Zener diode circuits

GOAL:

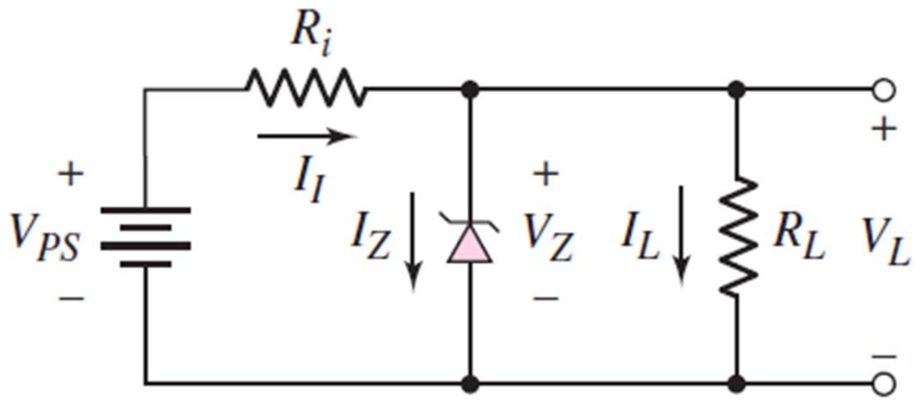
Study Zener diode voltage regulator circuit

- Zener diode useful in a voltage regulator, or a constant-voltage reference circuit.
- Ideal voltage reference circuit & the effects of including a nonideal Zener resistance.

State of the art voltage regulator is sophisticated integrated circuit (with desired breakdown voltage)

Ideal Voltage Reference Circuit:

Zener voltage regulator circuit



Output voltage should remain constant, even when the output load resistance varies over a fairly wide range, and when the input voltage varies over a specific range.

R_i limits the current through the Zener diode and drops the "excess" voltage between V_{PS} and V_Z

$$R_i = \frac{V_{PS} - V_Z}{I_I} = \frac{V_{PS} - V_Z}{I_Z + I_L}$$

Zener resistance is zero - assumed

$$I_Z = \frac{V_{PS} - V_Z}{R_i} - I_L \qquad I_L = V_Z / R_L$$

For proper operation of this circuit, the diode must remain in the breakdown region
and the power dissipation in the diode must not exceed its rated value.

1. The current in the diode is a minimum, $I_Z(\text{min})$, when the load current is a maximum, $I_L(\text{max})$, and the source voltage is a minimum, $V_{PS}(\text{min})$.

$$R_i = \frac{V_{PS}(\text{min}) - V_Z}{I_Z(\text{min}) + I_L(\text{max})}$$

V_{PS} and I_L are the variables

2. The current in the diode is a maximum, $I_Z(\text{max})$, when the load current is a minimum, $I_L(\text{min})$, and the source voltage is a minimum, $V_{PS}(\text{max})$.

$$R_i = \frac{V_{PS}(\text{max}) - V_Z}{I_Z(\text{max}) + I_L(\text{min})}$$

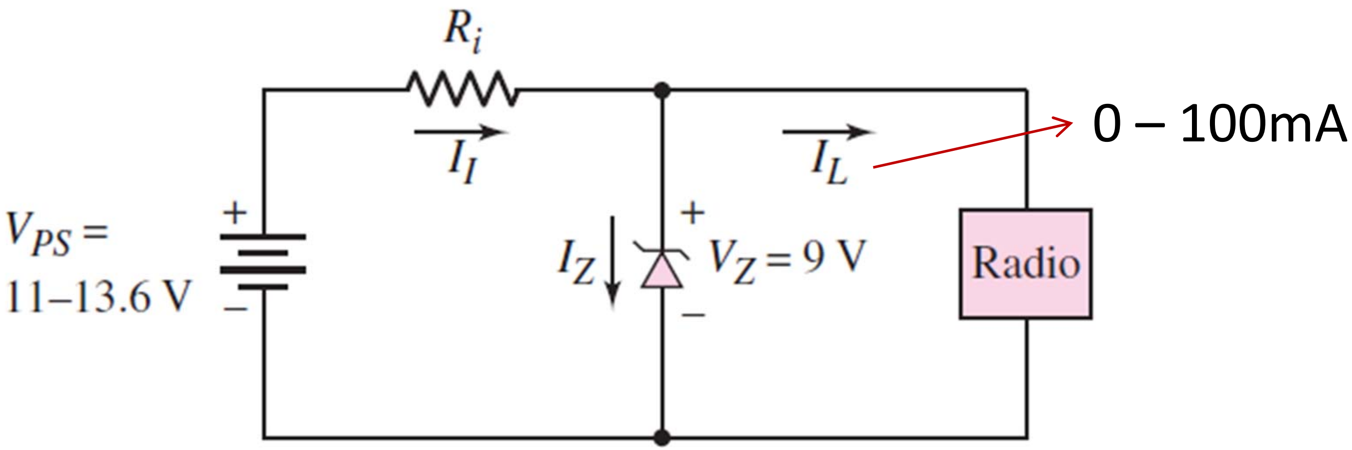
$$[V_{PS}(\min) - V_Z] \cdot [I_Z(\max) + I_L(\min)]$$
$$= [V_{PS}(\max) - V_Z] \cdot [I_Z(\min) + I_L(\max)]$$

