Helwan University - Faculty of Engineering (Helwan)
Electronics and Communications Engineering Department

Lec-3 Diodes: Applications

Presented By:

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Diode Applications

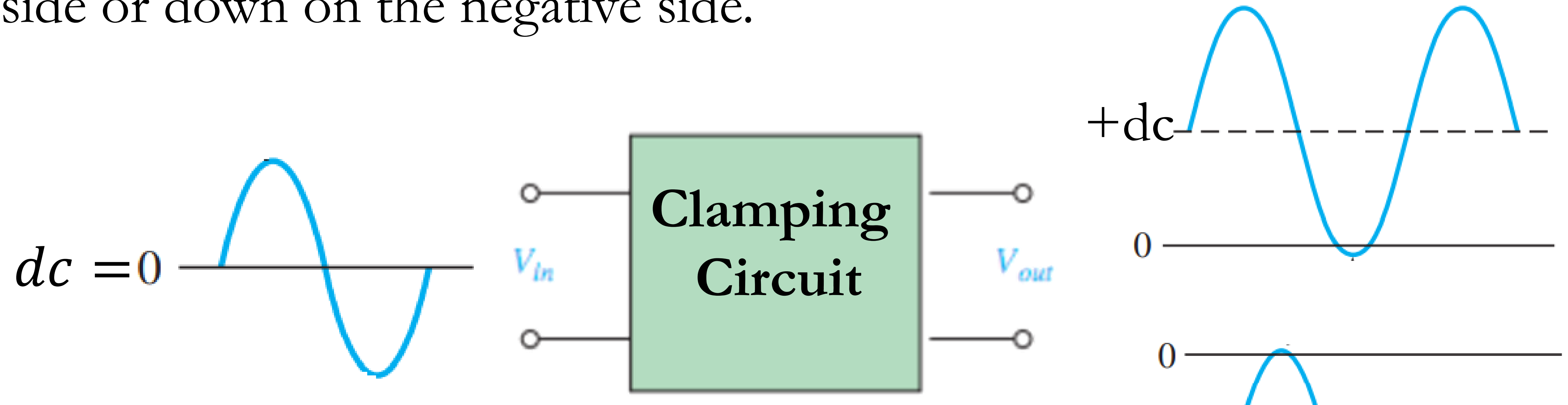
Diodes are used in many types of circuits such as:

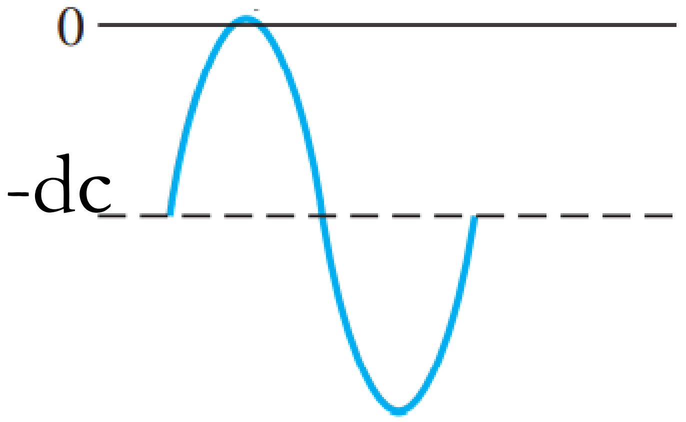
- ❑ Digital Circuits (**Logic Gates**).
- ❑ Clipping Circuits.
- ❑ Clamping Circuits.
- ❑ Rectifier Circuits.

❑ Clamping Circuits

Used to **change a dc level** of ac input voltage (**adds a dc level** to an ac voltage).

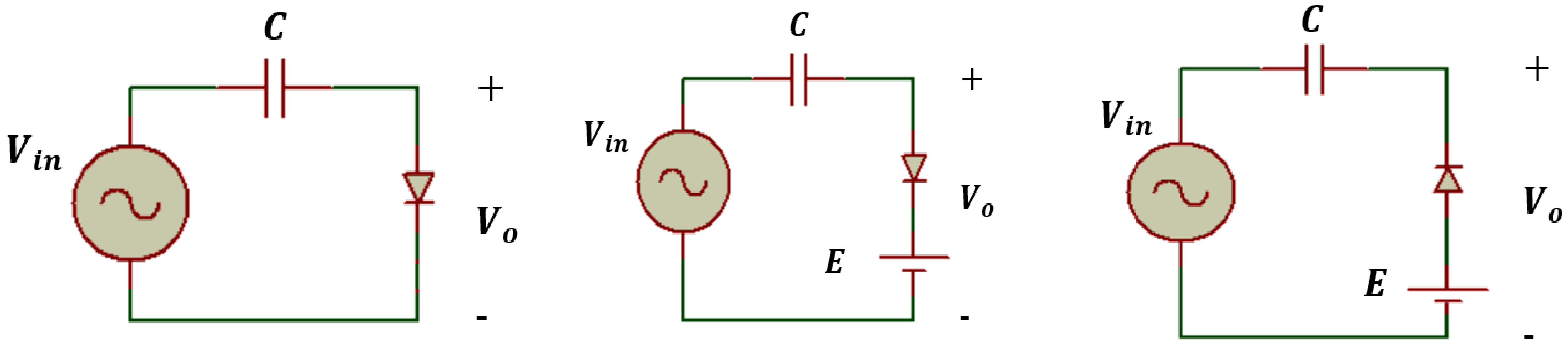
In other words, clamping circuit **shifts ac voltage** up on the positive side or down on the negative side.





The shape of the input and the output voltage waveform is identical, only the dc level is shifted.

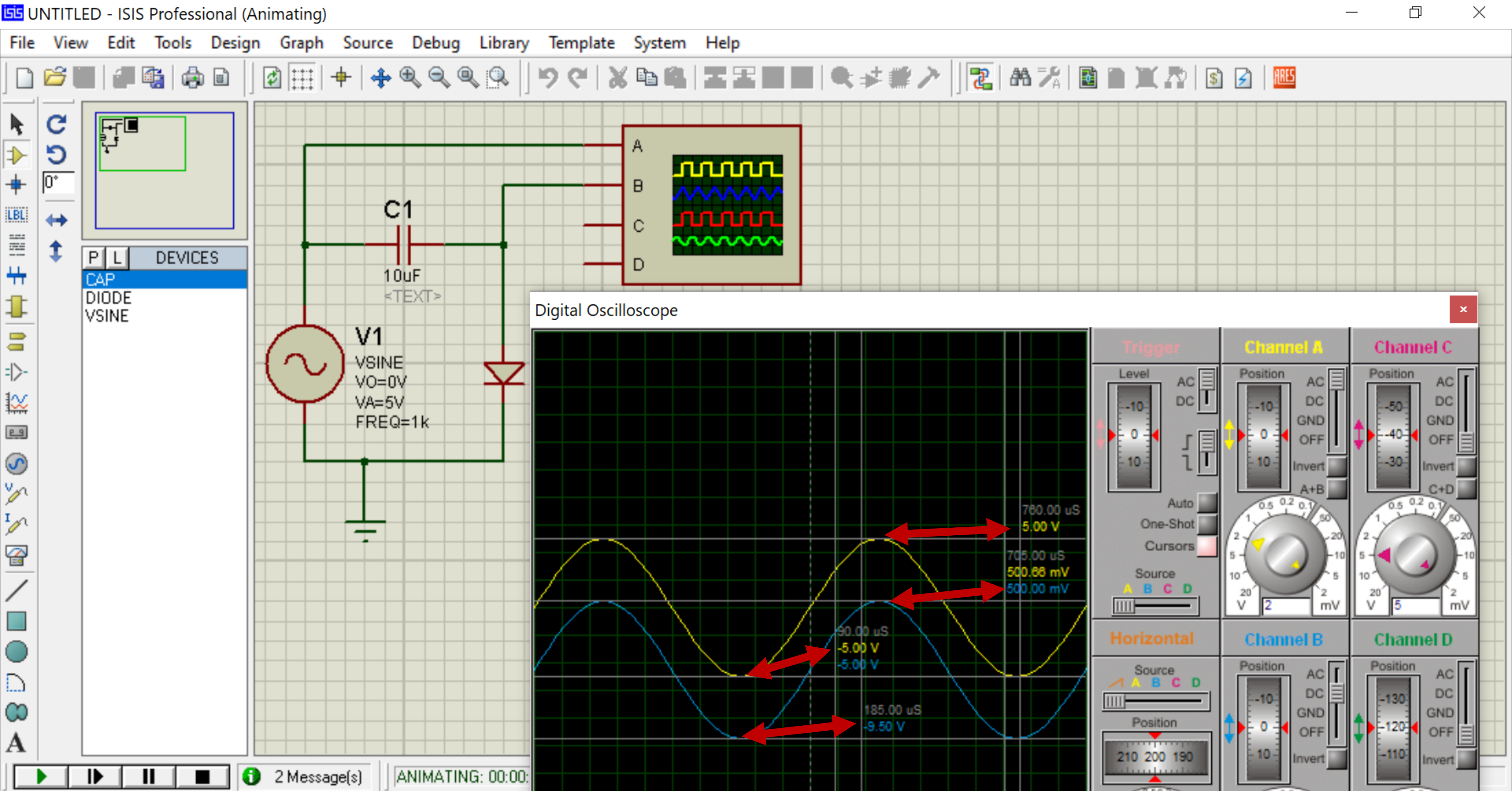
Clamping circuits can be made by combining diodes and capacitors.



