ECE 121 - Electronics (1)
Lecture 3

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CHAPTER OUTLINE

2–1 Diode Operation
2–2 Voltage-Current (*V*-*I*) Characteristics of a Diode
2–3 Diode Models
2–4 Half-Wave Rectifiers
2–5 Full-Wave Rectifiers
2–6 Power Supply Filters and Regulators
2–7 Diode Limiters and Clampers
2–8 Voltage Multipliers
2–9 The Diode Datasheet
2–10 Troubleshooting

CHAPTER OBJECTIVES

- Use a diode in common applications
- Analyze the voltage-current (*V*-*I*) characteristic of a diode
- Explain how the three diode models differ
- Explain and analyze the operation of half-wave rectifiers
- Explain and analyze the operation of full-wave rectifiers
- Explain and analyze power supply filters and regulators
- Explain and analyze the operation of diode limiters and clampers
- Explain and analyze the operation of diode voltage multipliers
- Interpret and use diode datasheets
- Troubleshoot diodes and power supply circuits

OR GATE

Determine V_o for the network of Fig. 2.39.

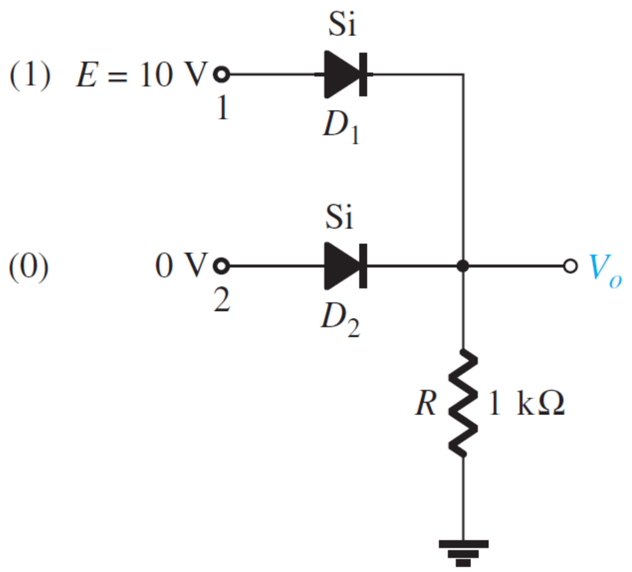


FIG. 2.39
Positive logic OR gate.

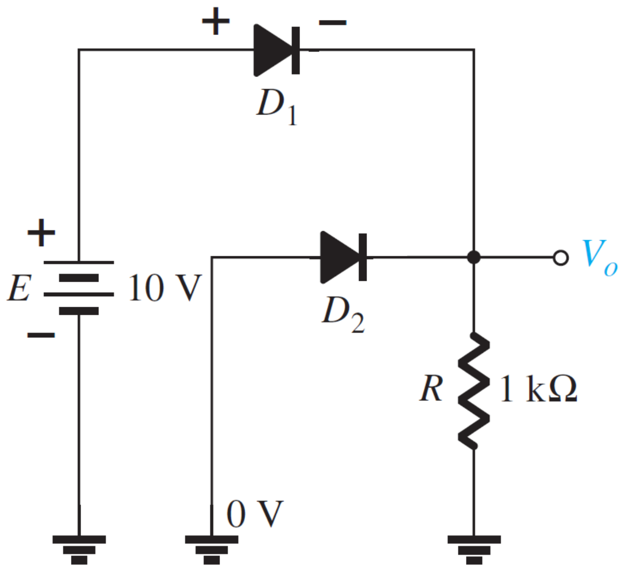


FIG. 2.40
Redrawn network of Fig. 2.39.

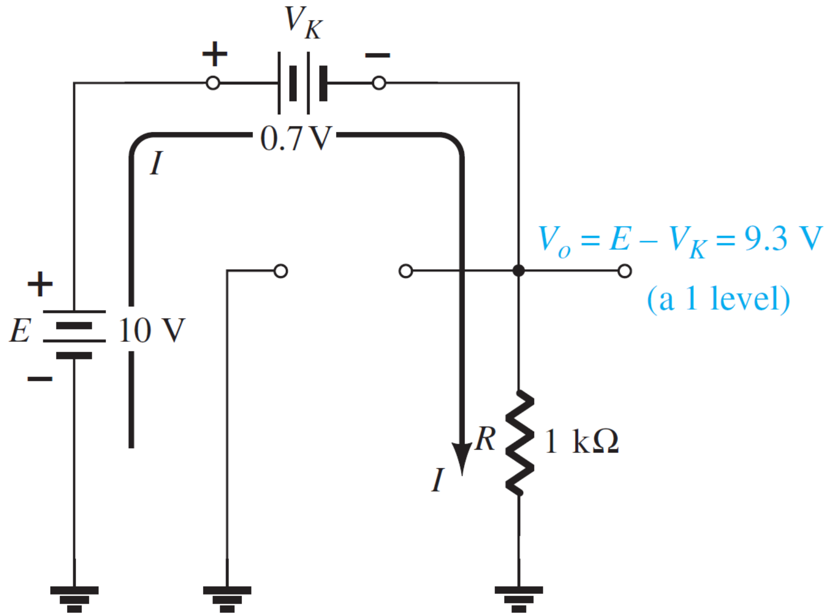


FIG. 2.41
Assumed diode states for Fig. 2.40.

10-V level is assigned a “1”
0-V level is assigned a “0.”

$$I = \frac{E - V_K}{R} = \frac{10\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \mathbf{9.3\text{ mA}}$$

AND GATE

Determine the output level for the positive logic AND gate of Fig. 2.42 .

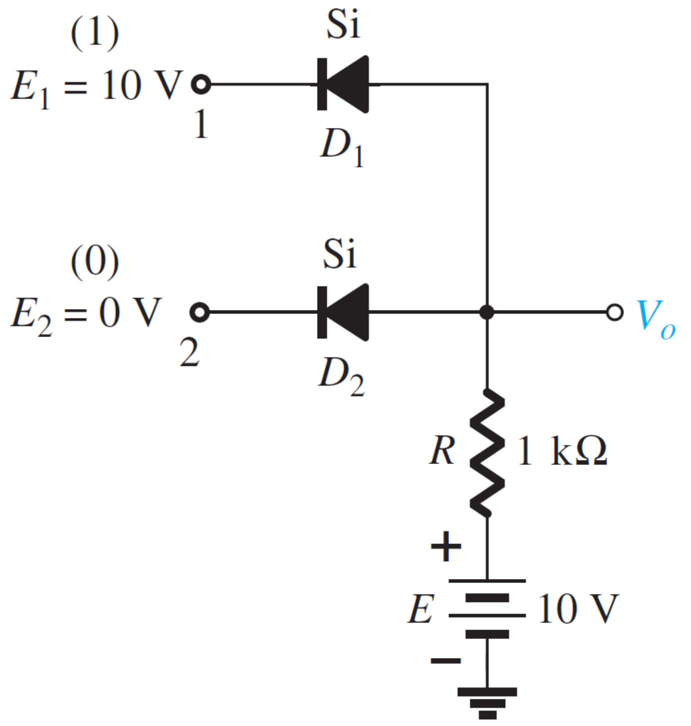


FIG. 2.42

Positive logic AND gate.

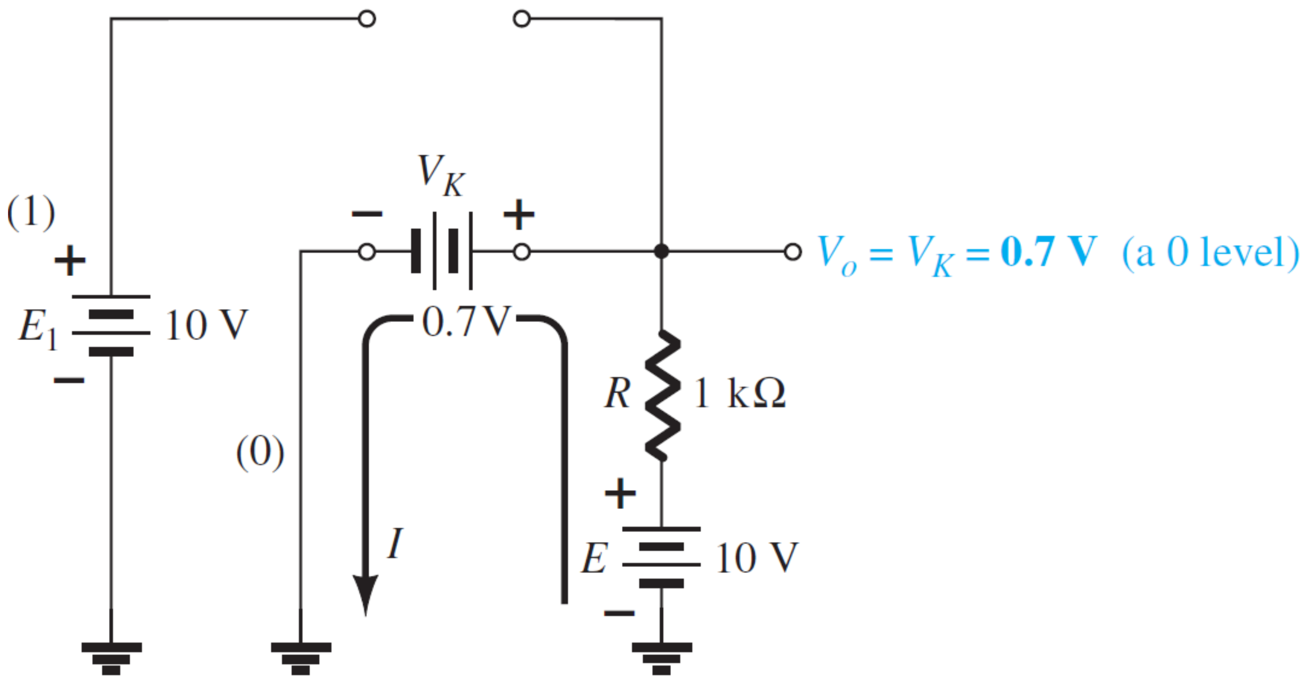


FIG. 2.43

Substituting the assumed states for the diodes of Fig. 2.42.

10-V level is assigned a "1"
0-V level is assigned a "0."

$$I = \frac{E - V_K}{R} = \frac{10\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \mathbf{9.3\ mA}$$

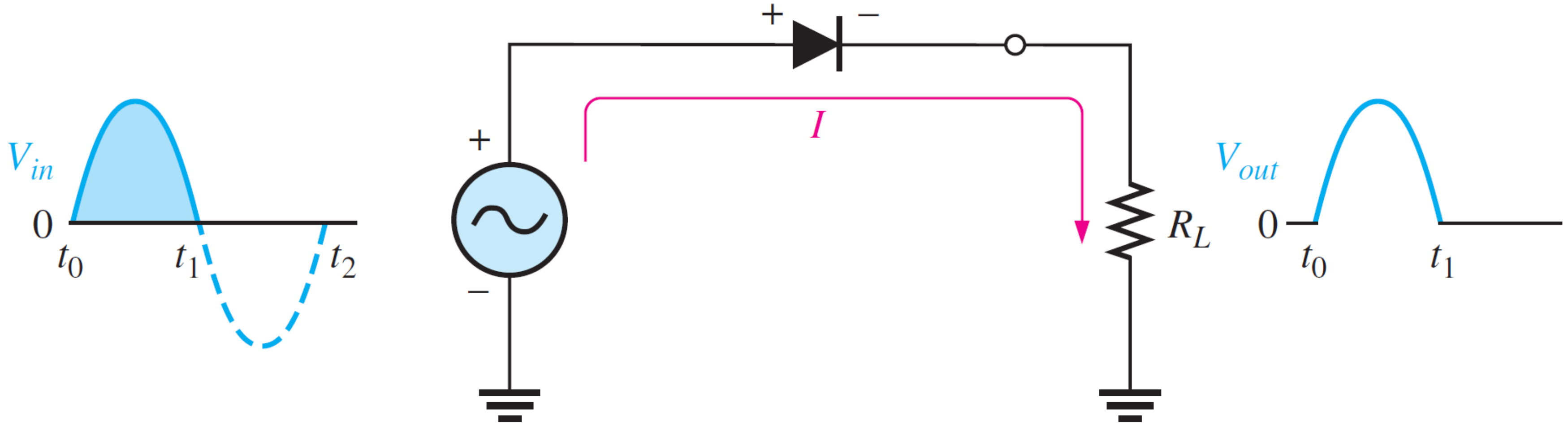
Half-Wave Rectifier Operation

- The process of removing one-half the input signal to establish a dc level is called ***half-wave rectification.***

Using the ideal model for the diode:

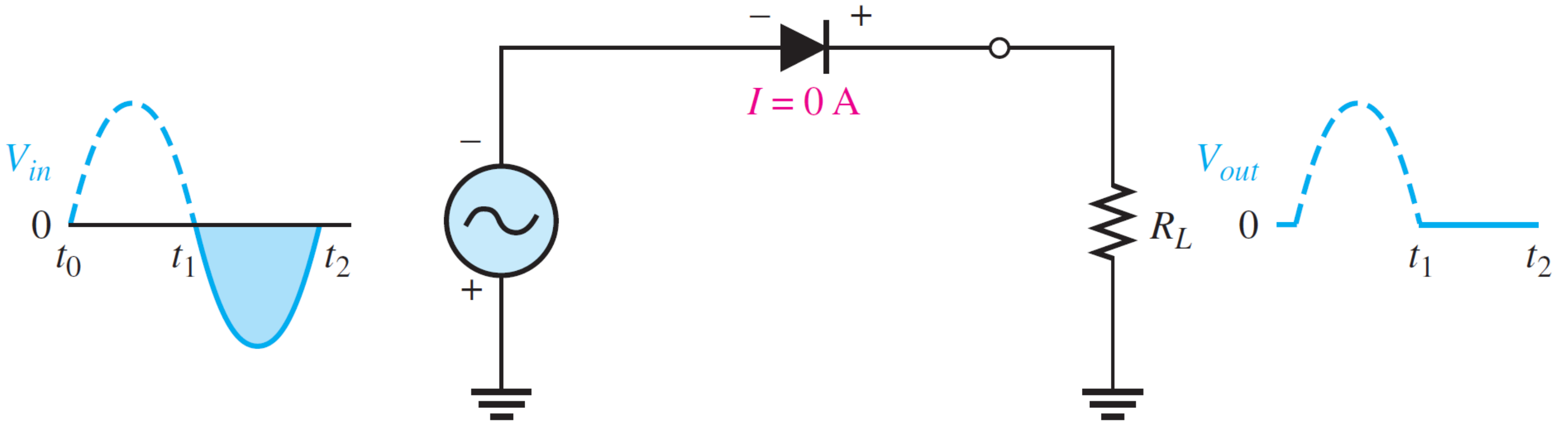
During the positive half cycle:

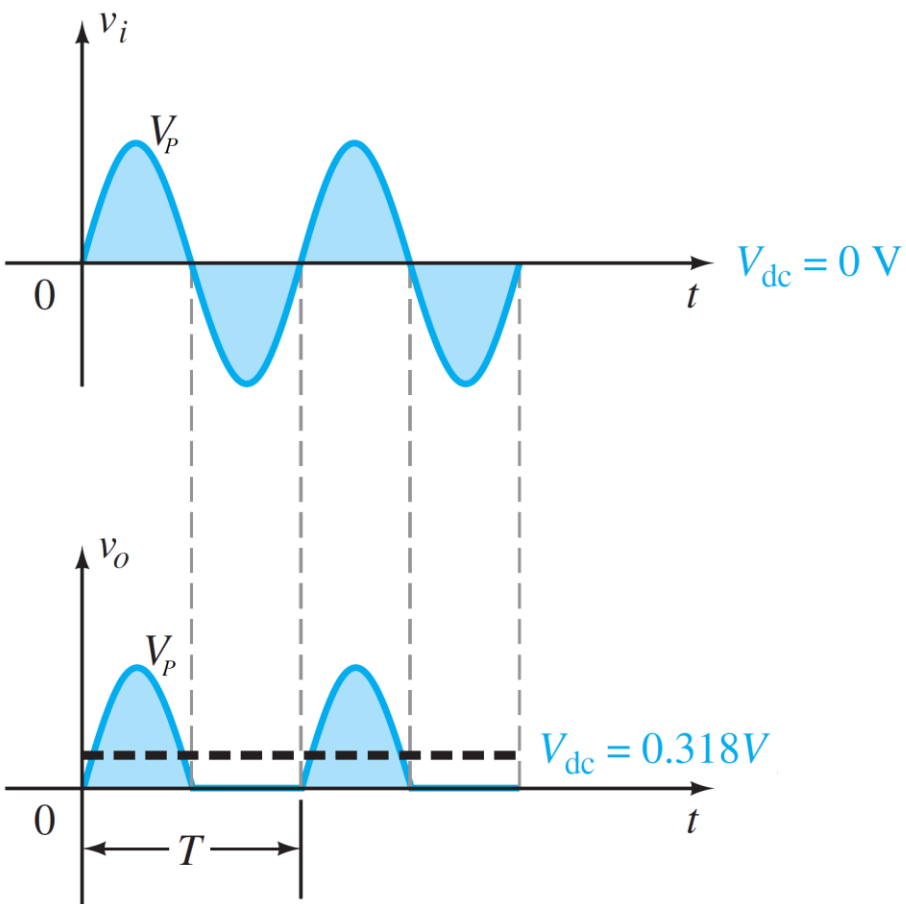
- v_{in} is positive → the diode is forward-biased (ON - closed switch).
- The output voltage has the same shape as the positive half-cycle of the input voltage. $(\boldsymbol{V_{out} = V_{in}})$



During the negative half cycle:

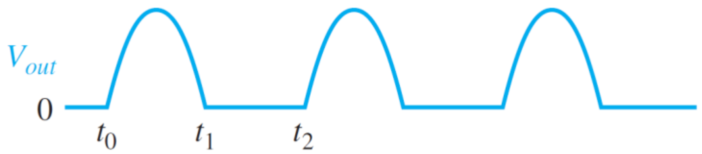
- v_{in} is negative → the diode is reverse-biased.
- the output voltage is $0\ V$ $(\boldsymbol{V_{out} = 0V})$





- Since the output does not change polarity it is a pulsating dc voltage with a frequency equal the input frequency

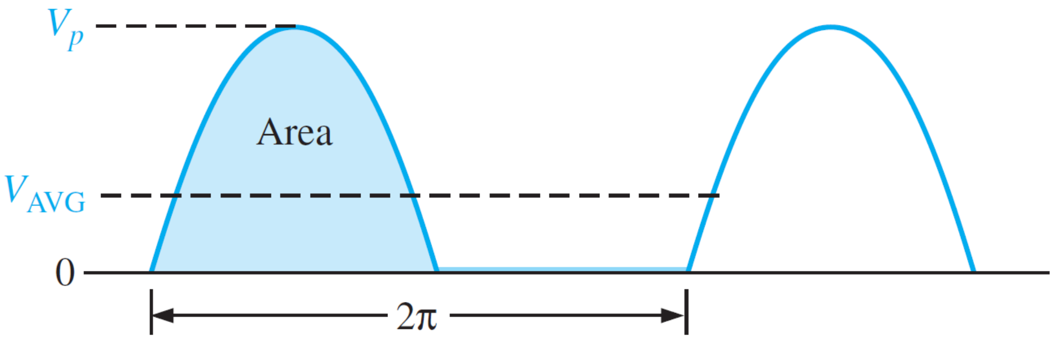
HWR: $(\boldsymbol{f_{out} = f_{in}})$

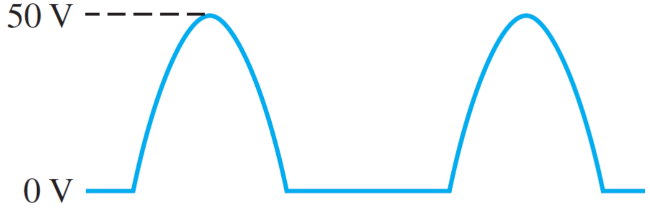


Average Value of the Half-Wave Output Voltage

- The average value of the half-wave rectified output voltage is the value you would measure on a dc voltmeter.
- Mathematically, it is determined by finding the area under the curve over a full cycle, and then dividing by 2π (the number of radians in a full cycle).

$$\boldsymbol{V_{AVG}\ or\ V_{dc} = \frac{V_P}{\pi} = 0.318\,V_P}$$





$$V_{AVG} = \frac{V_p}{\pi} = \frac{50\text{ V}}{\pi} = \mathbf{15.9\ V}$$

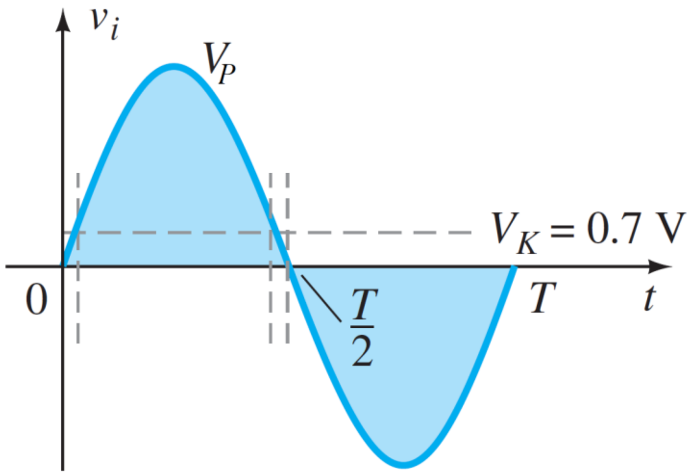
Notice that V_{AVG} is 31.8% of V_P.

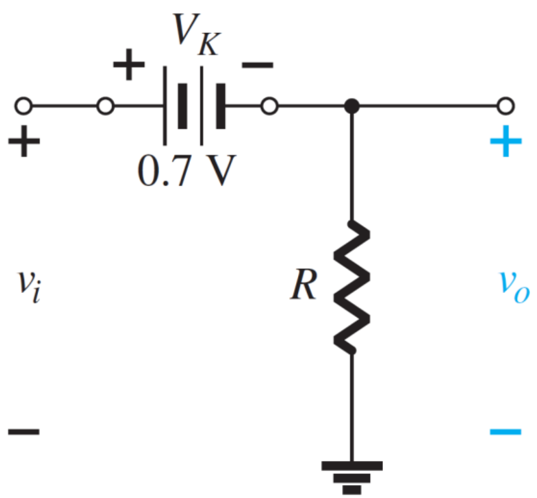
Effect of the Barrier Potential on the Half-Wave Rectifier Output
(Using the practical diode model)

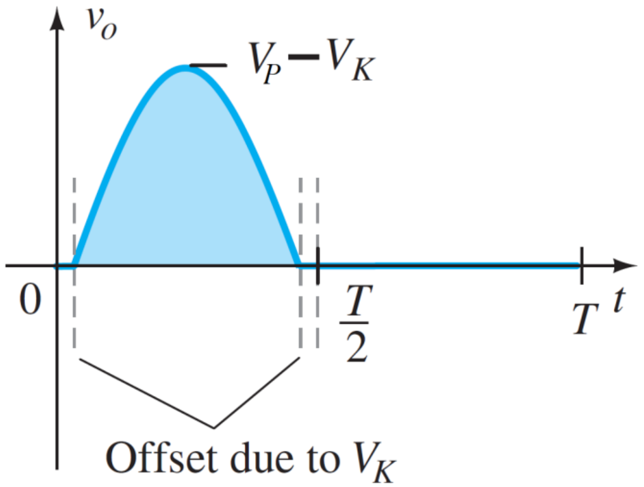
- When $V_{in} < 0.7$ the diode is OFF (O.C.) and ($V_{out} = 0V$)
- When $V_{in} > 0.7$ the diode is ON and ($V_{out} = V_{in} - 0.7$)
- The peak output $\left(V_{P(out)} = V_{P(in)} - 0.7\right)$

When $V_P \gg 0.7$ ➔ $$V_{AVG} \approx \frac{V_P - 0.7}{\pi}$$

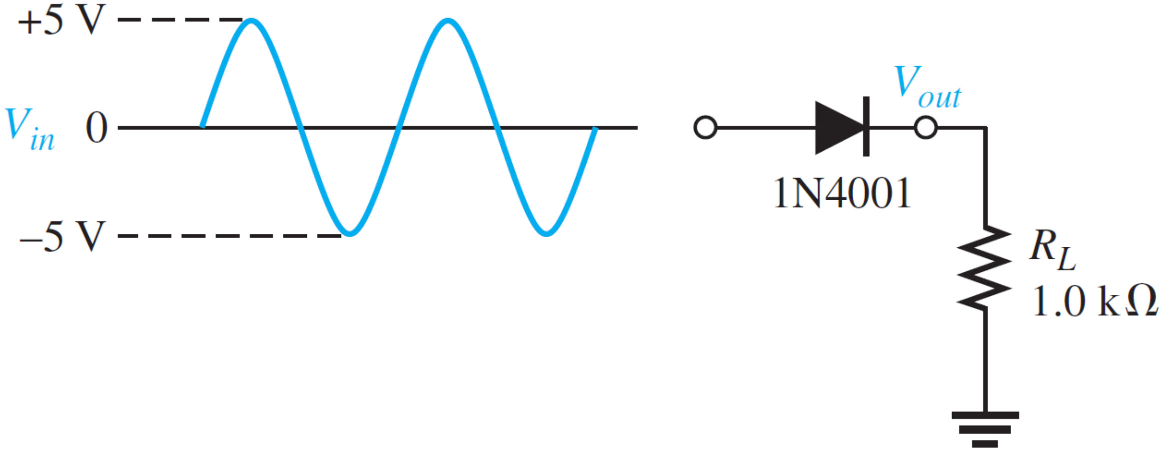
$$V_K = 0.7\ V$$



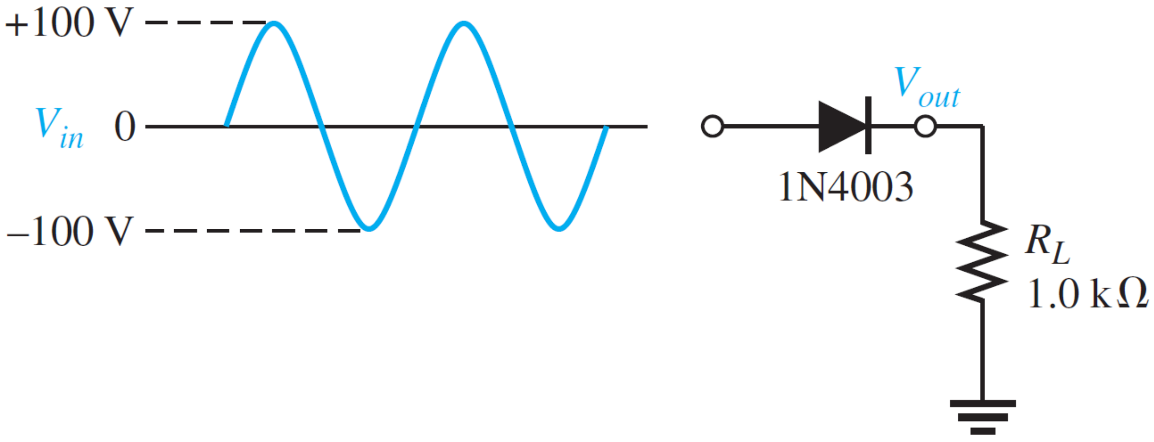




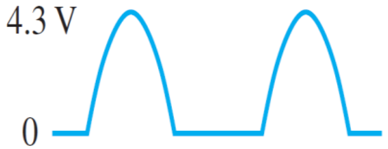
EXAMPLE1 Draw the output voltages of each rectifier for the indicated input voltages. The 1N4001 and 1N4003 are specific rectifier diodes.



