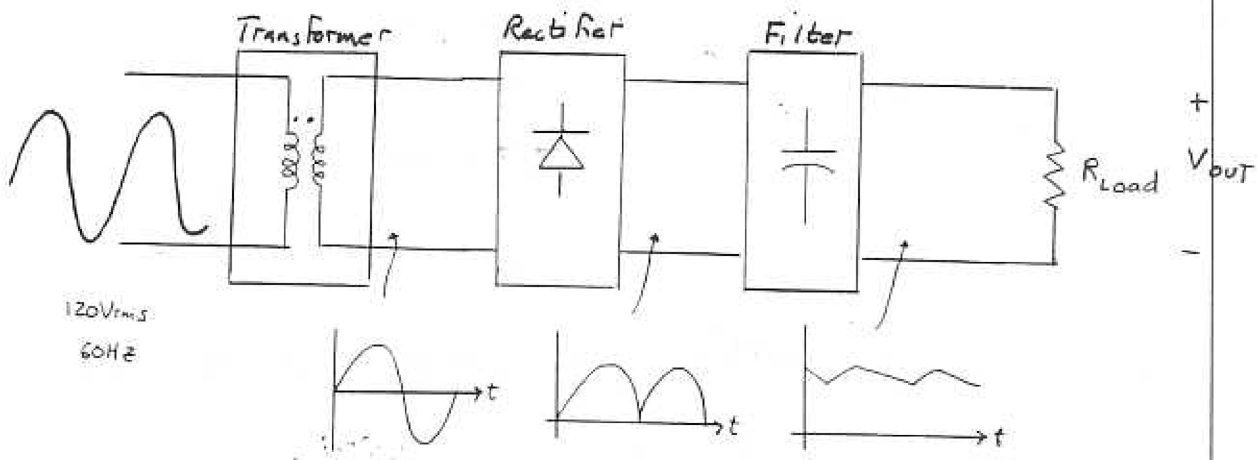
ZENER DIODE REGULATORS

(*) Thus far we have shown how to produce pulsating DC with a rectifier then how to reduce the ripple with a capacitor filter

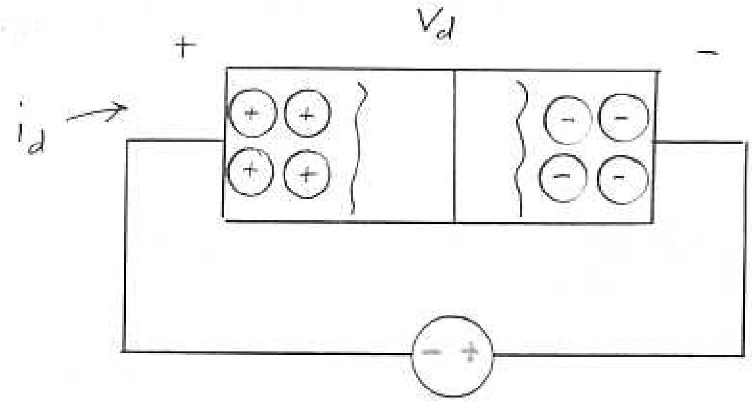


However, many electronic loads require a more precise value of DC with even less ripple → so we need to add a regulator

(*) The simplest (though not always the most practical) regulator is a specially-designed diode called a zener diode.

