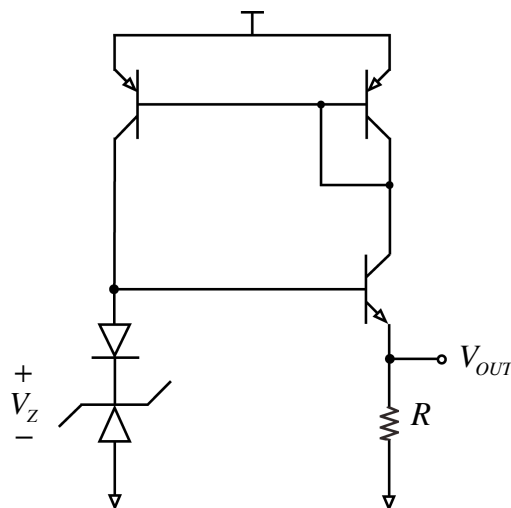# 6.301 Solid-State Circuits

Recitation 23: Zener Diode References (continued)

Prof. Joel L. Dawson

We've talked about this before, but it bears repeating: True DC performance is every bit as difficult to achieve as high-frequency performance. By "DC" performance, we're talking low DC offsets, in the case of amplifiers, and low drift performance. Usually with drift, temperature changes are the enemy.

With Zener references, we've already talked about using self-biasing to set the current through the diode. Why go to such pains? It turns out that with regards to temperature stability, Zener diodes tend to have a "sweet spot": run them at a <u>particular</u> current, and their temperature stability is especially good.

In the last class we looked at a particular self-biased cell. Let's look at it again.
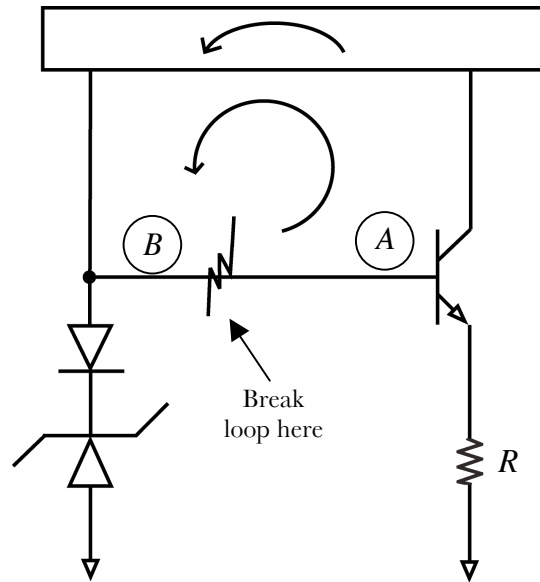

<u>CLASS EXERCISE</u>: Argue that the output impedance of this circuit must be negative.

6.301 Solid-State Circuits

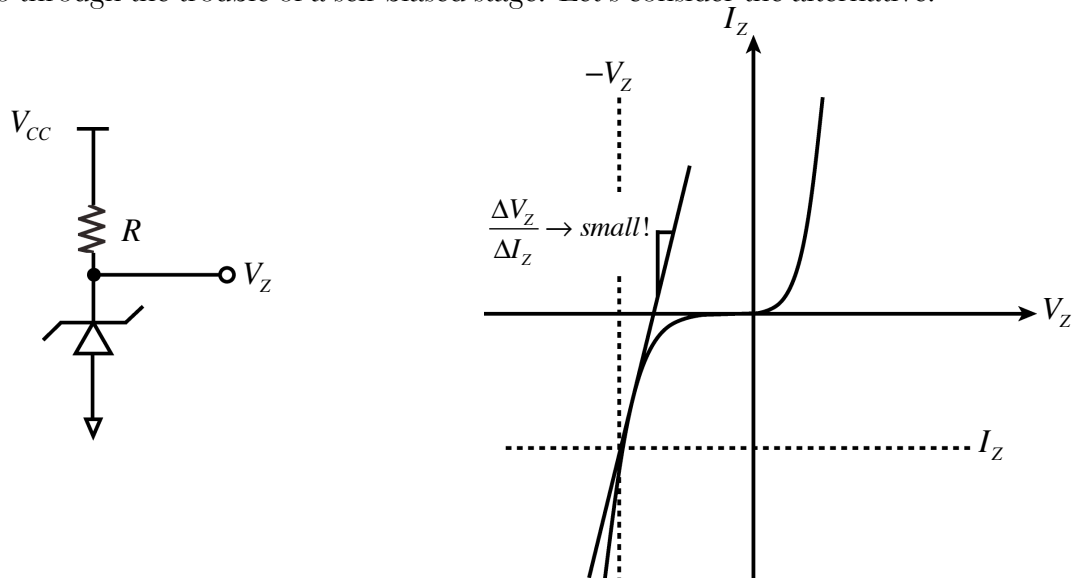Recitation 23: Zener Diode References (continued)
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Another interesting tidbit about this circuit is that it is actually an example of <u>positive</u> feedback:

After loop is broken, raising node (A) causes (B) to rise! We don't get into trouble because the gain around the loop is small (<1).

