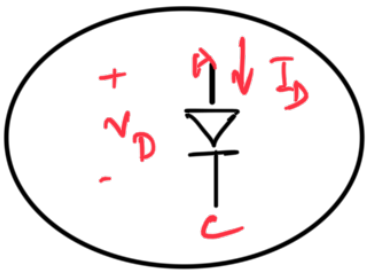
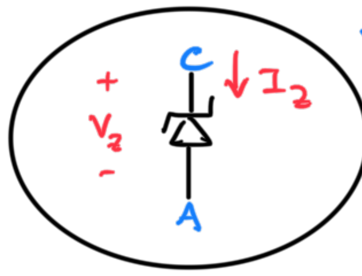
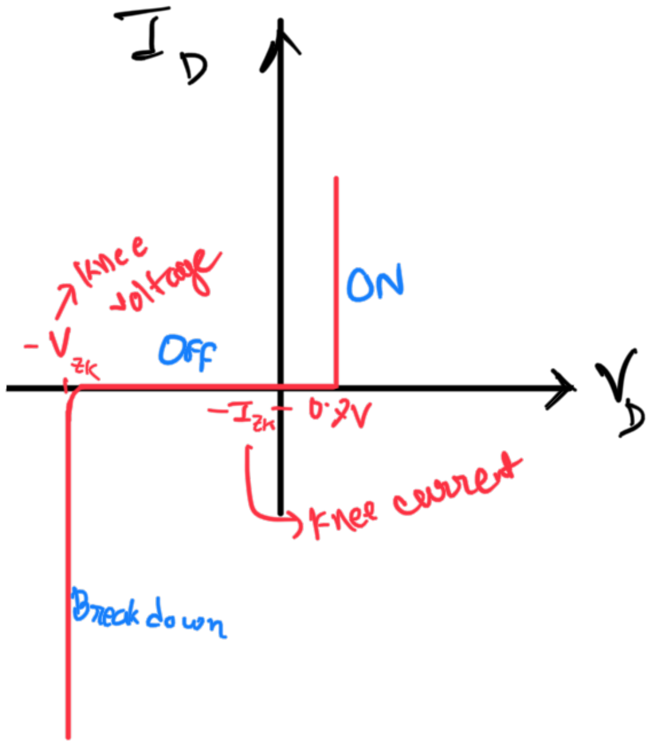


