EE/COE 152: Basic Electronics

Lecture 4

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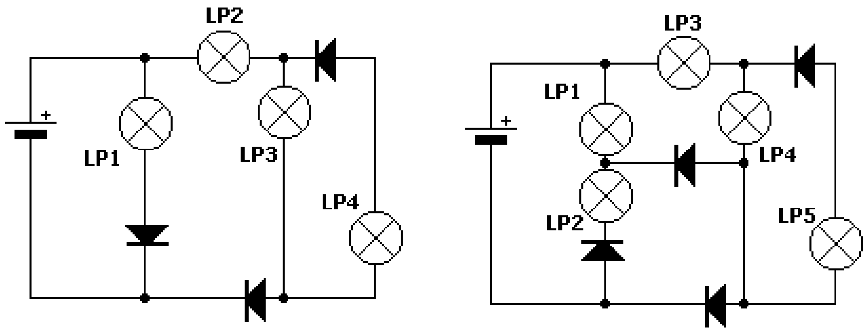
# Outline

- Filter Design
- Zener Diodes
- Diode Small-signal Analysis

# Diodes Recap: A Diode Puzzle

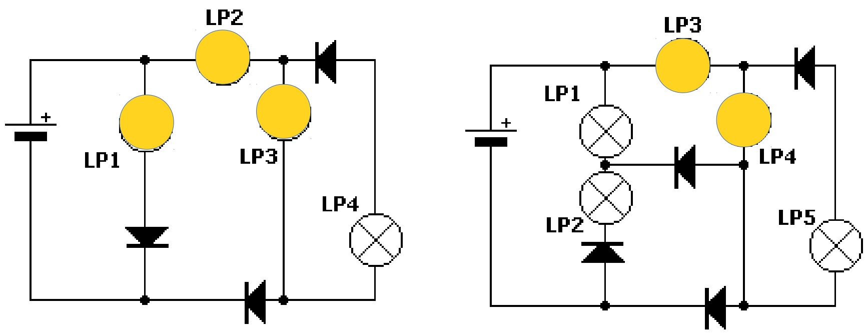
Which lamps will light up?



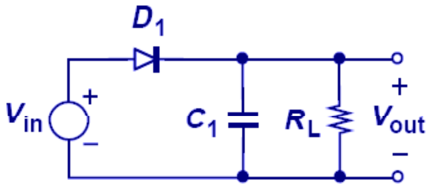


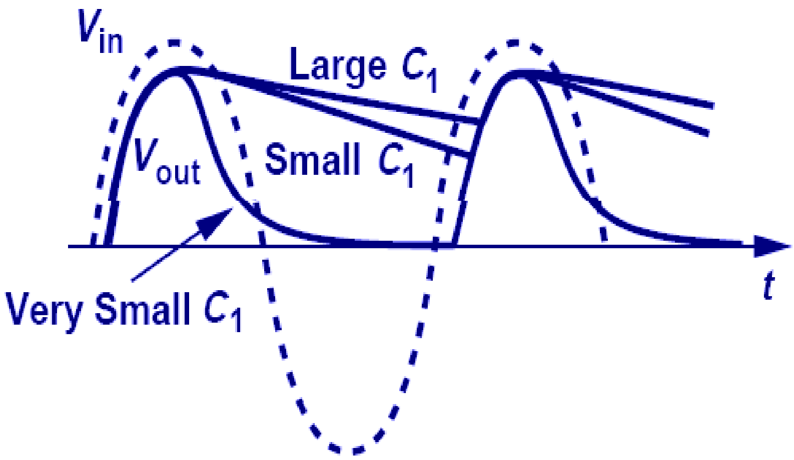

# A Diode Puzzle

Which lamps will light up?