Capacitor charges (retains a charge) when a diode is forward biased.

The capacitor voltage acts as a battery in series with the input voltage.

Then, a capacitor voltage is added to the input voltage.



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VSINE
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VA=5V
FREQ=1k
A
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Digital Oscilloscope
760.00 uS
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705.00 uS
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500.00 mV
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-5.00 V
-5.00 V
185.00 uS
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Trigger
Channel A
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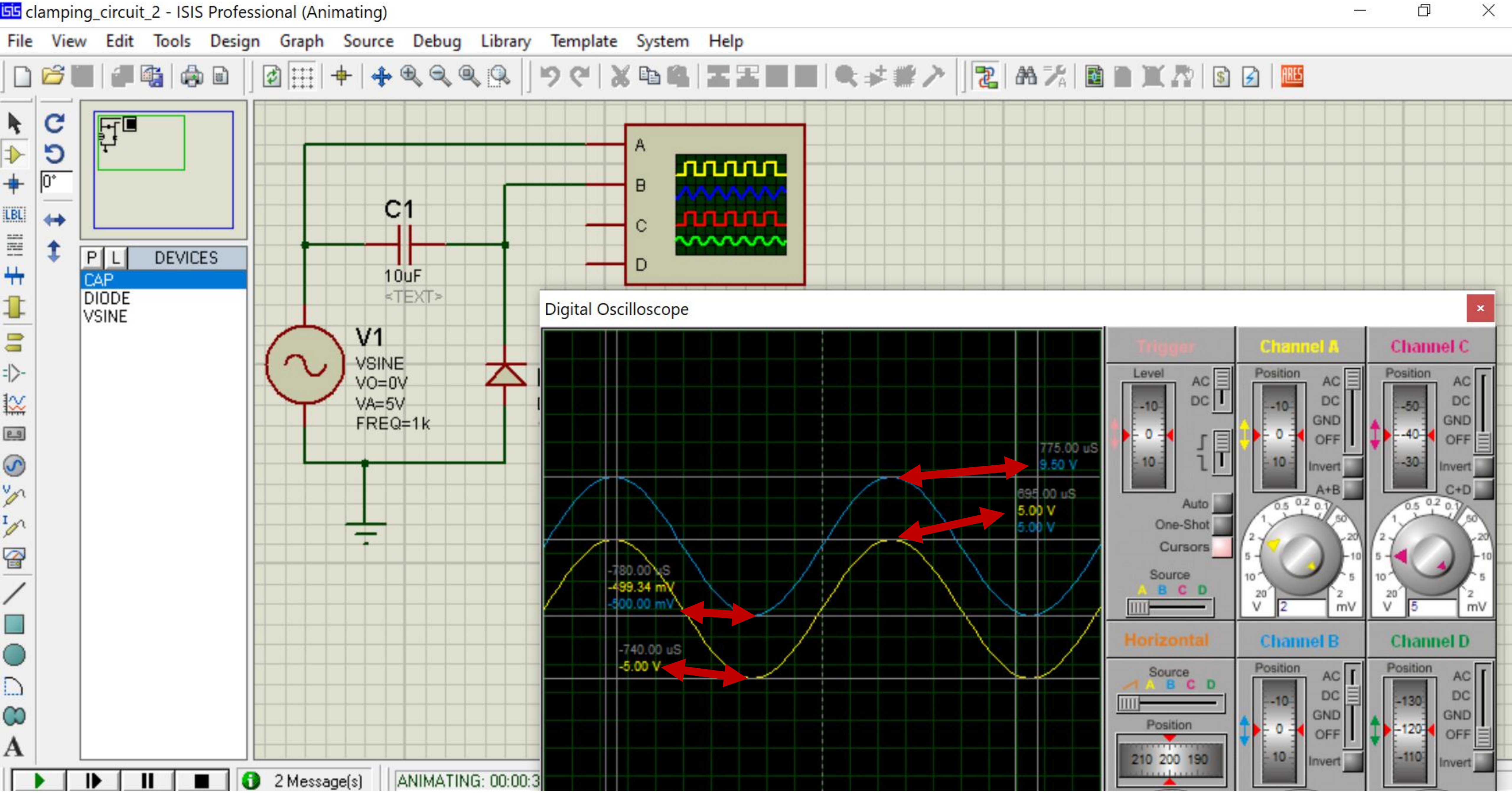

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CAP
DIODE
VSINE
Digital Oscilloscope
775.00 uS
9.50 V
695.00 uS
5.00 V
5.00 V
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Trigger
Channel A
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Invert
A+B
C+D
Auto
One-Shot
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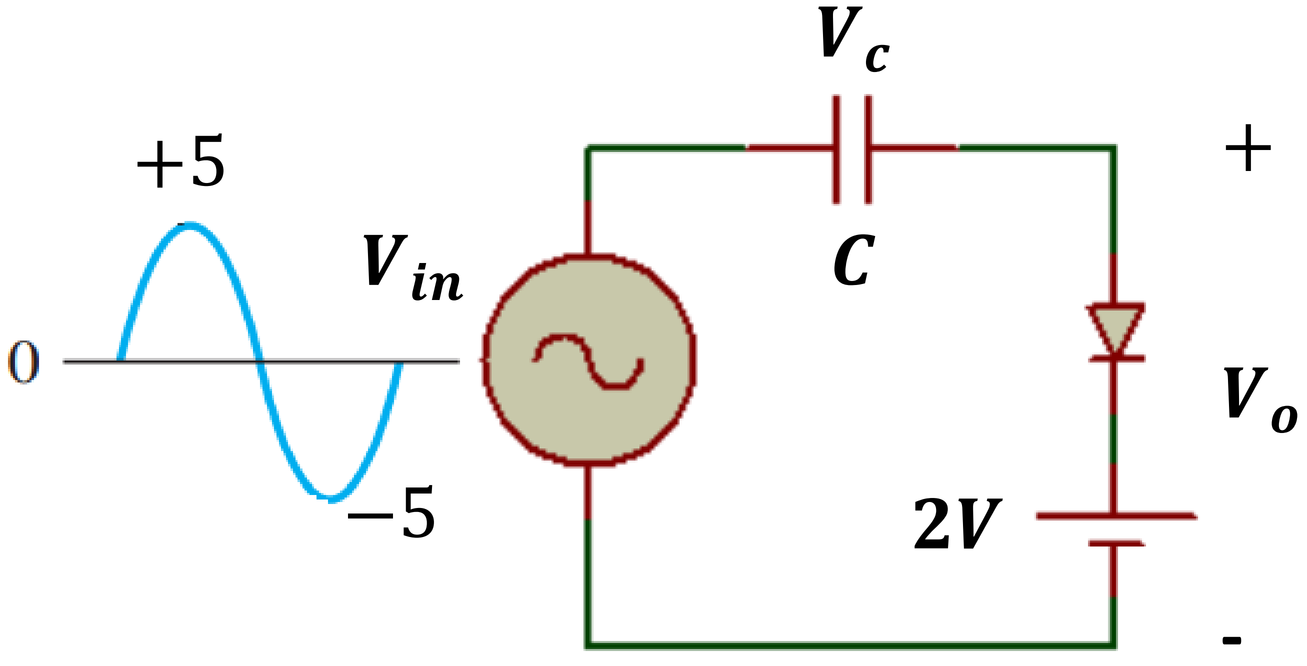
Sketch the output voltage waveform, assuming $V_B = 0.5V$ and $V_{in} = 5\ sinwt.$