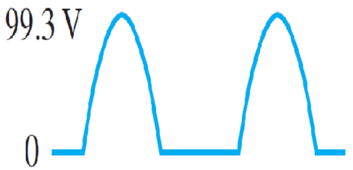
(a)



(b)



(a)



(b)

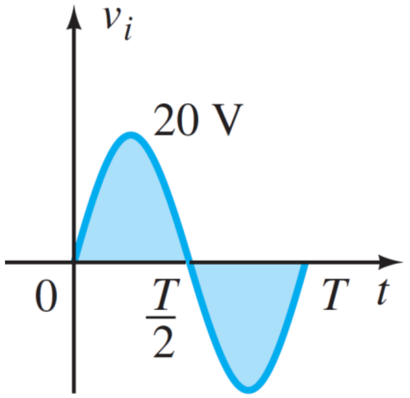
The peak output voltage for circuit (a) is

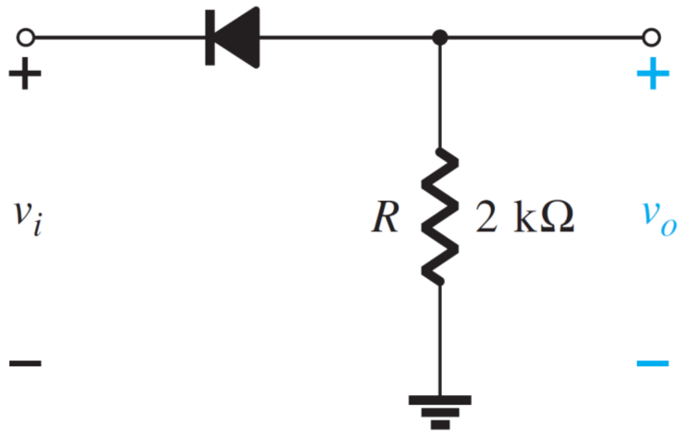
$$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 5\text{ V} - 0.7\text{ V} = \mathbf{4.30\text{ V}}$$

The peak output voltage for circuit (b) is

$$V_{p(out)} = V_{p(in)} - 0.7\text{ V} = 100\text{ V} - 0.7\text{ V} = \mathbf{99.3\text{ V}}$$

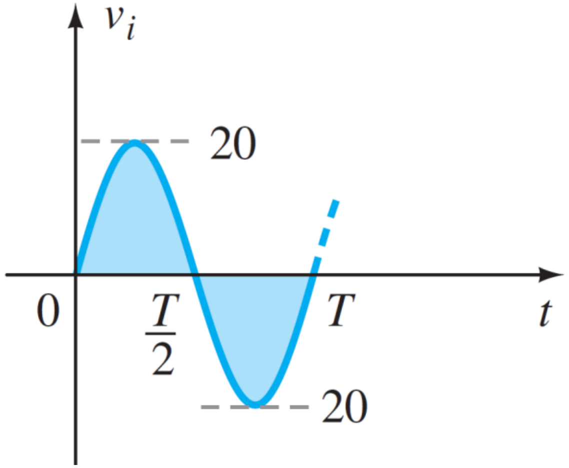
Example2 a. Sketch the output v_o and determine the dc level of the output.
b. Repeat part (a) if the ideal diode is replaced by a silicon diode.
c. Repeat parts (a) and (b) if V_m is increased to 200 V.

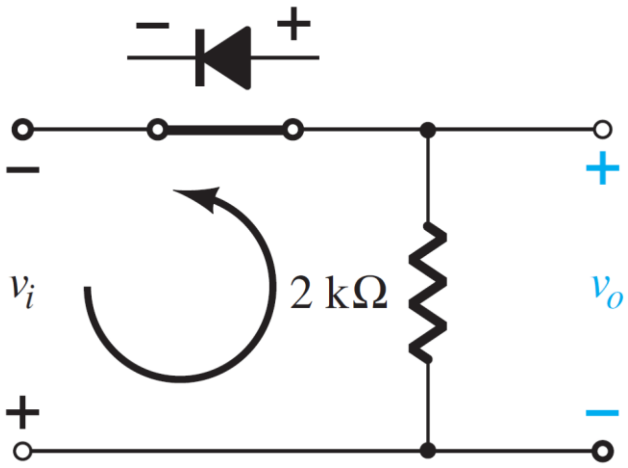


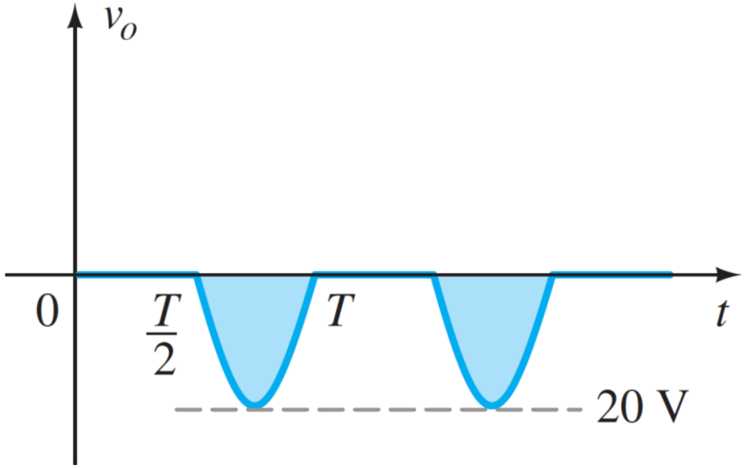


Solution (a)

- During the positive half cycle the diode is R.B.(O.C.) and $v_o = 0$
- During the negative half cycle the diode is F.B.(S.C.) and $v_o = v_{in}$
- $V_{dc} = -\frac{V_m}{\pi} = -0.318 \times 20 = -6.36V$



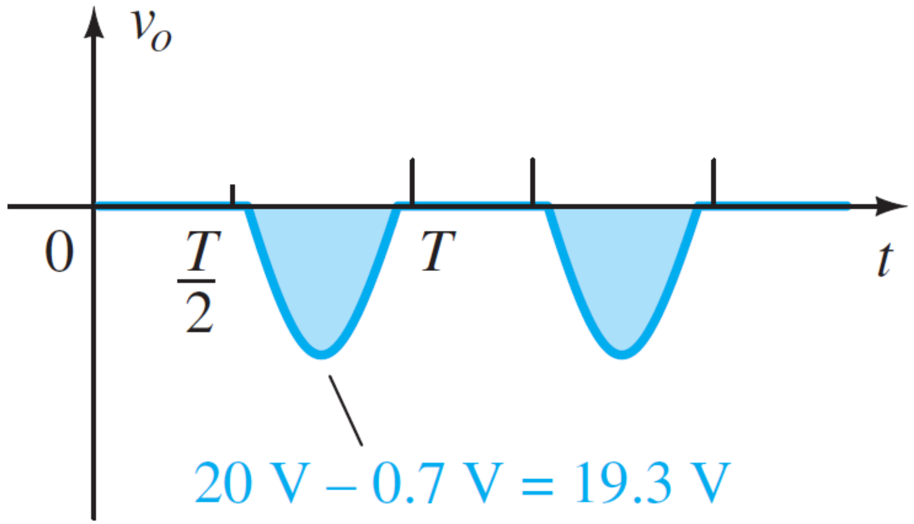




(b)For a silicon diode, the output has the appearance of Fig. below , and

$$V_{dc} \approx -0.318(V_m - 0.7\ V) = -0.318(19.3\ V) = \mathbf{-6.14\ V}$$

The resulting drop in dc level is 0.22 V, or about 3.5%.



(c) For $V_m = 200V$

<u>Ideal</u>: $V_{dc} = -\frac{V_m}{\pi} = -0.318 \times 200 = \mathbf{-63.6}\ V$

<u>Practical</u>: $V_{dc} \approx -0.318(V_m - 0.7\ V) = -0.318(199.3\ V) = \mathbf{-63.38\ V}$

which is a difference that can certainly be ignored for most applications

Peak Inverse Voltage (PIV)

- **The peak inverse voltage (PIV)** equals the peak value of the input voltage, and the diode must be capable of withstanding this amount of repetitive reverse voltage.

$$PIV = V_{P(in)}$$

- **The peak inverse voltage (PIV) rating** of the diode is the voltage rating that must not be exceeded in the reverse-bias region or the diode will enter the breakdown region.

$$PIV\ rating \geq V_{P(in)}$$

- A diode should be rated at least 20% higher than the PIV for better performance.

Half-wave rectifier with *transformer coupled* input voltage.

$$n(Turns\ ratio) = \frac{N_{sec}}{N_{pri}}$$

$$V_{sec} = nV_{pri}$$

If $n < 1$ ***step down*** transformer and $V_{sec} < V_{pri}$

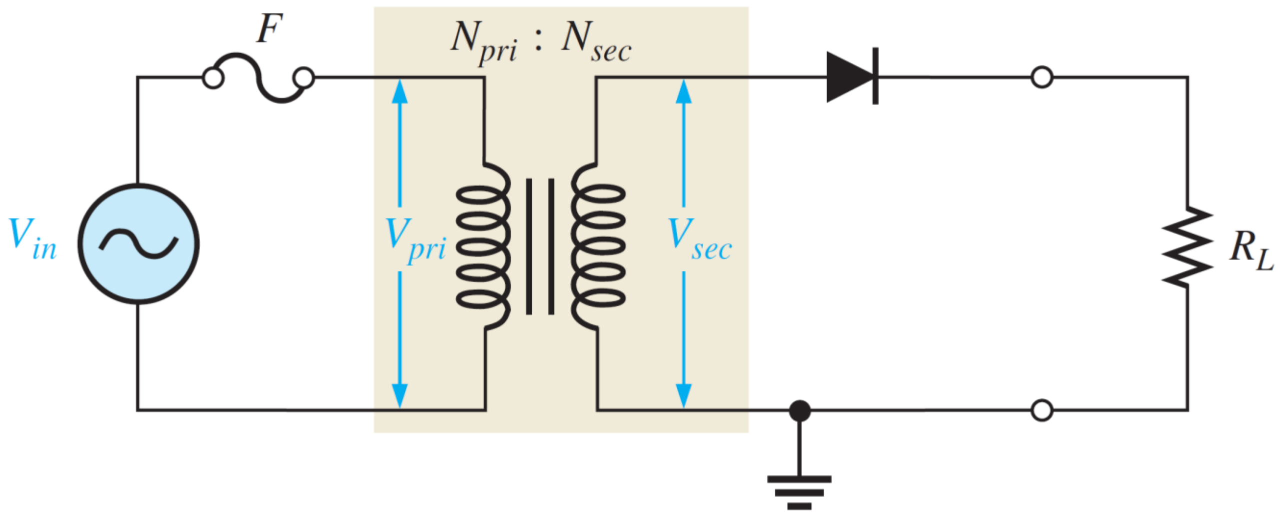
If $n > 1$ ***step up*** transformer and $V_{sec} > V_{pri}$

The peak output of the rectifier is:

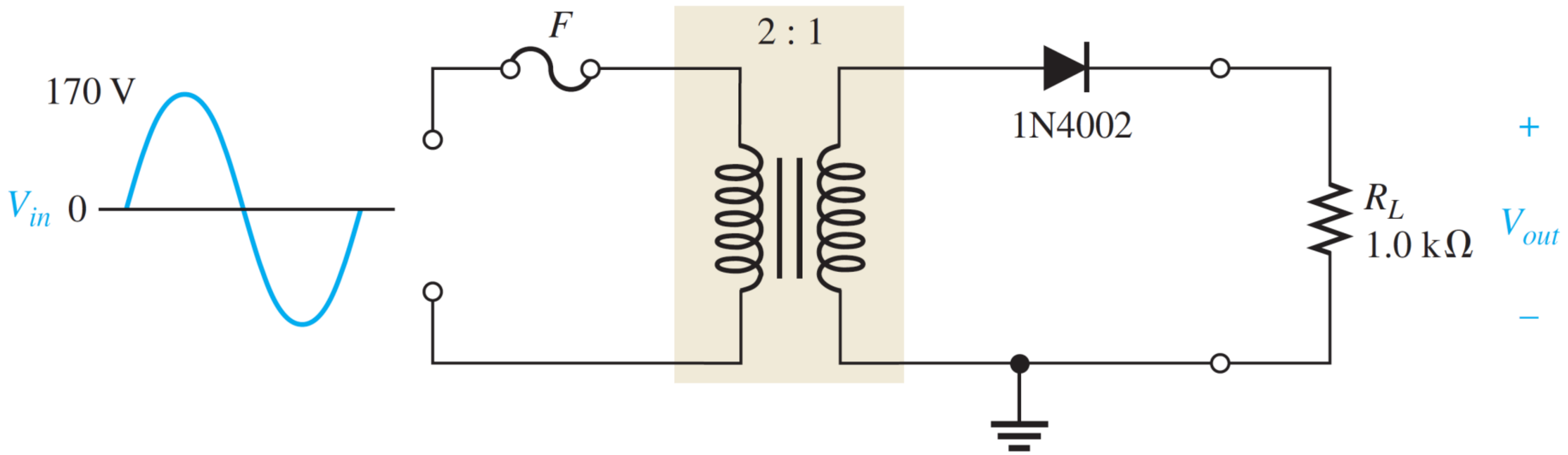
$$\boldsymbol{V_{p(out)} = V_{p(sec)} - 0.7}$$

and

$$\boldsymbol{PIV = V_{p(sec)}}$$



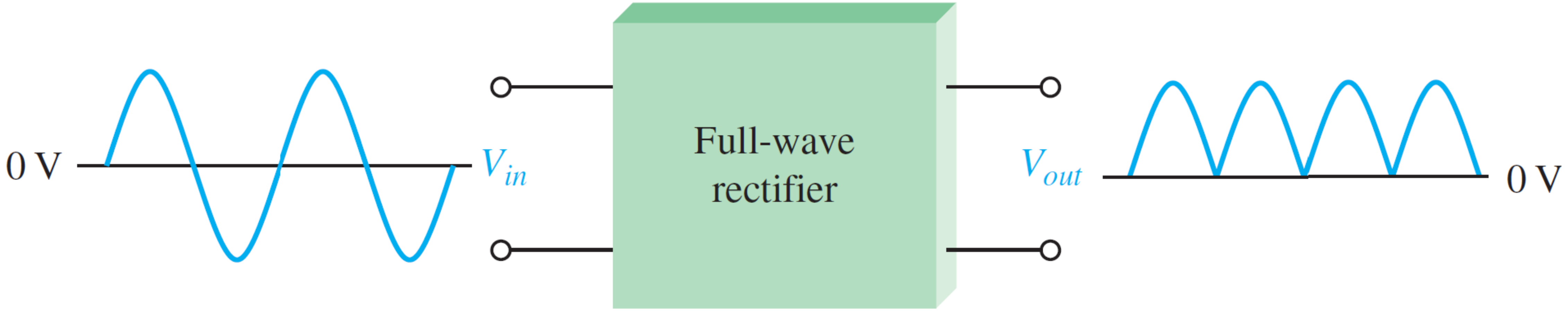
EXAMPLE 3 Determine the peak value of the output voltage.



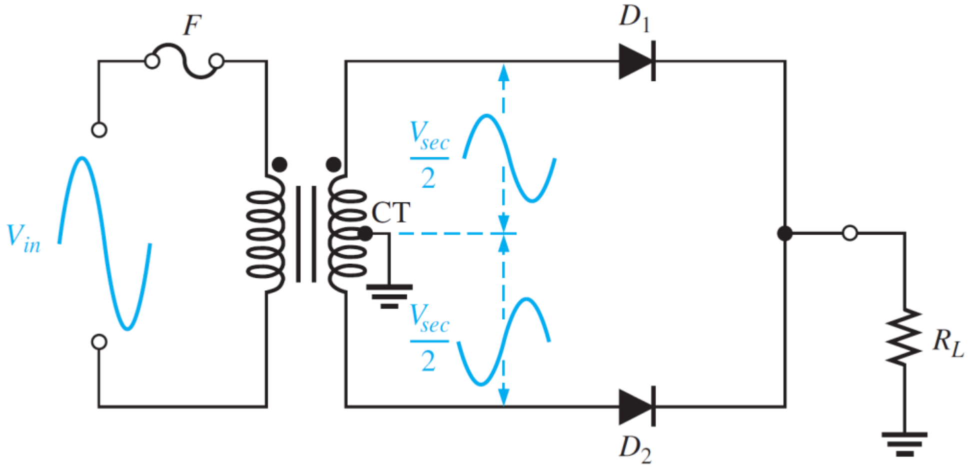
- $n = \frac{1}{2} = 0.5$
- $V_{p(sec)} = nV_{p(pri)} = 0.5 \times 170 = 85\ V$
- $\boldsymbol{V_{p(out)} = V_{p(sec)} - 0.7 = 84.3\ V}$
- $\boldsymbol{PIV = V_{p(sec)} = 85\ V}$

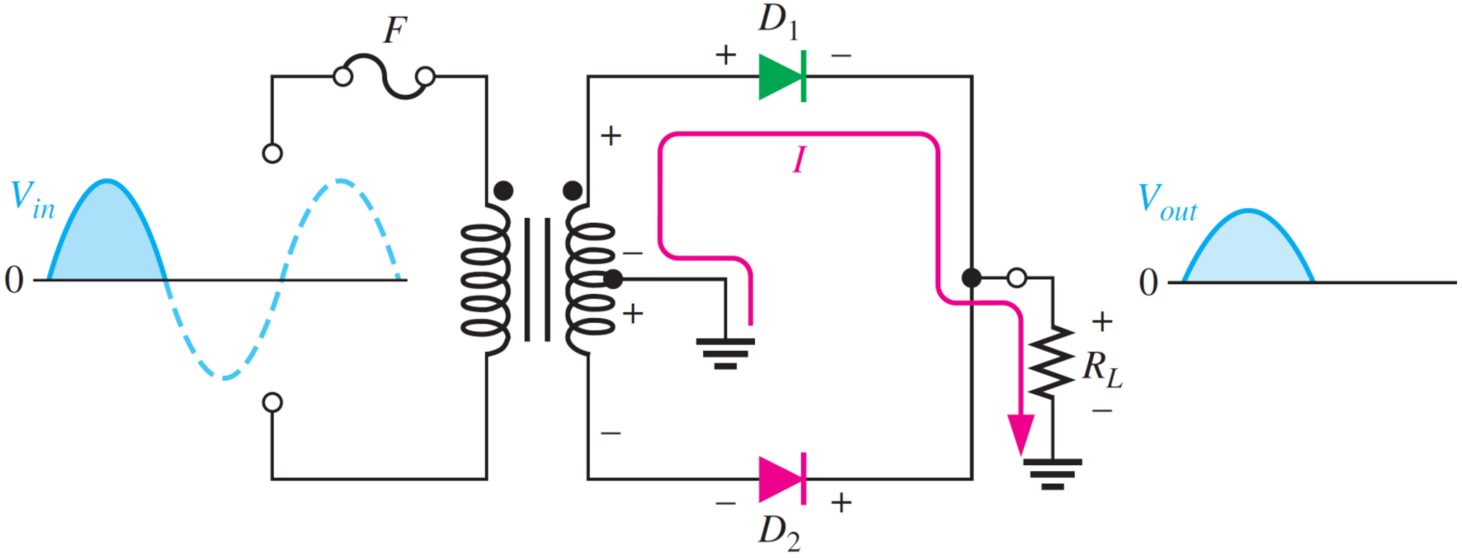
2–5 FULL-WAVE RECTIFIERS

- A **full-wave rectifier** allows unidirectional (one-way) current through the load during the entire cycle of the input, whereas a half-wave rectifier allows current through the load only during one-half of the cycle.
- **FWR :** $f_{out} = 2\, f_{input}$ [twice the input frequency]
- $V_{AVG} = \frac{2V_P}{\pi} = 0.637\, V_P$ [twice that of HWR]

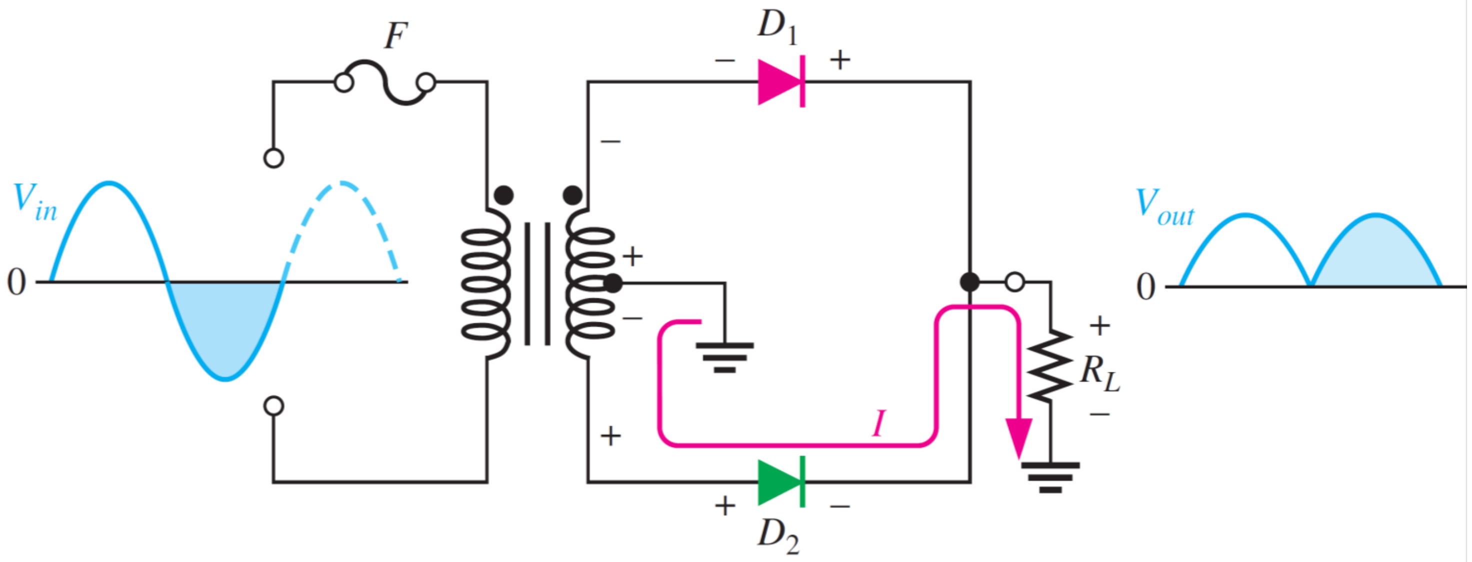


Center-Tapped Full-Wave Rectifier (CT-FWR)





(a) During positive half-cycles, D_1 is forward-biased and D_2 is reverse-biased.



(b) During negative half-cycles, D_2 is forward-biased and D_1 is reverse-biased.

- During the $+ve$ half cycle **D1 is ON** and **D2 is OFF**
- During the $-ve$ half cycle **D1 is OFF** and **D2 is ON**
- The current passes through R in the same direction in both half cycles

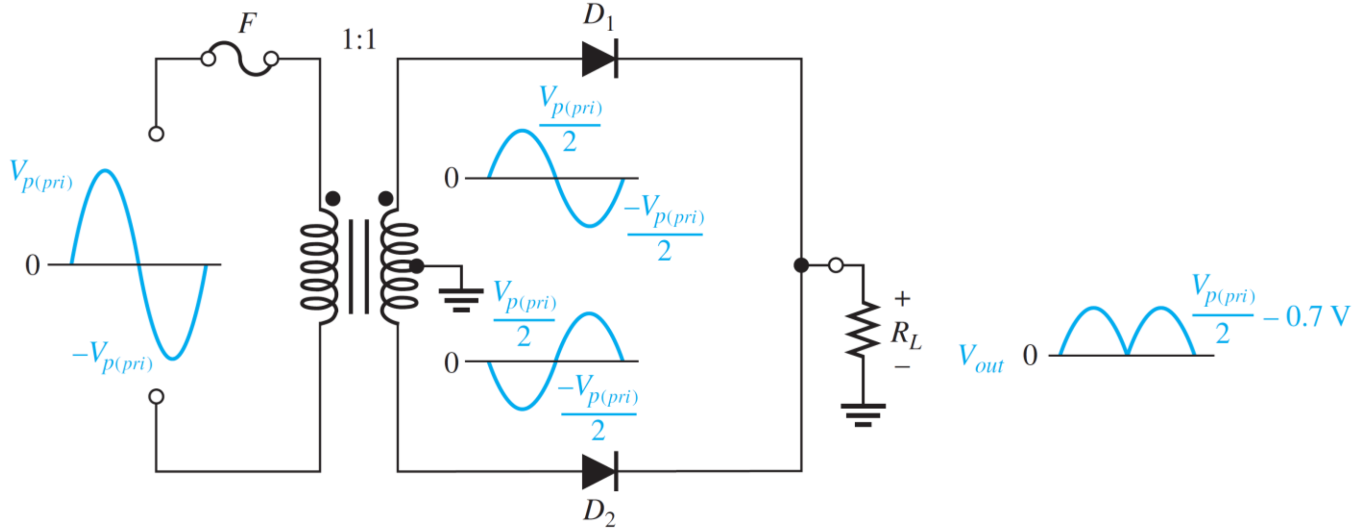
$$V_{out} = \frac{V_{sec}}{2} - 0.7$$

Effect of the Turns Ratio on the Output Voltage

- $n = 1$
- The total secondary voltage is:

$$V_{p(sec)} = V_{p(pri)}$$

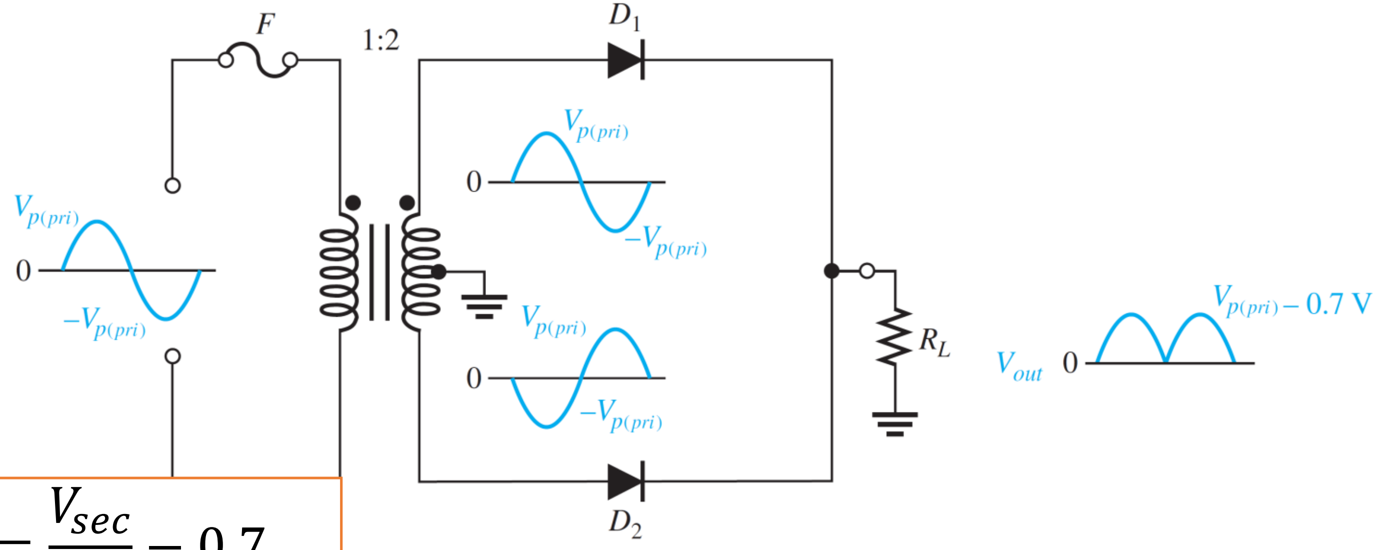
- $$\boldsymbol{V_{p(out)} = \frac{V_{p(sec)}}{2} - 0.7 = \frac{V_{p(pri)}}{2} - 0.7 = \frac{V_{p(input)}}{2} - 0.7}$$



- $n = 2$
- The total secondary voltage is:

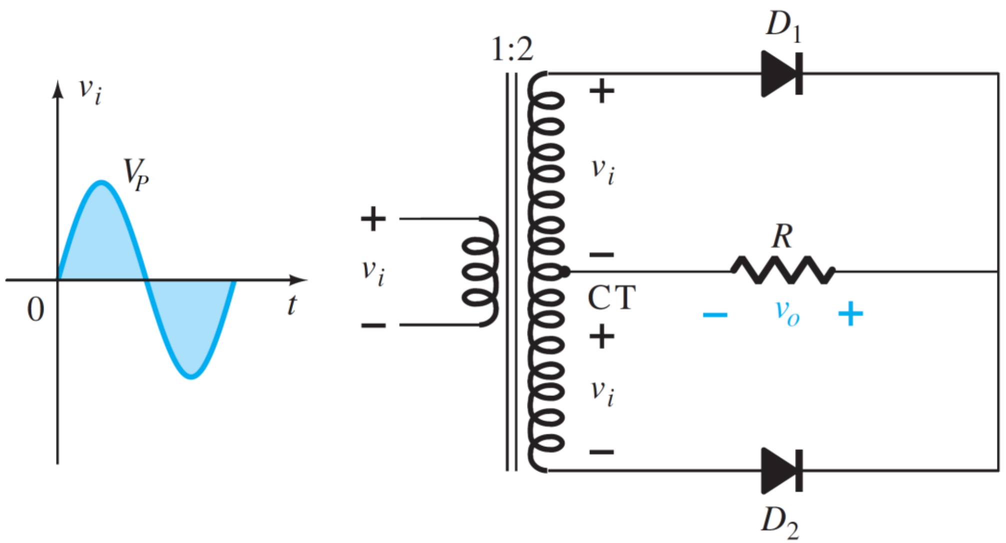
$$V_{p(sec)} = 2\,V_{p(pri)}$$

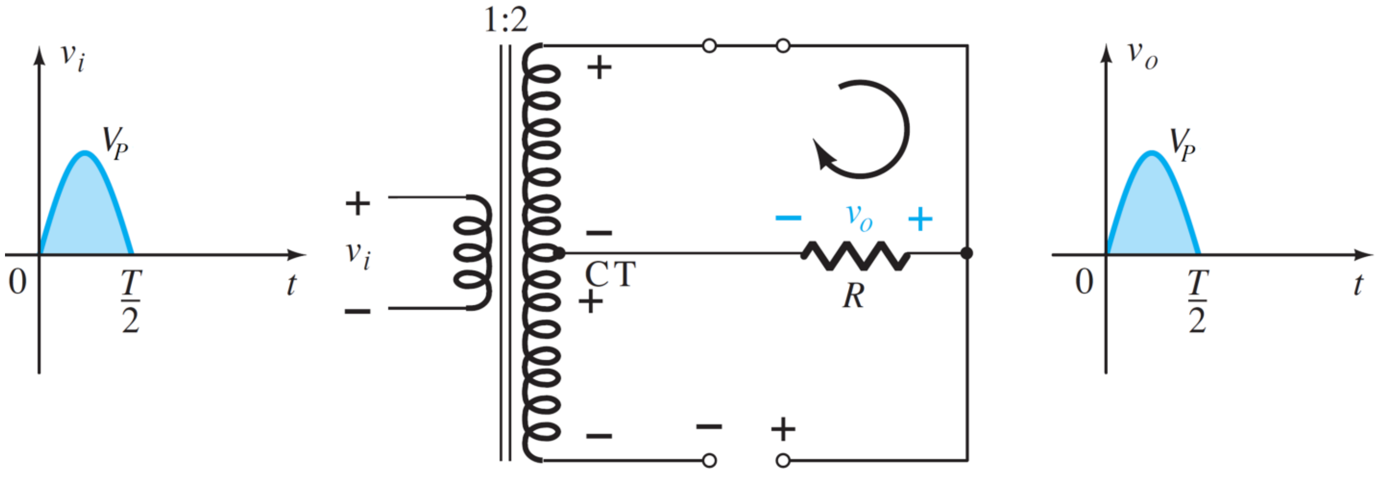
- $$\boldsymbol{V_{p(out)} = \frac{V_{p(sec)}}{2} - 0.7 = V_{p(pri)} - 0.7 = V_{p(input)} - 0.7}$$



$$V_{out} = \frac{V_{sec}}{2} - 0.7$$

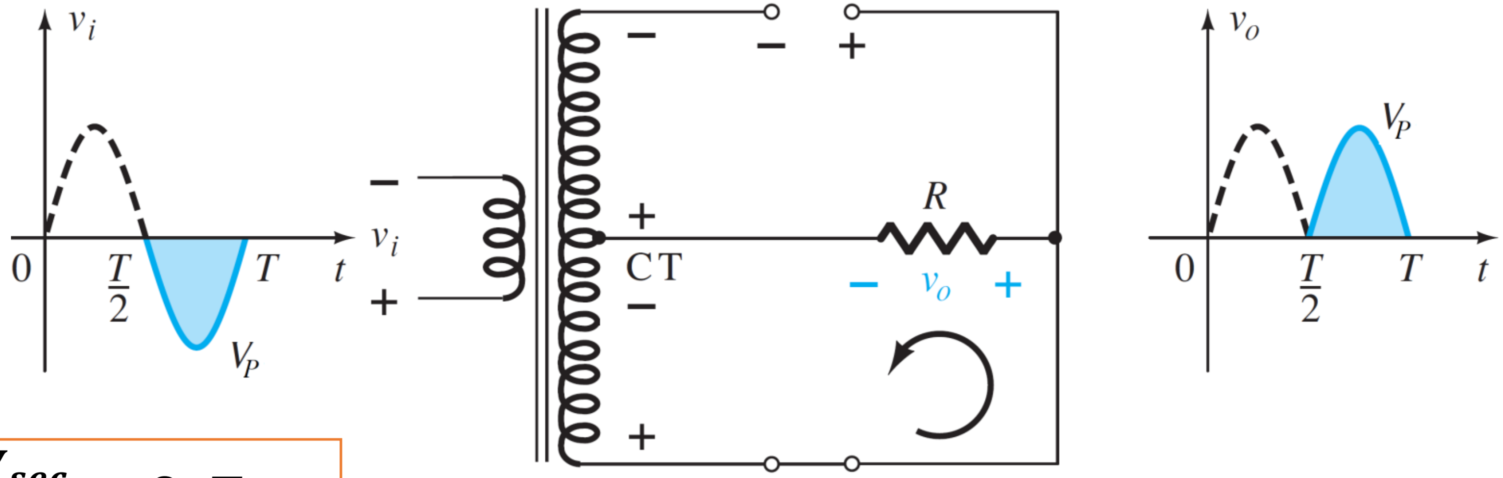
Center-Tapped Full-Wave Rectifier (CT-FWR) [(Similar configuration)]





Network conditions for the positive region of v_i.

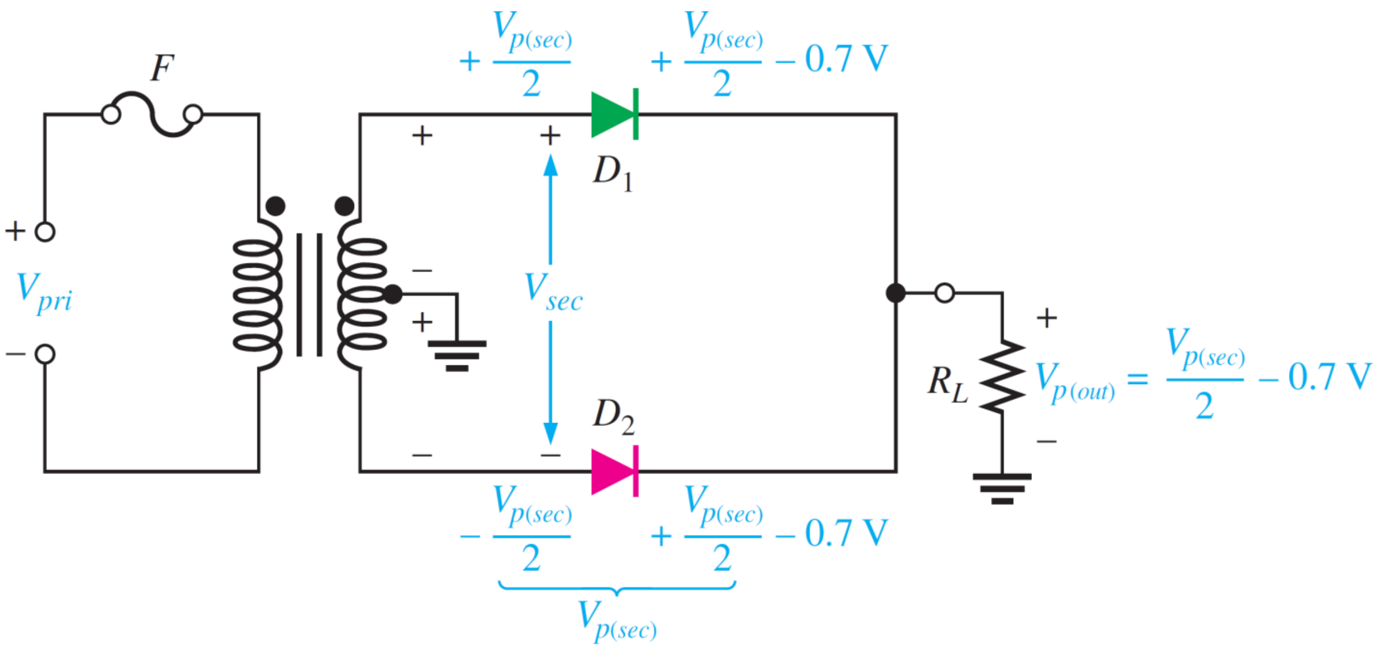
- During the $+ve$ half cycle **D1 is ON** and **D2 is OFF**
- During the $-ve$ half cycle **D1 is OFF** and **D2 is ON**
- The current passes through R in the same direction in both half cycles

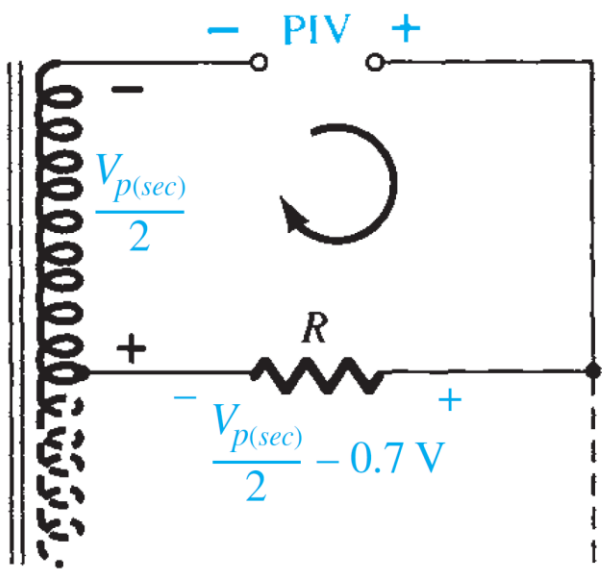


Network conditions for the negative region of v_i.