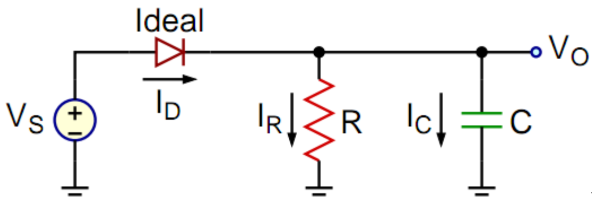
# Effect of Filter Capacitor Values on Rectifier Circuits



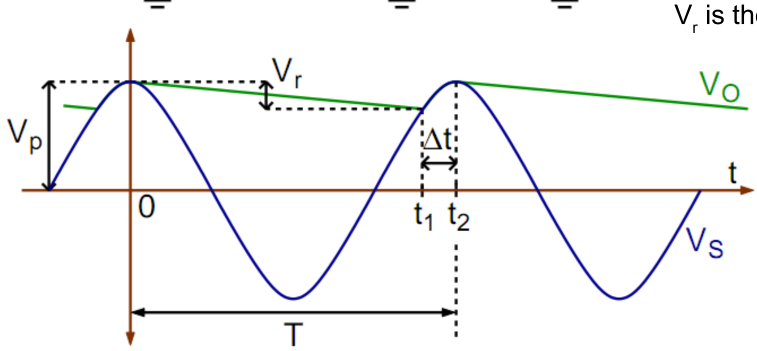






# Half-Wave Rectifier with a Filter Capacitor



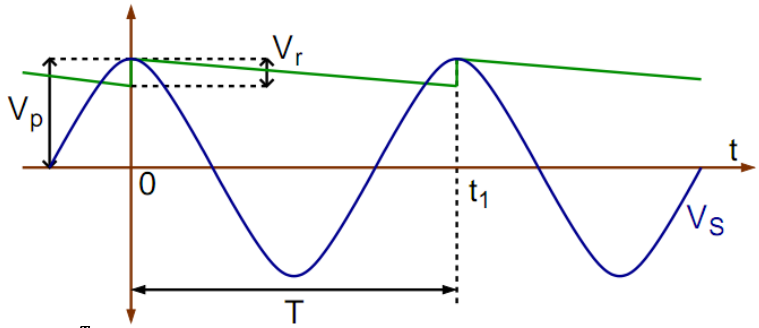

$V_r$ is the **Ripple Voltage**




$$V_0(t)=\begin{cases} V_s(t) \quad , & t_1<t<t_2 \\ V_p e^{-\frac{t}{RC}} \quad , & 0<t<t_1 \end{cases} \Rightarrow \quad V_0(t_1)=V_p e^{-\frac{t_1}{RC}}$$

# Half-Wave Rectifier with a Filter Capacitor

For minimum ripple effect: $t_1 \approx T$ , *the period*




$$V_o(t_1) \approx V_p e^{-\frac{T}{RT}}$$

$$for\ RC \gg T \Rightarrow e^{-\frac{T}{RC}} \approx 1 - \frac{T}{RC}$$

Peak-to-peak ripple voltage:

$$V_r = V_p - V_0(t_1) = V_p - v_p\left(1 - \frac{T}{RC}\right) \Rightarrow V_r = V_p \frac{T}{RC}$$



# Exercise: Rectifier with a Filter Capacitor

Half-wave rectifier peak-to-peak ripple voltage ratio:

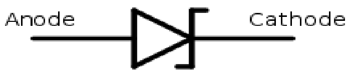
$$V_r(ratio) = \frac{V_r}{V_p} = \frac{T}{RC}$$

Exercise:

Show that the peak-to-peak ripple voltage ratio of a full-wave Rectifier is half that of a halt-wave rectifier

