

# Introduction to Electronics



*An introduction to electronic components and a study of circuits containing such devices.*

# Week 5: Diodes Part 2





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# Introduction to Electronics

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# Half-Wave Rectifiers

*Introduce diode half-wave rectifiers*



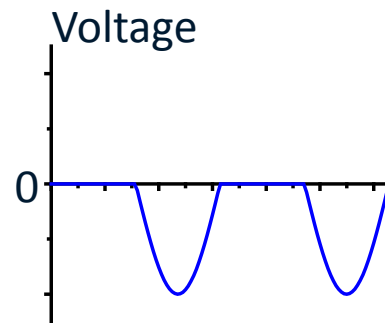
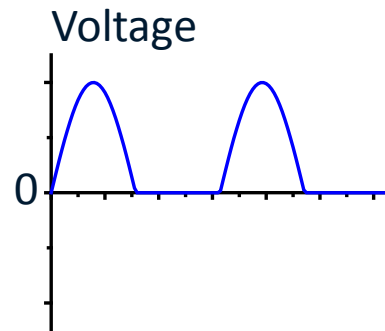
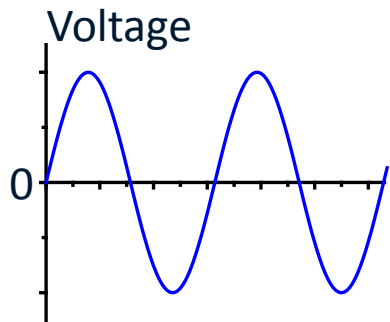
# Lesson Objectives

- Introduce half-wave rectifiers
- Examine their behavior for sinusoidal inputs
- Analyze a diode rectifier circuit

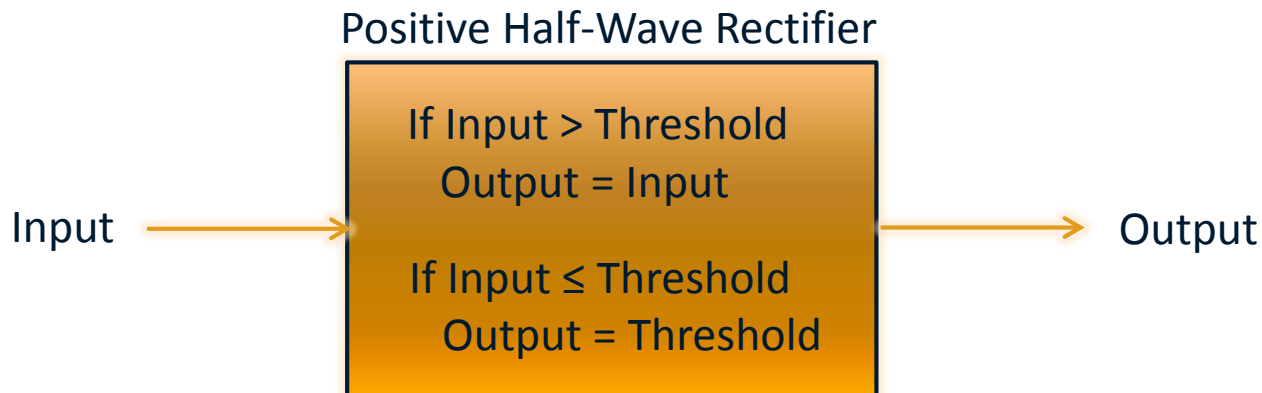
# Rectifier

- A non-linear device that modifies an input voltage such that the output voltage is greater than or less than a threshold value

# Sinusoidal Input Voltages

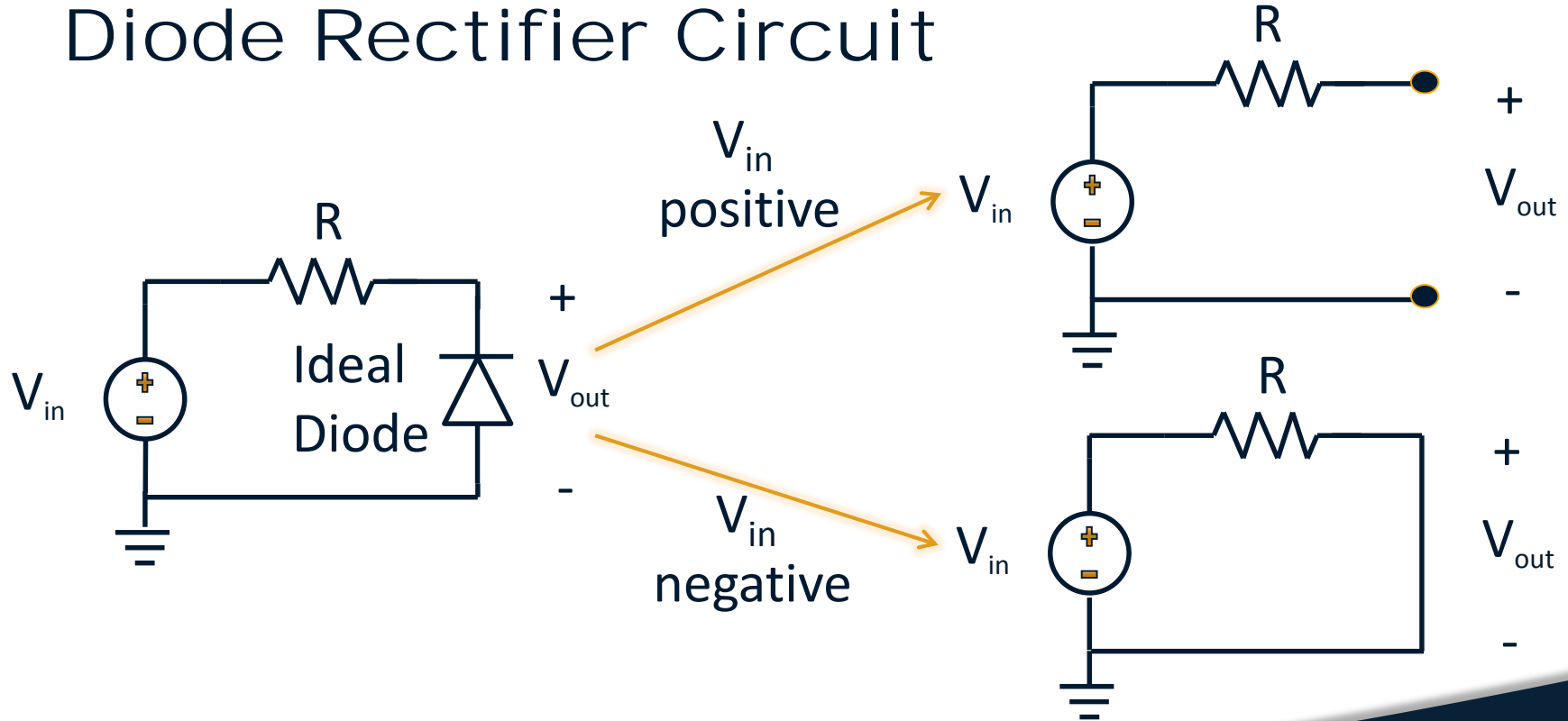


# Half-Wave Rectifier

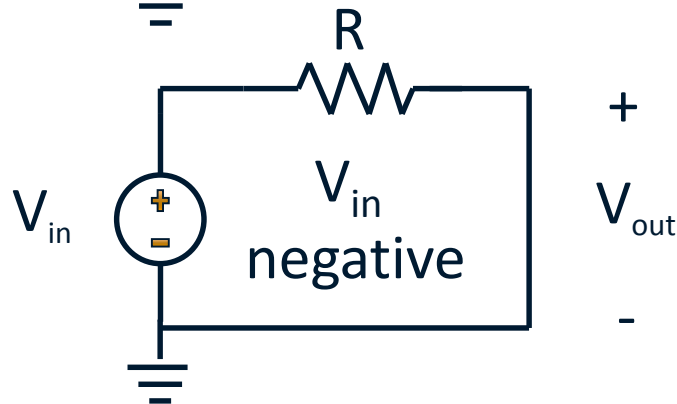
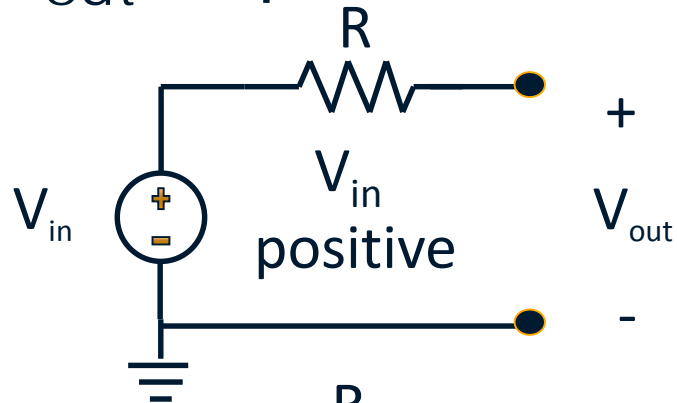




# Diode Rectifier Circuit

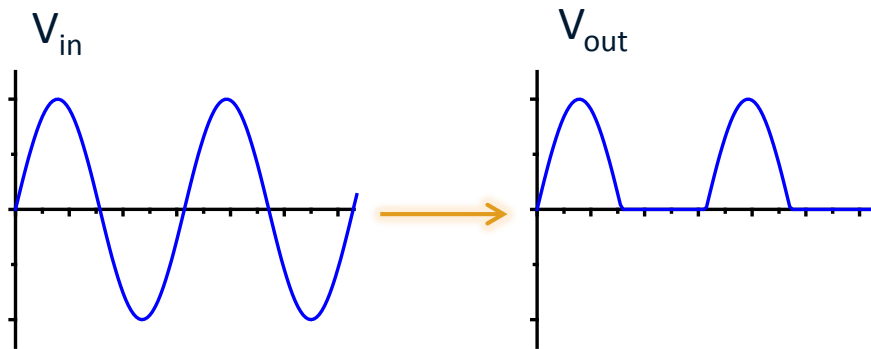


# $V_{out}$ Equations



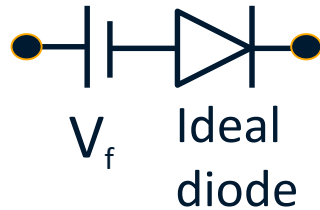
# Positive Half-Wave Rectifier

$$V_{\text{out}} = \begin{cases} V_{\text{in}} & V_{\text{in}} > 0 \\ 0 & V_{\text{in}} \leq 0 \end{cases}$$

