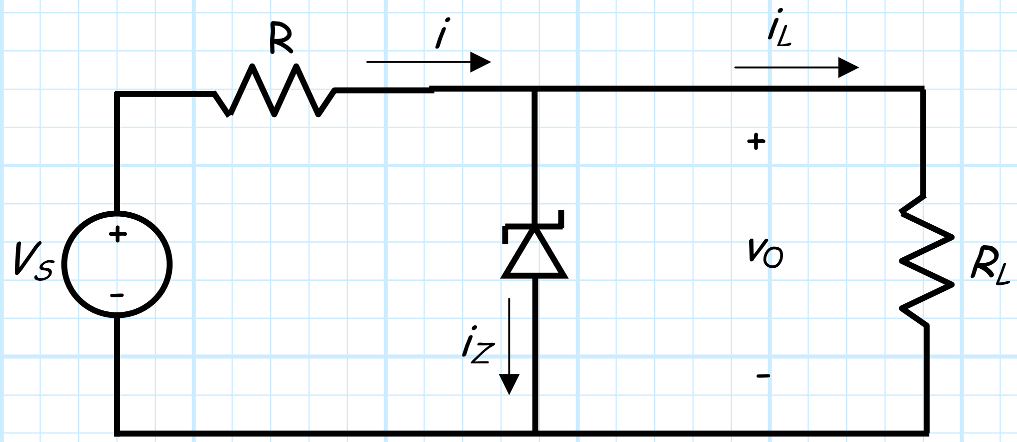
Load Regulation



For voltage regulators, we typically define a **load** R_L in terms of its **current** i_L, where:

$$i_L = \frac{v_O}{R_L}$$

Note that since the load (i.e., regulator) voltage v_O is a constant (approximately), specifying i_L is **equivalent** to specifying R_L, and vice versa!

Now, since the Zener diode in a shunt regulator has some small (but non-zero) dynamic resistance r_Z, we find that the load voltage v_O will also have a **very small** dependence on load resistance R_L (or equivalently, **load current** i_L).

In fact, if the load current i_L **increases** (decreases), the load voltage v_O will actually **decrease** (increase) by some small amount.

Q: ***Why** would the load current i_L ever change?*

A: You must realize that the load resistor R_L simply **models** a more **useful** device. The "load" may in fact be an amplifier, or a component of a cell phone, or a circuit board in a digital computer.

These are all **dynamic** devices, such that they may require **more** current at some times than at others (e.g., the computational load increases, or the cell phone begins to transmit).

As a result, it is more appropriate to represent the **total** load current as a time-varying signal ($i_L(t)$), consisting of both a **DC** component (I_L) and a **small-signal** component ($\Delta i_L(t)$):

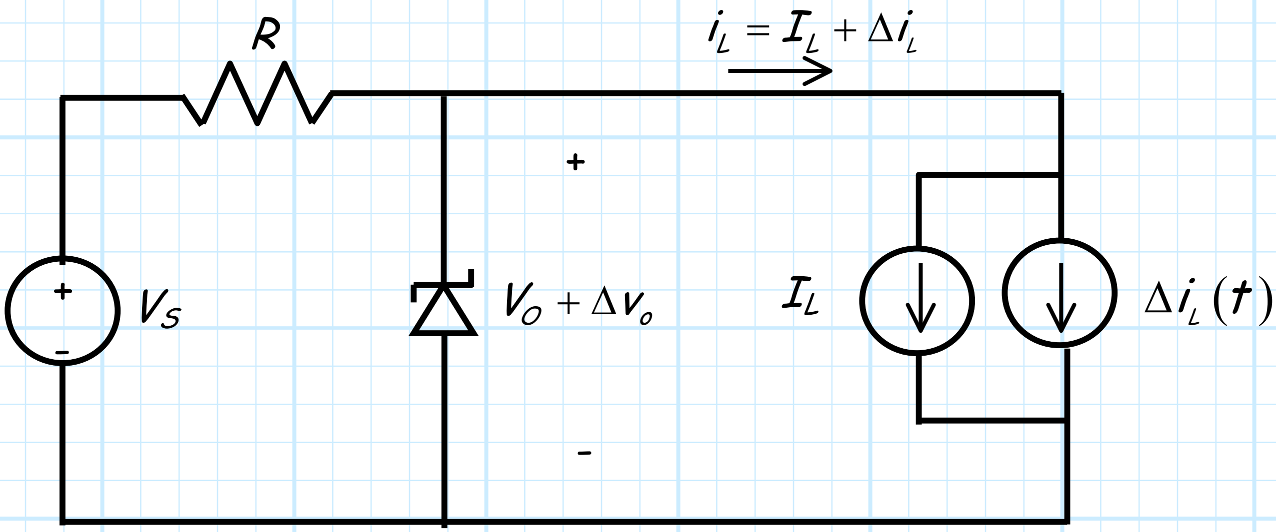
$$i_L(t) = I_L + \Delta i_L(t)$$

This small-signal load current of course leads to a load voltage that is **likewise** time-varying, with both a DC (V_O) and small-signal (Δv_o) component:

$$v_O(t) = V_O + \Delta v_o(t)$$

So, we know that the DC load current I_L produces the DC load voltage V_O, whereas the small-signal **load current** $\Delta i_L(t)$ results in the small-signal **load** voltage Δv_o.