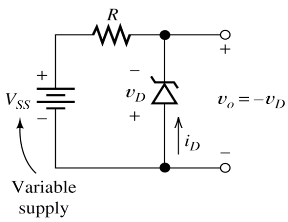
# Zener Diodes

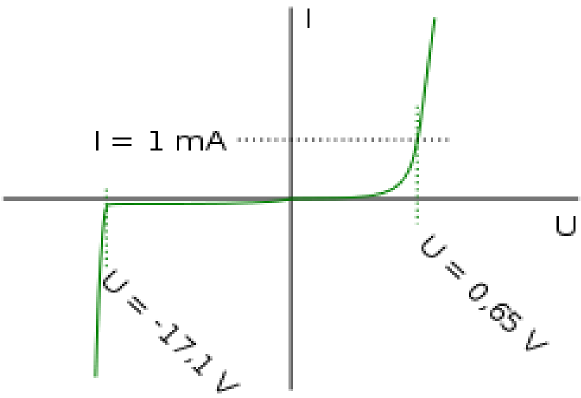
- Diodes in their normal operation will get destroyed when breakdown in the reverse bias mode
- Zener diode is a type of diode at can operate normally above the breakdown voltage (***Zener voltage)***
- They are normally used as Voltage regulators
- Zener diode will maintain a constant constant reverse bias voltage ($V_Z$) and ling as the zener current ($I_Z$) passes through



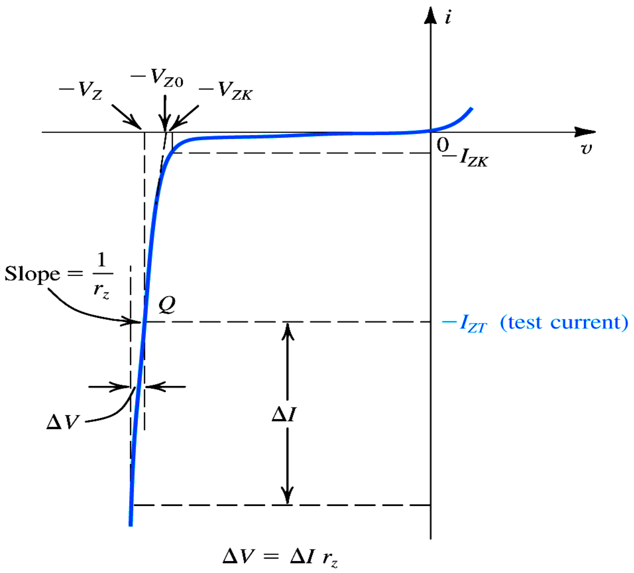


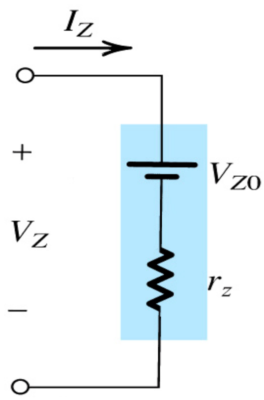

# Zener Diode Characteristics



# Zener Diode Model

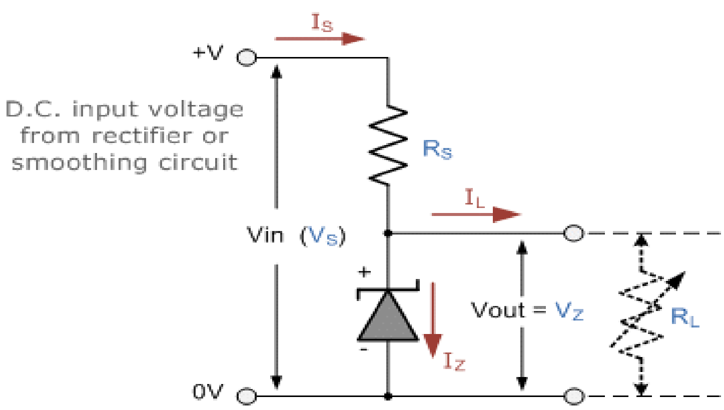



$$V_Z = V_{Z0} + r_Z I_Z$$



# Zener Diode Regulator




$R_s$ is used to limit the amount of current the flows through the Zener diode to $I_Z$