Again, why go through the trouble of a self-biased stage? Let's consider the alternative.

A good Zener diode will have a small incremental resistance, r_z. If we write out the response of the output voltage to changes in the supply, we get:

$$\frac{\Delta V_z}{\Delta V_{CL}} = \frac{r_z}{r_z + R}$$

Time for some numbers. Let $V_{CC} = 15V$, $r_z = 10\Omega$, $V_Z = 6.2V$. Further, suppose that the "sweet spot" for I_Z is 7.5mA, at which point the temperature coefficient is a mere 5ppm/°C. The value of R is determined by the sweet spot:

$$R = \frac{V_{CC} - V_Z}{7.5mA} = \frac{15V - 6.2V}{7.5mA} = 1.17k\Omega$$

Now, what happens when there is a 1% change in V_{CC}?

$$\Delta V_z = \left(\frac{R_z}{r_z + R}\right)\Delta V_{CC} = \left(\frac{10r}{1.18k\Omega}\right)150mV = 1.25mV$$

This, in the rarefied air of good voltage references, is huge. We can appreciate that by considering what temperature swing would correspond to this kind of change.

$$\frac{\Delta V_z}{V_z} = \frac{1.25mV}{6.2V} = 200\,ppm = \left(40°C\right)\left(5\,ppm\,/\,°C\right)$$
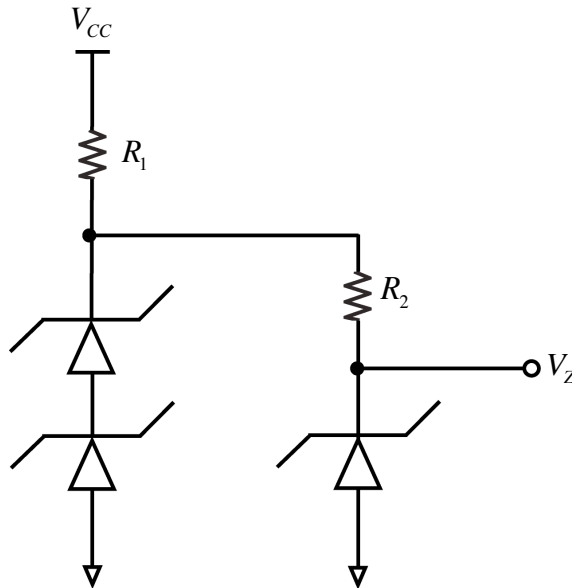
For those of us who work in Fahrenheit, it would take a temperature swing of 72°F to cause this much change! The point is that the care you took to temperature stabilize the Zener will be undermined by fluctuations or drift in the power supply.
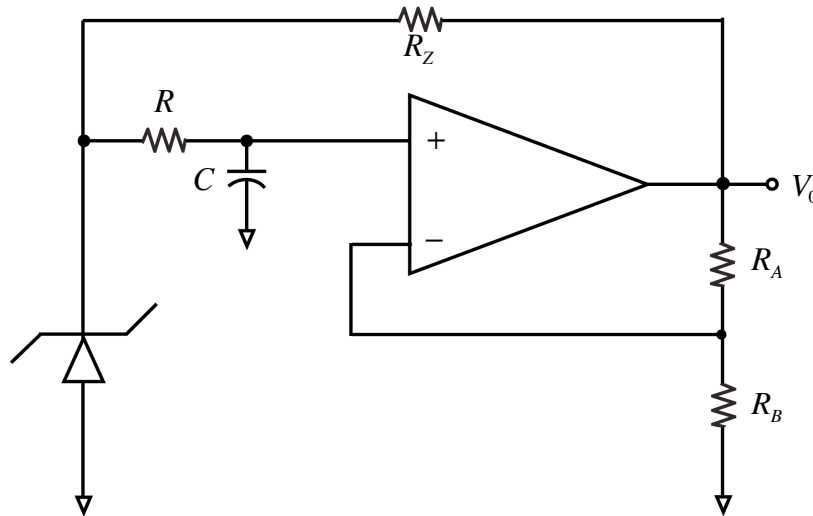
One way to improve things is to use pre-regulation:

Otherwise, we go to any number of self-biasing techniques. The class exercise is a good example.