HOW A ZENER DIODE WORKS

(*) Consider our "cartoon" picture of a diode with a reverse bias applied

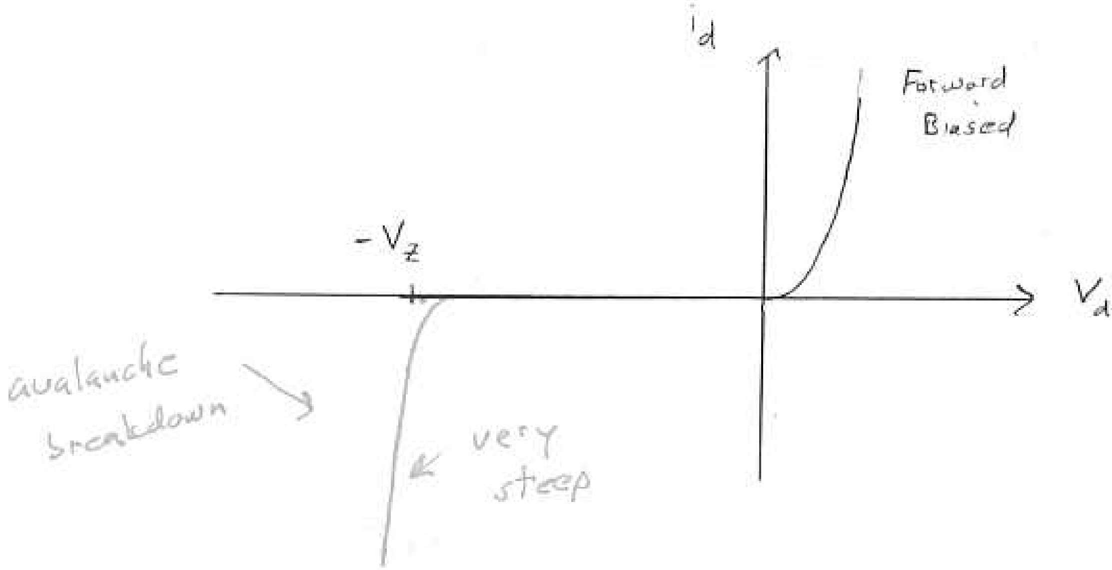


→ An electric field exists due to the charge separation

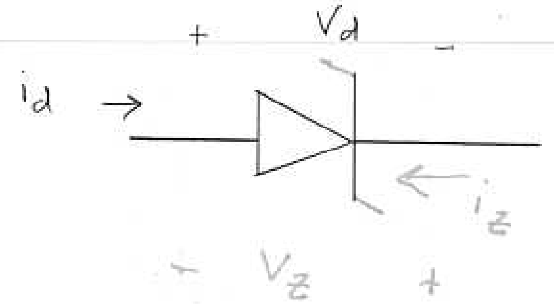
→ For a large enough reverse voltage applied, the field is strong enough to ionize additional carriers

→ Those carriers bump into other atoms, imparting energy, and ionizing them

→ This "avalanche" of carriers leads to a reverse current flowing through the zener diode



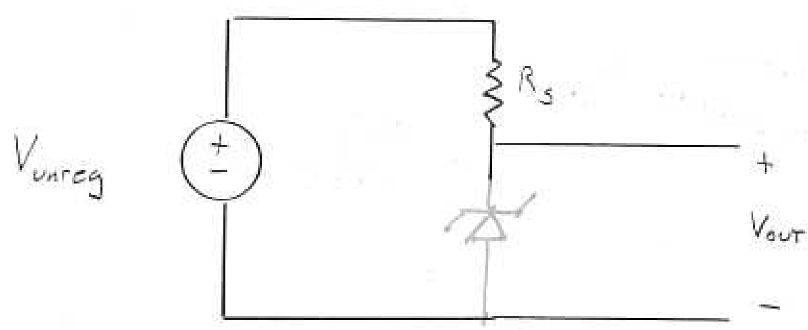
(*) The zener breakdown voltage V_z is a function of the doping of the p- and n-type material. Zener diodes can be manufactured to provide specific values of V_z. We differentiate it from a "regular Joe" diode by the circuit symbol



However since we normally operate it with reverse current and voltage, we relabel with i_z