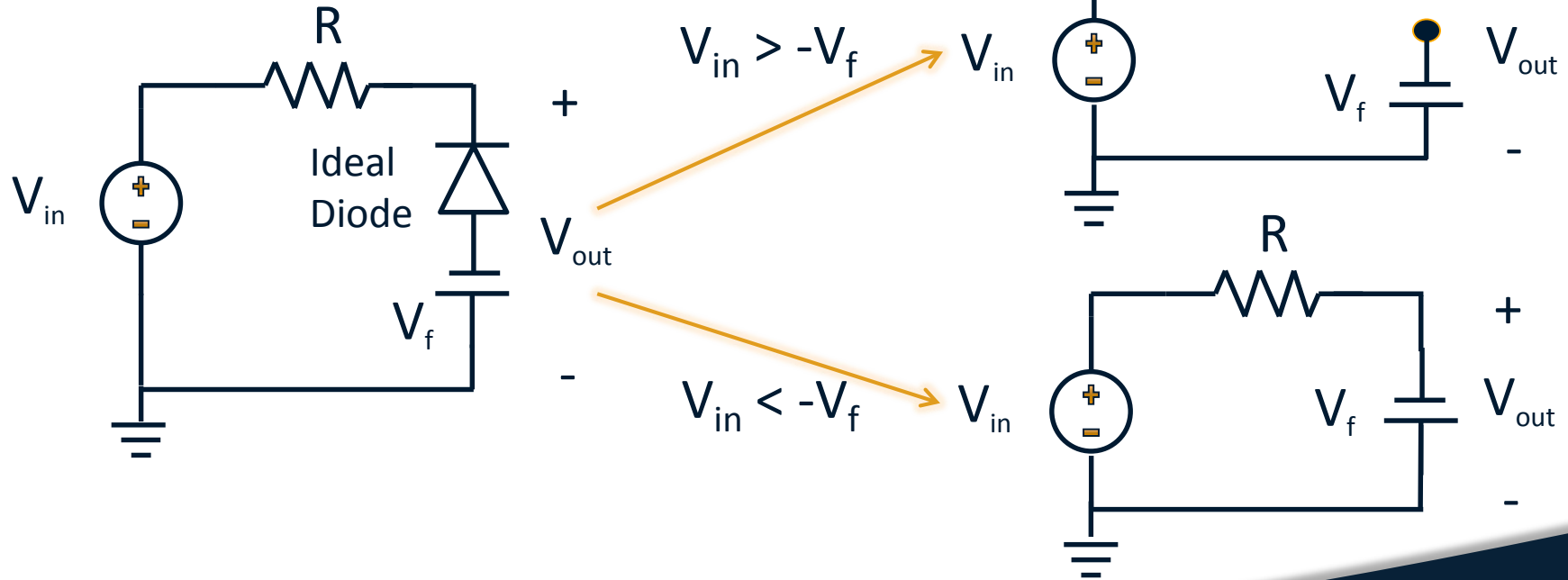


# Non-Ideal Diode

- How does a non-ideal diode change the behavior of the circuit?
- Include the forward voltage drop  $V_f$  by modeling the diode as an ideal diode in series with a voltage source



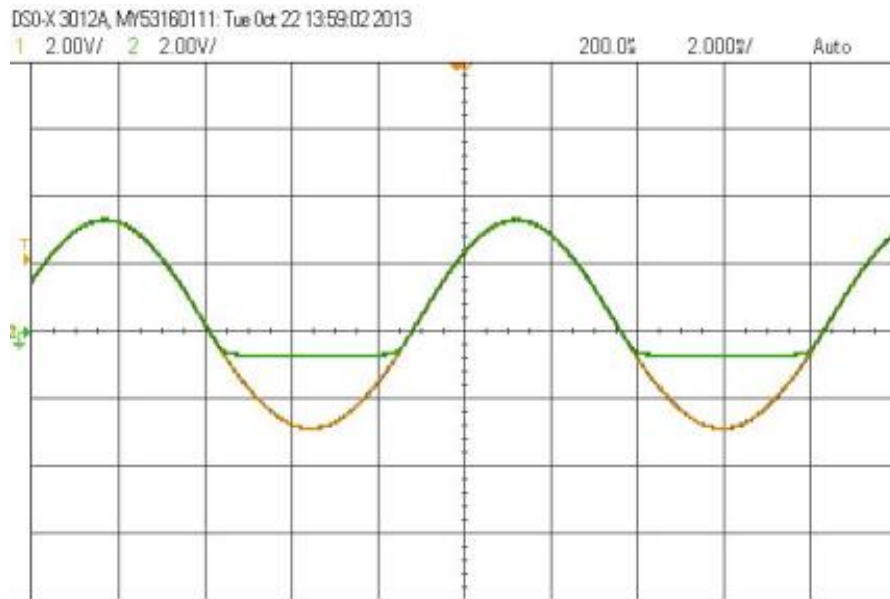
# Non-Ideal Diode Circuit



# Measured Output

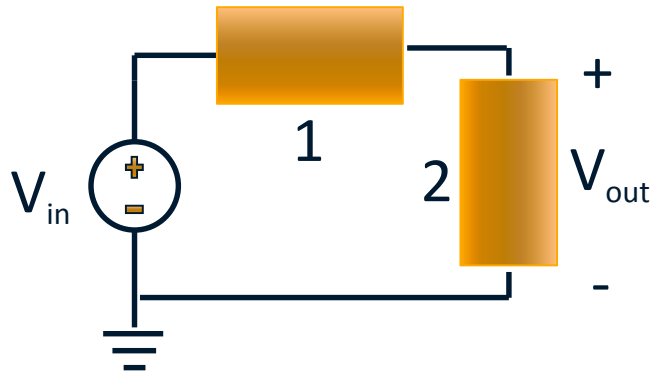
 $V_{in}$  and  $V_{out}$ 

$$V_{out} = \begin{cases} V_{in} & V_{in} > -V_f \\ -V_f & V_{in} \leq -V_f \end{cases}$$



# Other Possible Circuits

- Four different rectifiers can be constructed using a resistor and a diode.



# Other Possible Circuits

- Can you determine the equation for  $V_{\text{out}}$  in terms of  $V_{\text{in}}$  for each of the possible circuits assuming both ideal and non-ideal diodes?
- How does the output of each circuit change if it is taken across element 1 rather than element 2?



# Summary

- Rectification
- Half-Wave Rectifiers



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# Full-Wave Rectifiers

*Introduce diode full-wave rectifiers*



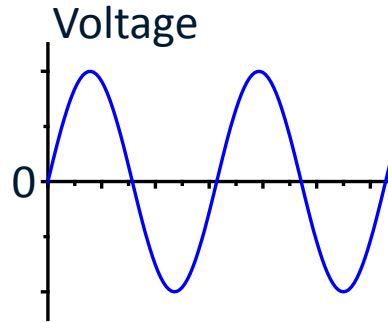
# Lesson Objectives

- Introduce full-wave rectifiers
- Examine their behavior for sinusoidal inputs
- Analyze diode full-wave rectifier circuit

# Rectifier

- A non-linear device that modifies an input voltage such that the output voltage is greater than or less than a threshold value

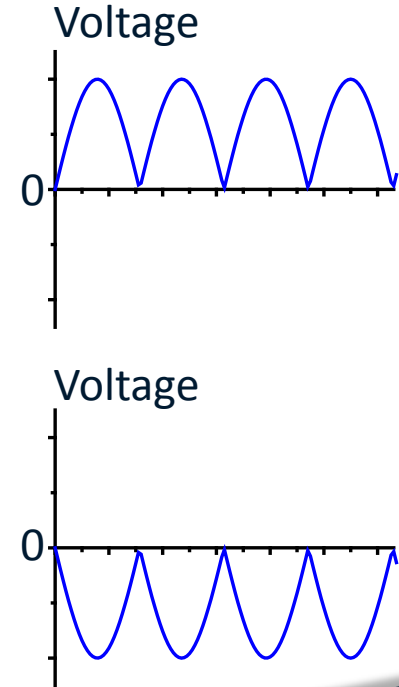
# Sinusoidal Input Voltages



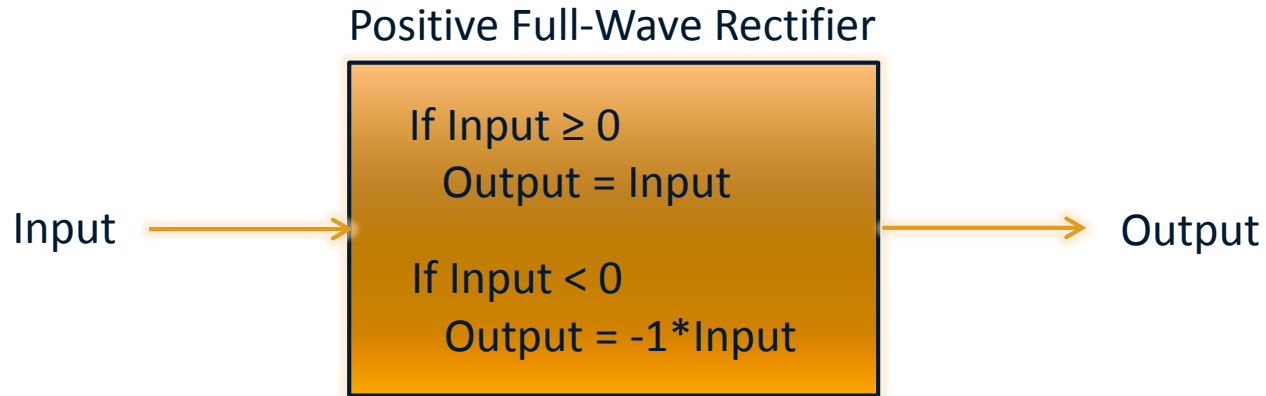
Input



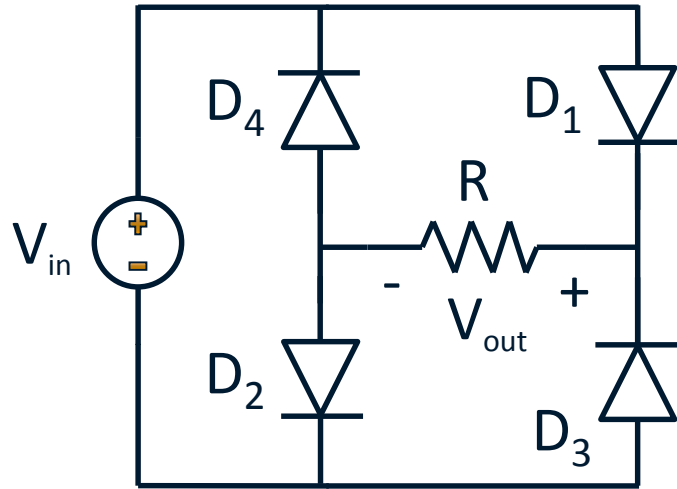
Output



# Full-Wave Rectifier



# Full-Wave Rectifier Circuit



Ideal Diodes

$V_{in}$   
positive

$V_{in}$



$V_{in}$   
negative

$V_{in}$



## $V_{out}$ Equation

- ⊙ A full-wave rectifier is also known as an absolute value circuit

$$V_{out} = \begin{cases} V_{in} & V_{in} \geq 0 \\ -V_{in} & V_{in} < 0 \end{cases}$$

