EE/COE 152: Basic Electronics

Lecture 4

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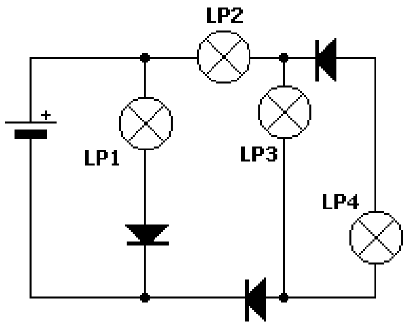
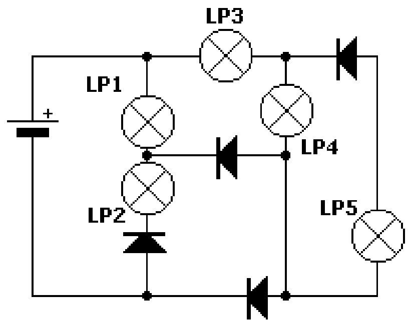
Outline

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

Diodes Recap: A Diode Puzzle

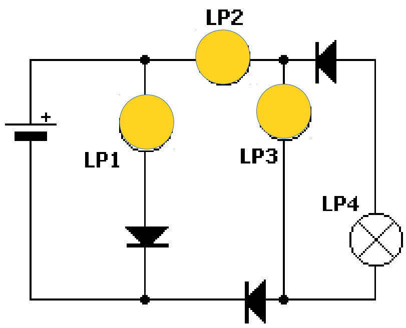
Which lamps will light up?

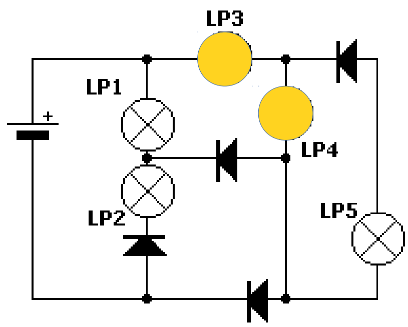




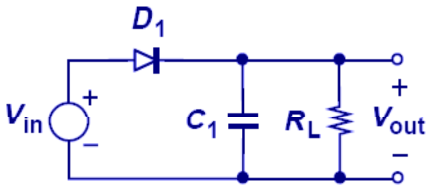
A Diode Puzzle

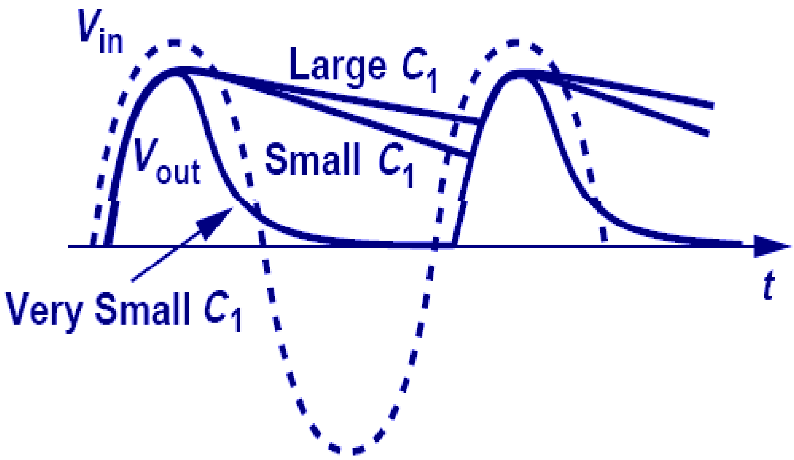
Which lamps will light up?



