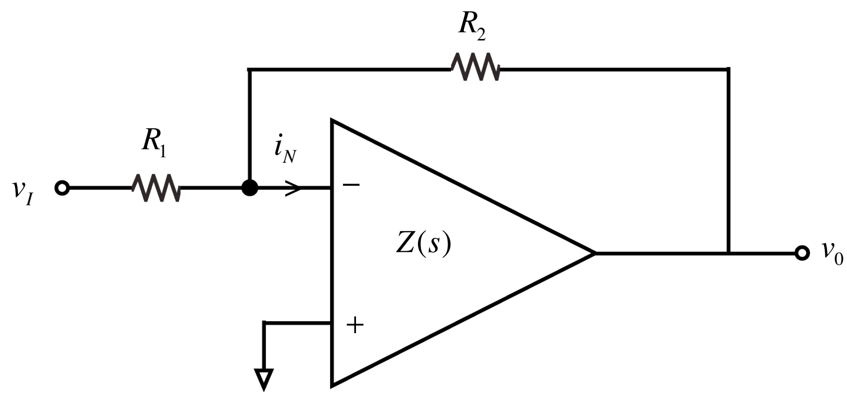
# 6.301 Solid-State Circuits

Recitation 22: More on Transimpedance Amplifiers, and Intro to Zener Diode References
Prof. Joel L. Dawson

Before we leave the topic of transimpedance amplifiers completely, there is one "biasing mystery" that is worth clearing up. First, let's review how a transimpedance amplifier is typically used:

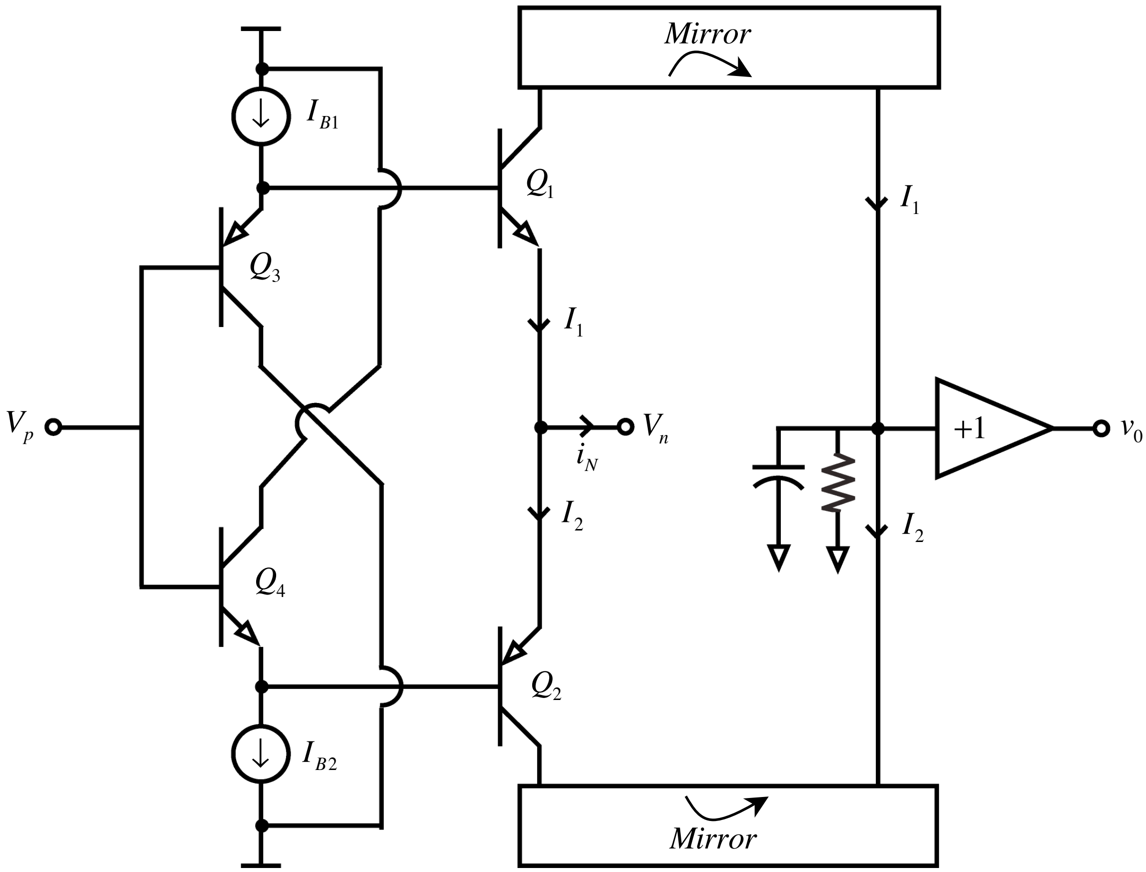



Recall that the output voltage, $v_0$, is given by

$$v_0 = -Z(s) \cdot i_N$$

Ideally, the tranimpedance $Z(s)$ is infinite…we work hard in our design to come as close to that ideal as possible. Accepting for the moment that we have achieved a very large transimpedance, what does that imply about $i_N$? Simple: If $Z(s)$ is huge, and $v_0$ is not, $i_N$ must be vanishingly small. This winds up being a key observation for figuring out how these "diamond buffer" circuits work.

