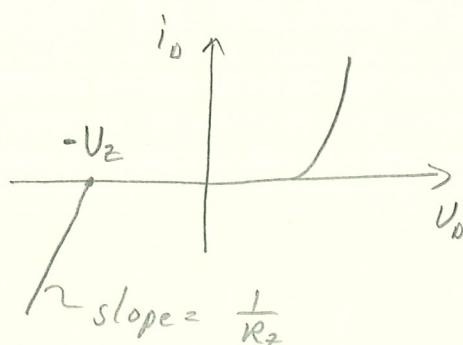
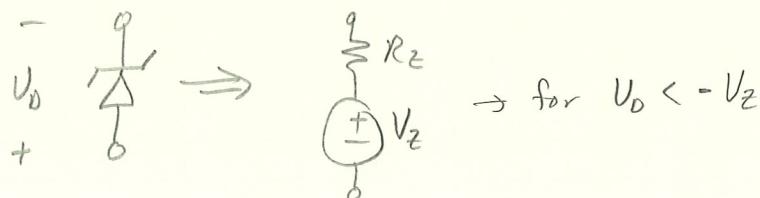


# I) Circuit Analysis with Diodes in Reverse Breakdown

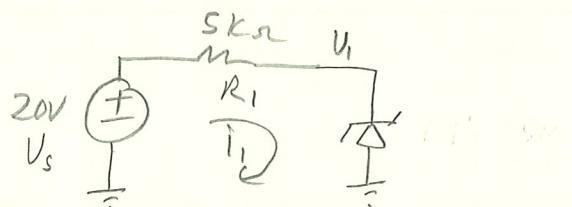
Zener diode :



model for zener diode in reverse breakdown



Ex: Zener diode with  $V_Z = 5V$ ,  $R_Z = 100\Omega$



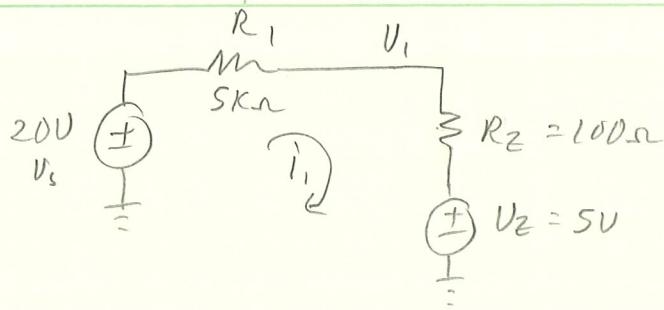
diode is reversed biased

if  $V_1 < V_Z \rightarrow$  diode is off

$$\rightarrow i_D = 0$$

$$\rightarrow V_1 = 20V$$

$\therefore$  diode is in reverse breakdown

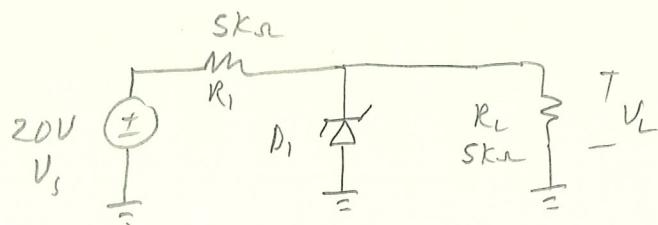


$$U_1 = V_Z + \frac{(V_s - V_Z) R_2}{R_1 + R_2} = 5 + \frac{(20-5) 100}{100 + 5000} = 5.29V$$

notice that  $U_1 \approx V_Z$

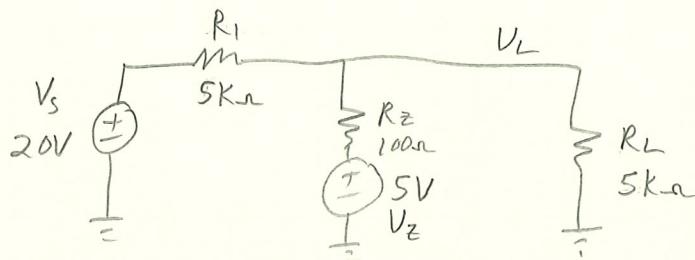
→ important application of zener diodes → Voltage Regulation

