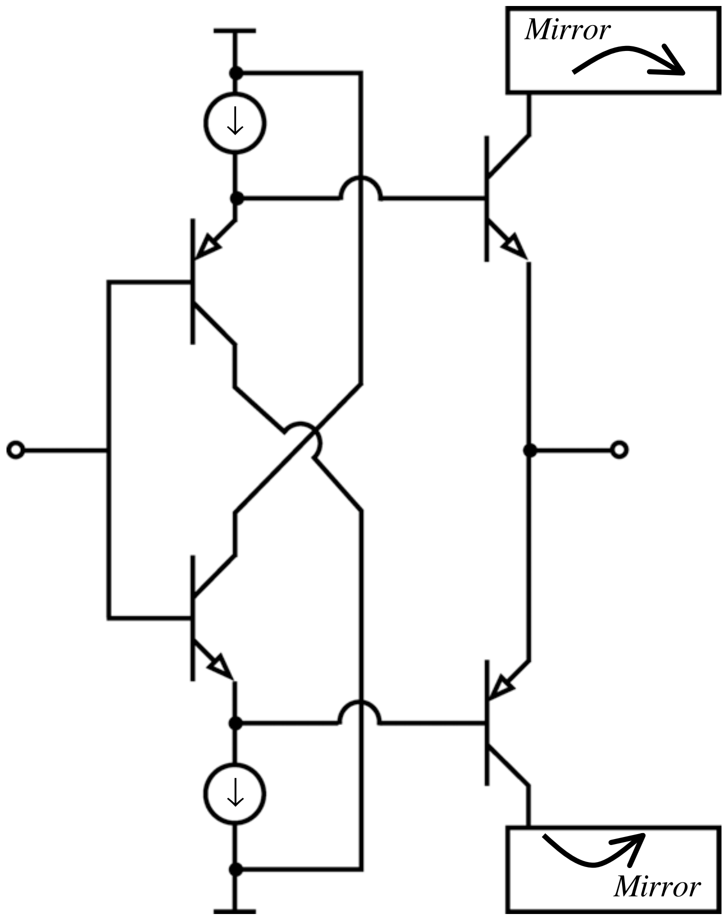
Rearranging:



So you can fix your bandwidth by choosing R_2, and set your gain by choosing R_1 in relation to R_2.

We'll close by looking at a common input buffer structure.

Buffer circuit topology: (sometimes called a "diamond circuit")



For design project, <u>read</u> course notes about slew rate for transimpedance amplifiers.

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