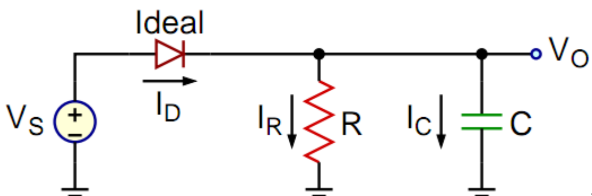


Effect of Filter Capacitor Values on Rectifier Circuits

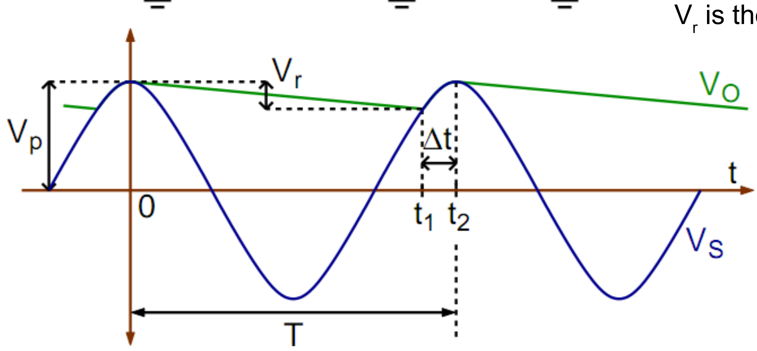




Half-Wave Rectifier with a Filter Capacitor



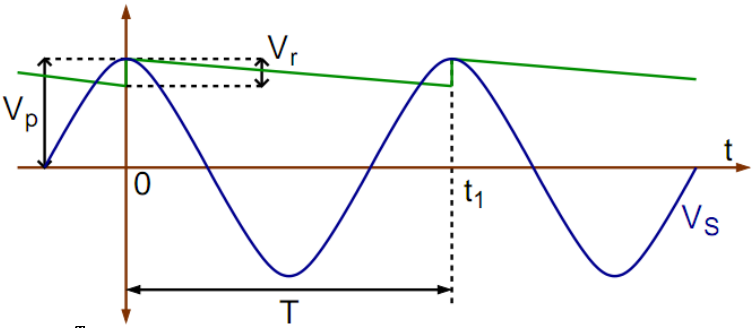
V_r is the **Ripple Voltage**



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

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:

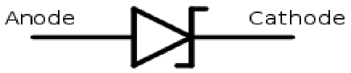
$$V_r(ratio) = \frac{V_r}{V_p} = \frac{T}{RC}$$

Exercise:

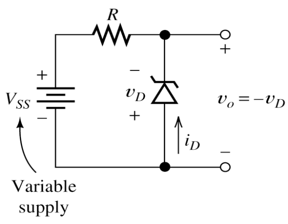
Show that the peak-to-peak ripple voltage ratio of a full-wave Rectifier is half that of a half-wave rectifier

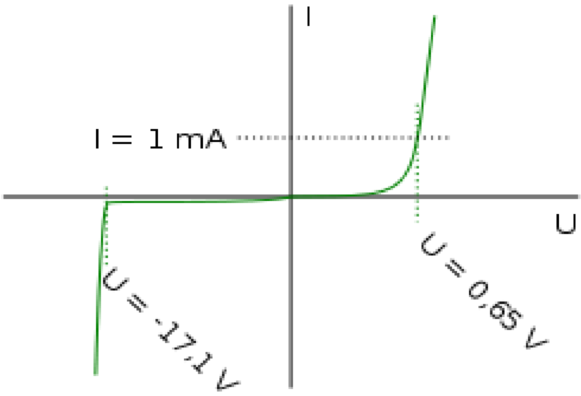
Zener Diodes

- 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 reverse bias voltage (V_Z) when a constant reverse bias current (I_Z) passes through