consider :



$$D_1: V_Z = 5V, R_2 = 100\Omega$$

Assume  $D_1$  is in reverse breakdown



$$\frac{U_L - V_s}{R_1} + \frac{U_L - V_Z}{R_2} + \frac{U_L}{R_L} = 0$$

$$U_L \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_L} \right) = \frac{V_s}{R_1} + \frac{V_Z}{R_2}$$

$$U_L = \frac{\frac{V_s}{R_1} + \frac{V_Z}{R_2}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_L}} = \frac{\frac{20}{5K} + \frac{5}{100}}{\frac{1}{5K} + \frac{1}{100} + \frac{1}{5K}} = 5.19V$$

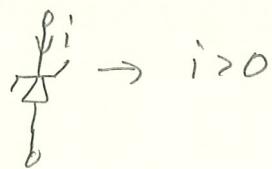
Observe: Let  $V_s = 10V$ , with all other values the same

$$\therefore V_L = \frac{\frac{10}{5k} + \frac{5}{100}}{\frac{1}{5k} + \frac{1}{100} + \frac{1}{5k}} = 5.0V$$

$$\text{Let } V_s = 50V \rightarrow V_L = \frac{\frac{50}{5k} + \frac{5}{100}}{\frac{1}{5k} + \frac{1}{100} + \frac{1}{5k}} = 5.77V$$

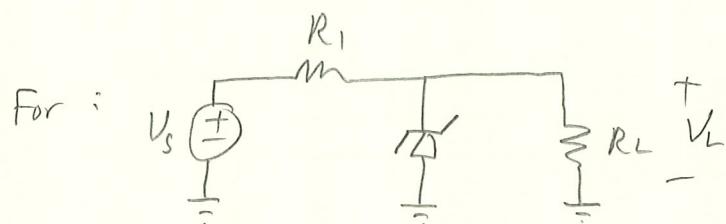
### Limitations

$V_s$  and  $R_L$  must be such that positive current flows in the reversed biased Zener diode



If  $i \leq 0 \rightarrow$  the regulator has "dropped out of regulation"

limitation of the load resistance:  $i > I_z$

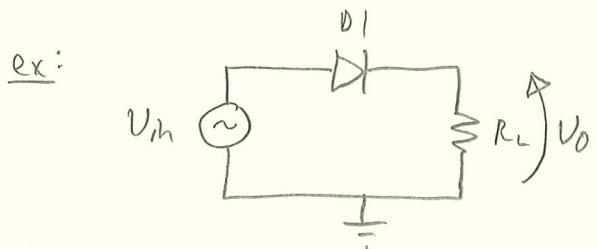
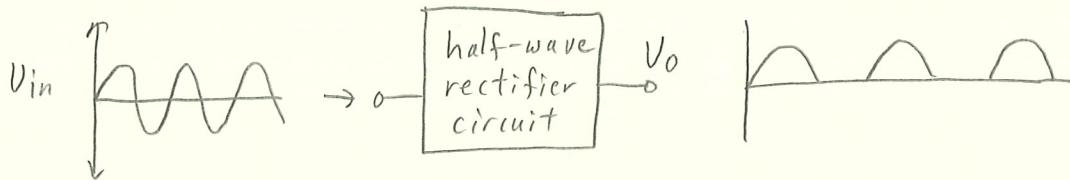


Ignoring  $R_2$ :