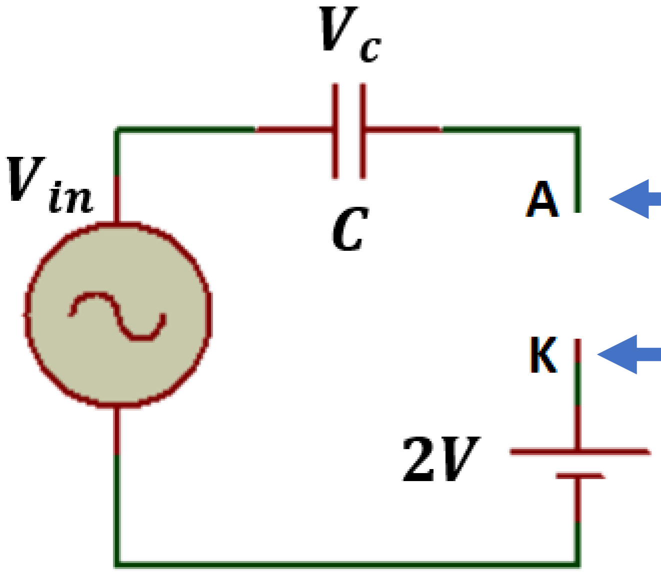


Diode is reverse and appears as open switch $(R_r = \infty)$ when:

$$V_A \leq V_K + V_B$$

$$V_{in} \leq 2 + 0.5$$

$$V_{in} \leq 2.5$$

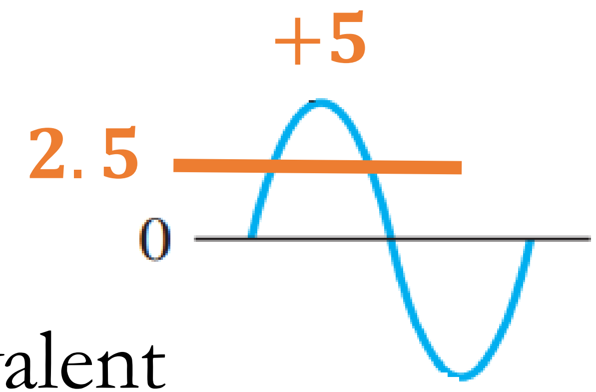


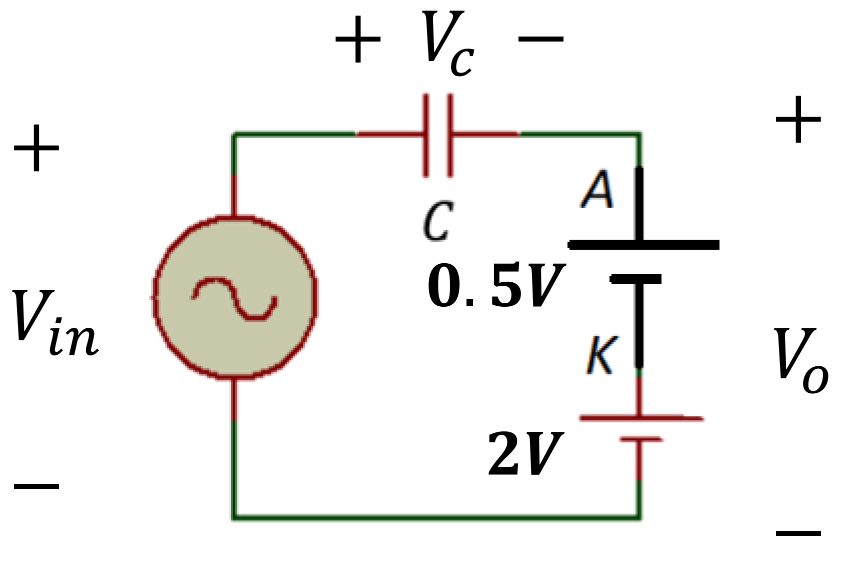
$V_A = V_{in}$ *assume* $V_c(intial) = 0$

$V_K = 2V$

Diode is forward when:

$$V_{in} > 2.5$$





Then, substitute the equivalent circuit of a diode in forward region.

The output voltage: $V_o - 0.5 - 2 = 0$ $\Rightarrow$ $V_o = 2.5V$

Capacitor: charges

$$V_{in} - V_c - V_o = 0$$

$$V_c = 5 - 2.5$$

$$V_c = 2.5V$$

Diode is reverse ($R_r = \infty$) when:

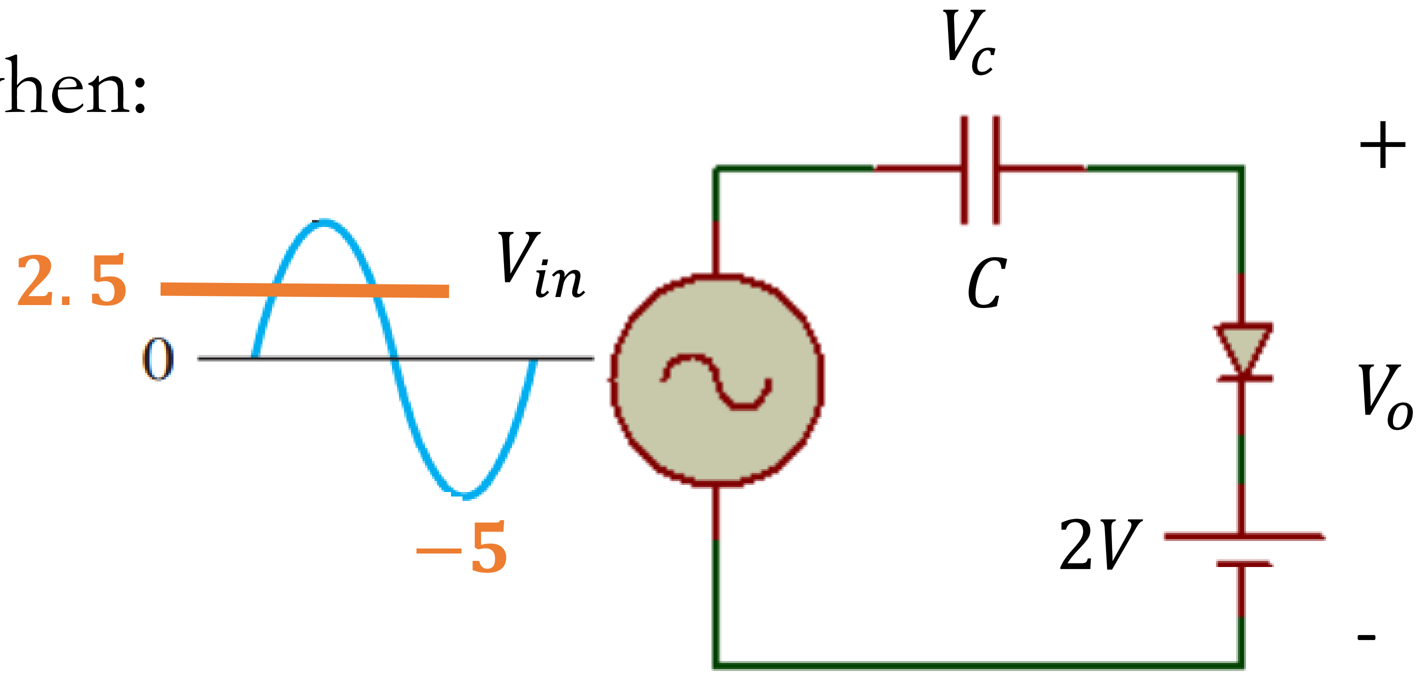
$V_{in} \leq 2.5$

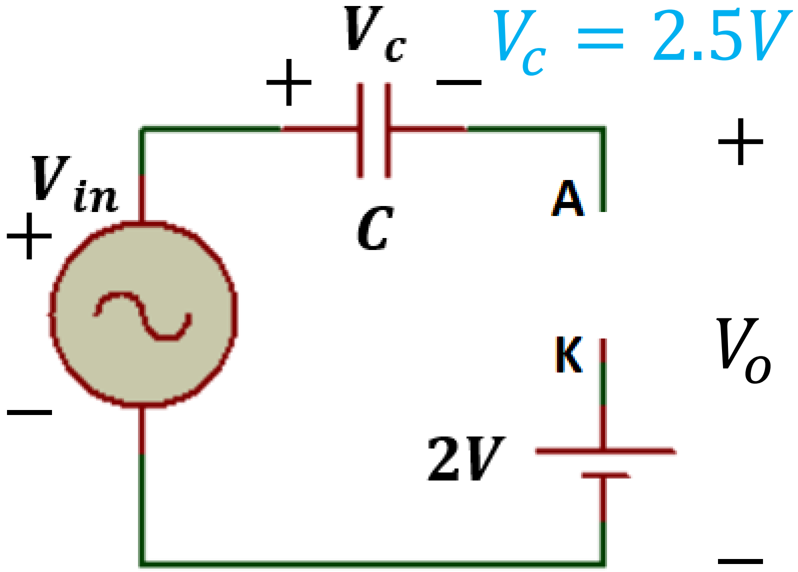
$V_{in} - V_c - V_o = 0$

$V_o = V_{in} - V_c$

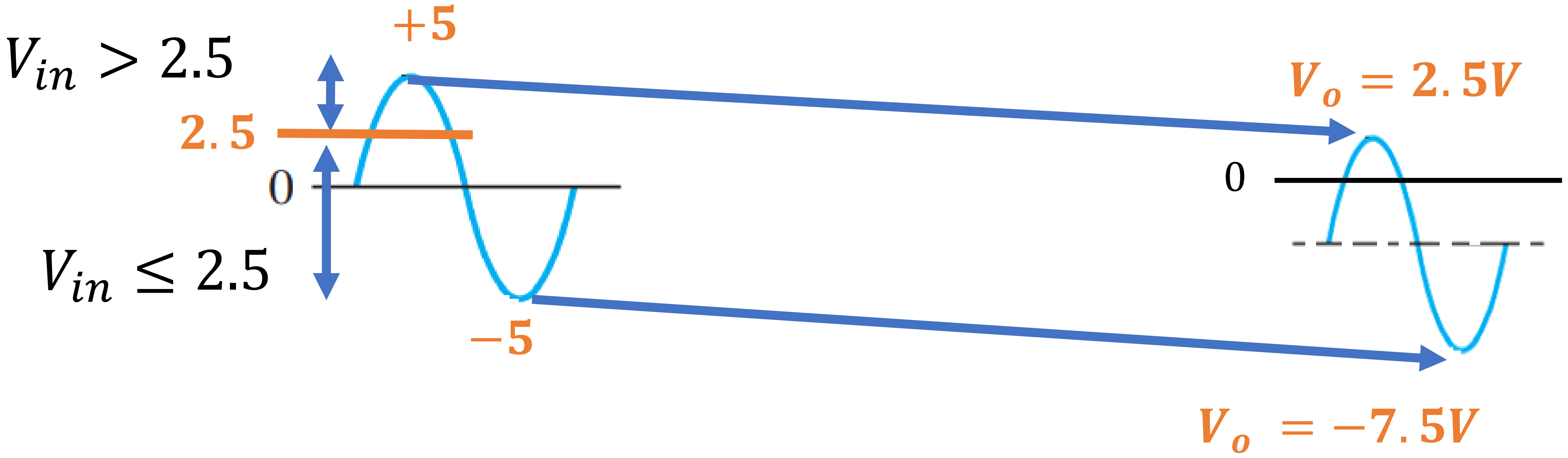
$V_o = -5 - (2.5)$

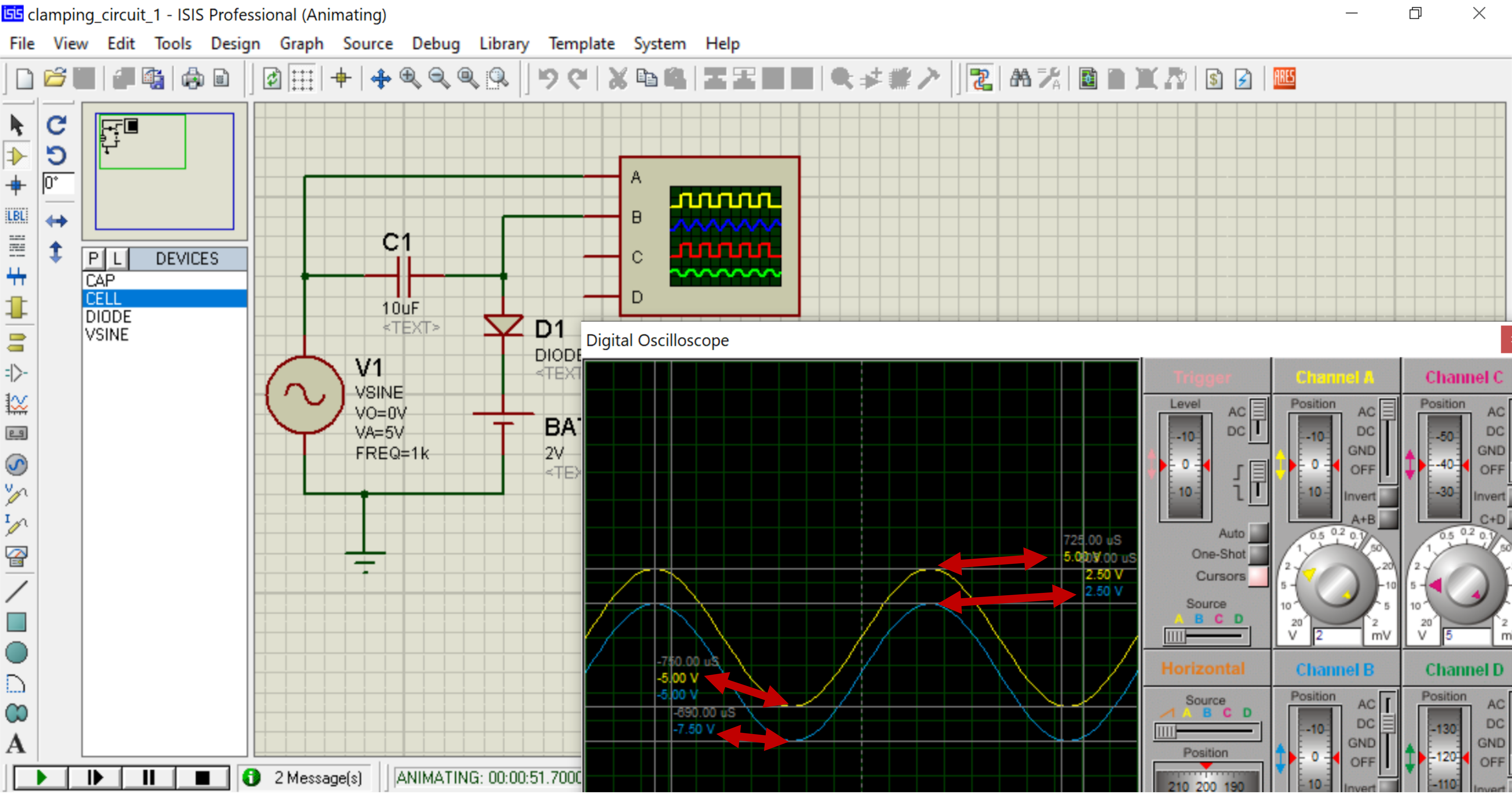
$\boldsymbol{V_o = -7.5V}$





The output voltage waveform:





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File View Edit Tools Design Graph Source Debug Library Template System Help
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CELL
DIODE
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C1
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DIODE
V1
VSINE
VO=0V
VA=5V
FREQ=1k
2V
A
B
C
D
Digital Oscilloscope
725.00 uS
2.50 V
2.50 V
-750.00 uS
-5.00 V
-5.00 V
-890.00 uS
-7.50 V
Trigger
Channel A
Channel C
Channel B
Channel D
Horizontal
Level
Position
Auto
One-Shot
Cursors
Source
2 Message(s)
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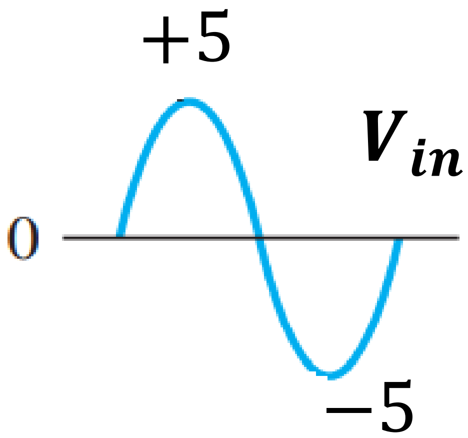
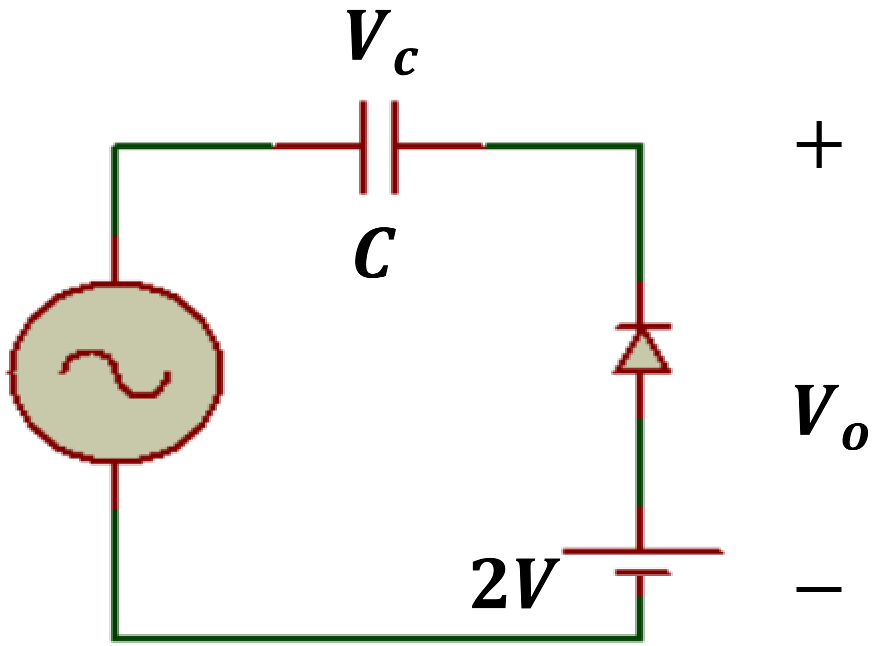
Sketch the output voltage waveform, assuming $V_B = 0.5V$ and $V_{in} = 5\ sinwt.$