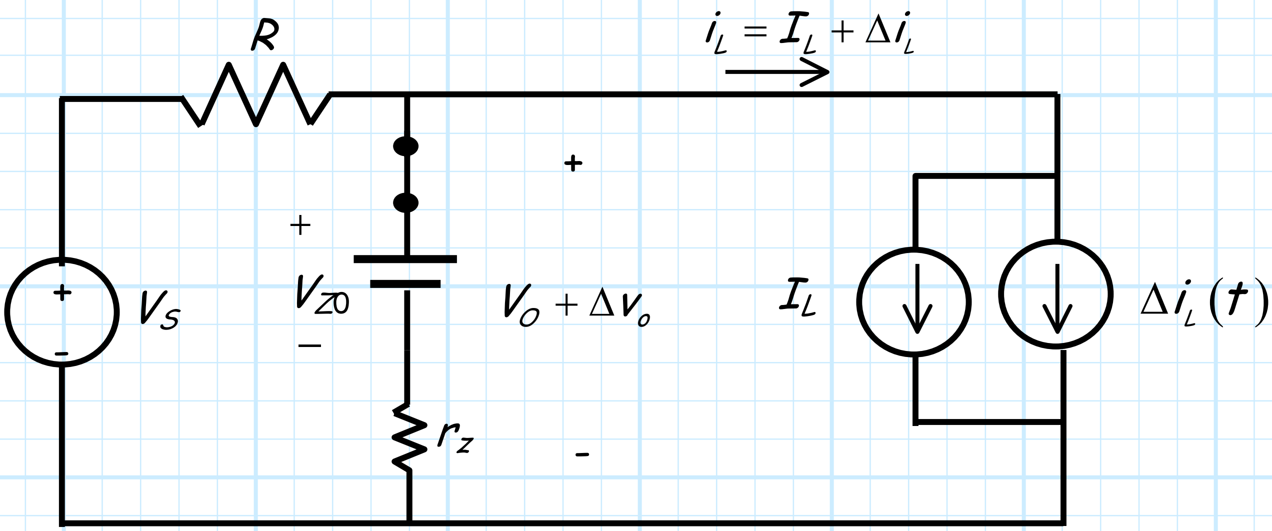
We can **replace** the load resistor with **current sources** to represent this load current:



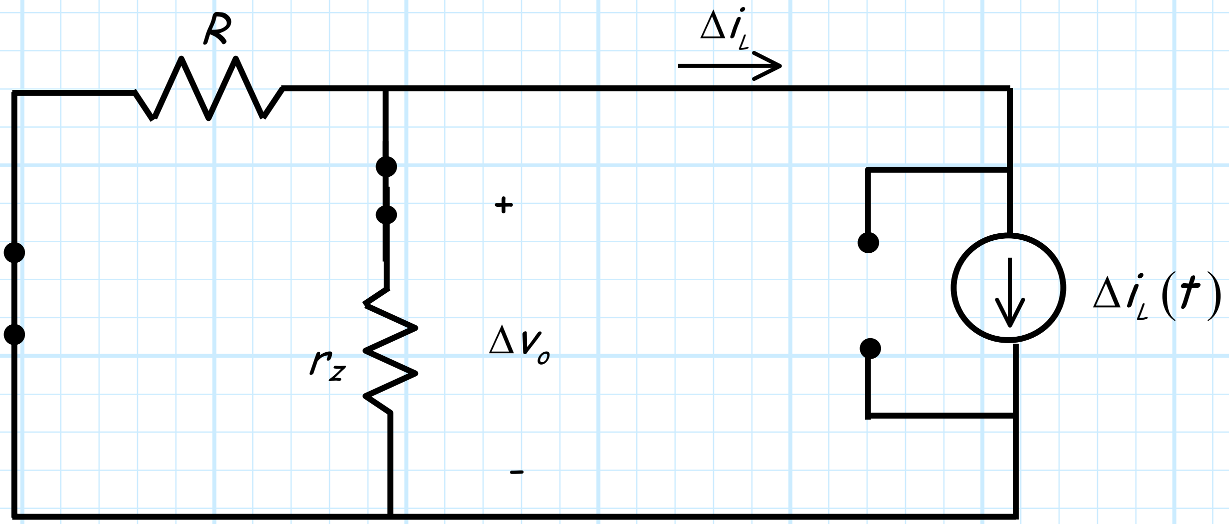
Q: *Just how are Δi_L and Δv_o **related**? I mean, if Δi_L equals, say, **50 mA**, what will value of Δv_o be?*

A: Determining this answer is **easy**! We simply need to perform a **small-signal analysis**.

In other words, we first replace the Zener diode with its **Zener PWL model**.



We then turn **off** all the **DC** sources (including V_{ZO}) and analyze the remaining **small-signal circuit**!



From **Ohm's Law,** it is evident that:

$$\begin{aligned}\Delta v_o &= -\Delta i_L \left(r_Z \| R \right) \\ &= -\Delta i_L \left(\frac{r_Z R}{r_Z + R} \right)\end{aligned}$$

Rearranging, we find:

$$load\ regulation \doteq \frac{\Delta v_o}{\Delta i_L} = -\frac{r_Z R}{r_Z + R} = -r_Z \| R \approx -r_z \qquad [Ohms]$$

This equation describes an important performance parameter for shunt regulators. We call this parameter the **load regulation.**

* Note load regulation is expressed in units of **resistance** (e.g., Ω).

* Note also that load regulation is a **negative** value. This means that **increasing** i_L leads to a **decreasing** v_O (and vice versa).

* Load regulation allows us to determine the **amount** that the load voltage changes (Δv_o) when the load current changes (Δi_L).

* For example, if load regulation is -0.0005 KΩ, we find that the load voltage will **decrease** 25 mV when the load current **increases** 50mA
(i.e.,$\Delta v_o = -0.0005\, \Delta i_L = -0.0005(50) =$ - 0.025 V).

* **Ideally**, load regulation is **zero**. Since dynamic resistance r_Z is typically very small (i.e., $r_Z \ll R$), we find that the load regulation of most shunt regulators is likewise **small** (this is a **good** thing!).