$$R_L > \frac{R_1}{\left(\frac{V_s}{V_z} - 1\right)} = R_{L\min}$$

## 2) Rectifier Circuits

→ converts an ac voltage to a pulsating dc voltage

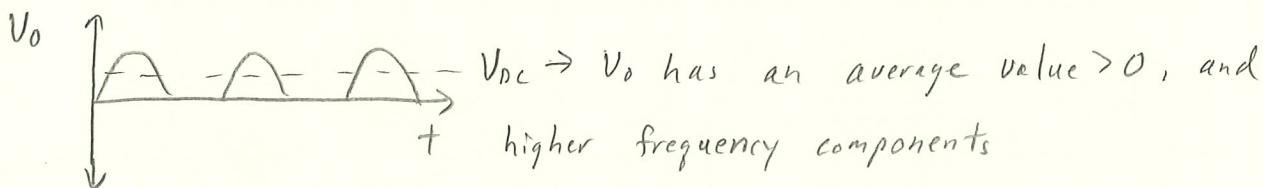


$$V_{o_{max}} = V_p - V_{on}$$

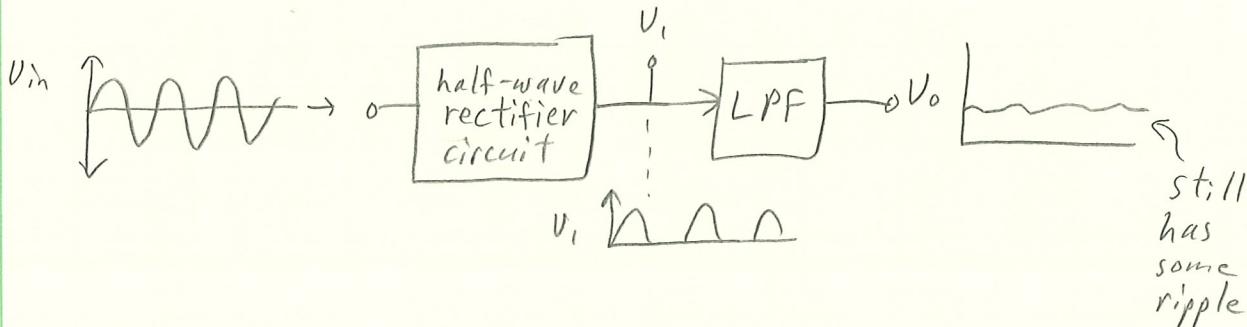
$$\text{Let } V_{in} = V_p \sin(\omega t)$$

for  $V_{in} > V_{on} \rightarrow V_o = V_{in} - V_{on} \rightarrow \text{diode is on}$

for  $V_{in} < V_{on} \rightarrow V_o = 0 \rightarrow \text{diode is off}$

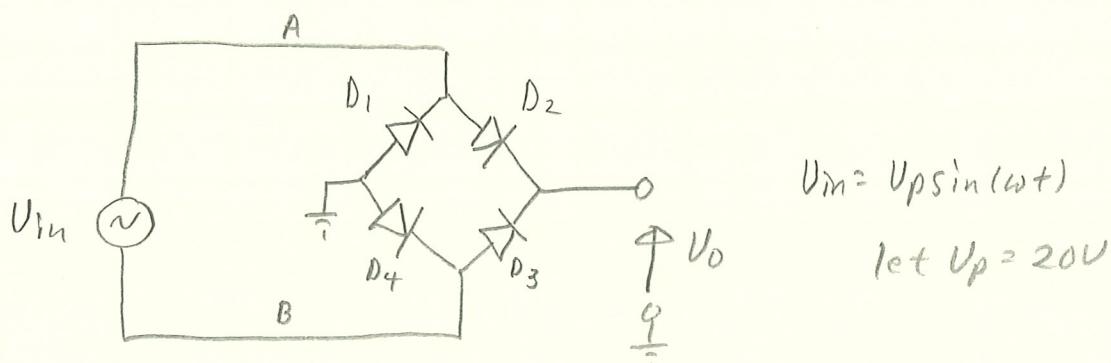


→ use a lowpass filter to recover the dc portion



(also AM envelope detector)