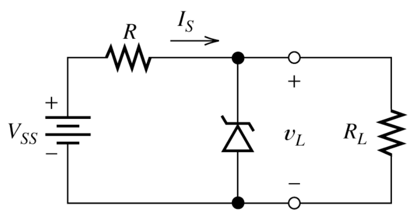
This allows a constant voltage drop of $V_z$ across the diode and hence the load

# Some Typical Zener Diode Standard Voltages

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| BZX55 Zener Diode Power Rating 500mW | | | | | | | |
| 2.4V | 2.7V | 3.0V | 3.3V | 3.6V | 3.9V | 4.3V | 4.7V |
| 5.1V | 5.6V | 6.2V | 6.8V | 7.5V | 8.2V | 9.1V | 10V |
| 11V | 12V | 13V | 15V | 16V | 18V | 20V | 22V |
| 24V | 27V | 30V | 33V | 36V | 39V | 43V | 47V |
| BZX85 Zener Diode Power Rating 1.3W | | | | | | | |
| 3.3V | 3.6V | 3.9V | 4.3V | 4.7V | 5.1V | 5.6 | 6.2V |
| 6.8V | 7.5V | 8.2V | 9.1V | 10V | 11V | 12V | 13V |
| 15V | 16V | 18V | 20V | 22V | 24V | 27V | 30V |
| 33V | 36V | 39V | 43V | 47V | 51V | 56V | 62V |



# Example: Zener Diode Regulator




(a) Regulator circuit with load

Consider the Zener diode regulator shown in (a) above. Find the load voltage, $v_L$ and the source current $i_s$ if $V_{ss}$ = 24V, R = 1.2kΩ and $R_L$ = 6kΩ

# Solution

First find the Thevenin equivalent circuit

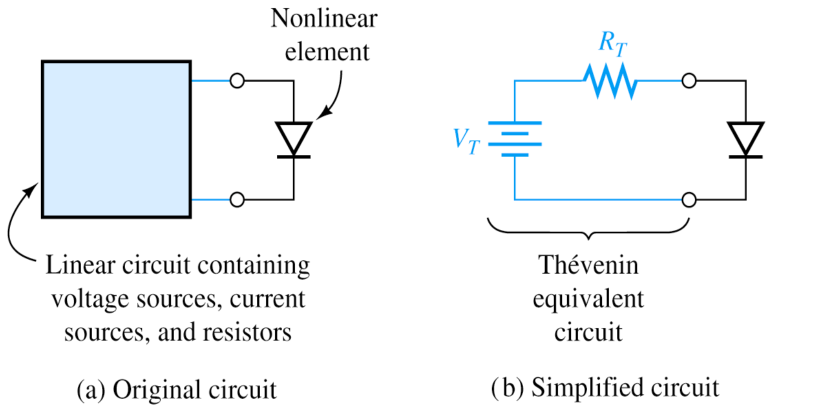



**Figure 10.11** Analysis of a circuit containing a single nonlinear element can be accomplished by load-line analysis of a simplified circuit.