Reasonably, we can assume that we know the range of input voltage, the range of output load current, and the Zener voltage.

Equation then contains two unknowns, I_Z (min) and I_Z (max). We may assume $I_Z(\min) = 0.1\, I_Z(\max)$

$$I_Z(\max) = \frac{I_L(\max) \cdot [V_{PS}(\max) - V_Z] - I_L(\min) \cdot [V_{PS}(\min) - V_Z]}{V_{PS}(\min) - 0.9V_Z - 0.1V_{PS}(\max)}$$

Maximum current thus obtained gives maximum required power rating of the Zener diode. Using the above maximum current we can get R_i, as well.



$$I_Z(\max) \cong 300\,\text{mA}$$

$$P_Z(\max) = I_Z(\max) \cdot V_Z = (300)(9) \Rightarrow 2.7\,\text{W}$$

$$R_i = 15.3\,\Omega$$

Visualization using load lines:

$$\frac{v_{PS} - V_Z}{R_i} = I_Z + \frac{V_Z}{R_L}$$

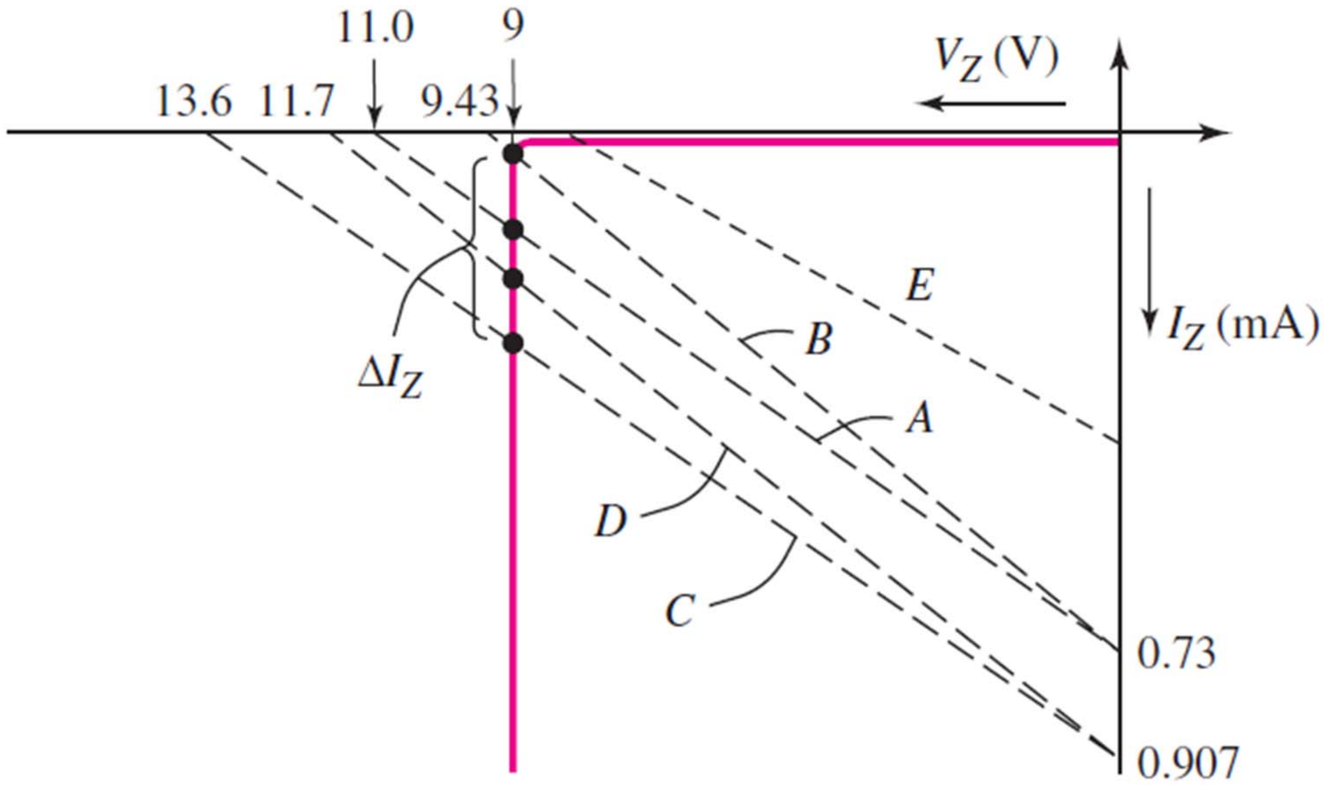
$$V_Z = v_{PS}\left(\frac{R_L}{R_i + R_L}\right) - I_Z\left(\frac{R_i R_L}{R_i + R_L}\right)$$

