Line Regulation

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 have a **small** dependence on source voltage V_S.

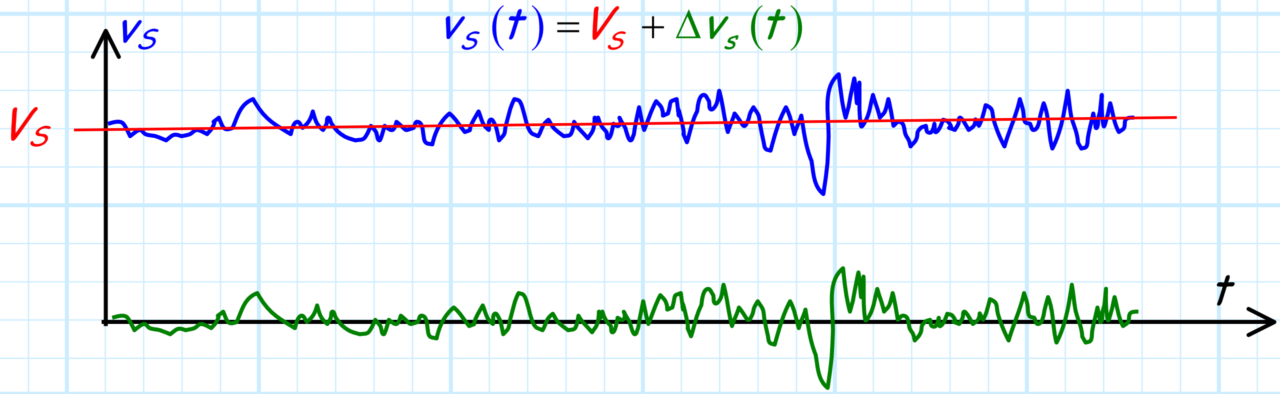
In other words, if the source voltage V_S **increases** (decreases), the load voltage V_O will **likewise** increase (decrease) by some very small amount.

Q: ***Why*** *would the source voltage V_S ever change?*

A: There are **many** reasons why V_S will not be a perfect constant with time. Among them are:

1. Thermal **noise**
2. Temperature **drift**
3. Coupled **60 Hz** signals (or digital clock signals)

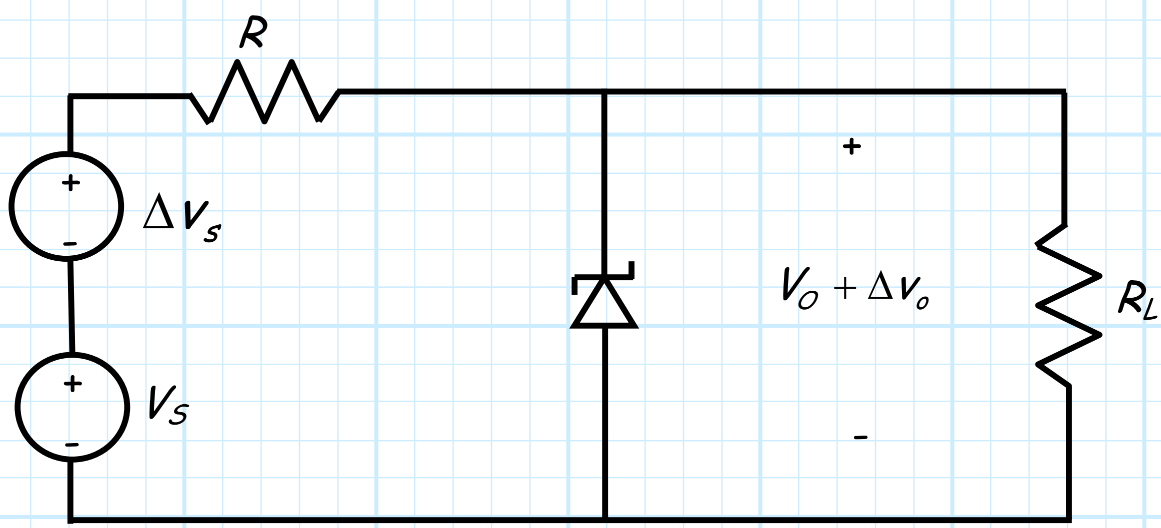
As a result, it is more appropriate to represent the **total** source voltage as a time-varying signal ($v_S(t)$), consisting of both a **DC** component (V_S) and a **small-signal** component ($\Delta v_s(t)$):



As a result of the small-signal source voltage, the total **load** voltage is likewise time-varying, with both a DC (V_O) and small-signal (Δv_o) component:

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

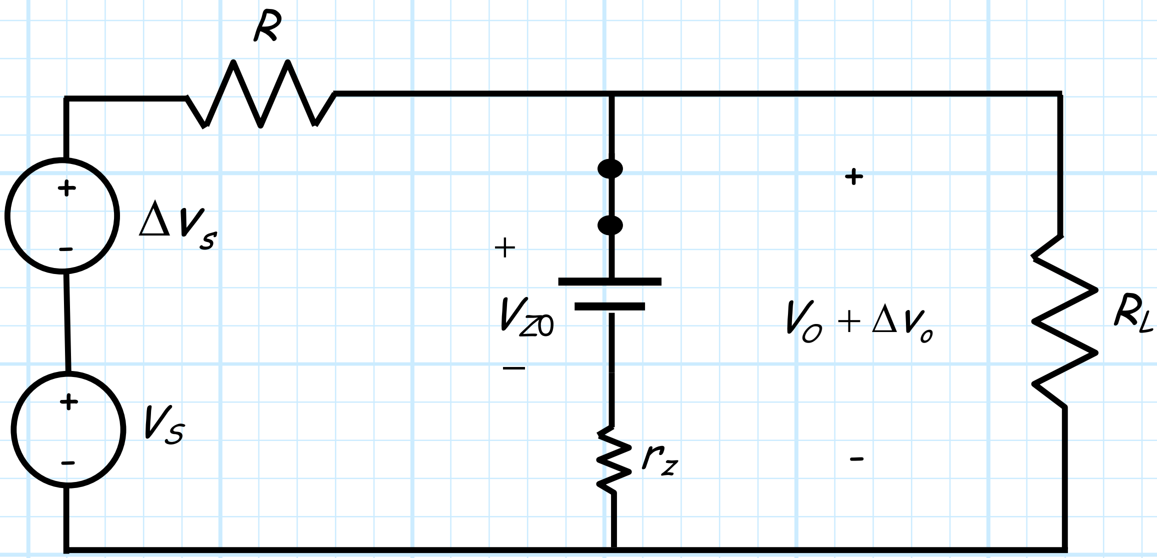
So, we know that the DC source V_S produces the DC load voltage V_O, whereas the small-signal **source** voltage Δv_s results in the small-signal **load** voltage Δv_o.



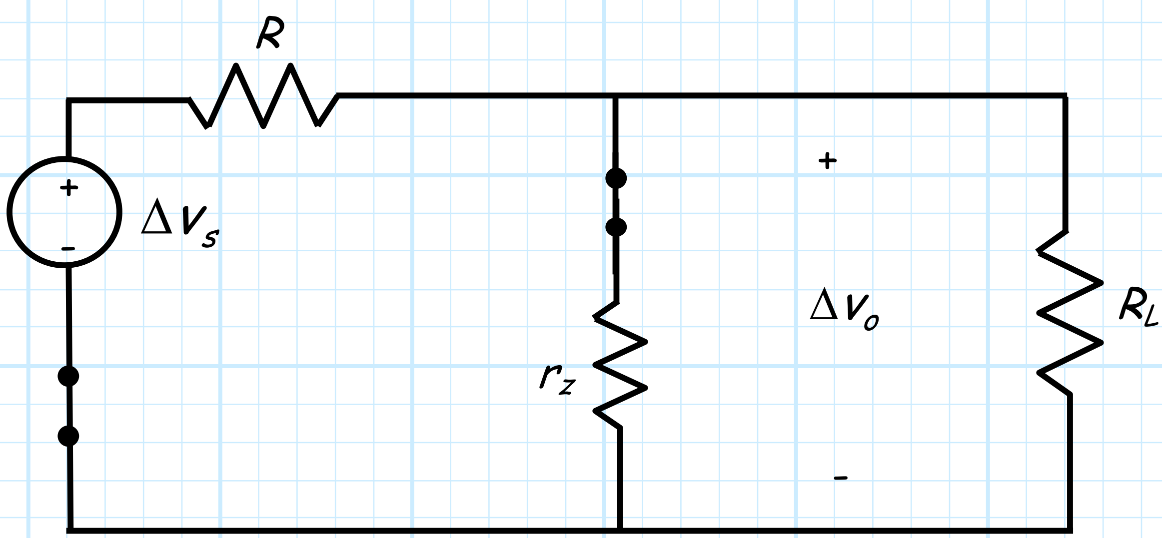
Q: *Just how are Δv_s and Δv_o **related**? I mean, if Δv_s equals, say, **500 mV**, what will value of Δv_o be?*

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 **voltage division**, we find: $$\Delta v_o = \Delta v_s \left(\frac{r_Z \| R_L}{R + r_Z \| R_L} \right)$$

However, recall that the value of a Zener dynamic resistance r_Z is **very small**. Thus, we can assume that $r_Z >> R_L$, and therefore $r_Z \| R_L \approx r_Z$, leading to:

$$\Delta v_o = \Delta v_s \left(\frac{r_Z \| R_L}{R + r_Z \| R_L} \right)$$
$$\approx \Delta v_s \left(\frac{r_Z}{r_Z + R} \right)$$

Rearranging, we find:

$$\frac{\Delta v_o}{\Delta v_s} = \frac{r_Z}{r_Z + R} \doteq \textit{ line regulation}$$

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

* Line regulation allows us to determine the **amount** that the load voltage changes (Δv_o) when the source voltage changes (Δv_s).

* For example, if line regulation is 0.002, we find that the load voltage will increase 1 mV when the source voltage increases 500mV
(i.e.,$\Delta v_o = 0.002\, \Delta v_s = 0.002(0.5) = \ 0.001\text{ V}$).

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