# Solution

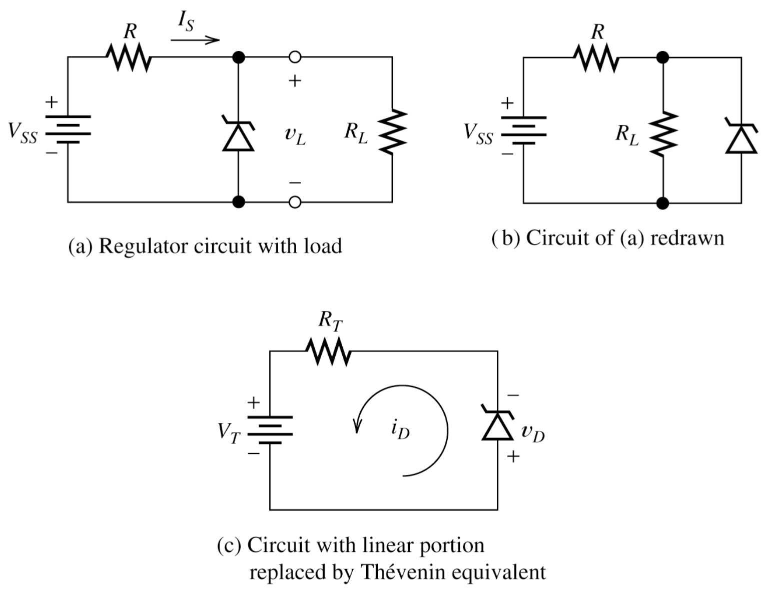
*Thevenin equivalent*

$$V_T = V_{ss}\frac{R_L}{R+R_l} = 20\text{V}$$

$$R_T = \frac{RR_L}{R+R_L} = 1\text{k}\Omega$$

*Load Line Equation*

$$V_T + R_t i_D + V_D = 0$$



# Solution

Plot load line on
Zener diode charateristic
Curve.

Determine $V_D$ and $i_D$
From the Q-point

*F.rom Graph*

$$V_I = -V_D = 10\text{V}$$
$$i_D = -10\text{mA}$$

Now find $i_S$

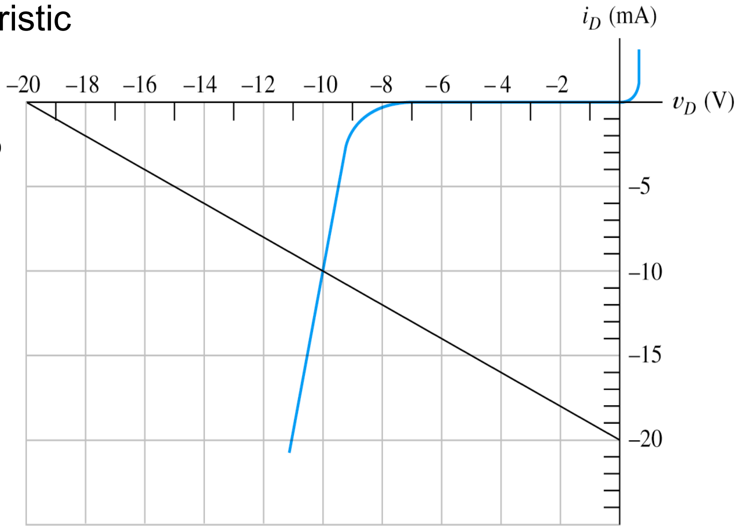
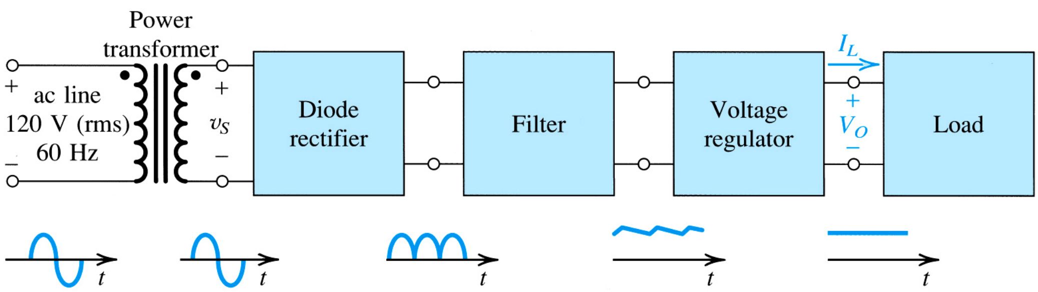