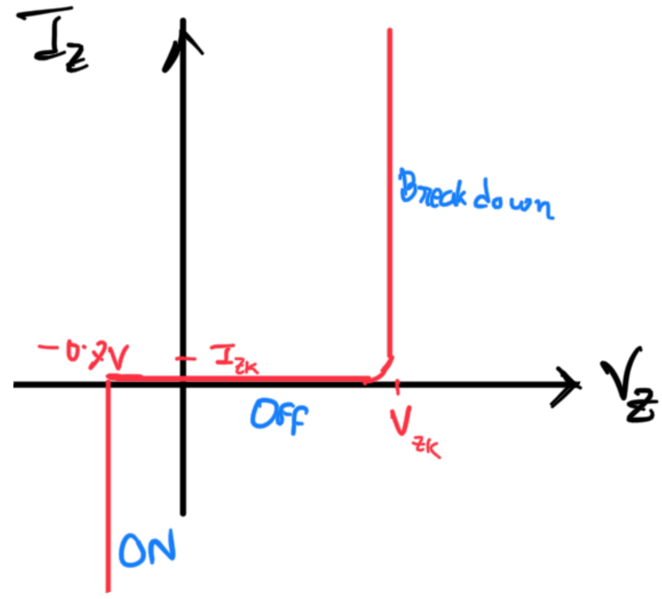
$I_Z = -I_D$

$V_Z = -V_D$

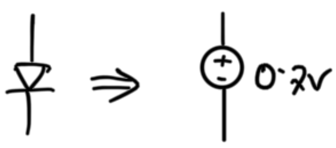


Zener Diode





ON when $I_D > 0$

$\Rightarrow$ 

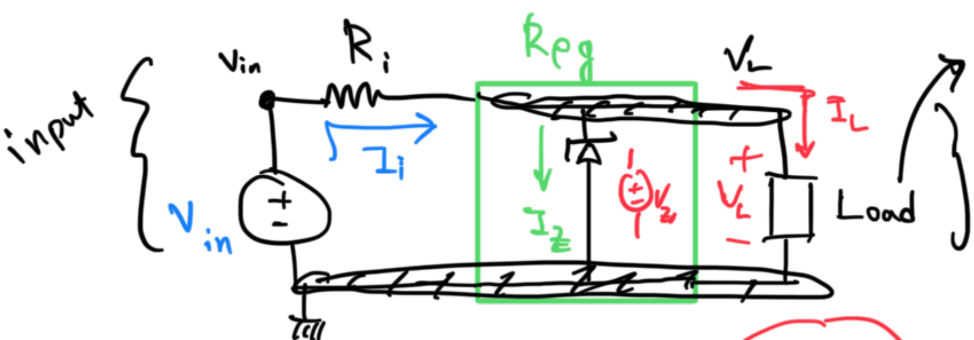
$V_D = 0.7V$

B.D. when $I_Z \geq I_{ZK}$

$\Rightarrow$ 

$V_Z = V_{ZO}$

Application $\Rightarrow$ Voltage Regulator



current consuming device

RADIO, R, Is

Load side $\Rightarrow$ works only when zener is in B.D

$\boxed{I_Z \geq I_{ZK}}$

$\boxed{V_L = V_Z}$

Eqn: $I_i = \dfrac{V_{in} - V_L}{R_i}$

$I_i = I_Z + I_L$

$\Rightarrow \boxed{I_Z = I_i - I_L = \dfrac{V_{in} - V_L}{R_i} - I_L}$

$V_{in} \uparrow\downarrow \Rightarrow I_Z \uparrow\downarrow$

$I_L \uparrow\downarrow \Rightarrow I_Z \downarrow\uparrow$

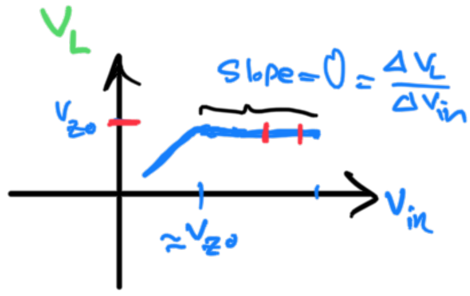
For regulator to work, zener MUST be in Breakdown