### 3) Full-Wave Bridge Rectifier Circuit



define:  $V_{in}$  positive:  $V_A > 0, V_B < 0$

$V_{in}$  negative:  $V_A < 0, V_B > 0$

For  $V_{in}$  positive:  $D_1$  is RB

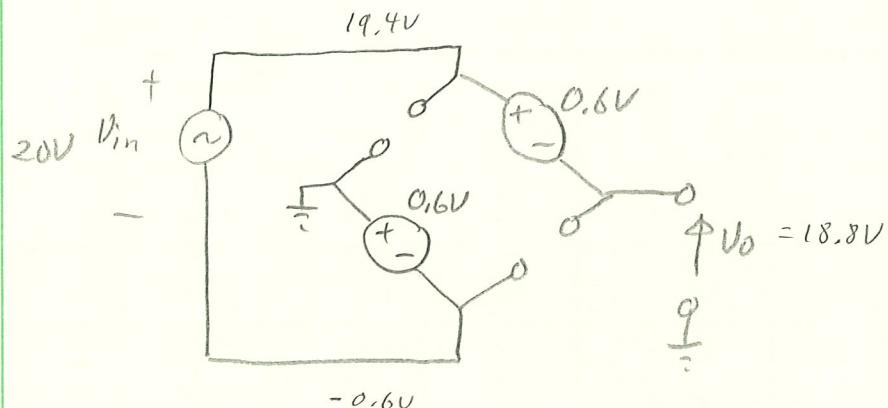
$D_2$  is FB

$D_3$  is RB

$D_4$  is FB

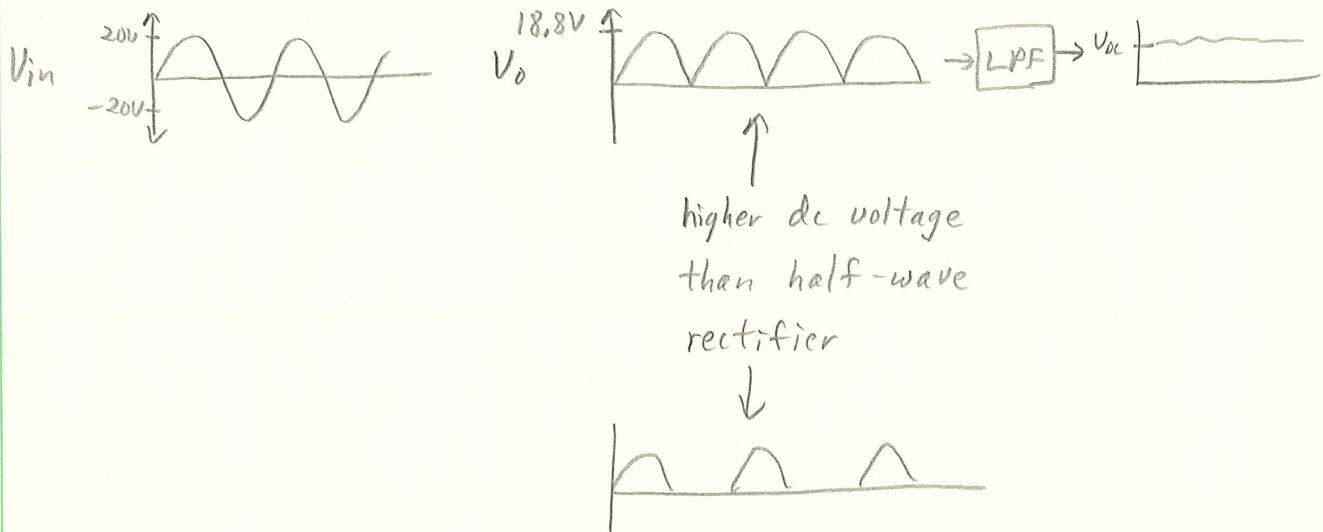
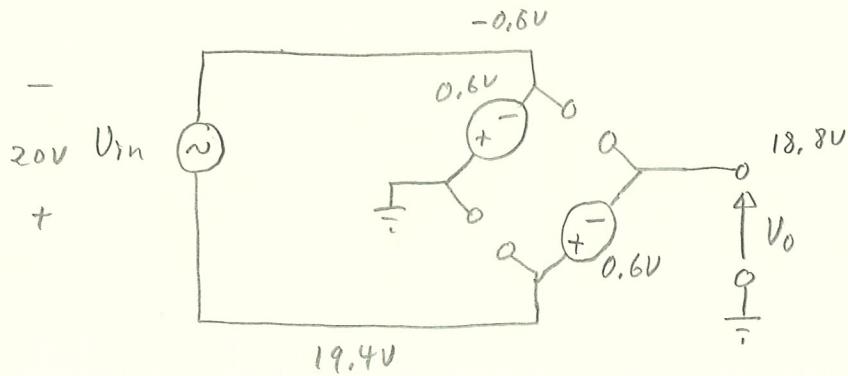
} Assumes  $|V_{in}| > V_{on}$

redraw circuit:



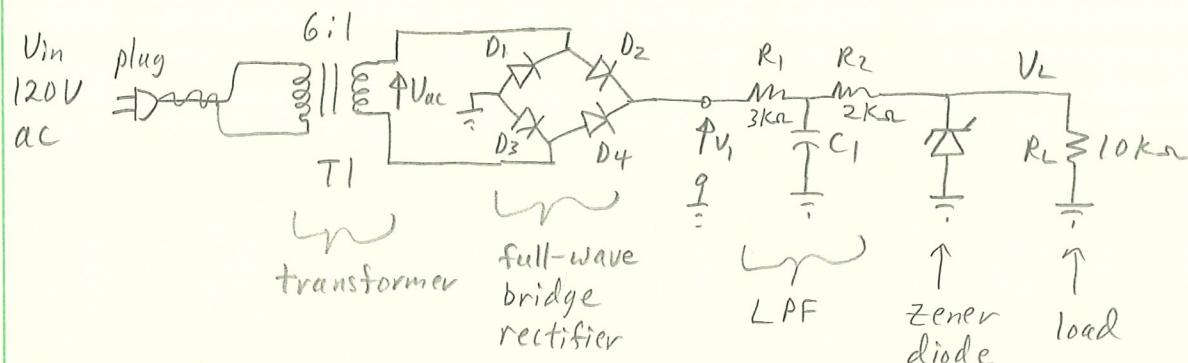
For  $V_{in}$  negative:  $D_1$  is FB  
 $D_2$  is RB } Assumes  $|V_{in}| > V_{on}$   
 $D_3$  is FB  
 $D_4$  is RB

redraw circuit:



∴ Full-wave rectifier is more efficient than half-wave rectifier

Design a 5V voltage regulator circuit for a 10k $\Omega$  load that plugs into a 120V ac outlet



$$V_{in} = 120V_{rms}$$

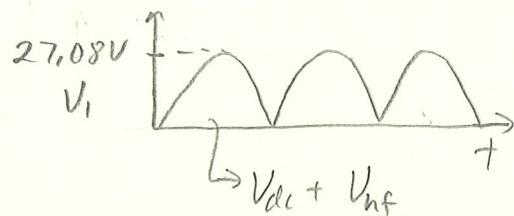
$$V_p = \sqrt{2}(120) = 169.7V \rightarrow \text{amplitude of input voltage}$$

$$V_{ac} = \frac{V_1}{6} = \frac{169.7}{6} = 28.28V$$

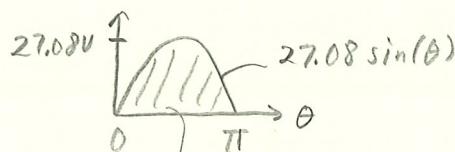
$$V_1 = V_{ac} - 2V_{on} = 28.28 - 2(0.6) = 27.08V$$

LPF:  $C_1 \underset{DC}{\approx} \text{open circuit}$   $\rightarrow$  LPF passes dc

$C_1 \underset{\substack{\text{high} \\ \text{freq}}}{\approx} \text{short circuit} \rightarrow$  LPF blocks high frequencies