$D_1$  and  $D_2$  on  
 $D_3$  and  $D_4$  off

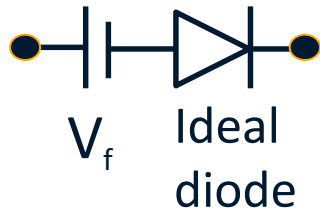
$D_1$  and  $D_2$  off  
 $D_3$  and  $D_4$  on

$$V_{out} = |V_{in}|$$

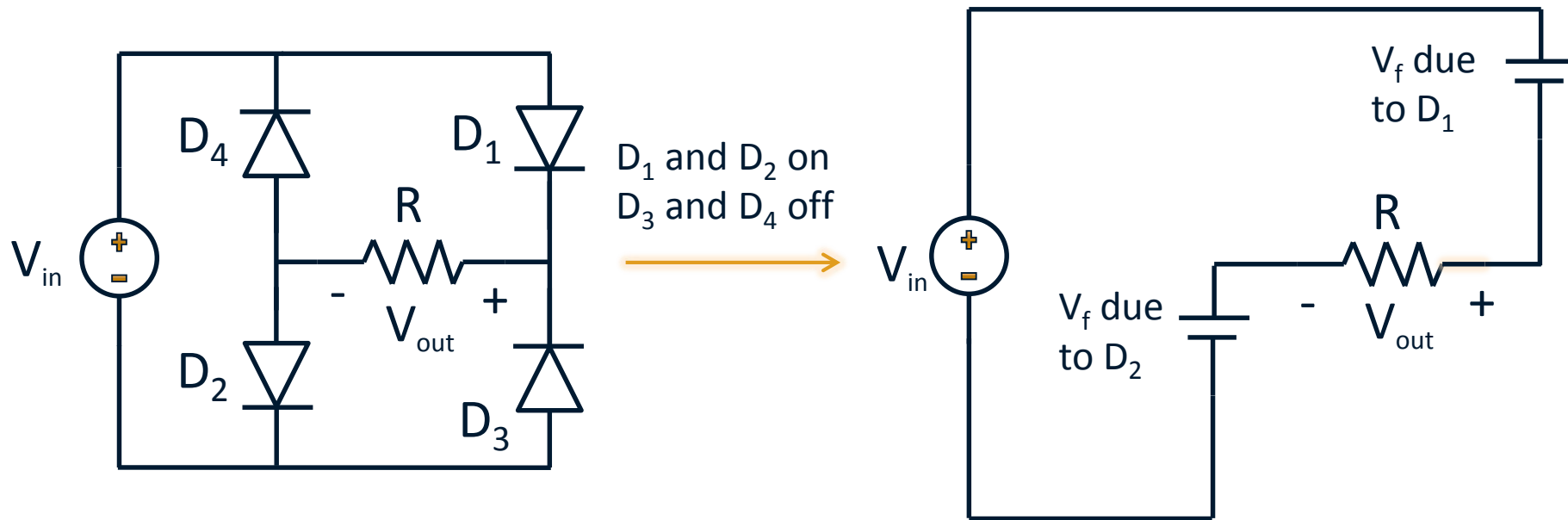


# Non-Ideal Diode

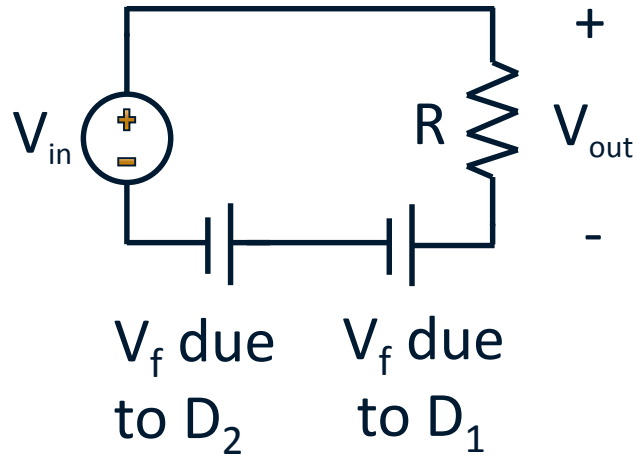
- How does a non-ideal diode change the behavior of the circuit?
- Include the forward voltage drop  $V_f$  by modeling the diode as an ideal diode in series with a voltage source



# Non-Ideal Diode Circuit

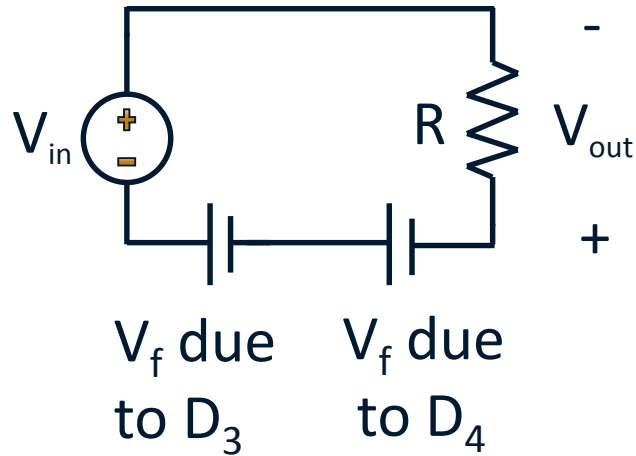


# Circuit for $D_1$ and $D_2$ On



$$V_{in} > 2V_f$$

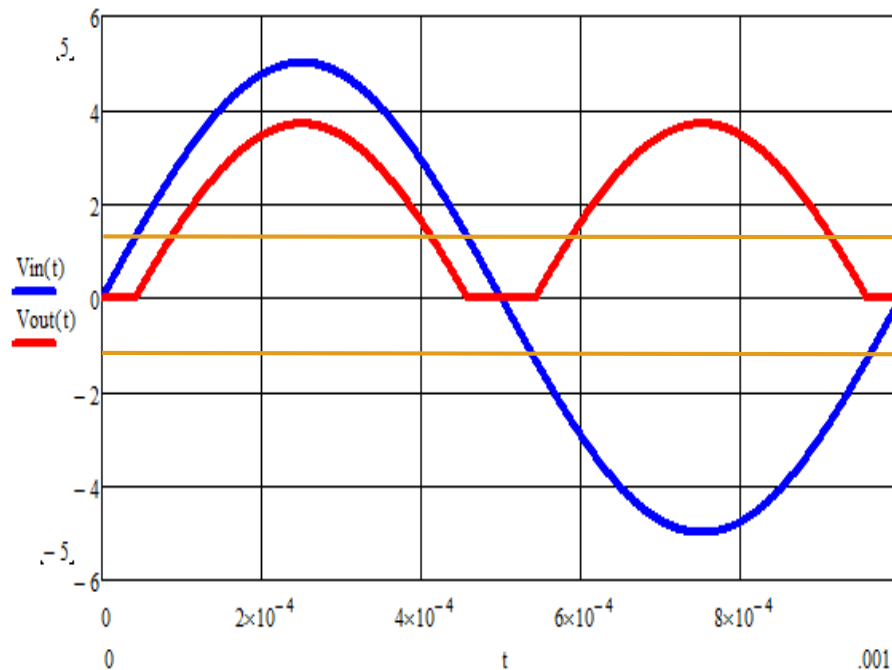
# Circuit for $D_3$ and $D_4$ On



$$V_{in} < -2V_f$$

# $V_{out}$ Equation

$$V_{out} = \begin{cases} V_{in} - 2V_f & V_{in} > 2V_f \\ -V_{in} - 2V_f & V_{in} < -2V_f \\ 0 & \text{Otherwise} \end{cases}$$



# Other Possible Configurations

- How does the output voltage change if the directions of all diodes are reversed?
- How does the output voltage change if the direction of any one diode is reversed?

# Summary

- Full-Wave Rectifiers



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# Voltage Transfer Characteristics

*Introduce voltage transfer characteristics*





# Lesson Objectives

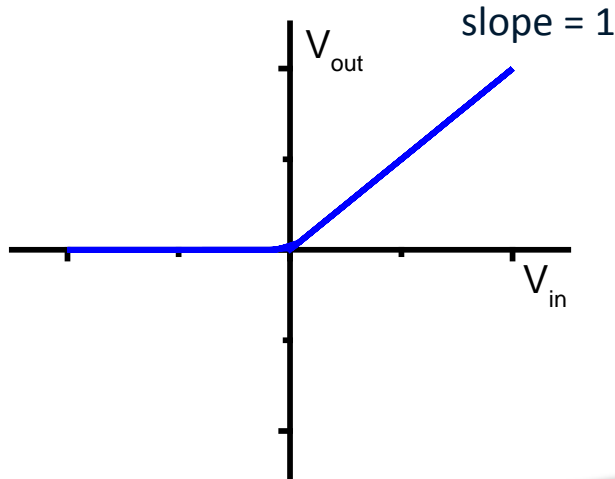
- Introduce voltage transfer characteristics (VTCs)
- Use VTC to determine output for given input
- Determine VTC from given input and output plots

# Voltage Transfer Characteristic (VTC)

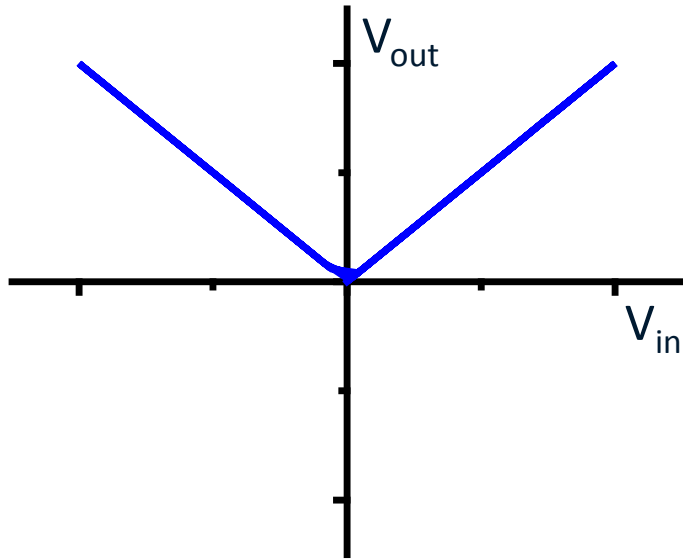
- A graphical description of the behavior of a nonlinear circuit
- A plot of output voltage versus input voltage

Positive Half-Wave Rectifier

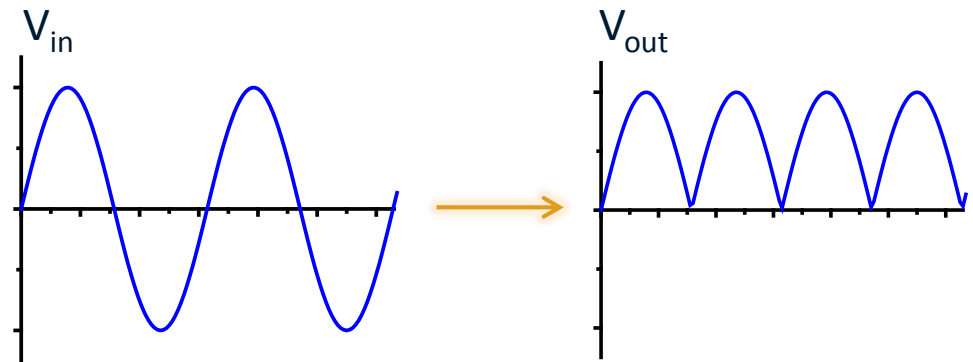
$$V_{\text{out}} = \begin{cases} V_{\text{in}} & V_{\text{in}} > 0 \\ 0 & V_{\text{in}} \leq 0 \end{cases}$$