Another Self-Biasing Technique

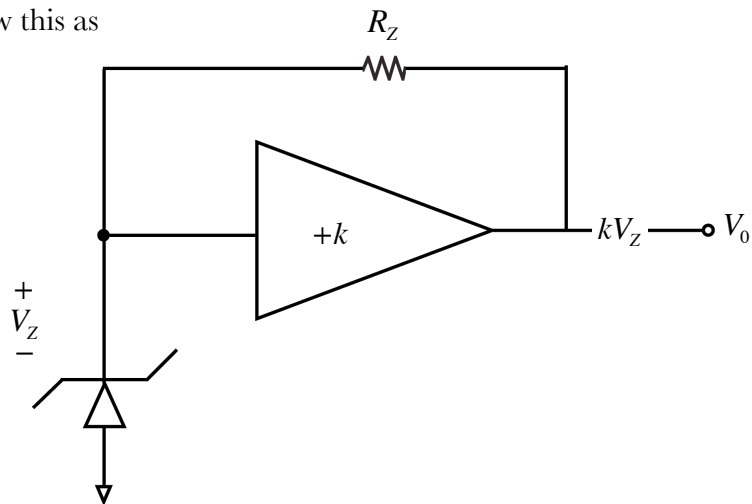As usual, our old friend the op-amp comes in handy here.

Notice that the op-amp is just connected as a non-inverting amplifier of gain k. For purposes of the DC bias calculation, notice that R and C have no impact.

Simplifying, we can draw this as

And now I_z is straightforward to calculate:

$$I_z = \frac{kV_z - V_z}{R_z} = \left(\frac{k-1}{R_z}\right)V_z$$

The nice thing about this circuit is that it let's us get stable voltage references at values other than V_z. For example, suppose that we need an output voltage of 10V, and our Zener diode has a V_z of 6.2V with a "sweet spot" current of 7.5mA. We select k according to

$$kV_z = 10V \Rightarrow k = \frac{10V}{6.2V} = 1.61$$

Then, we choose R_z to get the I_z that we want.

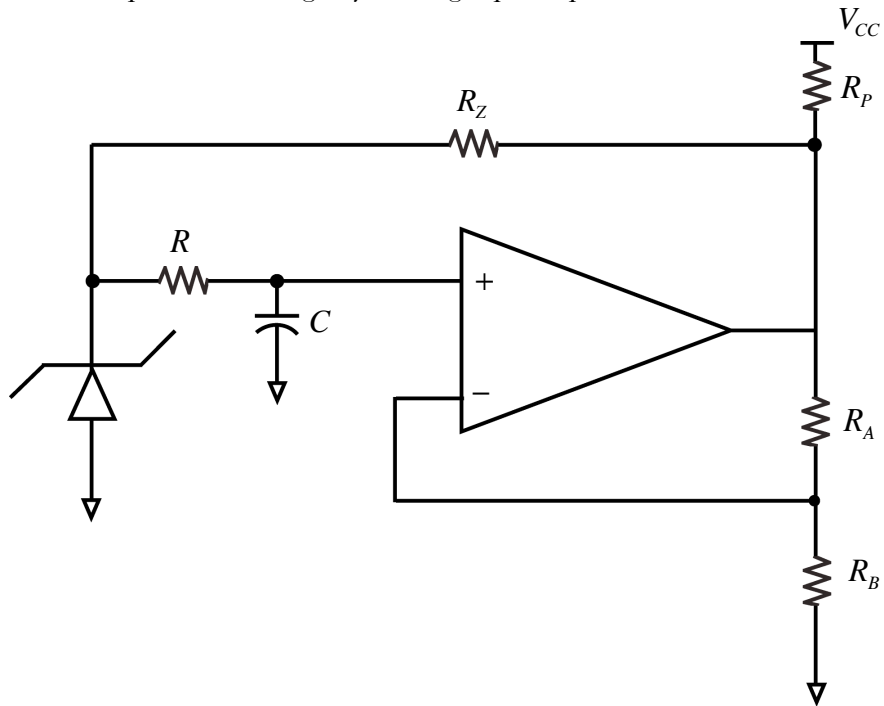$$7.5mA = \left(\frac{1.61-1}{R_z}\right)(6.2V)$$

$$\boxed{R_z = \left(\frac{0.61}{7.5mA}\right)(6.2V) = 504\Omega}$$

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Recitation 23: Zener Diode References (continued)
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This circuit has the drawback of demanding a relatively large amount of current from the output of the op-amp. We can improve on things by adding a pull-up resistor as follows:

R_p can be chosen to provide much of the Zener current. In addition, it helps with <u>startup</u> for this circuit.