$$R_L = \infty(I_L = 0) \text{ to } R_L = 9/0.1 = 90\ \Omega(I_L = 100\ \text{mA})$$

$$R_i = 15\ \Omega$$

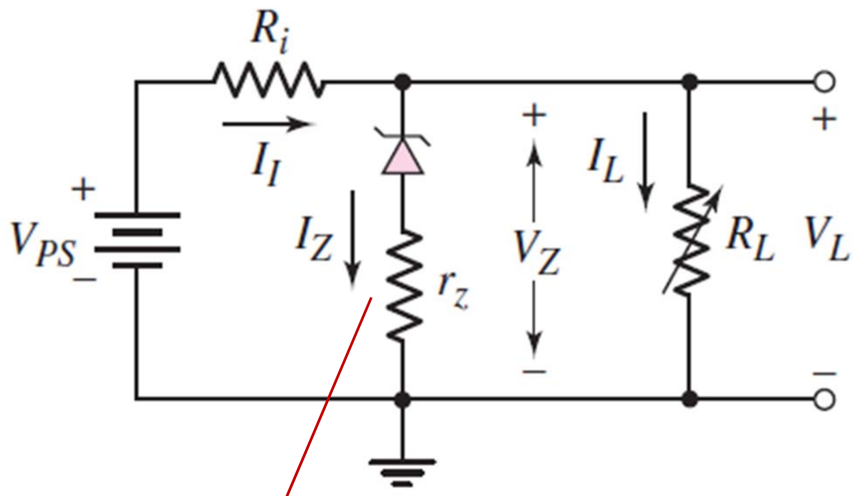
A: $v_{PS} = 11\ \text{V}$, $R_L = \infty$; $V_Z = 11 - I_Z(15)$
B: $v_{PS} = 11\ \text{V}$, $R_L = 90\ \Omega$; $V_Z = 9.43 - I_Z(12.9)$
C: $v_{PS} = 13.6\ \text{V}$, $R_L = \infty$; $V_Z = 13.6 - I_Z(15)$
D: $v_{PS} = 13.6\ \text{V}$, $R_L = 90\ \Omega$; $V_Z = 11.7 - I_Z(12.9)$

E: B with $R_i = 25\ \Omega$



Zener Resistance and Percent Regulation:

- In ideal Zener diode, the Zener resistance is zero
- In actual, this is not the case and there will be slight fluctuations in the output if there is one in the input or load resistance



Zener voltage changes slightly with Zener diode current

$$V_L = V_z = V_z' + I_z r_z$$

At 0 load:

$$I_z = \frac{V_{PS} - V_Z'}{R_i + r_z}$$

At finite load:

$$I_z = \frac{V_{PS} - V_Z}{R_i} - I_L = \frac{V_{PS} - (V_z' + I_z r_z)}{R_i} - I_L$$

Two figures of merit-

Source regulation: measure of the change in output voltage with a change in source

Load regulation: measure of the change in output voltage with a change in load current

$$\text{Source regulation} = \frac{\Delta v_L}{\Delta v_{PS}} \times 100\%$$

At 0 load

$$\text{Load regulation} = \frac{v_{L,\text{no load}} - v_{L,\text{full load}}}{v_{L,\text{full load}}} \times 100\%$$

The circuit approaches that of an ideal voltage regulator as the source and load regulation factors approach zero.