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?

**CLASS EXERCISE:**
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: $\frac{Y(s)}{X(s)} = \frac{G}{1 + GH}$
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”…

Current-Feedback Amplifiers
Let’s look at the implementation of a typical tranimpedance amplifier.
The underlying assumption is that $i_1$, $i_2$, and $i_N$ together satisfy KCL. Thus,

\begin{align*}
(1) & \quad i_1 + i_N = i_2 \\
(2) & \quad i_1 = i_2 + i_C \\
\hline
(1) \rightarrow (2) & \quad i_C = -i_N \quad \Rightarrow \quad v_0 = i_C z = -Zi_N
\end{align*}

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, $V_+ = V_-$ \((= 0)\). The reasons 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.

\( Z \gg R_2 \)

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

\[ v_0 \approx -\frac{R_2}{R_1} v_{IN} \]

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, read course notes about slew rate for transimpedance amplifiers.