Ideal : $V_{out} = \frac{V_{sec}}{2}$ **Practical :** $V_{out} = \frac{V_{sec}}{2} - 0.7$

Peak Inverse Voltage





$$\text{PIV} = \left(\frac{V_{p(sec)}}{2} - 0.7\text{ V}\right) - \left(-\frac{V_{p(sec)}}{2}\right) = \frac{V_{p(sec)}}{2} + \frac{V_{p(sec)}}{2} - 0.7\text{ V}$$
$$= V_{p(sec)} - 0.7\text{ V}$$

$$\text{PIV} = \frac{V_{p(sec)}}{2} + \frac{V_{p(sec)}}{2} - 0.7\text{ V}$$
$$= V_{p(sec)} - 0.7\text{ V}$$

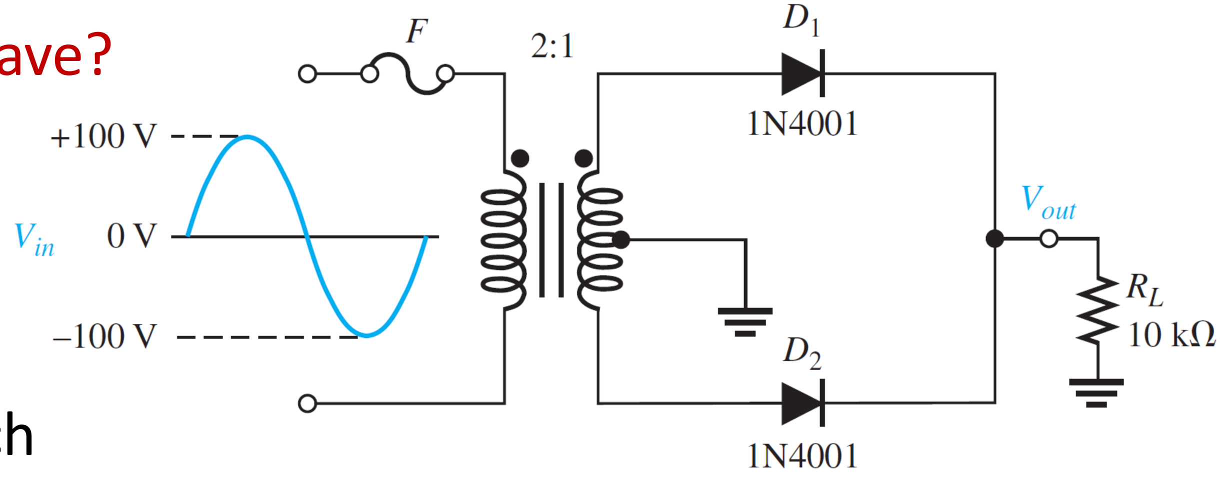
$$\boldsymbol{PIV = V_{p(sec)} - 0.7}$$

Example 4

(a) Show the voltage waveforms across each half of the secondary winding and across R_L

(b) Find the DC value of the output.

(c) What minimum PIV rating must the diodes have?



Solution (a) $n = \frac{1}{2} = 0.5$

- The total peak secondary voltage is:

$$V_{p(sec)} = nV_{p(pri)} = 0.5 \times 100 = 50\ V$$

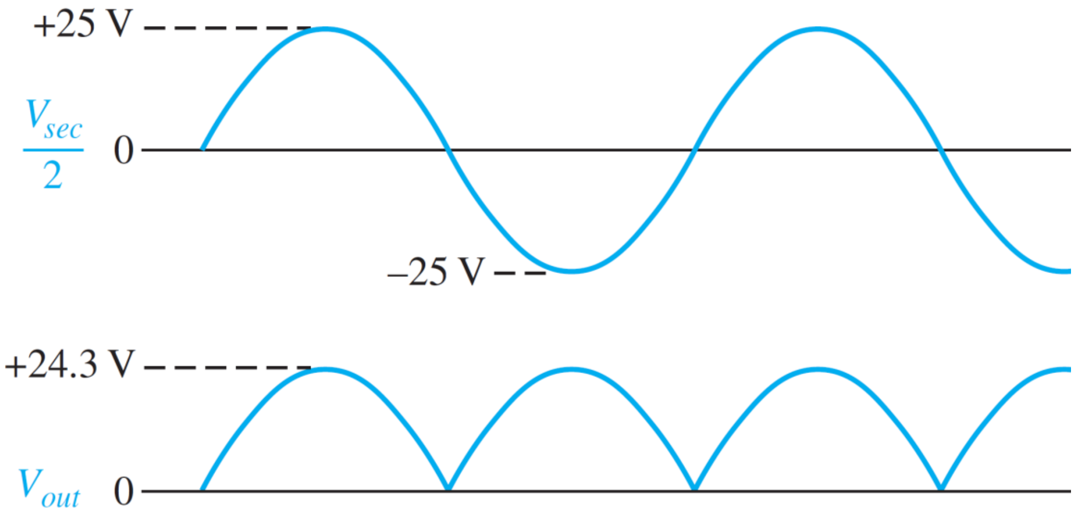
- Hence There is a $\frac{V_{p(sec)}}{2} = 25$ V peak across each half of the secondary with respect to ground.
- The load voltage has a peak value:

$$V_{p(out)} = \frac{V_{p(sec)}}{2} - 0.7 = 24.3\ V$$

(b) $V_{AVG} = \frac{2V_{P(out)}}{\pi} = 0.637\ V_{P(out)} = 15.48\ V$

(c) Each diode must have a minimum PIV rating of

$$PIV = V_{p(sec)} - 0.7 = 49.3\ V$$



Bridge Full-Wave Rectifier

During the positive half-cycle

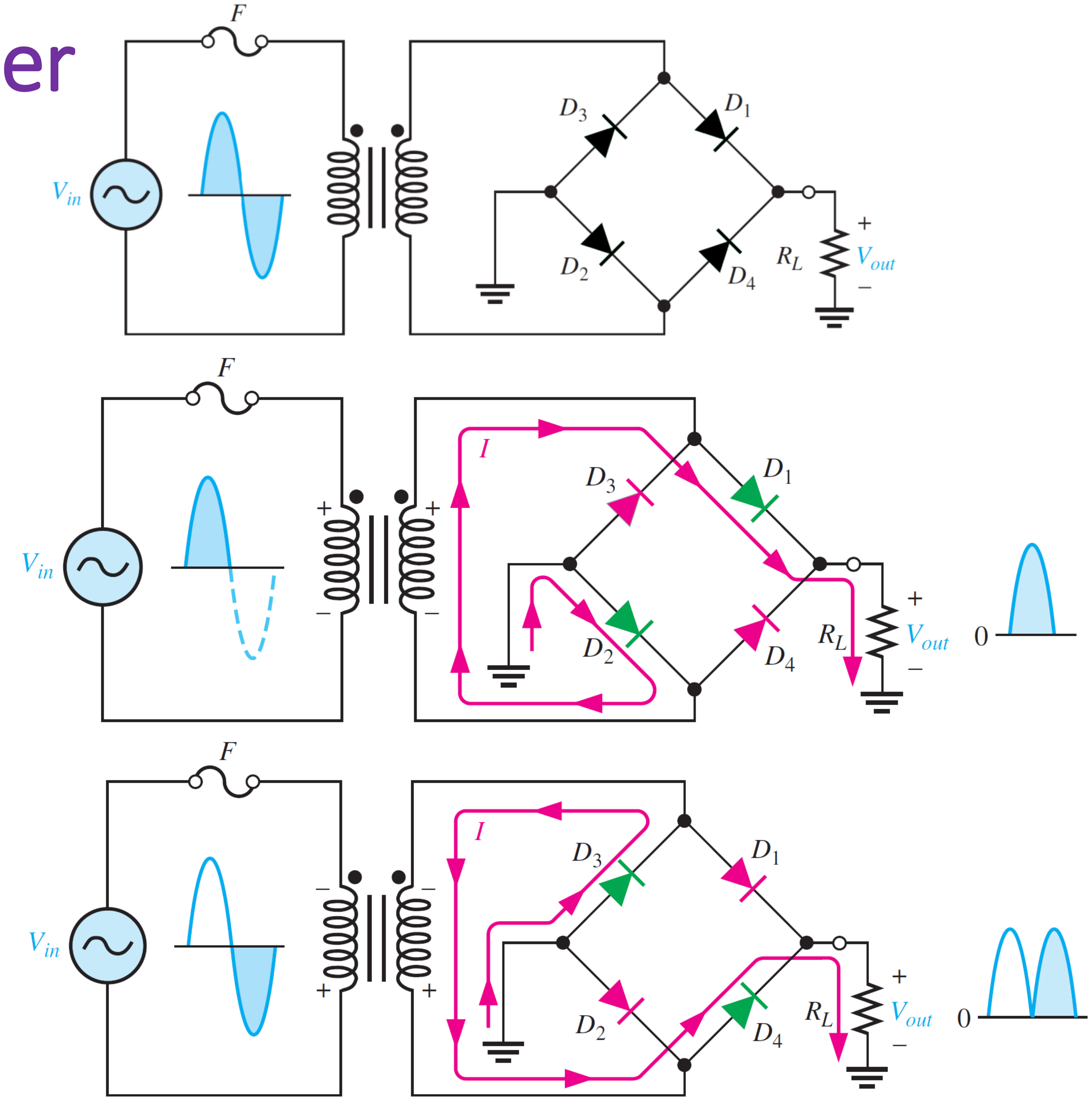
- D_1 and D_2 are forward-biased and conduct current.
- D_3 and D_4 are reverse-biased.

During the negative half-cycle

- D_3 and D_4 are forward-biased and conduct current.
- D_1 and D_2 are reverse-biased.

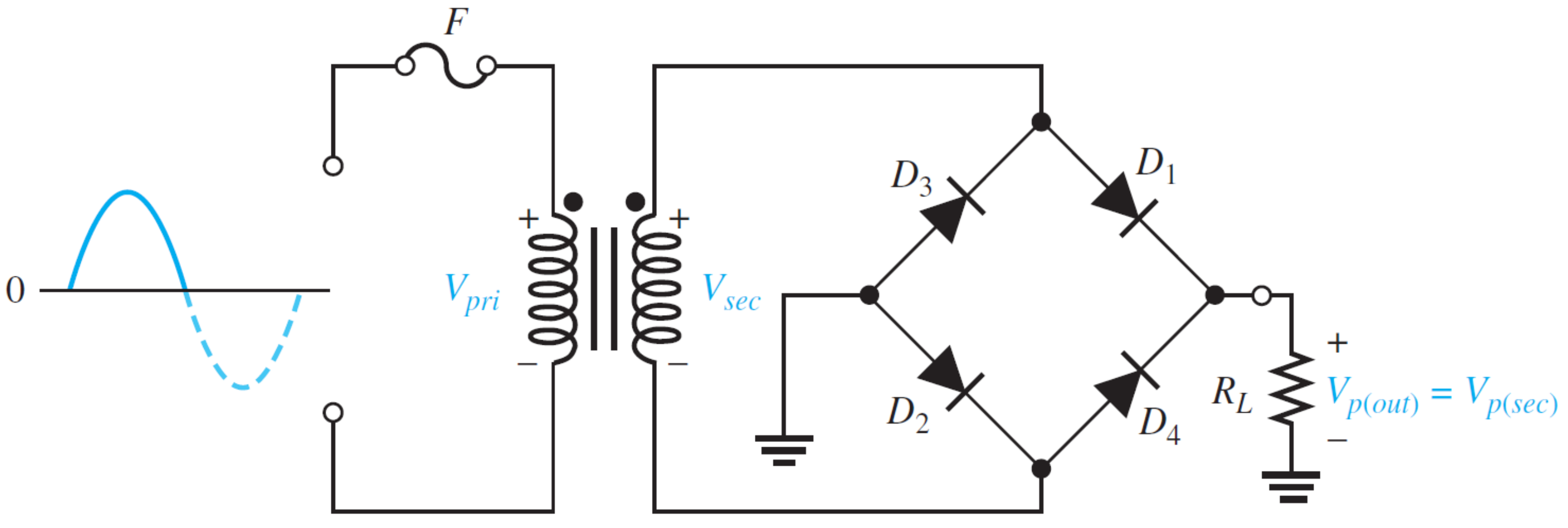
Practical:

$$V_{p(out)} = V_{p(sec)} - 1.4$$



Ideal:

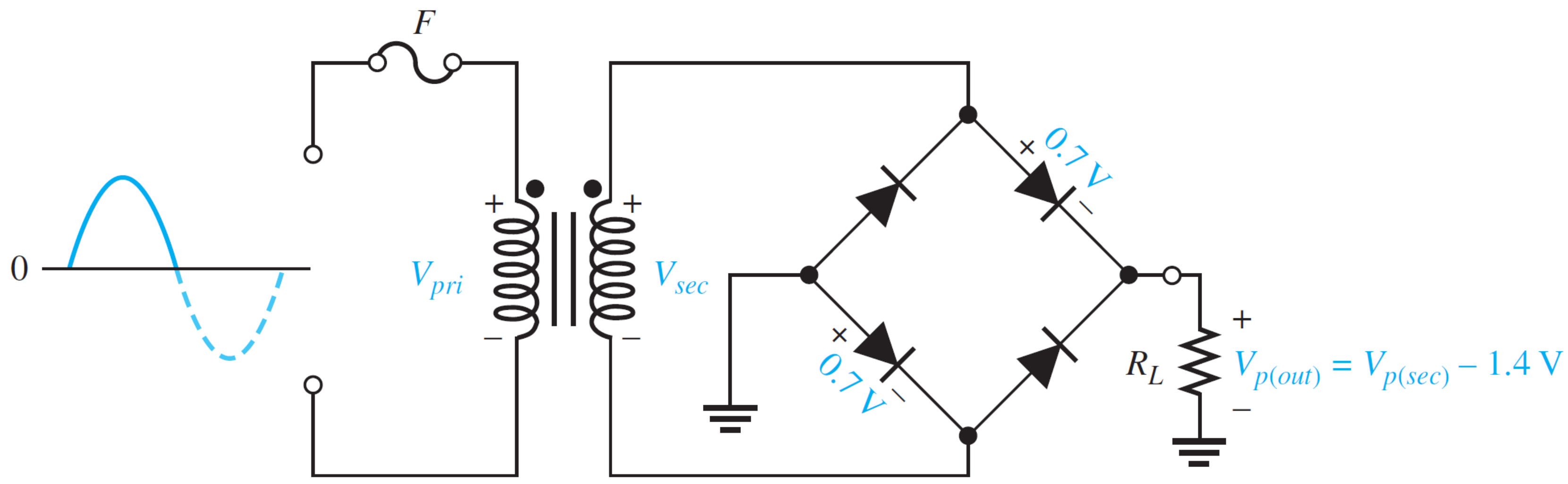
$$V_{p(out)} = V_{p(sec)}$$



(a) Ideal diodes

Practical:

$$V_{p(out)} = V_{p(sec)} - 1.4$$

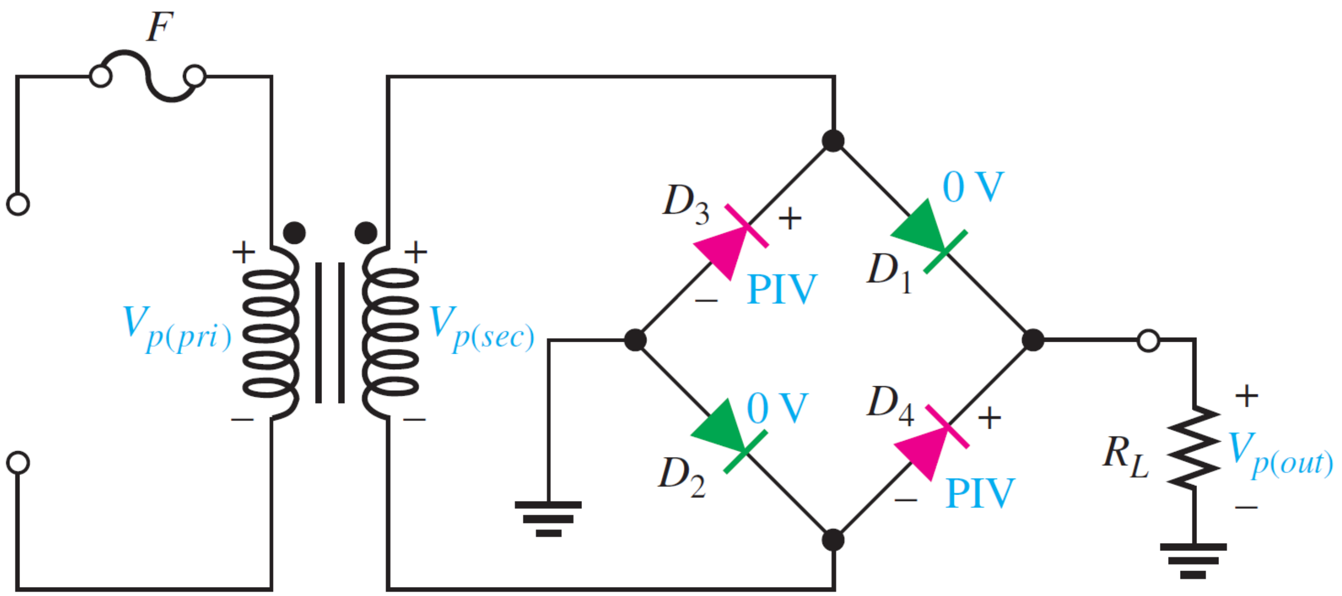


(b) Practical diodes (Diode drops included)

Peak Inverse Voltage

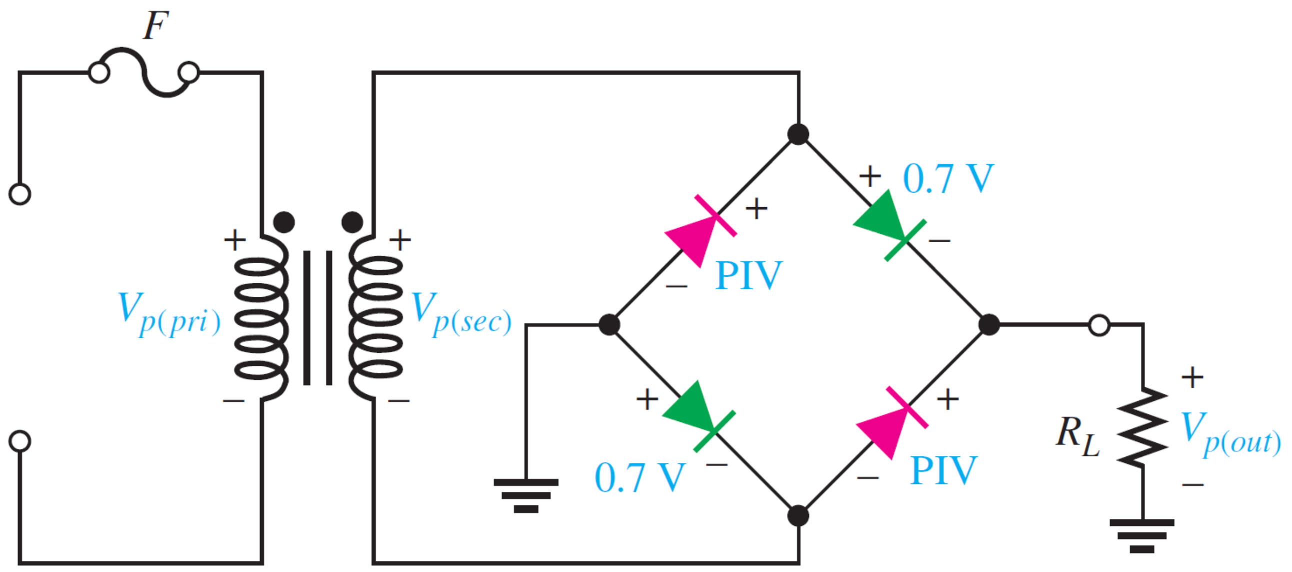
Ideal:

$$PIV = V_{p(out)}$$



Practical:

$$PIV = V_{p(out)} + 0.7$$

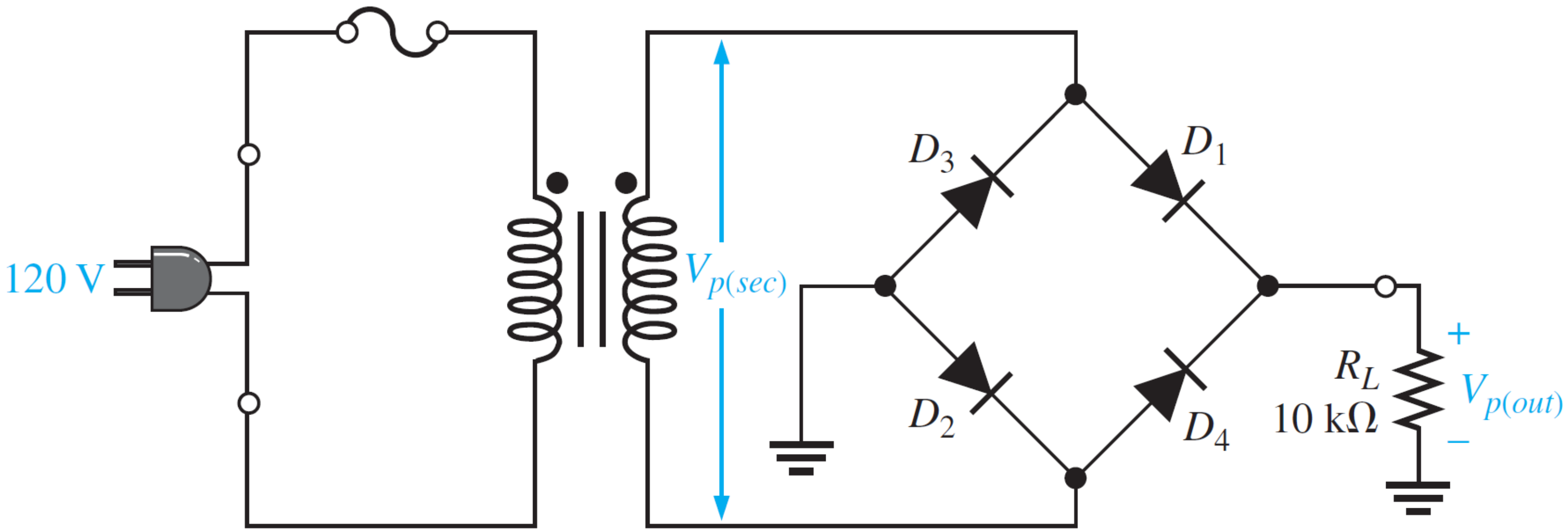


Example 5

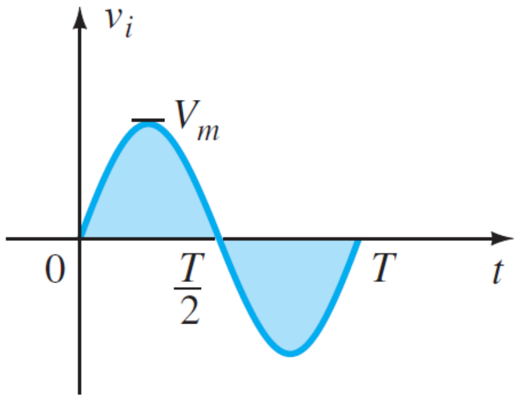
Determine the peak output voltage for the bridge rectifier in Figure. Assuming the practical model, what PIV rating is required for the diodes? The transformer is specified to have a $12\ V\ rms$ secondary voltage for the standard 120 V across the primary.

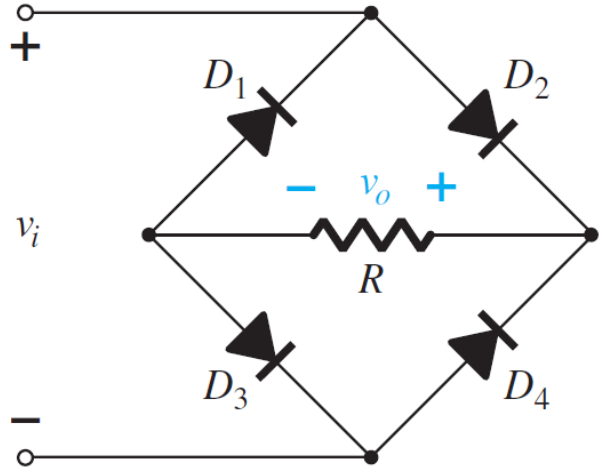
Solution

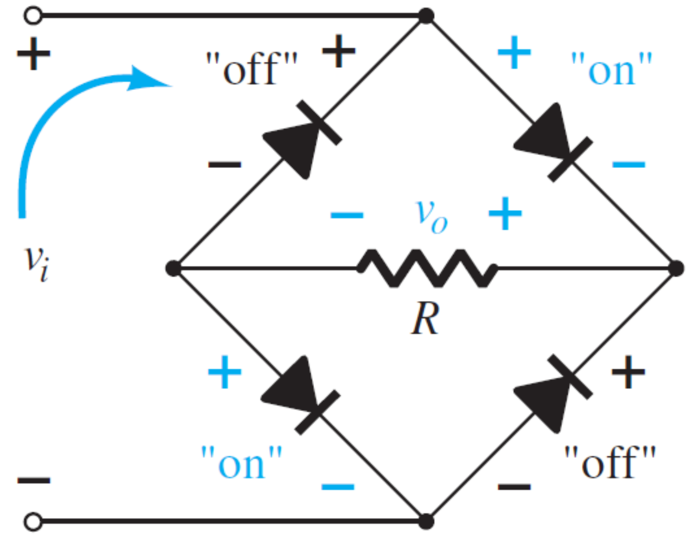
- The peak secondary voltage is : $V_{p(sec)} = \sqrt{2}V_{rms(sec)} = \sqrt{2} \times 12 = 17\ V$
- The peak output voltage is: $V_{p(out)} = V_{p(sec)} - 1.4 = 15.6\ V$
- The PIV rating for each diode is : $PIV = V_{p(out)} + 0.7 = 16.3\ V$