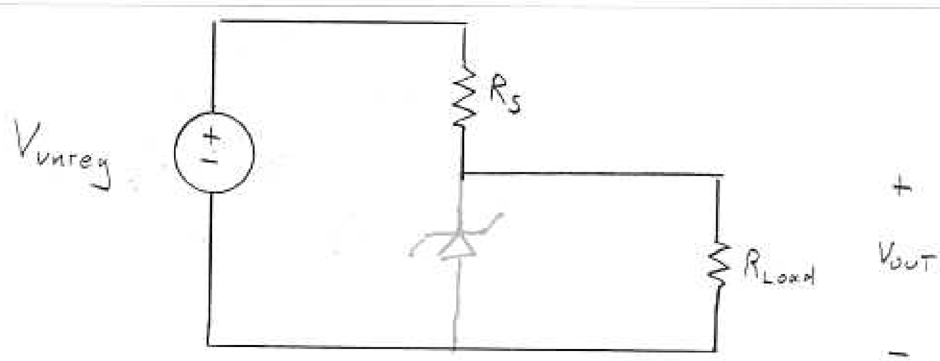
ZENER DIODE AS REGULATOR

(*) Consider that we place a zener diode in the following circuit



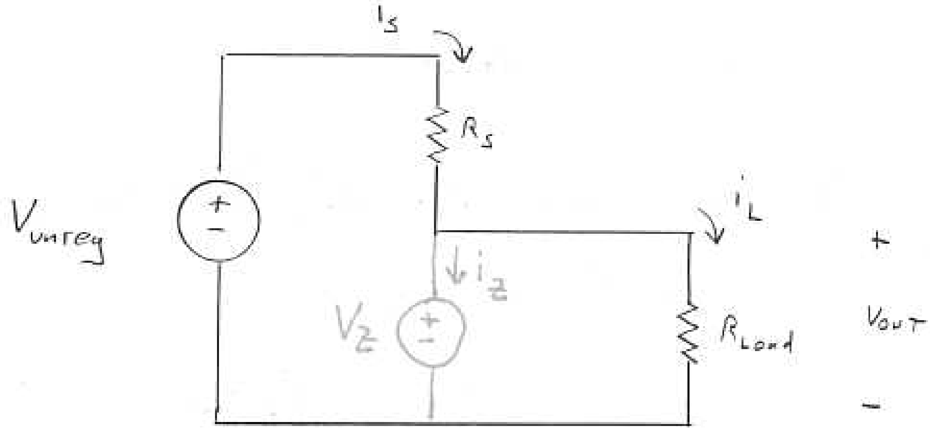
Then based on the i-v characteristic, current will flow if $V_{unreg} > V_Z$. Then $V_{OUT} = V_Z$

(*) If we next attach a load resistance



Q How do we determine if the zener diode is in breakdown or not?

A. Assume that it IS and replace it by a source voltage with value V_Z



Circuit analysis (think nodal) tells us that

$$\rightarrow \quad i_L = \frac{V_Z}{R_{Load}}$$

$$\rightarrow \quad i_S = \frac{V_{unreg} - V_Z}{R_S}$$

and Finally KCL yields

$$\rightarrow \quad i_Z = i_S - i_L$$

substituting

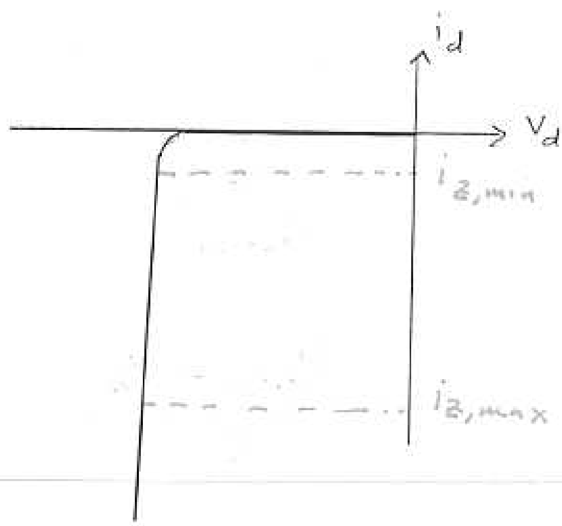
$$i_Z = \frac{V_{unreg} - V_Z}{R_S} - \frac{V_Z}{R_{Load}}$$

(*) Two factors restrict the zener current :

(1) We need enough to be beyond the zener " knee "