Let's look now at a typical implementation of a transimpedance amplifier.




Big question: What sets the quiescent values of $I_1$ and $I_2$?

The way to answer is to recognize that we have a Gilbert loop formed by the base-emitter junctions of $Q_1 - Q_4$. Let's assume that the PNPs are perfectly matched to each other, and that the NPNs are also matched to each other. We have:

$$\frac{I_{C3}}{\cancel{I}_{sp}} \cdot \frac{I_{C4}}{\cancel{I}_{sN}} = \frac{I_{C1}}{\cancel{I}_{sN}} \cdot \frac{I_{C2}}{\cancel{I}_{sp}}$$

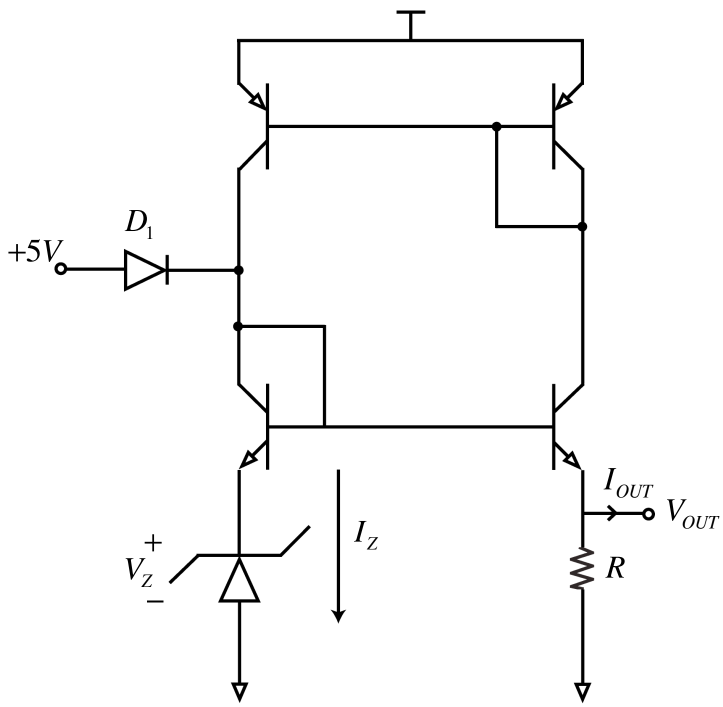
Now, $I_{C3} = I_{B1}$, $I_{C4} = I_{B2}$, <u>and</u> $I_{C1} = I_{C2}$ because we can assume that we're using the amplifier in a negative feedback configuration. So at the end of the day,

$$I_{C1}^{\ 2} = I_{B1} I_{B2}$$

$$I_{C1} = I_{C2} = \sqrt{I_{B1} I_{B2}} \quad (\textit{And normally}, I_{B1} = I_{B2})$$

A useful technique when using Zener diodes is to employ some form of "self biasing." That is to say, the bias current through the Zener diode is determined by the Zener voltage itself, rather than by the voltage supply. We'll talk about that in a minute, but first let's see if we can get a handle on the self-biasing concept.

<u>CLASS EXERCISE</u>: For the following circuit, ignore $D_1$ at first.




(1) Determine $I_Z$ and $V_{OUT}$.
(2) Explain why $D_1$ is important.

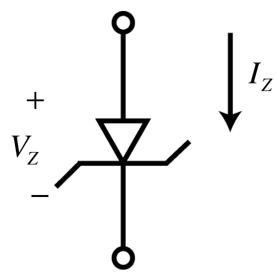
(Workspace)

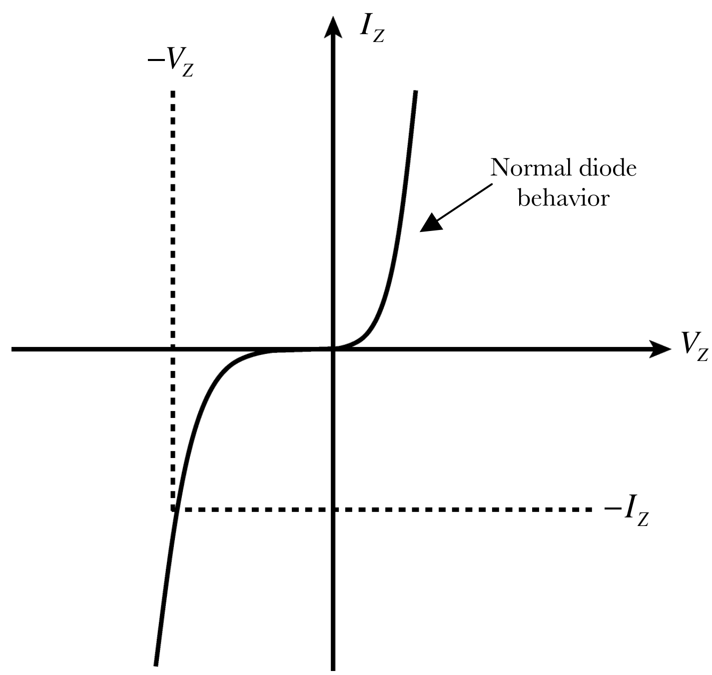
Self biasing is important because in order for the Zener diode to provide us with a good, solid voltage reference, it is often critically* important that its current $I_Z$ be precisely set. If we can help it, we don't want that current to be dependent in any way on the power supply voltage, which can change.