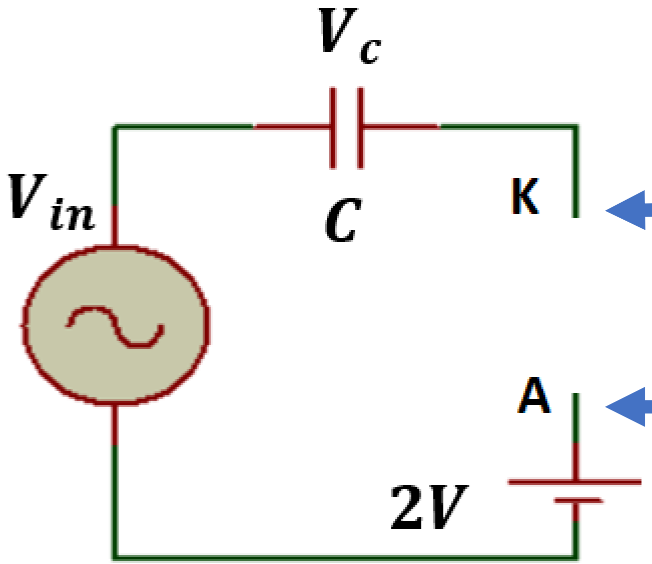


Diode is reverse and appears as open switch ($R_r = \infty$) when:

$$V_A \leq V_K + V_B$$

$$2 \leq V_{in} + 0.5$$

$$1.5 \leq V_{in}$$



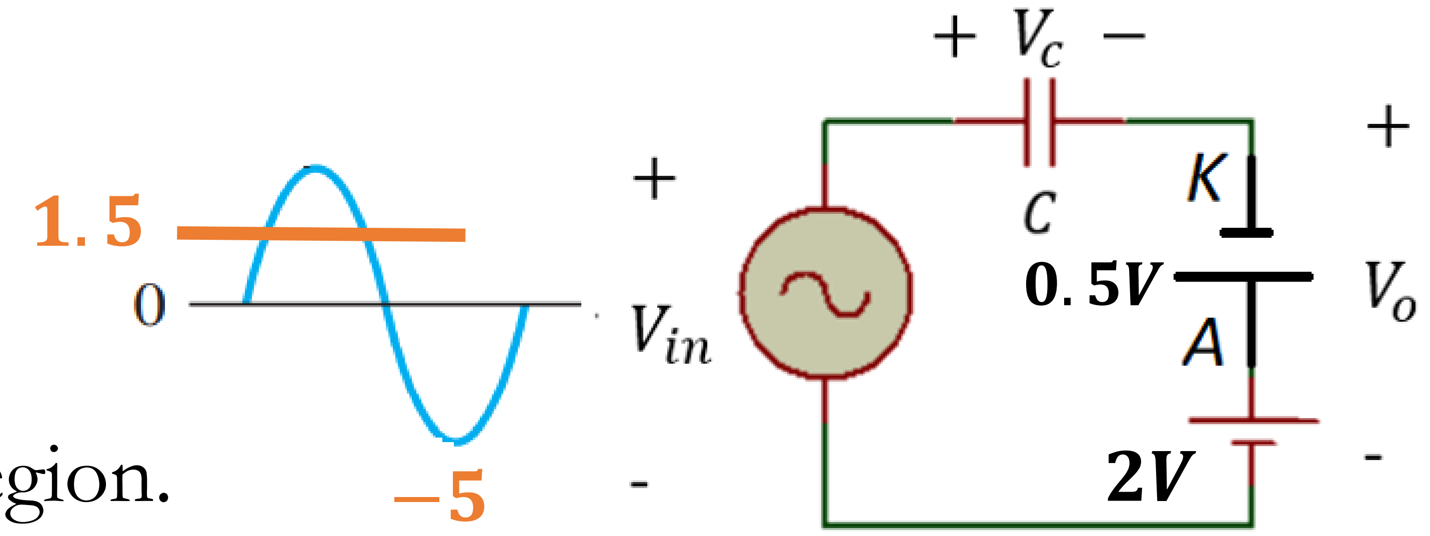
$V_A = V_{in}$ *assume* $V_c(intial) = 0$

$V_A = 2V$

Diode is forward when:

$$V_{in} < 1.5$$

Then, substitute the equivalent circuit of a diode in forward region.



The output voltage: $V_o + 0.5 - 2 = 0$ $\Rightarrow$ $\boldsymbol{V_o = 1.5V}$

Capacitor: charges

$$V_{in} - V_c - V_o = 0$$

$$V_c = V_{in} - V_o$$

$$V_c = (-5) - (1.5) = -6.5V$$

Diode is reverse ($R_r = \infty$) when:

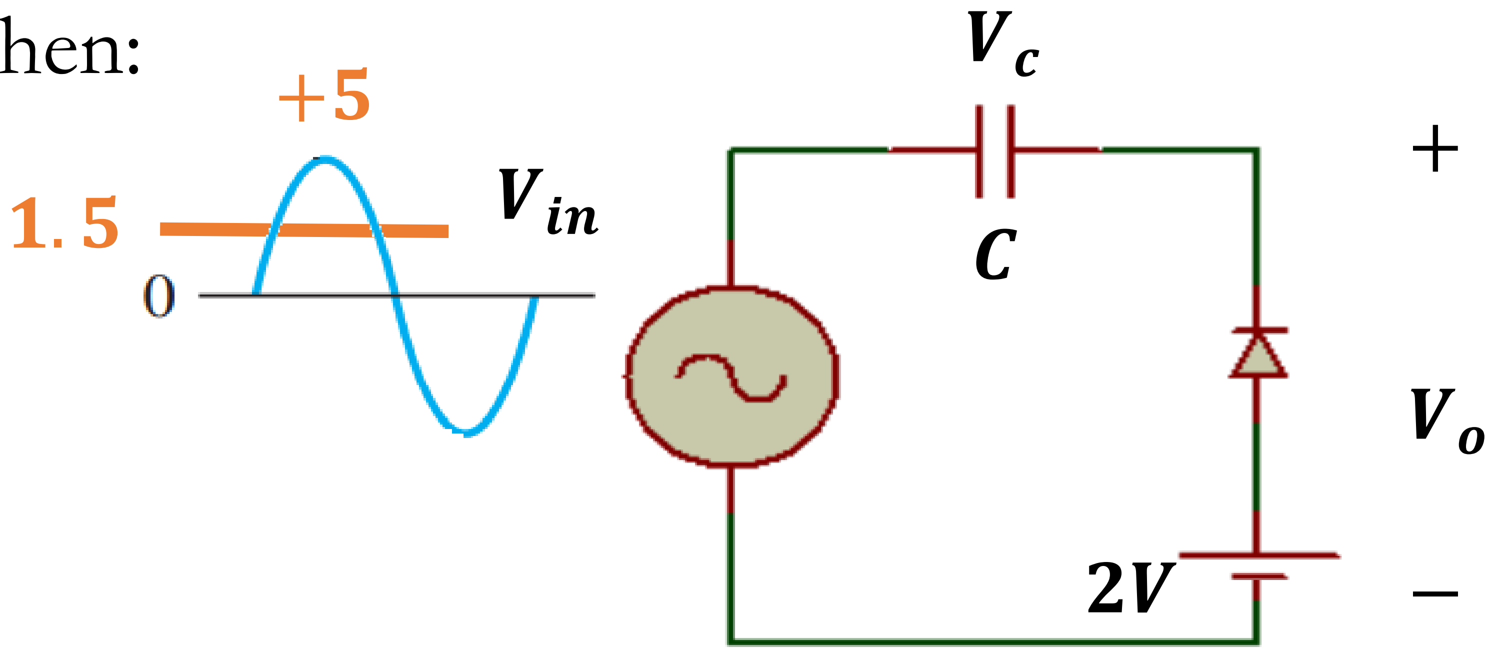
$V_{in} \geq 1.5$

$V_{in} - V_c - V_o = 0$

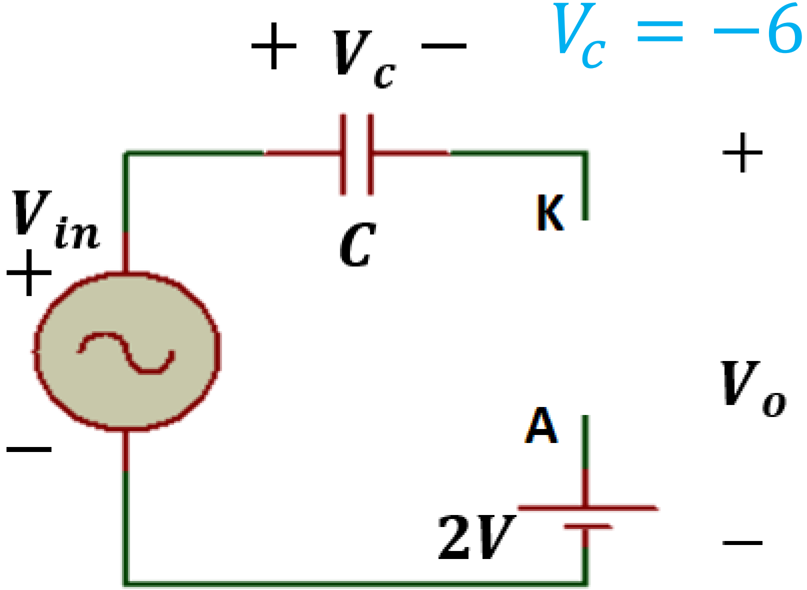
$V_o = V_{in} - V_c$

$V_o = (5) - (-6.5)$

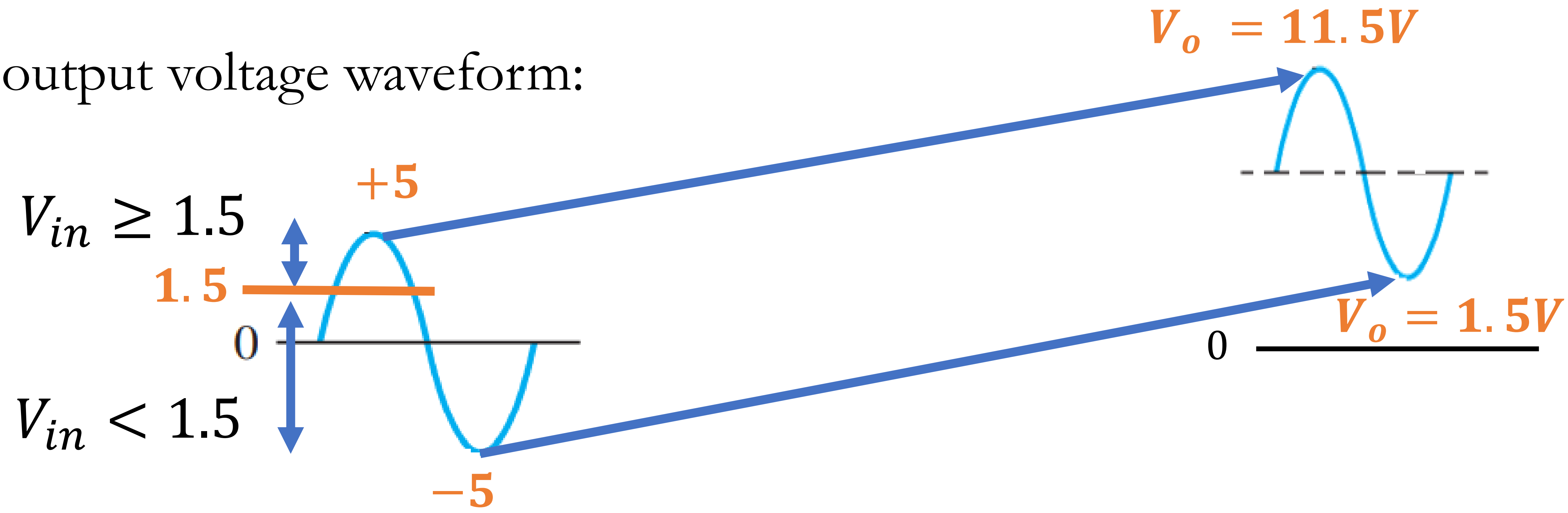
$\boldsymbol{V_o = 11.5V}$

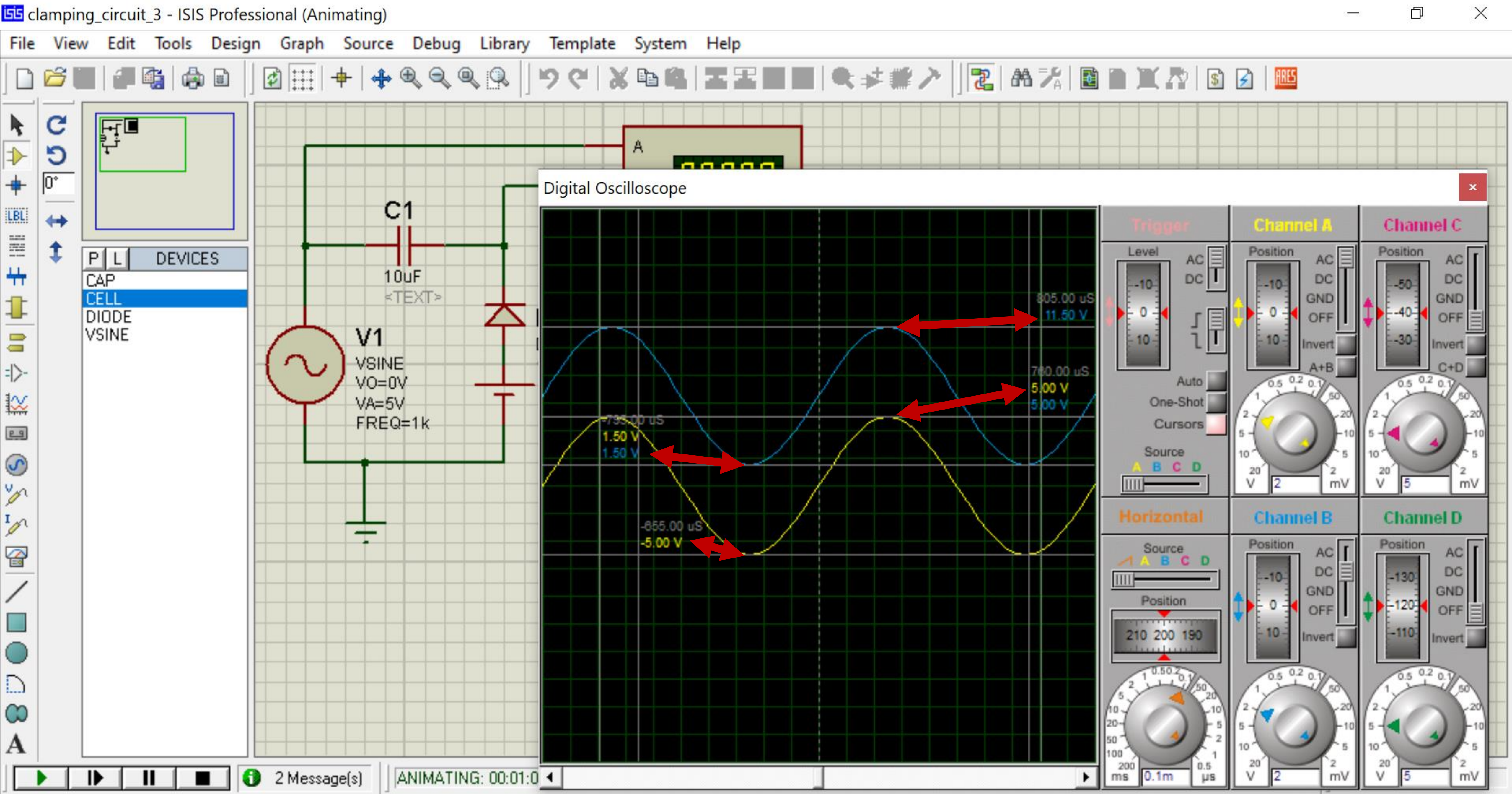


$V_c = -6.5V$



The output voltage waveform:

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Digital Oscilloscope
805.00 uS
11.50 V
760.00 uS
5.00 V
5.00 V
-735.00 uS
1.50 V
1.50 V
-655.00 uS
-5.00 V
Trigger
Level
AC
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Auto
One-Shot
Cursors
Source
A B C D
Horizontal
Position
Channel A
Channel B
Channel C
Channel D
GND
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A+B
C+D
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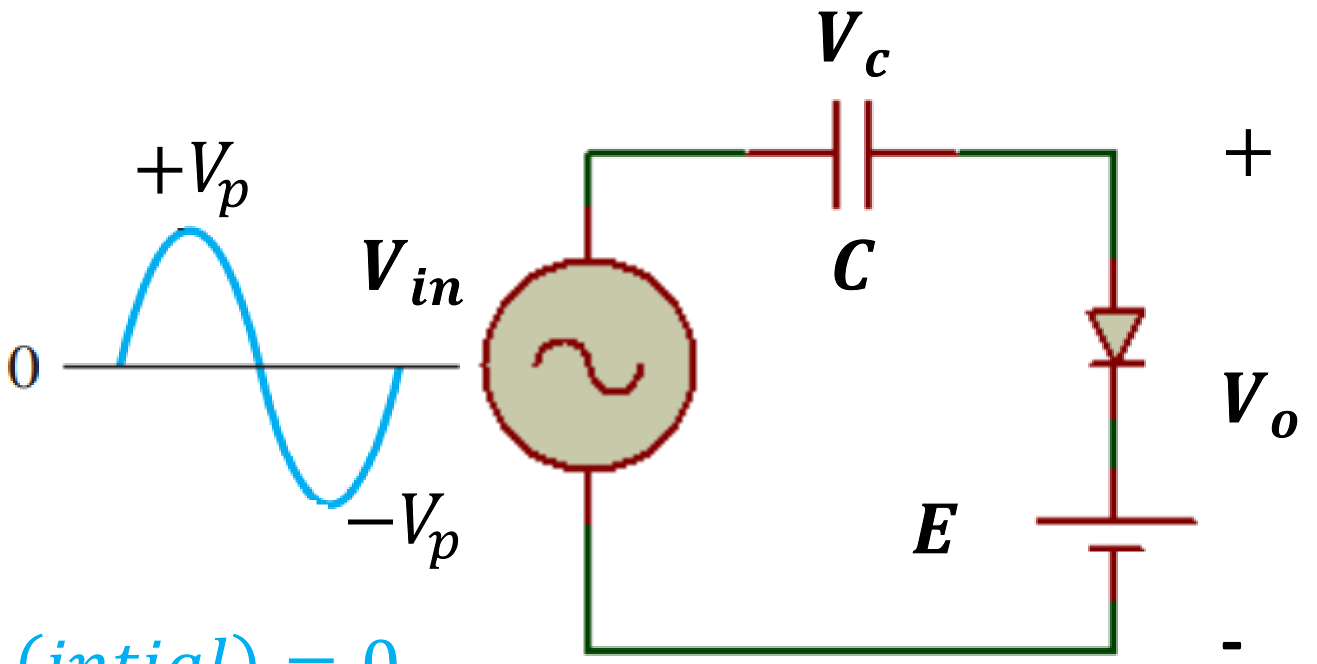
Sketch the output voltage waveform, assuming ideal diode and $\boldsymbol{V_{in} = 5\ sinwt}$.

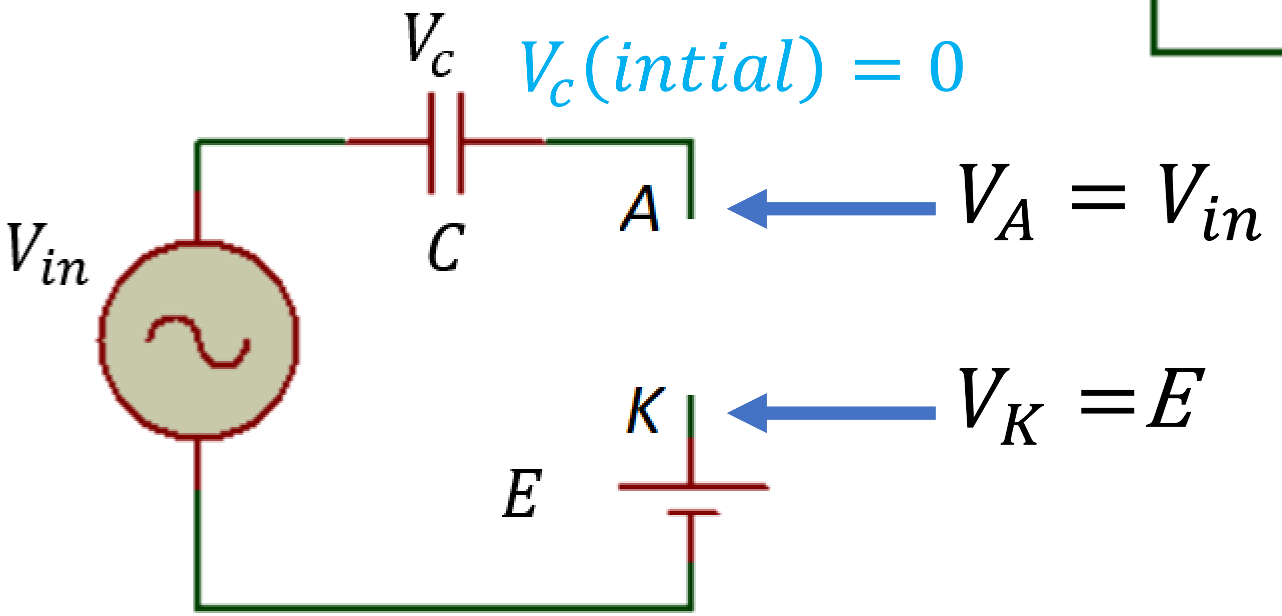


Diode is reverse and appears as open switch ($R_r = \infty$) when:

$$V_A \leq V_K + V_B$$

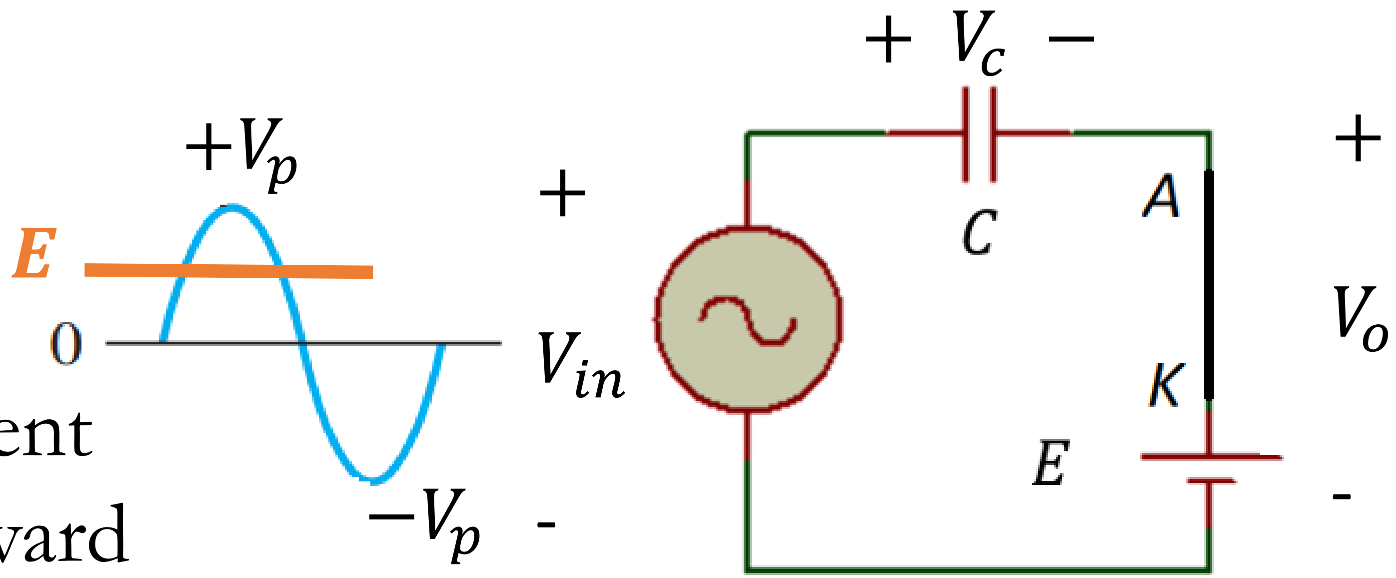
$$V_{in} \leq E + 0$$

$$V_{in} \leq E$$



Diode is forward when:

$$V_{in} > E$$



Then, substitute the equivalent circuit of ideal diode in forward region (closed switch).