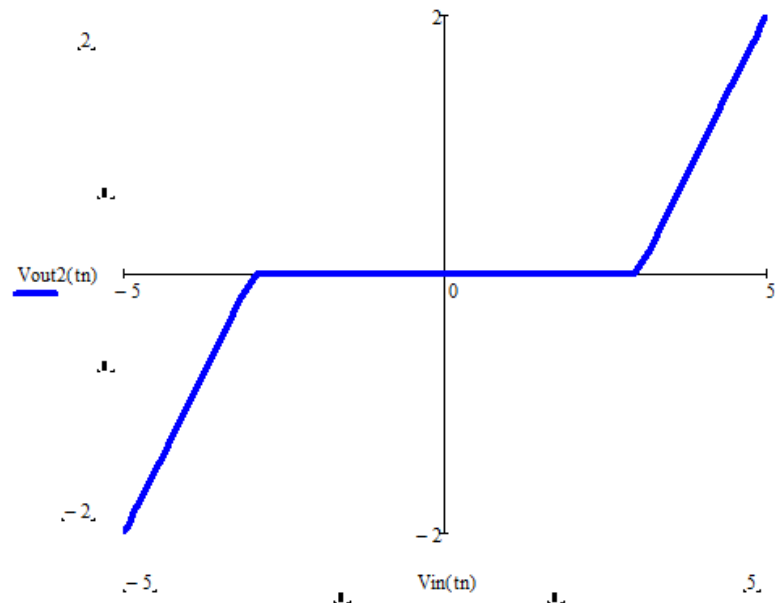
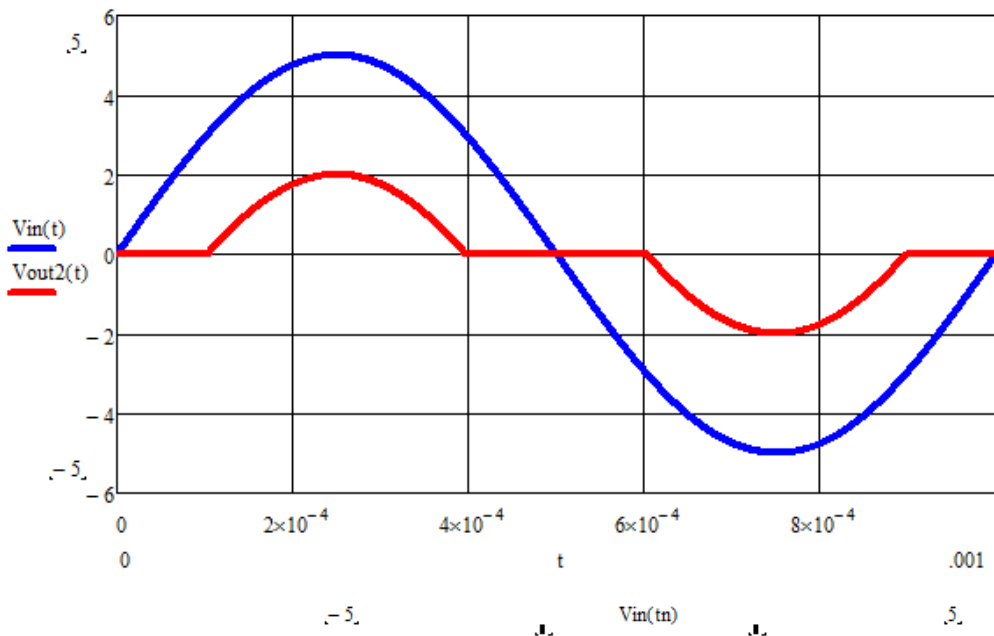
# Example VTC



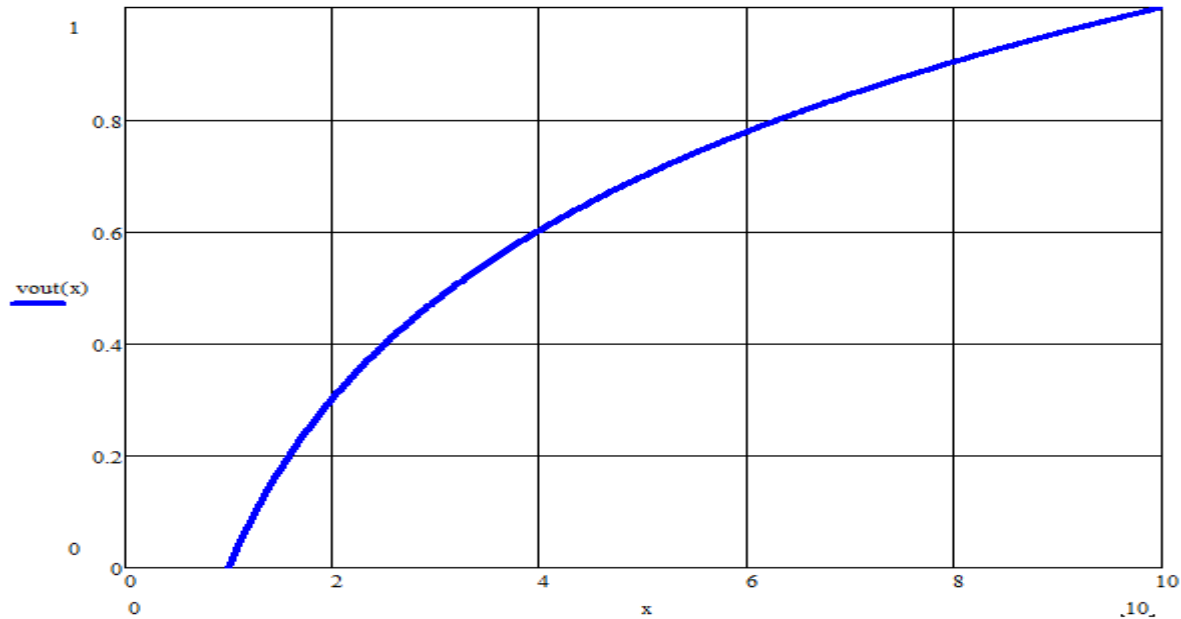
## Positive Full-Wave Rectifier



# VTC from Input and Output Waveforms



# Designing with a VTC



# Summary

- Voltage transfer characteristics are plots of output voltage versus input voltage
- VTCs quickly indicate a circuit's behavior



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# AC to DC Conversion

*Introduce ac to dc conversion*



# Lesson Objectives

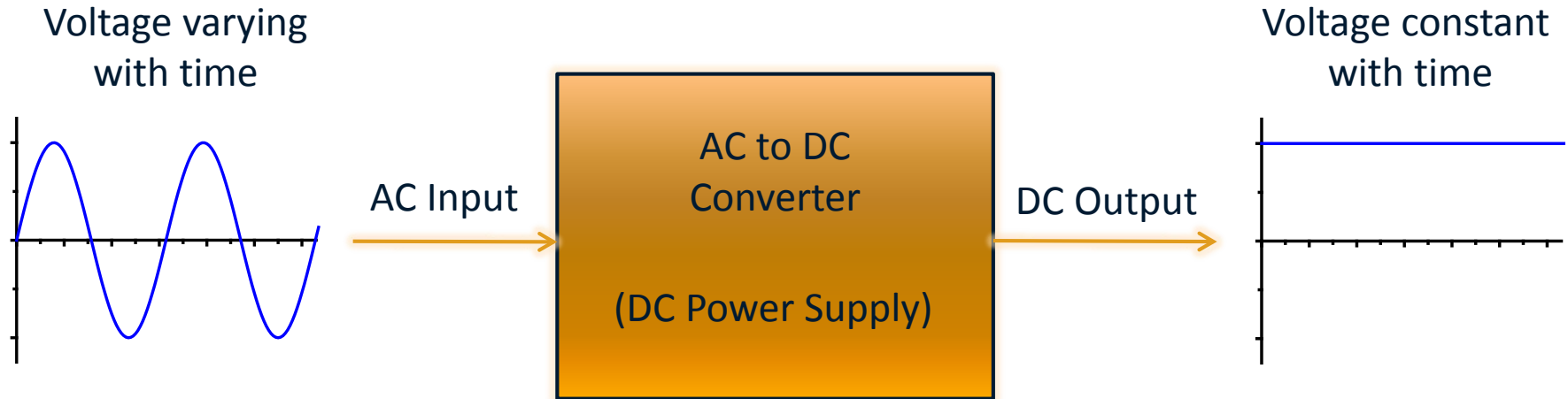
- Introduce ac to dc conversion
- Examine circuits that perform this conversion



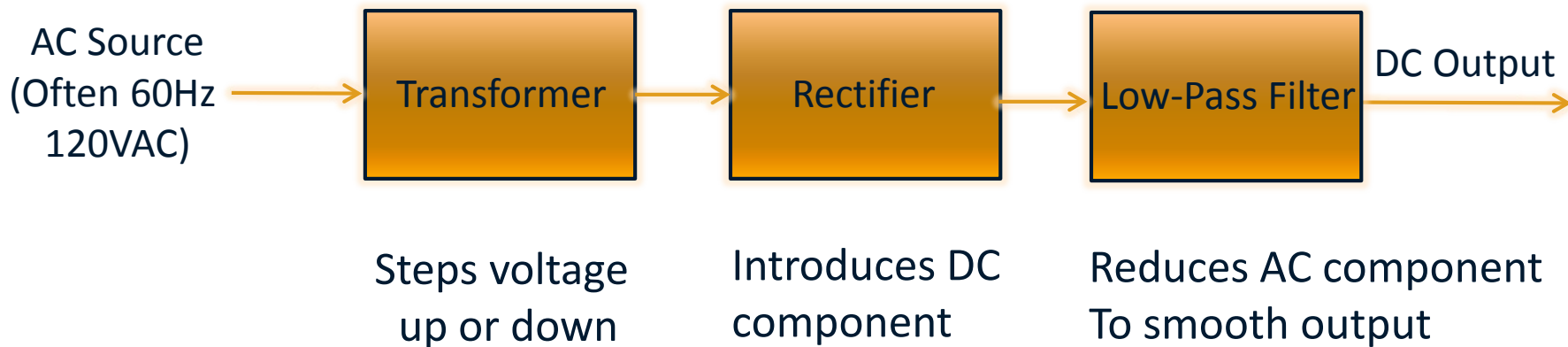
# AC to DC Conversion

- AC used in power transmission
- DC used to power electronics
- Diode rectifiers are used in converting an alternating current to a direct current