$\hookrightarrow I_Z \geq I_{ZK}$

This means $\Rightarrow$ ① V_{in} should be high

② I_L should be low

} For regulator to work properly



Design Guideline: Make sure regulator works even in the worst case scenario

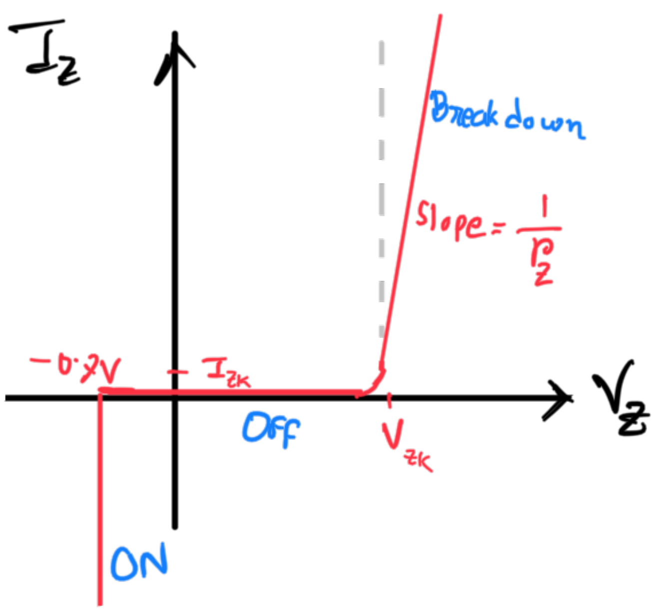
(i) $V_{in} = V_{in}(MIN)$

(ii) $I_L = I_L(MAX)$

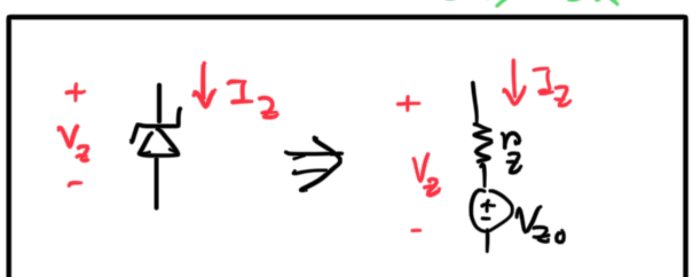
(iii) $I_Z = I_Z(MIN) = I_{ZK}$

$\boxed{I_Z \leq I_Z(MAX)}$

"REAL" Zener Diode



$I_Z \geq I_{ZK}$



$V_L = \boxed{V_Z = V_{Z0} + I_Z r_Z}$

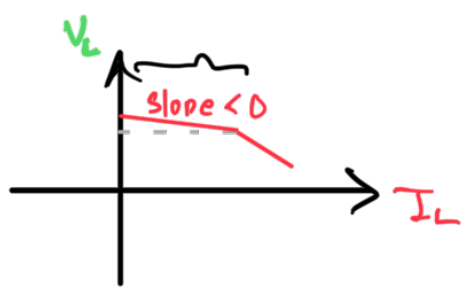
This implies V_Z changes with I_Z

Reminder: $V_{in} \uparrow \Rightarrow I_Z \uparrow$

$I_L \uparrow \Rightarrow I_Z \downarrow$

line regulation

$\left[\frac{\Delta V_L}{\Delta V_{in}} \text{ (mV/V)}\right]$

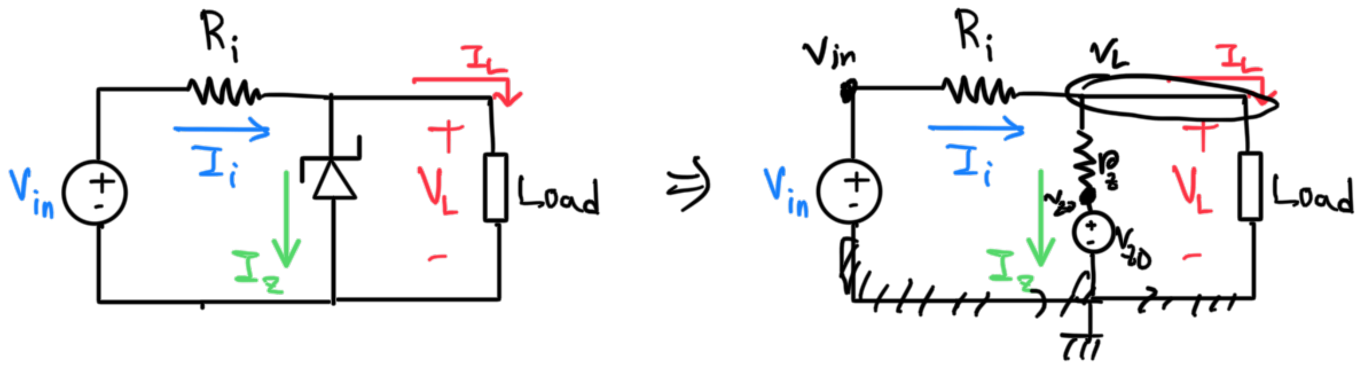


load regulation

$\left[\frac{\Delta V_L}{\Delta I_L} \text{ (mV/mA)}\right]$

What are the values of the slopes?

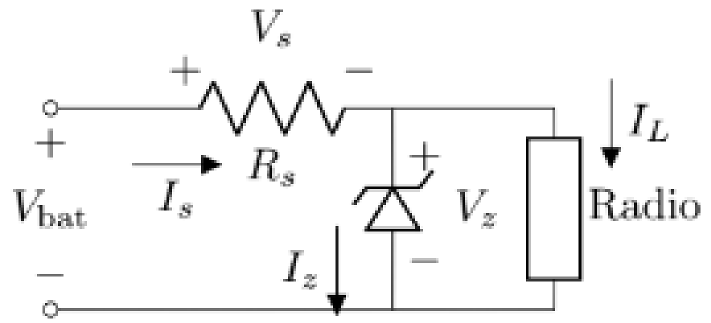
when the regulator is working



$$V_L = V_Z = \underbrace{\overbrace{\left(\frac{r_Z}{R_i + r_Z}\right)}^{\text{changes with } V_{in}}}_{\text{line}} V_{in} + \underbrace{\overbrace{\left(-\frac{r_Z R_i}{R_i + r_Z}\right)}^{\text{changes with } I_L}}_{\text{load}} I_L + \underbrace{\frac{R_i}{R_i + r_Z} V_{Z0}}_{\text{const.}}$$