(2) We avoid too big to exceed the thermal limitations →

$$P_z = V_z \, i_z$$



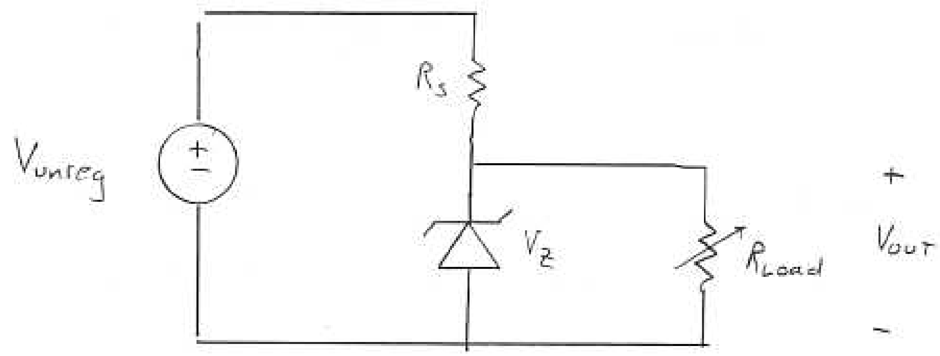
(*) Let's use the following rules of thumb to set values to each

$$i_{z,max} = \underset{\text{safety}}{0.8} \, \frac{P_z}{V_z}$$

$$i_{z,min} = \frac{i_{z,max}}{50}$$

(*) This will guide us in our selection of V_{unreg} & R_s

HOW TO CHOOSE V_{UNREG} & R_S



PROBLEM : (1) V_Z set by desired V_{OUT} (what we want)

(2) V_{unreg} will vary between a peak and a minimum value

(3) R_{Load} varies from an open circuit to some minimum value
("our" loads turning ON + OFF)

→ We need to keep the zener in breakdown and not blown up

Returning to $i_Z = \left(\frac{V_{unreg} - V_Z}{R_S}\right) - \frac{V_Z}{R_{Load}}$

- The max current occurs when

$$i_{Z,max} = \frac{V_{unreg,max} - V_Z}{R_S} - \frac{V_Z}{R_{Load,max}}$$

- The min current occurs when

$$i_{Z,min} = \frac{V_{unreg,min} - V_Z}{R_S} - \frac{V_Z}{R_{Load,min}}$$

where

$$R_{Load,min} < R_{Load} < R_{Load,max}$$

(*) This gives us 2 equations in 3 unknowns (R_S, $V_{unreg,max}$ and $V_{unreg,min}$). Let's probe this flexibility with an example.

ex. Suppose you choose a 0.5W, 9V zener diode for a load application where $300\Omega < R_{Load} < \infty$. Determine the range of V_{unreg} for $R_S = 20\Omega, 100\Omega, 500\Omega$

Step 1: Establish target values for $i_{Z,min}$ and $i_{Z,max}$

$$i_{Z,max} = 0.8\frac{P_Z}{V_Z} = 0.8\frac{0.5W}{9V} = 44.4mA$$

$$i_{Z,min} = \frac{i_{Z,max}}{50} = 0.89mA$$

Step 2a For $R_s = 20\Omega$

unknown

$$i_{z,min} = .89mA = \frac{V_{unreg,min} - V_z}{R_s} - \frac{V_z}{R_{Load,min}} \leftarrow 300\Omega$$

$$i_{z,max} = 44.4mA = \frac{V_{unreg,max} - V_z}{R_s} - \frac{V_z}{R_{Load,max}} \leftarrow \infty$$

yields

$$V_{unreg,min} = 9.62V$$

$$V_{unreg,max} = 9.89V$$

Step 2b Repeating for $R_s = 100\Omega$ and $R_s = 500\Omega$

	$R_s = 100\Omega$	$R_s = 500\Omega$
$V_{unreg,min}$	12.09V	24.45V
$V_{unreg,max}$	13.44V	31.2V

Step 3 What about the max power dissipated in R_s?

$$P_{R_{S,max}} = \frac{(V_{unreg,max} - V_z)^2}{R_s}$$

	20Ω	100Ω	500Ω
$P_{R_{S,max}}$	.04W	.197W	.985W

- If we desire smaller ripple for V_{unreg}, we need more capacitance.

- If we accept higher ripple, we need higher voltage levels and more dissipation in the resistance R_S