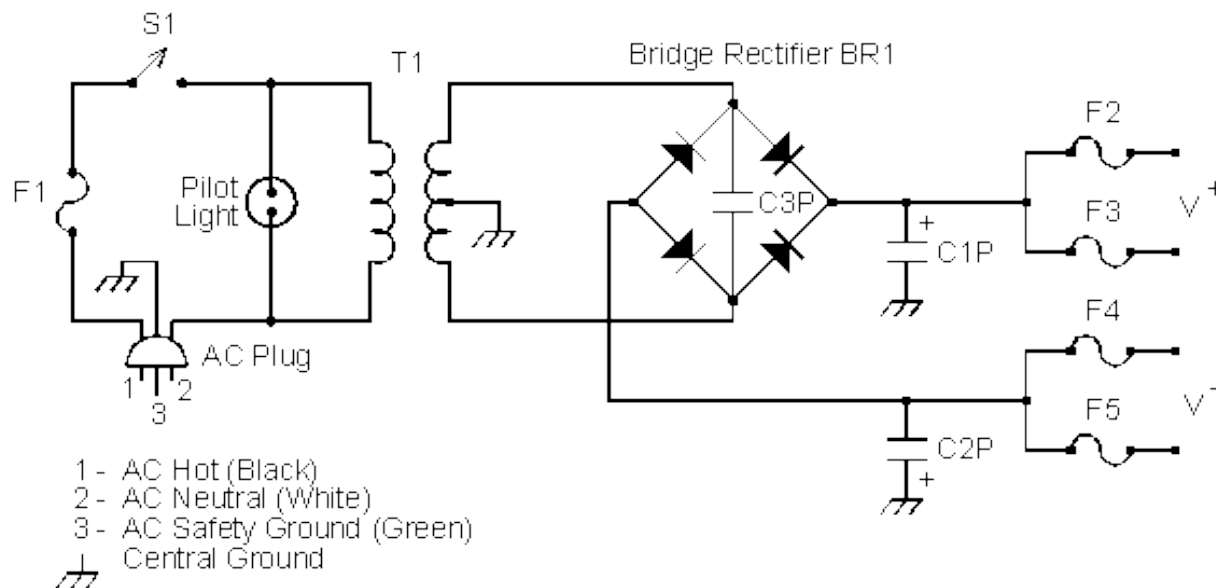
# Sinusoidal Input Voltage



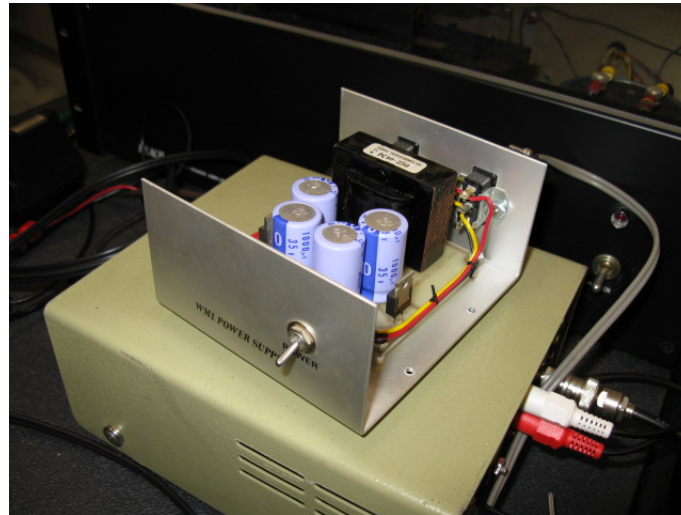
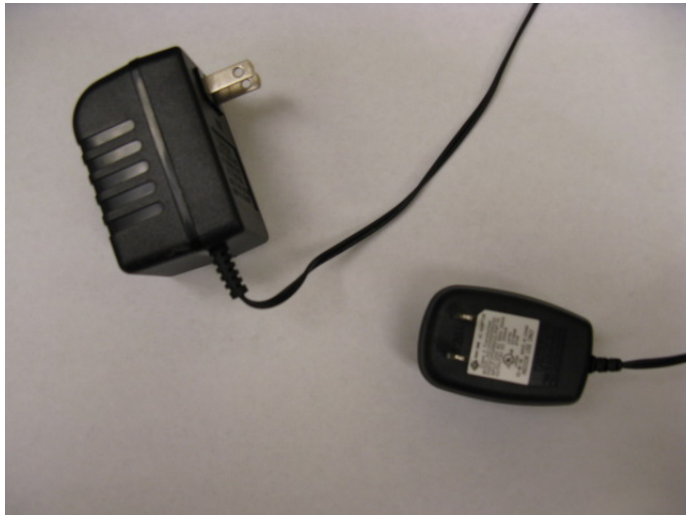
# DC Power Supply Components



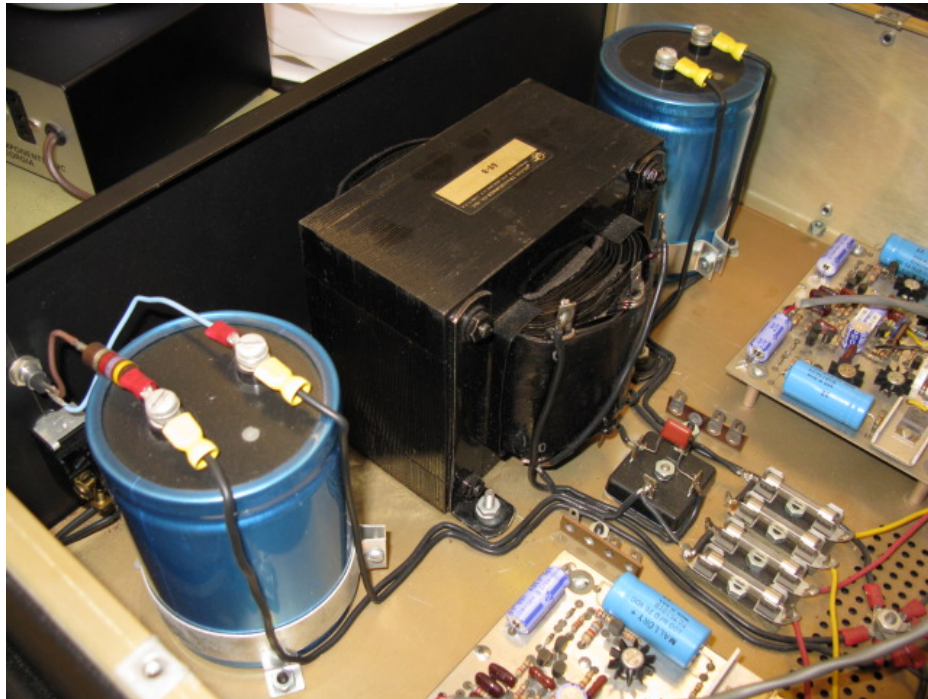
# Bipolar DC Power Supply Schematic



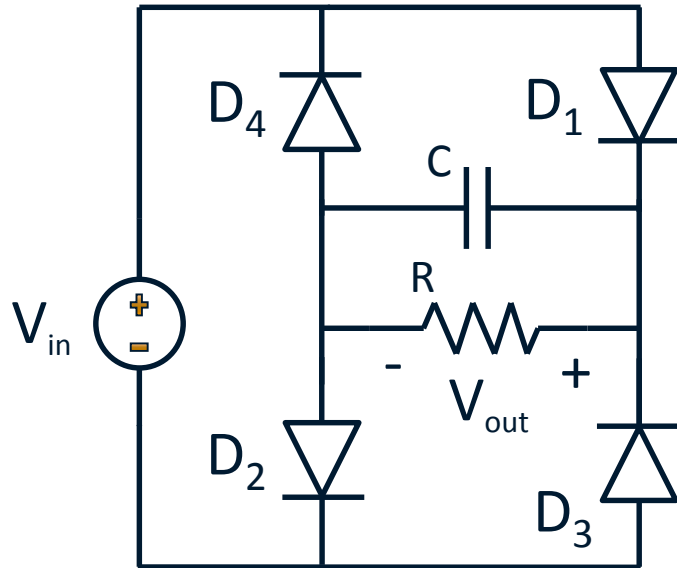
# Example DC Power Supplies



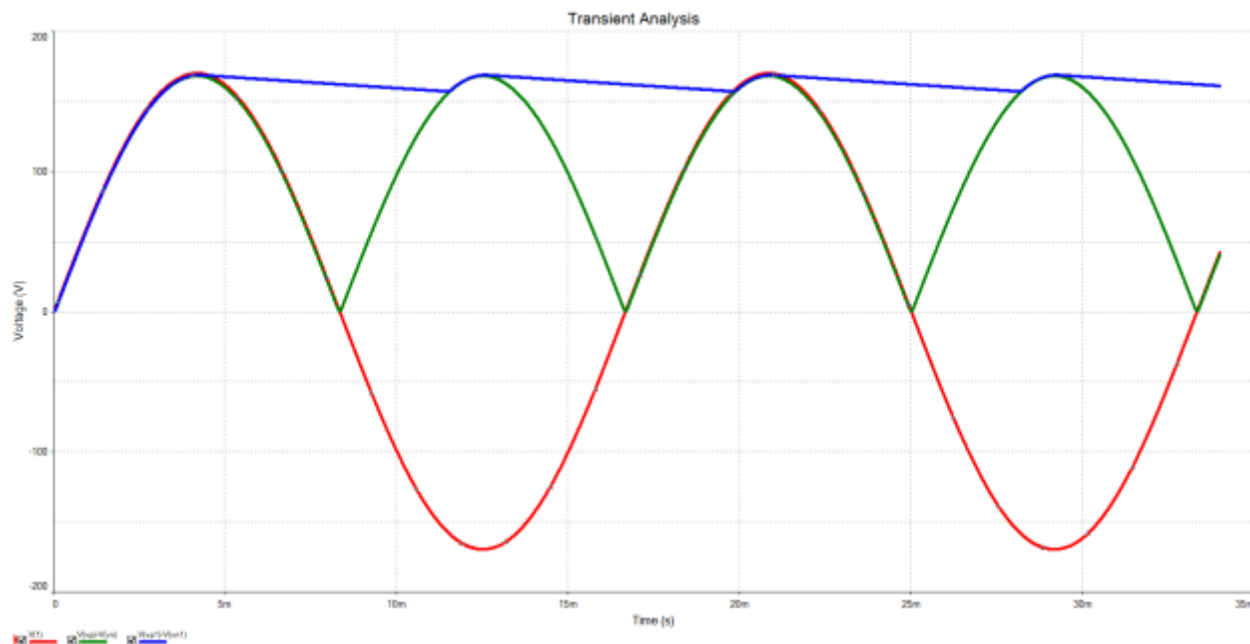
# Example DC Power Supplies



# Rectifier with Filter Capacitor



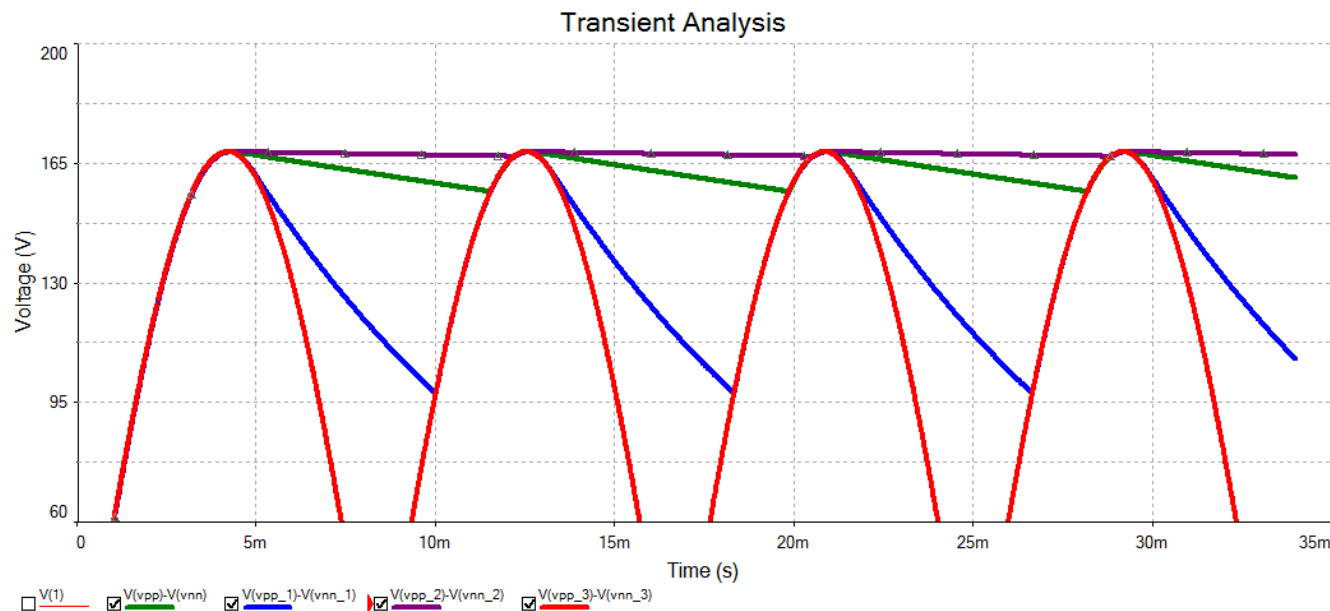
# Circuit Voltages





# Varying Capacitor Values

$$\tau = RC$$




- Larger time constant = slower discharge
- Smaller time constant = faster discharge