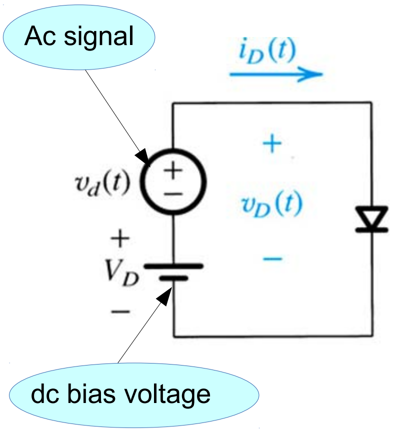

**Figure 10.13** Zener-diode characteristic for Example 10.4 and Exercise 10.4.

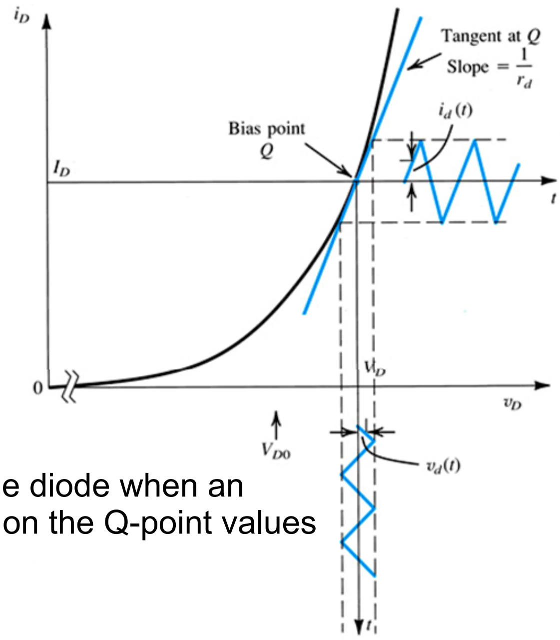


At this point you should be able to design a DC power supply
With all the Blocks shown below




# Diode Small Signal Model




We looking at the operation of the diode when an small ac signal is superimposed on the Q-point values



# Small-signal Approximation

*Using KVL*

$$v_d(t) = V_D + v_d(t)$$

*Using Shockley (Diode) Equation:*

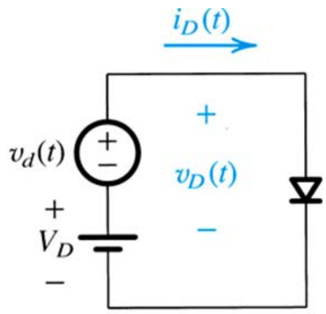
$$i_D(t) = I_s e^{\frac{v_D(t)}{nV_t}} = I_s e^{\frac{V_D}{nV_T}} e^{\frac{v_d(t)}{nV_T}} = I_D e^{\frac{v_d}{nV_T}}$$

*where* $V_D, I_D$ *are the* $Q-$ *point values*

*under small* $-$ *signal condition:* $\frac{v_d}{nV_T} \ll 1$

$$i_d(t) \approx I_D\left(1 + \frac{v_d}{nV_T}\right) = I_D + i_d$$

*Small* $-$ *signal resistance:* $r_d = \frac{I_D}{nV_T}$

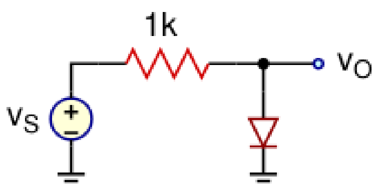


# Small-Signal Circuit Analysis

- Choose proper dc analysis technique or model to obtain Q-point by elimination all ac sources
- Calculate small signal parameters ($r_d$)
- Eliminate DC sources, replace diode with its small signal equivalent model ($r_d$)



# Example




$v_S = 5 + 0.2\sin(\omega t), \quad n = 2$

Find $v_O(t)$.

**DC Solution:**

$$V_O = 0.7 \text{ V} \qquad I_D = \frac{5 - 0.7}{1k} = 4.3 \text{ mA}$$

$$r_d = \frac{nV_T}{I_D} = \frac{50 \text{ mV}}{4.3 \text{ mA}} = 11.6\ \Omega$$

**AC Solution:**

$$v_o(t) = \frac{11.6}{10^3 + 11.6} 0.2\sin(\omega t) = 2.3 \times 10^{-3}\sin(\omega t)$$

$$\text{Total: } v_O(t) = V_O + v_o(t) = 0.7 + 2.3 \times 10^{-3}\sin(\omega t)$$