$V_{dc}$  = average voltage over 1 period

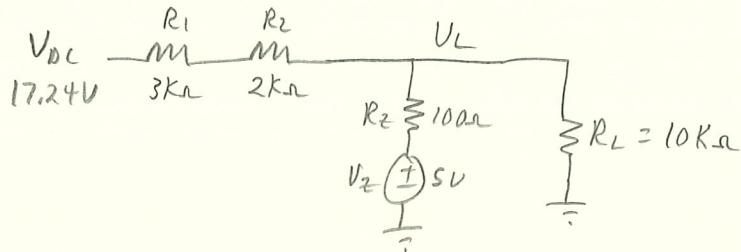


$$\hookrightarrow \text{Area} = \int_0^{\pi} 27.08 \sin(\theta) d\theta = 27.08 [-\cos(\theta)]_0^{\pi} = 54.17 \text{ V-rad}$$

$$V_{dc} = \frac{\text{Area}}{\pi} = \frac{54.17}{3.14159} = 17.24V$$

Analyze regulator circuit with  $V_{DC}$

Zener diode  $\rightarrow$  use  $V_z = 5V$ ,  $R_z = 100\Omega$



solve for  $V_L$

$$\frac{V_L}{R_L} + \frac{V_L - V_z}{R_z} + \frac{V_L - V_{DC}}{R_1 + R_2} = 0$$

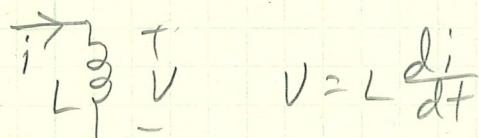
$$V_L \left( \frac{1}{R_L} + \frac{1}{R_z} + \frac{1}{R_1 + R_2} \right) = \frac{V_z}{R_z} + \frac{V_{DC}}{R_1 + R_2}$$

$$V_L = \frac{\frac{V_z}{R_z} + \frac{V_{DC}}{R_1 + R_2}}{\frac{1}{R_L} + \frac{1}{R_z} + \frac{1}{R_1 + R_2}} = \frac{\frac{5}{100} + \frac{17.24}{5k}}{\frac{1}{10k} + \frac{1}{100} + \frac{1}{5k}} = 5.189V$$

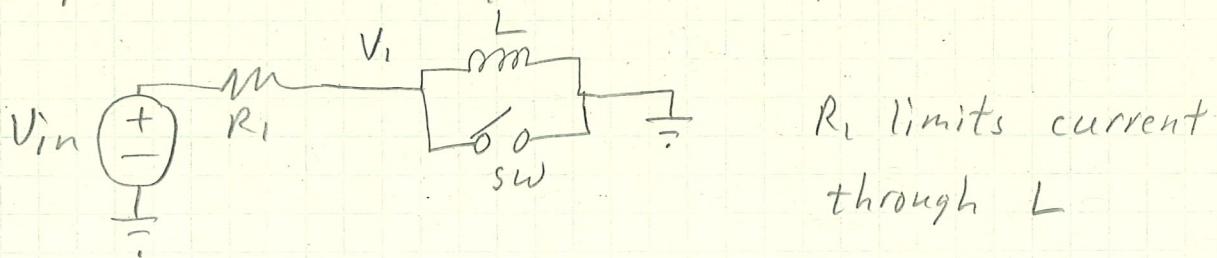
$$i_{Dz} = \frac{5.189 - 5}{100} = 1.89mA \rightarrow D_z \text{ is in reverse breakdown}$$

Flyback Diode - diode application

→ to eliminate "flyback", the voltage spike across an inductor when the supply current is suddenly reduced or interrupted

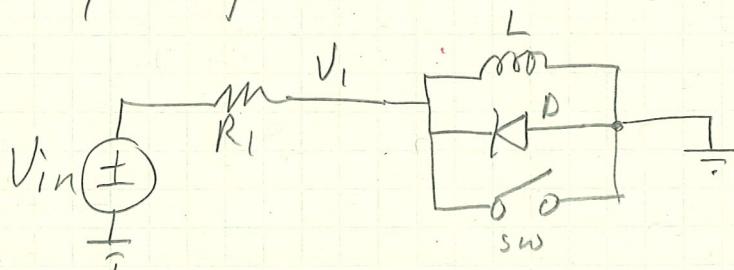


examples : motors, relays, solenoids, power inductors



When switch is closed,  $V_i$  spikes negative to force more current through  $L \rightarrow$  could damage power supply

Add flyback diode to allow current through  $L$  to slowly change when switch is closed



$D$  is off, except right after switch is closed. It clamps  $V_i$  to  $-V_{on}$  of the diode while the inductor discharges through  $D$