# Output Voltage Level

For a sine wave:  $V_{\text{peak}} = V_{\text{rms}} * \sqrt{2}$

$$V_{\text{DC}} = V_{\text{peak}} - 2V_f$$

Two diode voltage drops  
are lost in the full-wave rectifier



$$V_{\text{DC}} = V_{\text{rms}} * \sqrt{2} - 2V_f$$

$$V_{\text{DC}} = 120 * \sqrt{2} - 2(0.65) = 168.4 \text{ V}$$

# Summary

- AC to DC conversion is performed using a transformer, a rectifier, and a filter capacitor
- Larger filter capacitors result in a smoother output voltage

# Limiters



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*Introduce diode limiters*



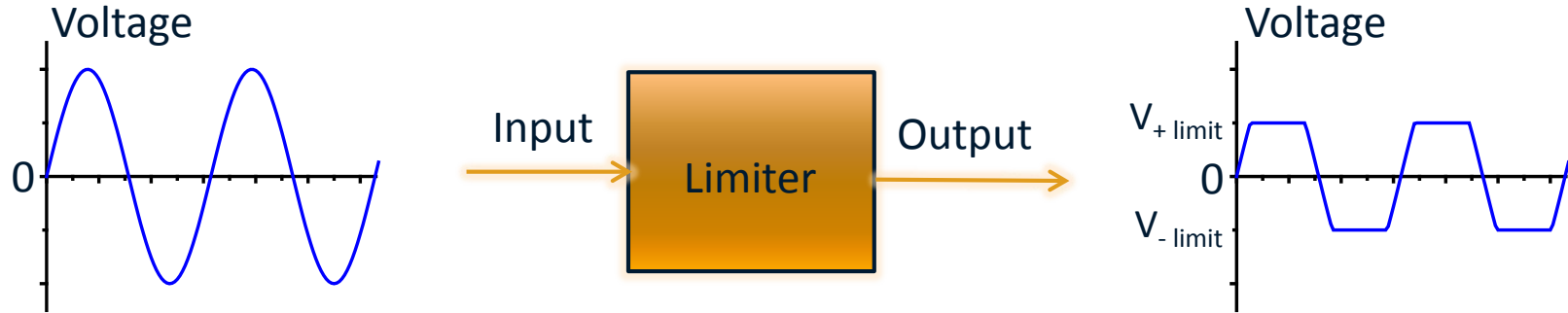
# Lesson Objectives

- Introduce limiters
- Examine their behavior for sinusoidal inputs
- Analyze limiter circuits

# Limiter (or Clipper)

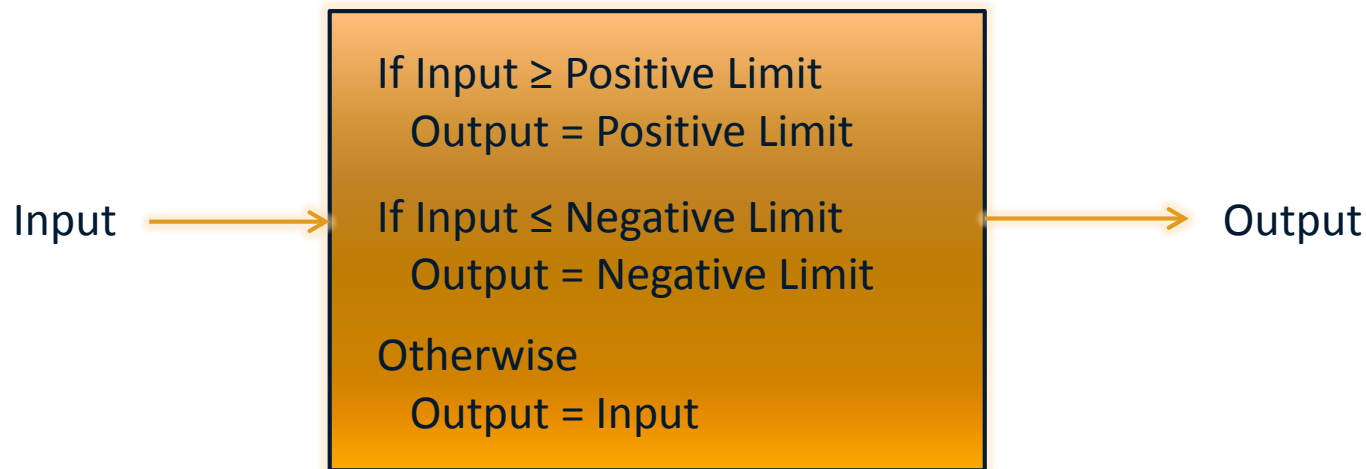
- A non-linear device that limits the output voltage to a particular level