$$\therefore \text{Line regulation} = \frac{\Delta V_L}{\Delta V_{in}} = \frac{r_Z}{R_i + r_Z}$$

$$\therefore \text{Load regulation} = \frac{\Delta V_L}{\Delta I_L} = -\frac{r_Z R_i}{R_i + r_Z}$$



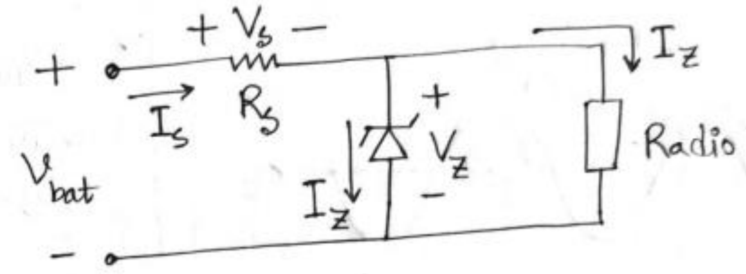
The circuit above is a voltage regulator used to power a car radio (which requires ≈ 9 V) from the car battery, V_{bat} whose voltage may vary between 11 and 13.6 V. The current in the radio, I_L, will vary between 0 (off) to 9 mA (full volume). The Zener diode in the circuit is specified with parameter $V_{z_0} = 9$ V, $r_z = 0.05$ kΩ, and $I_{\text{zk}} = 1\ mA$.

(a) **Identify** the worst-case conditions and **calculate** the Zener current (I_z), Zener voltage (V_z), the input voltage (V_{bat}), and the load current (I_L) in this worst-case scenario. [1+1+1+1+1]

(b) **Calculate** the current (I_s) and the voltage (V_s) the input resistor R_s in the worst-case scenario. [2]

(c) **Design** the circuit, i.e., find the value of R_s, such that even in the worst-case scenario voltage regulation is maintained. Calculate the line regulation for this circuit. [2+1]

(5)



Given that, $V_{bat} = 11v \sim 13.6v$

$I_L = 0 \sim 9\ mA$

$V_{Z0} = 9v$, $r_z = 0.05\ K\Omega$, $I_{ZK} = 1\ mA$

(a) Worst case conditions:

(1) $V_{bat(min)} = 11v.$

(2) $I_{Z(min)} = I_{ZK} = 1\ mA.$

So, $I_Z = 1\ mA$. (Ans) $V_{bat} = 11v$. (Ans)

$V_Z = V_{Z0} + I_Z r_Z$

$\Rightarrow V_Z = 9 + 1\times10^{-3} \times 0.05\times10^{3}$

$\Rightarrow V_Z = 9.05v$. (Ans)

$I_L = I_{L(max)} = 9\ mA.$

(b) Applying KVL we get, $v_{bat} = v_s + v_z$

$\hookrightarrow v_s = v_{bat} - v_z$

$\hookrightarrow v_s = (11 - 9.05)\,v$

$\hookrightarrow v_s = 1.95\,v$. (Ans)

Applying KCL we get,

$I_s = I_Z + I_L$

$\hookrightarrow I_s = (1+9)\,mA$

$\hookrightarrow I_s = 10\ mA$. (Ans)

(c) $R_s = \frac{V_s}{I_s} = \frac{1.95}{10 \times 10^{-3}} = 195\,\Omega$. (Ans)

Line Regulation,

$$\frac{\Delta V_L}{\Delta V_{bat}} = \frac{r}{r+R}$$

$$= \frac{0.05 \times 10^3}{0.05 \times 10^3 + 195}\ V/V$$

$$= 0.20408\ V/V$$

$$= 204.08\ mV/V. \text{ (Ans)}$$

here,

$r = r_z = 0.05\ K\Omega$

$R = R_s = 195\,\Omega$