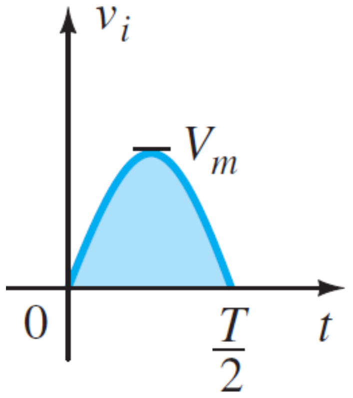


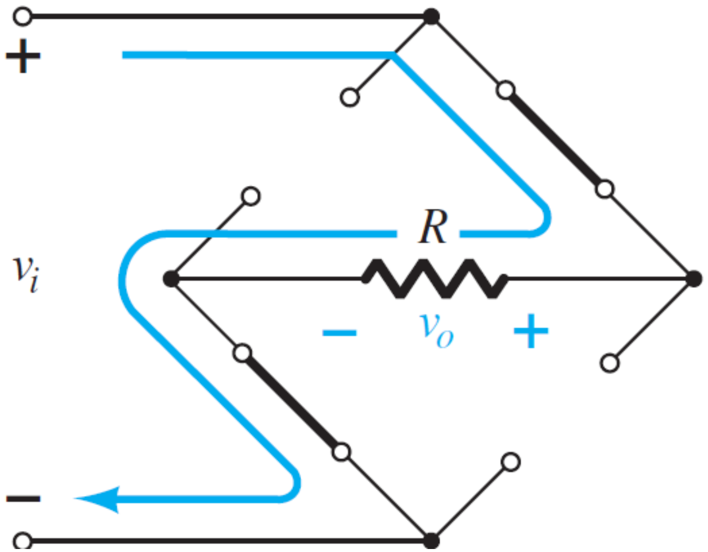
Bridge FWR (similar configuration)

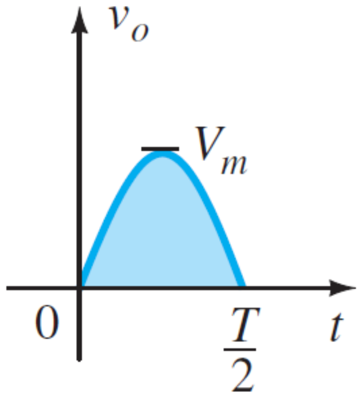






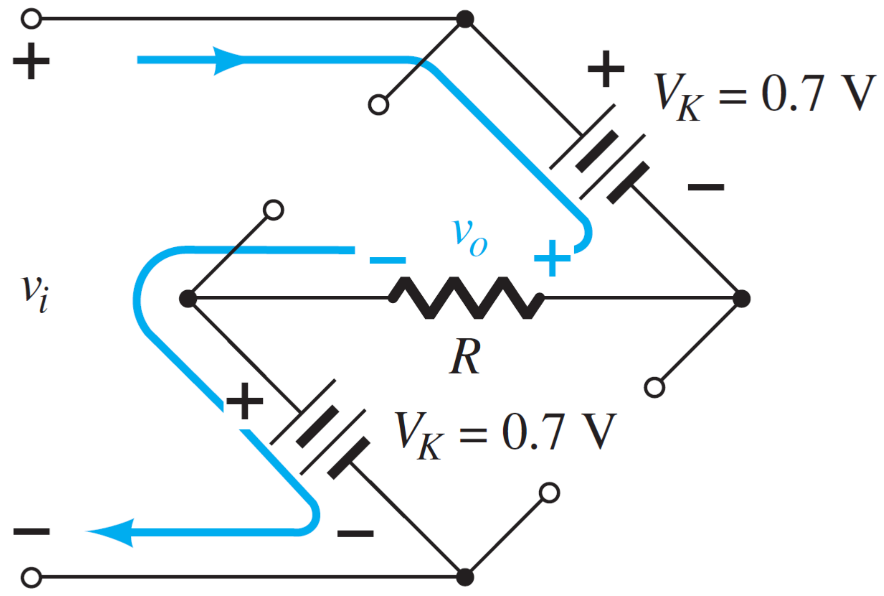


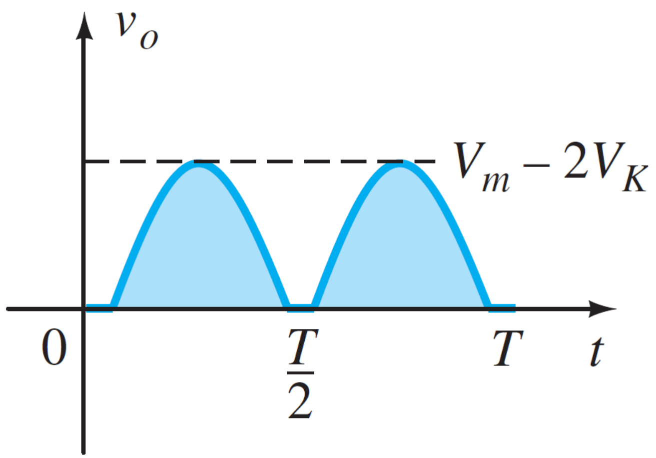




During the positive half cycle

$$V_{o(peak)} = V_m - 1.4$$





Ideal: $PIV = V_{p(out)}$

Practical: $PIV = V_{p(out)} + 0.7$

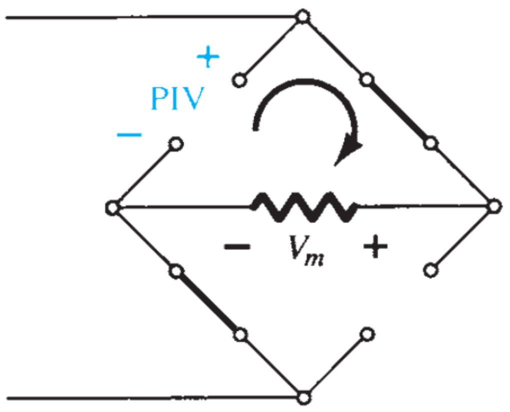
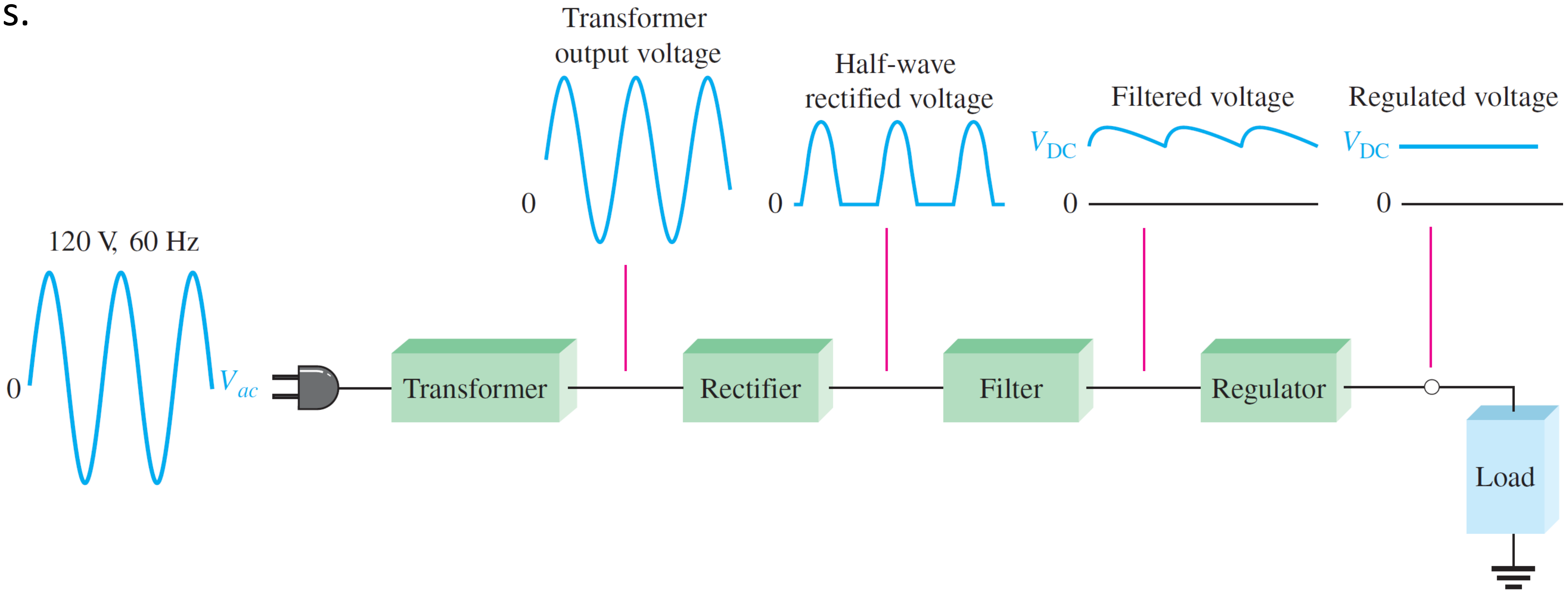


FIG. 2.59
Determining the required PIV for the bridge configuration.

The Basic DC Power Supply

- The **dc power supply** converts the standard 220 V, 60 Hz ac voltage available at wall outlets into a constant dc voltage.
- The voltage produced is used to power all types of electronic circuits including consumer electronics (televisions, DVDs, etc.), computers, industrial controllers, and most laboratory instrumentation systems and equipment.
- The dc voltage level required depends on the application, but most applications require relatively low voltages.



The Basic DC Power Supply

- The ac input line voltage is stepped down to a lower ac voltage with a transformer
- A **transformer** changes ac voltages based on the turns ratio between the primary and secondary. If the secondary has more turns than the primary, the output voltage across the secondary will be higher and the current will be smaller.
- If the secondary has fewer turns than the primary, the output voltage across the secondary will be lower and the current will be higher.
- The rectifier can be either a half-wave rectifier or a full-wave rectifier.
- The **rectifier** converts the ac input voltage to a pulsating dc voltage.
- The **filter** eliminates the fluctuations in the rectified voltage and produces a relatively smooth dc voltage.
- The **regulator** is a circuit that maintains a constant dc voltage for variations in the input line voltage or in the load.

Multisim

- Open the Multisim file E02-01 in the Examples folder. Measure the voltages across the diode and the resistor in both circuits.

- Open the Multisim file E02-03 in the Examples folder. For the inputs specified in the example, measure the resulting output voltage waveforms.

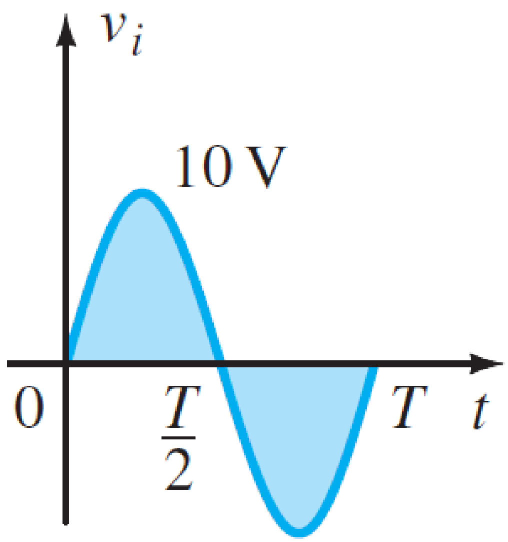
- Open the Multisim file E02-04 in the Examples folder. For the specified input, measure the peak output voltage.

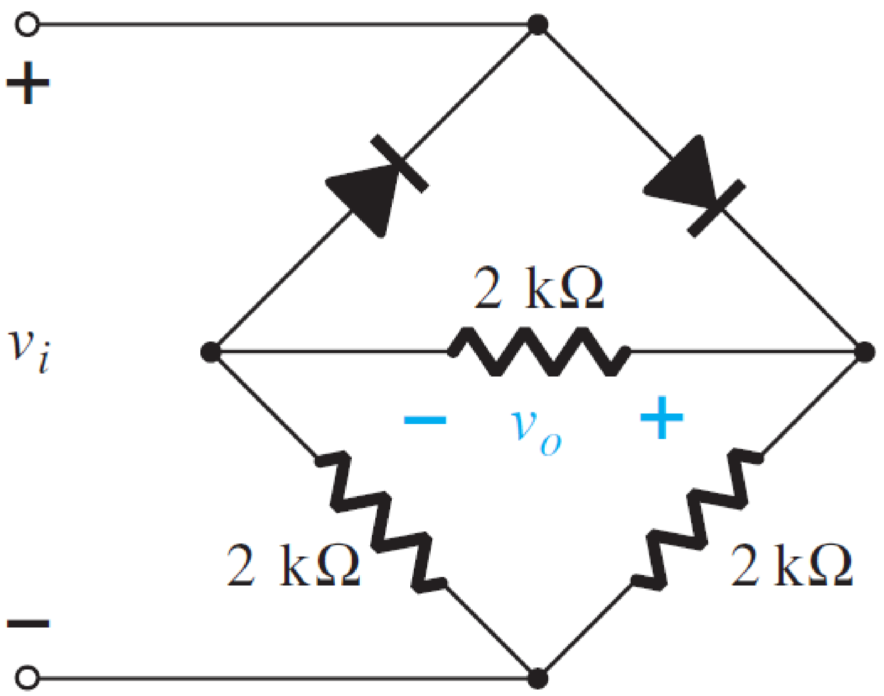
- Open the Multisim file E02-06 in the Examples folder. For the specified input voltage, measure the voltage waveforms across each half of the secondary and across the load resistor.

- Open the Multisim file E02-07 in the Examples folder. Measure the output voltage and compare to the calculated value.

Homework

- **Determine the output waveform for the network of Figure below and calculate the output dc level and the required PIV of each diode.**





Homework

- **Determine v_o, calculate the output dc level and the required PIV rating of each diode for the configuration of Fig. below . In addition, determine the maximum current through each diode. (solve for ideal and practical diodes)**