# Sinusoidal Input Voltages



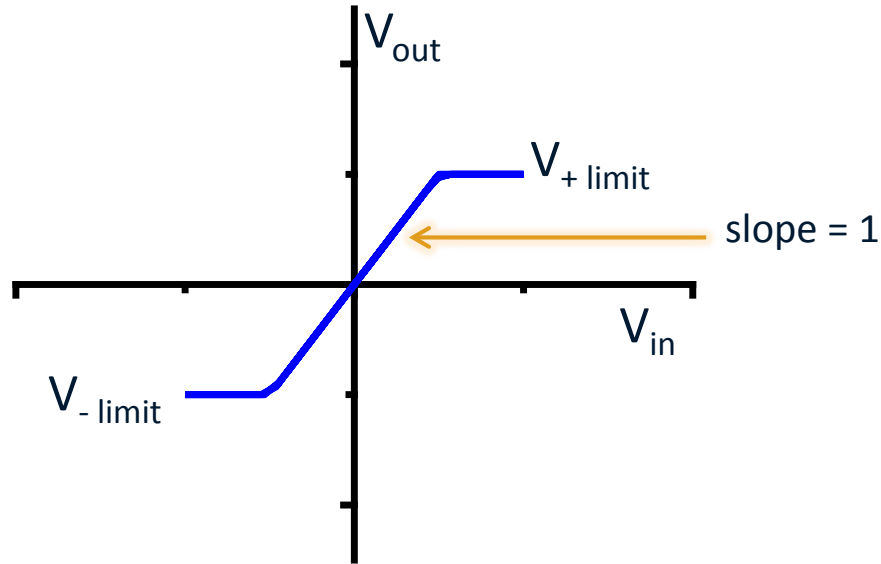
# Limiter

## Limiter

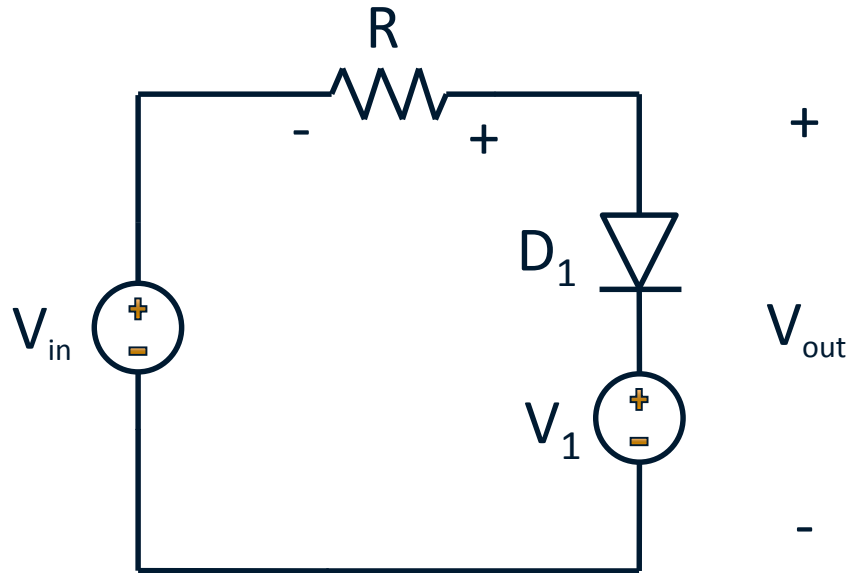




# Voltage Transfer Characteristic

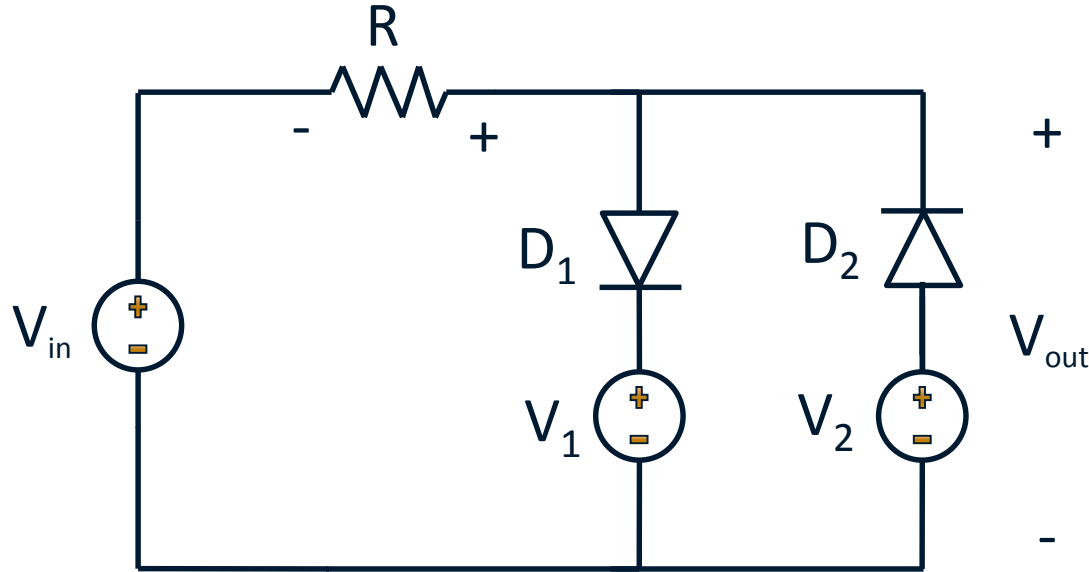


# Positive Limiter Circuit



Ideal Diode

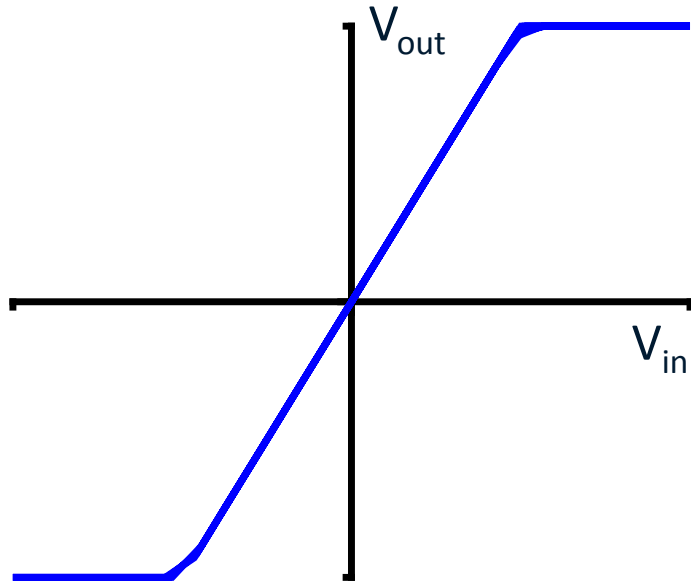
# Positive and Negative Limiter Circuit



Ideal Diodes

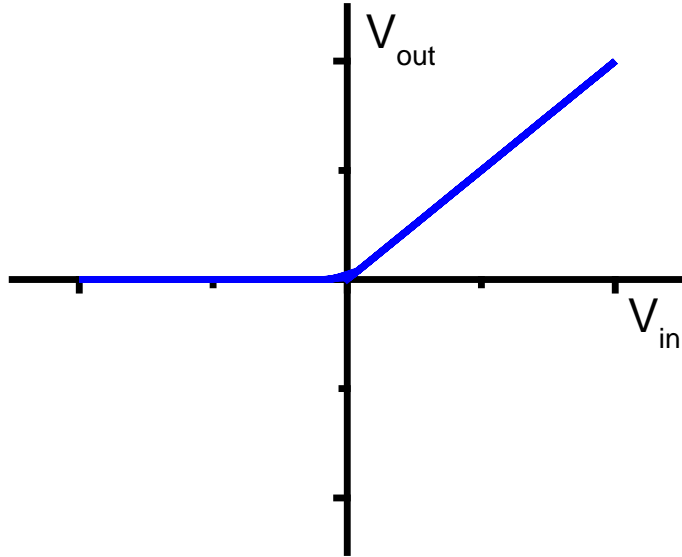
$$V_1 > V_2$$

# Voltage Transfer Characteristic



# Half-Wave Rectifier

- A special case of a limiter



# Summary

- Limiter operation
- Limiter circuits



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# Voltage Regulators

*Introduce diode voltage regulators*



# Lesson Objectives

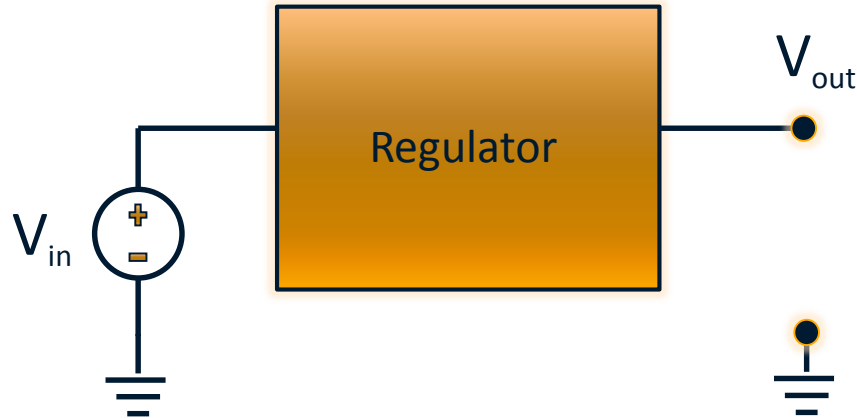
- Introduce voltage regulation
- Examine diode regulator circuits



# Ideal DC Voltage Regulator

- A device that maintains a constant dc output voltage regardless of variations in input voltage or load

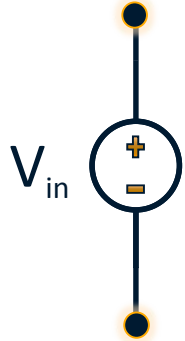
# DC Regulator



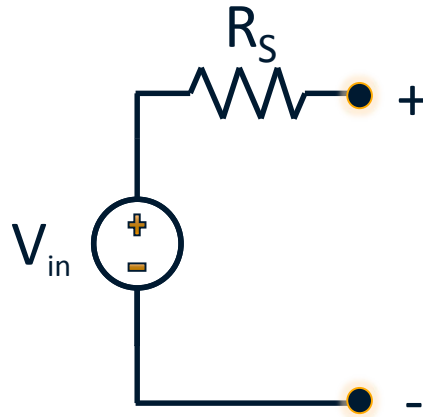
$$\text{Line Regulation} = \Delta V_{out} / \Delta V_{in}$$

$$\text{Load Regulation} = \Delta V_{out} / \Delta I_L$$

# Ideal and Real Voltage Sources

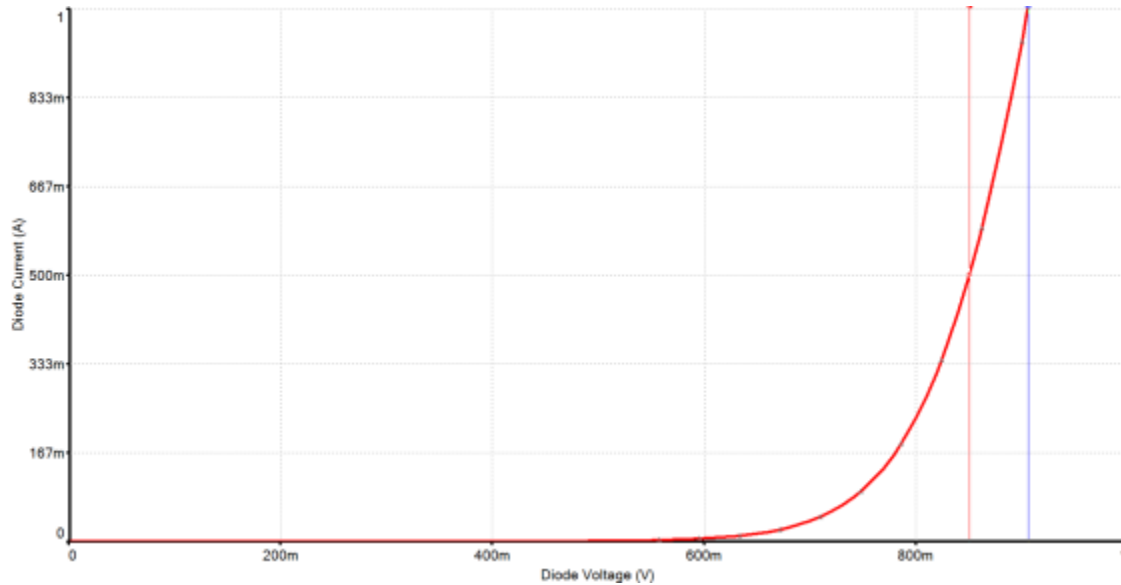


Ideal Voltage  
Source

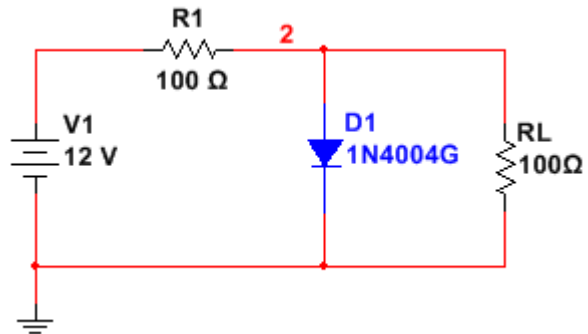


Real Voltage  
Source

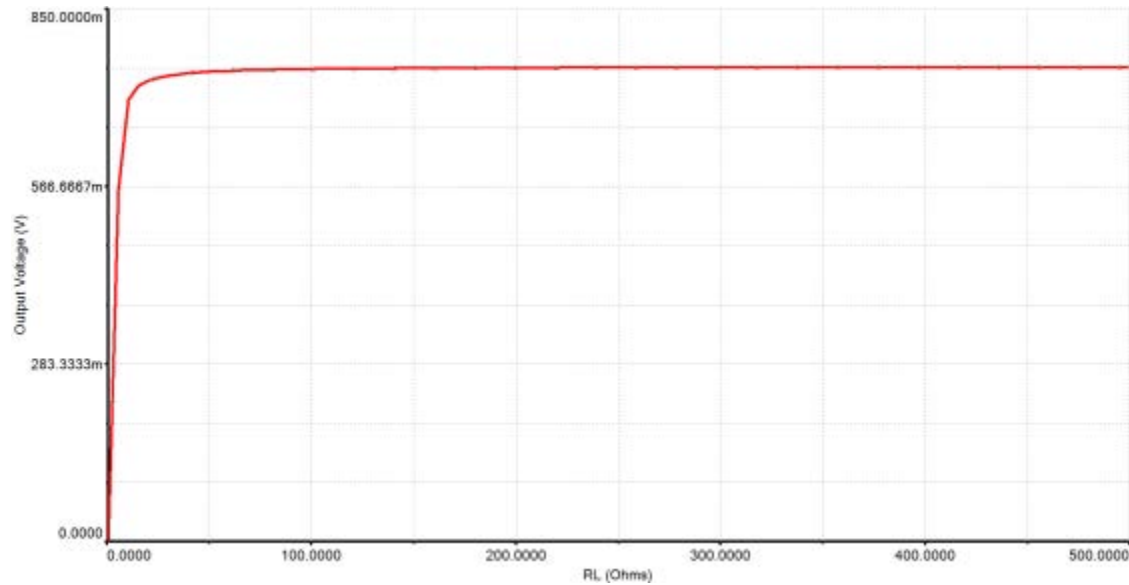
# Diode I-V Curve



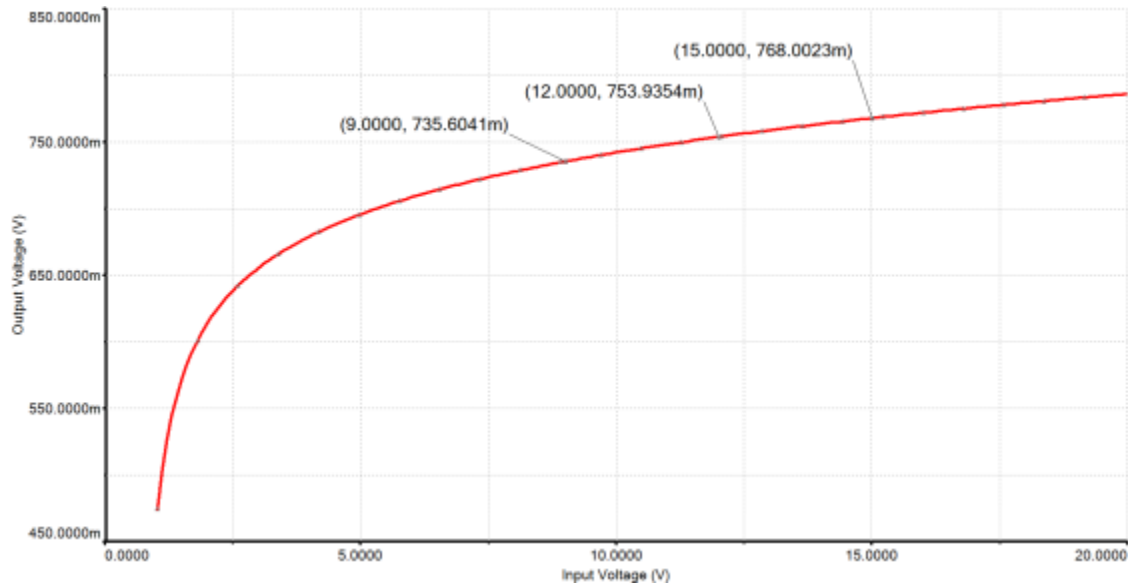
# Diode Regulator



# Output Voltage vs. Load Resistance

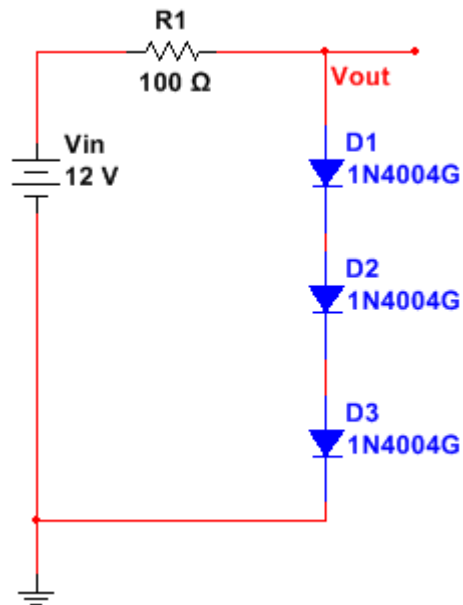


# Output Voltage vs. Input Voltage



# Higher Output Voltage

- How can the output voltage be increased?