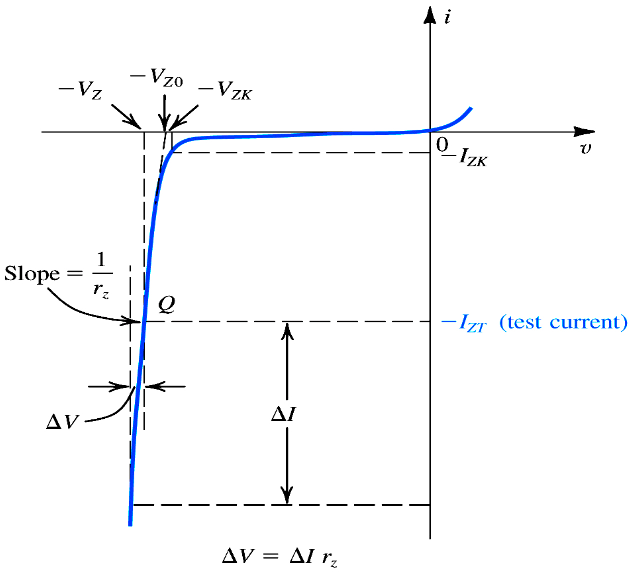


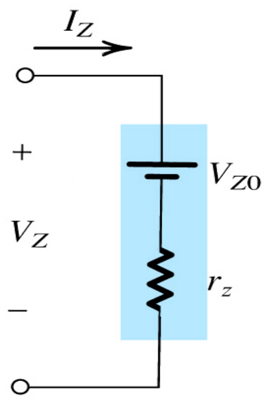
Zener Diode Characteristics





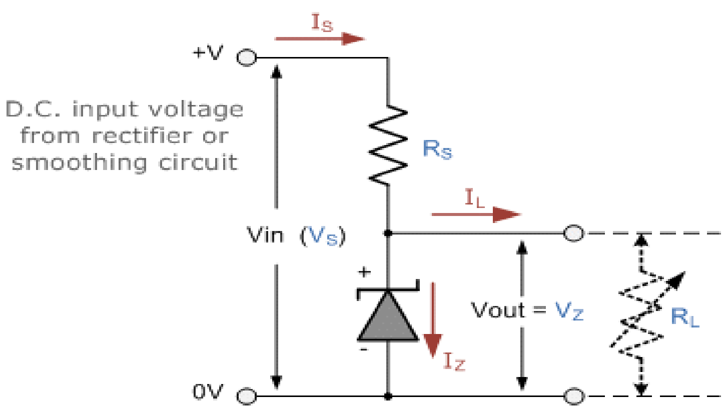
Zener Diode Model





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

Zener Diode Regulator



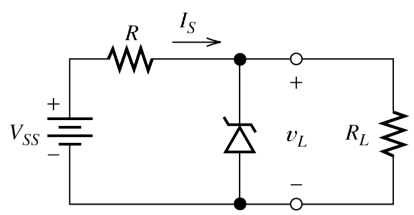
R_s is used to limit the amount of current the flows through the Zener diode to I_Z

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 $V_{ss} = 24V$, $R = 1.2k\Omega$ and $R_L = 6k\Omega$

Solution

First find the Thevenin equivalent circuit

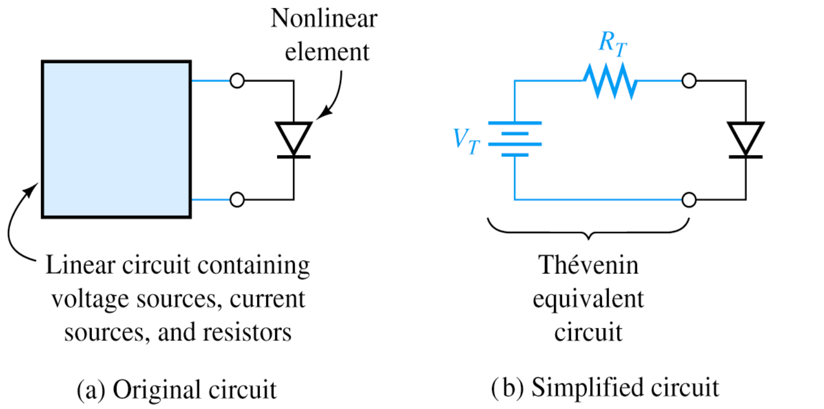


Figure 10.11 Analysis of a circuit containing a single nonlinear element can be accomplished by load-line analysis of a simplified circuit.