*By "critically," we mean that if we want tiny temperature drifts (~1-2 ppm), we have to be this careful.

Zener Diodes

It turns out that "reverse breakdown" for a diode is not a destructive event. With good engineering, diodes can be made to be useful under reverse bias as voltage references.




By choosing the doping profile of the pn junction, the actual breakdown mechanism traces to one of two phenomena:

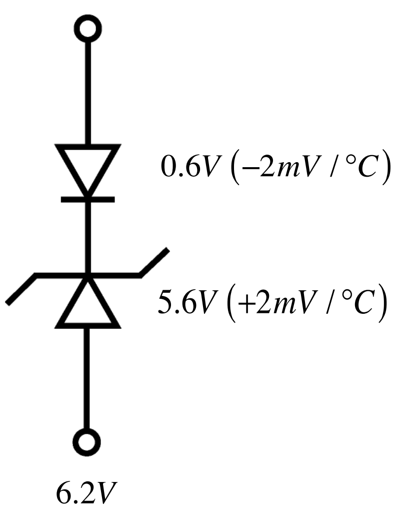
(1) Zener Breakdown (Quantum Mechanical Tunneling). Associated Zener voltages are $V_Z < 5V$. These diodes have a soft I/V characteristic and a negative temperature coefficient.
(2) Avalanche Breakdown. $V_Z > 7V$ (more or less), sharp I/V characteristic, and positive temperature coefficient.

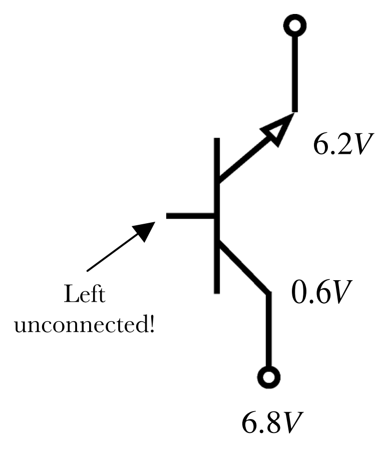
Most "Zener" diodes actually rely on avalanche breakdown.

<u>Temperature Compensated Zener Diodes</u>
There are known relationships between the Zener voltage and the resulting temperature coefficient of the device. Here are a few examples:

| Zener Voltage | $T_C$ |
|---|---|
| 5 V | ≈ 0 mV/°C |
| 6 V | ≈ +2 mV/°C |
| 8 V | ≈ +4 mV/°C |
| 10 V | ≈ +6 mV/°C |

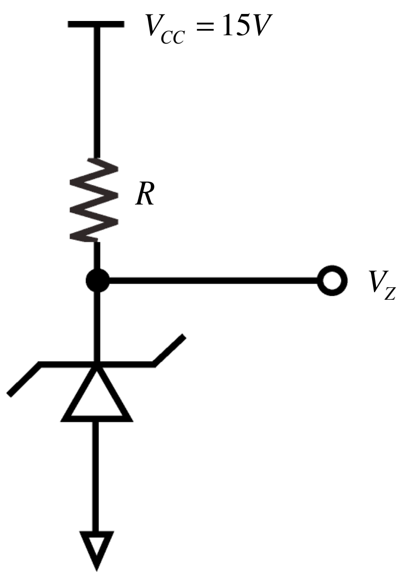
If we know these numbers, we can use ordinary diodes, with their −2 mV/°C $T_C$, to build a temperature compensated reference:



If you look at the spec sheet for a commercial Zener diode, you'll see that there is often one bias current at which the diode's Zener voltage is most stable with changes in temperature. When using Zener diodes, then, we often must go to great lengths to keep the bias current where we want it. The circuit shown in the class exercise is one method that we use. Notice that it has a negative output impedance: As $I_{OUT}$ increases, $V_{OUT}$ also increases.

Here's an example of how to suboptimally Bias a Zener diode:




$$I_Z = \frac{V_{CC} - V_Z}{R}$$

$$\frac{\Delta V_Z}{\Delta V_{CC}} = \frac{r_Z}{R + r_Z}$$

$r_Z$ is small signal impedance of the Zener diode.

Numbers: $I_Z = 7.5\ mA$, $V_Z = 6.2V \Rightarrow R = 1.17k\Omega$

A 1% change in $V_{CC}$ means that $V_Z$ changed by

$$\Delta V_Z = \left( \frac{r_Z}{r_Z + R} \right) \Delta V_{CC} = \frac{10\Omega}{(1.18k\Omega)} \cdot 150mV = 1.25mV$$

To see that this is huge, compare:

$$\frac{\Delta V_Z}{V_Z} = \frac{1.25mV}{6.2V} = 200\,ppm = (40°C)(5\,ppm\,/\,°C)$$