# Component of DC Power Supply

# Summary

- Introduced voltage regulation
- Examined diode regulator circuit



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# Envelope Detector Demonstration

*Demonstrate demodulation of an amplitude modulated waveform*



# Lesson Objectives

- Introduce amplitude modulation and demodulation
- Introduce envelope detector circuit

# Amplitude Modulation (AM)

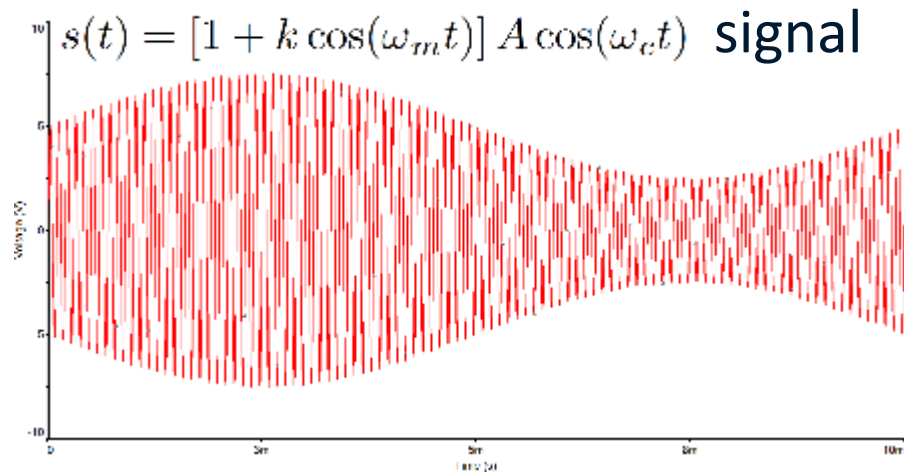
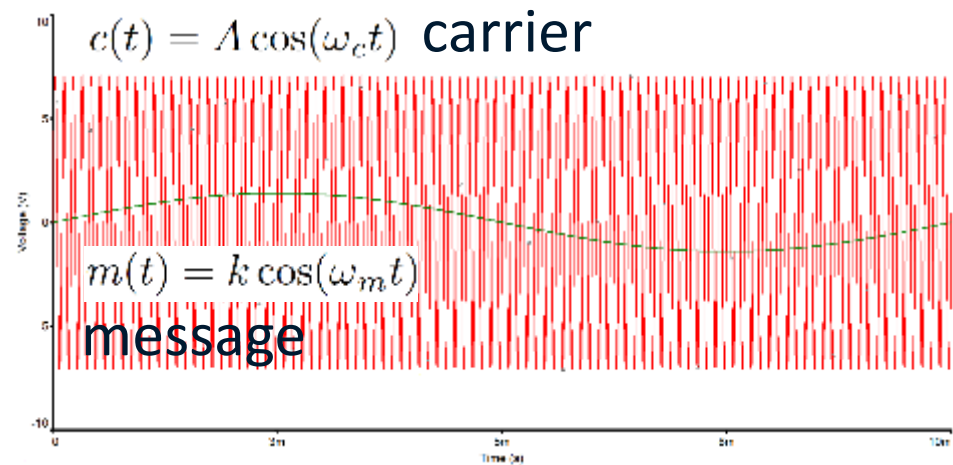
- Modification of the amplitude of a waveform by variation of a second waveform

$$c(t) = A \cos(\omega_c t) \quad \text{carrier}$$

$$m(t) = k \cos(\omega_m t) \quad \text{message}$$

$$s(t) = [1 + k \cos(\omega_m t)] A \cos(\omega_c t) \quad \text{signal}$$

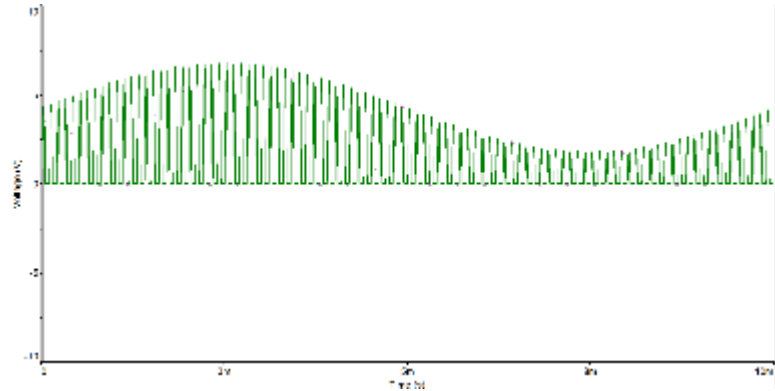
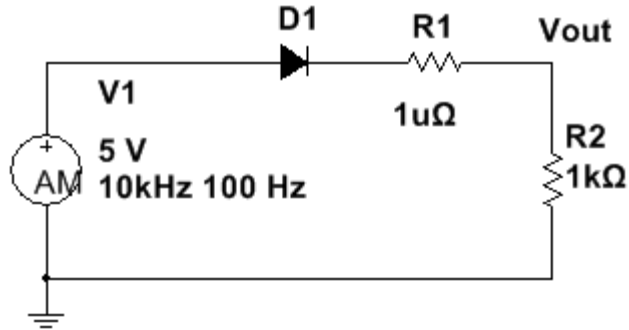
# Waveforms



# AM Uses

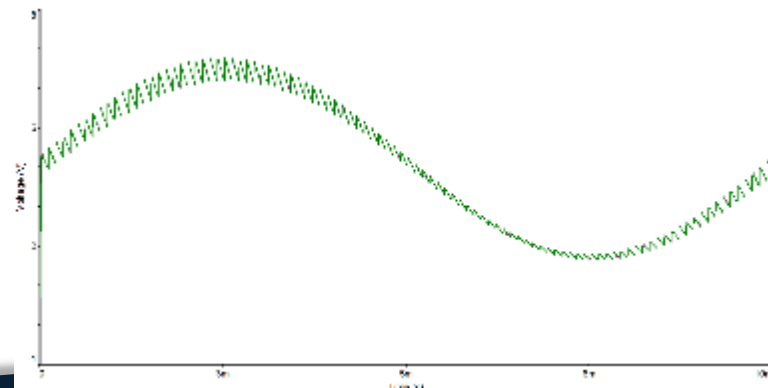
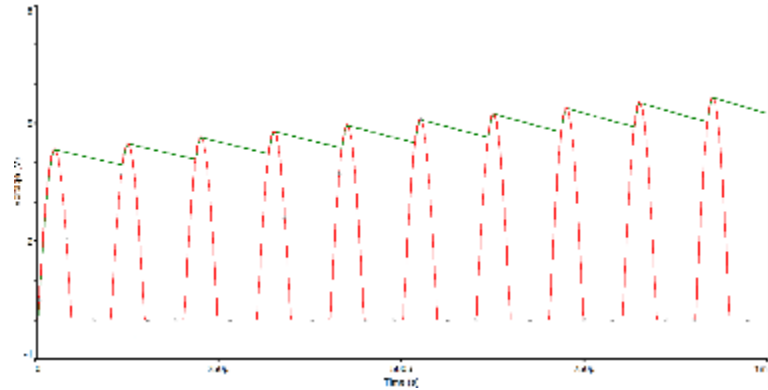
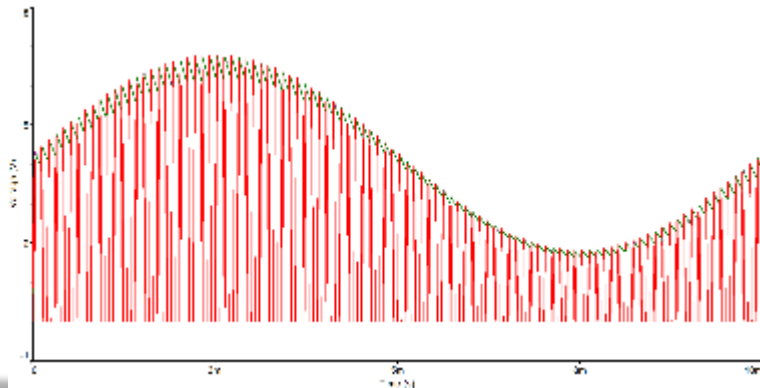
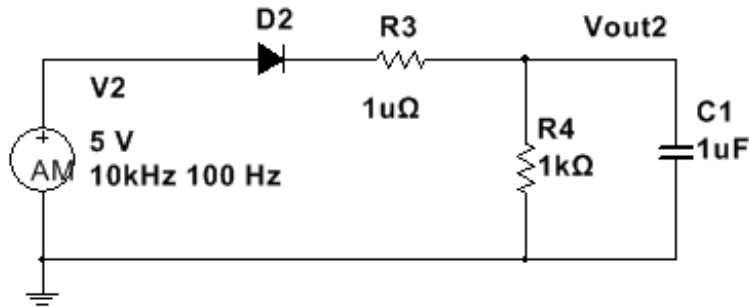
- ⦿ Transmitting information (AM Radio)
- ⦿ Creating sound effects

# Envelope Detector (AM Demodulator)

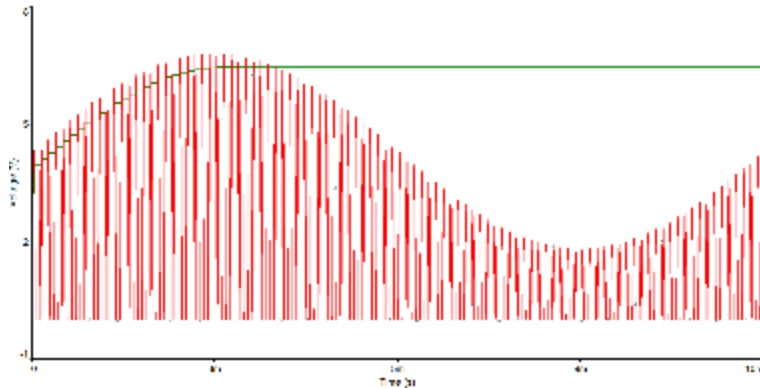




# Envelope Detector (AM Demodulator)



# AC to DC Conversion



# Summary

- Introduced amplitude modulation and demodulation
- Examined diode envelope detector circuit