Solution

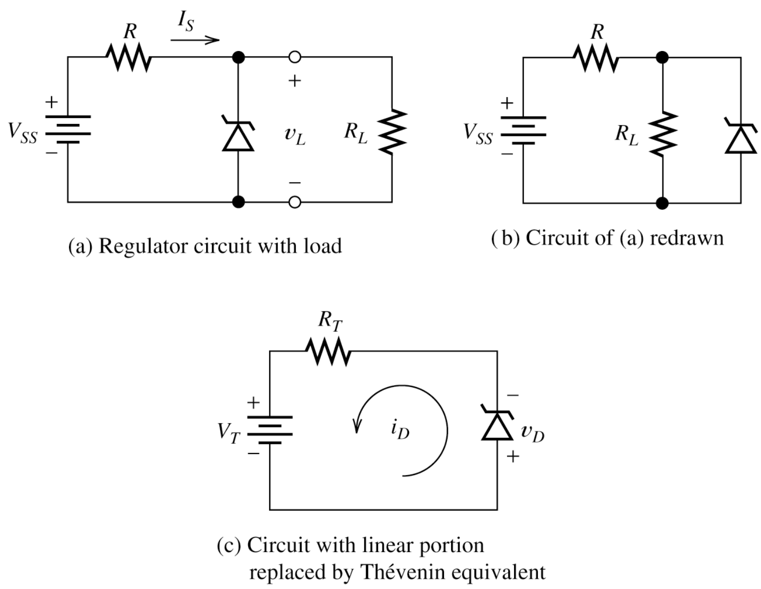
Thevenin equivalent

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

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

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

$V_I = -V_D = 10V$

$i_D = -10mA$

Now find i_S

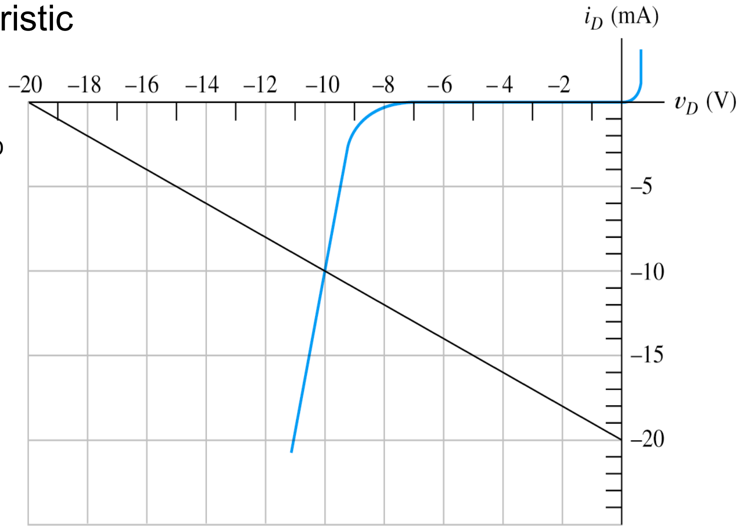
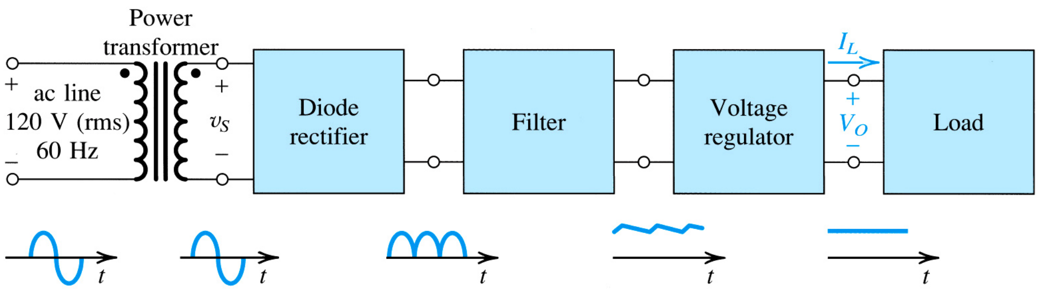
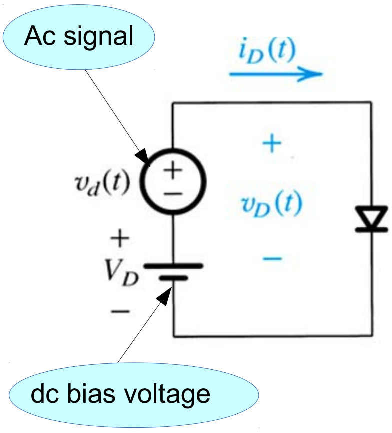


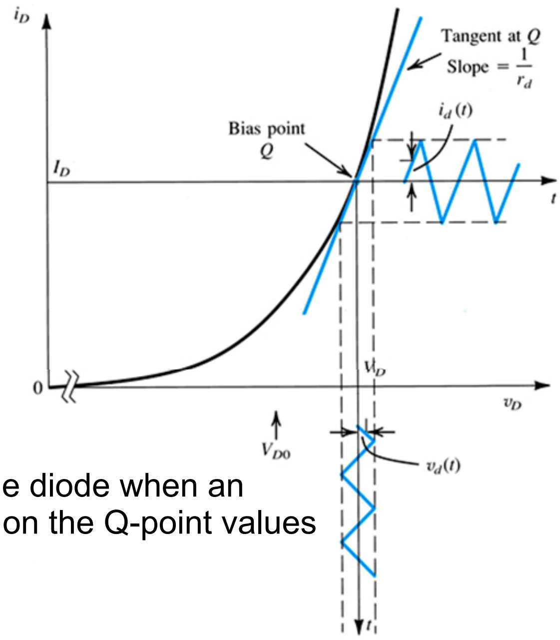
Figure 10.13 Zener-diode characteristic for Example 10.4 and Exercise 10.4.

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:

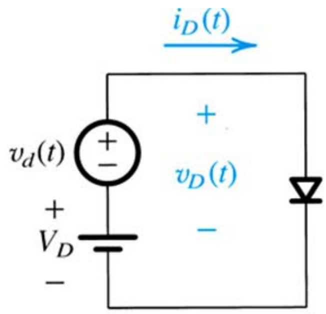
$$i_D(t) = I_s e^{\frac{v_D(t)}{nV_t}} = I_s e^{\frac{V_D}{nV_T}} e^{\frac{v_d(t)}{nV_T}} = I_D e^{\frac{v_d}{nV_T}}$$

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

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

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

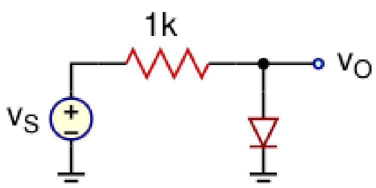
Small $-$ *signal resistance:* $r_d = \frac{nV_T}{I_D}$



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:

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

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