The output voltage: $V_o = E$

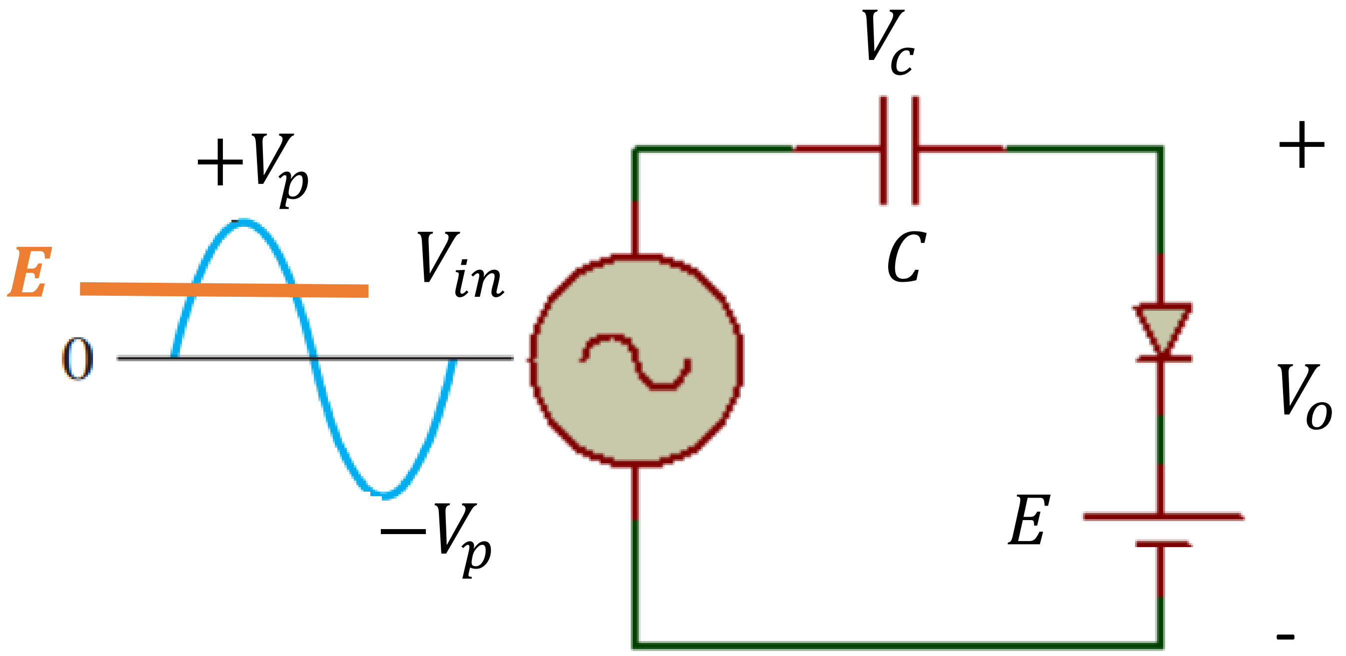
Capacitor will charge to maximum value of input voltage ($V_{in} = +V_p$)

$$V_{in} - V_c - V_o = 0$$

$$V_c = V_{in} - V_o$$

$$V_c = (+V_p) - (E)$$

Diode is reverse ($R_r = \infty$) when:



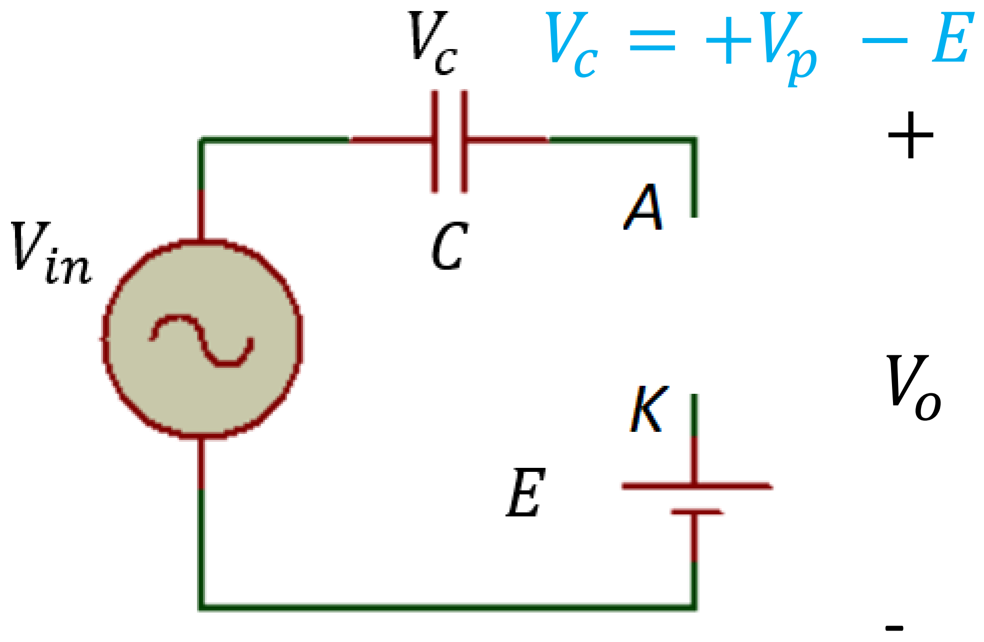
$$V_{in} \leq E$$

$$V_o = V_{in} - V_c$$

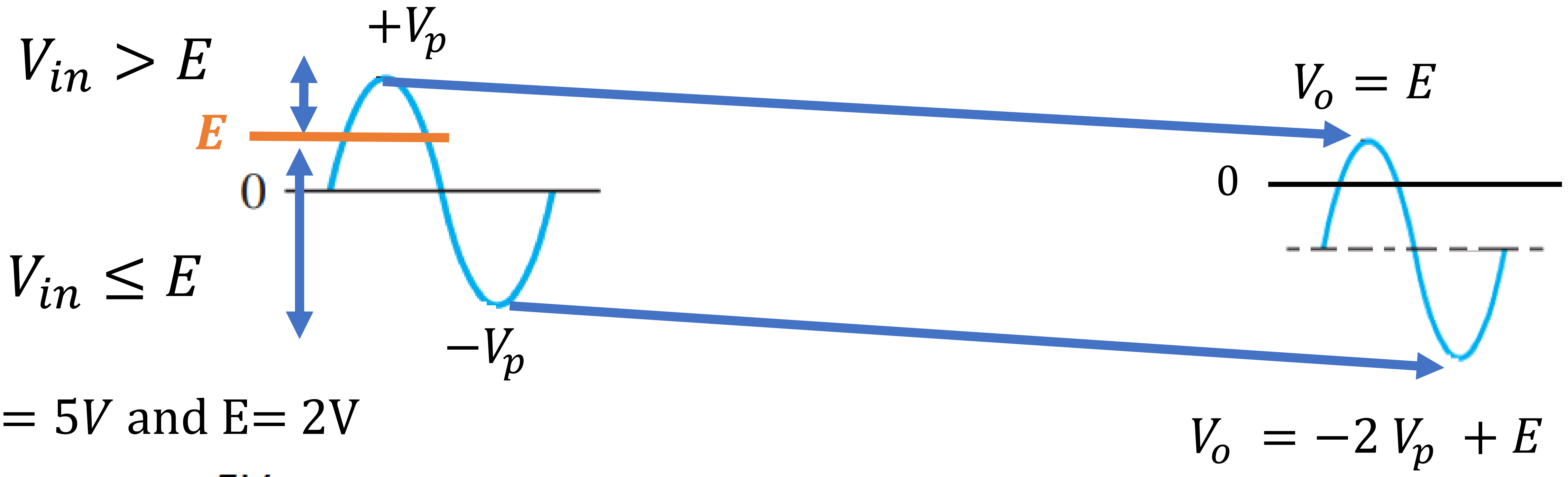
$$V_o = (-V_p) - (+V_p - E)$$

$$V_o = -V_p - V_p + E$$

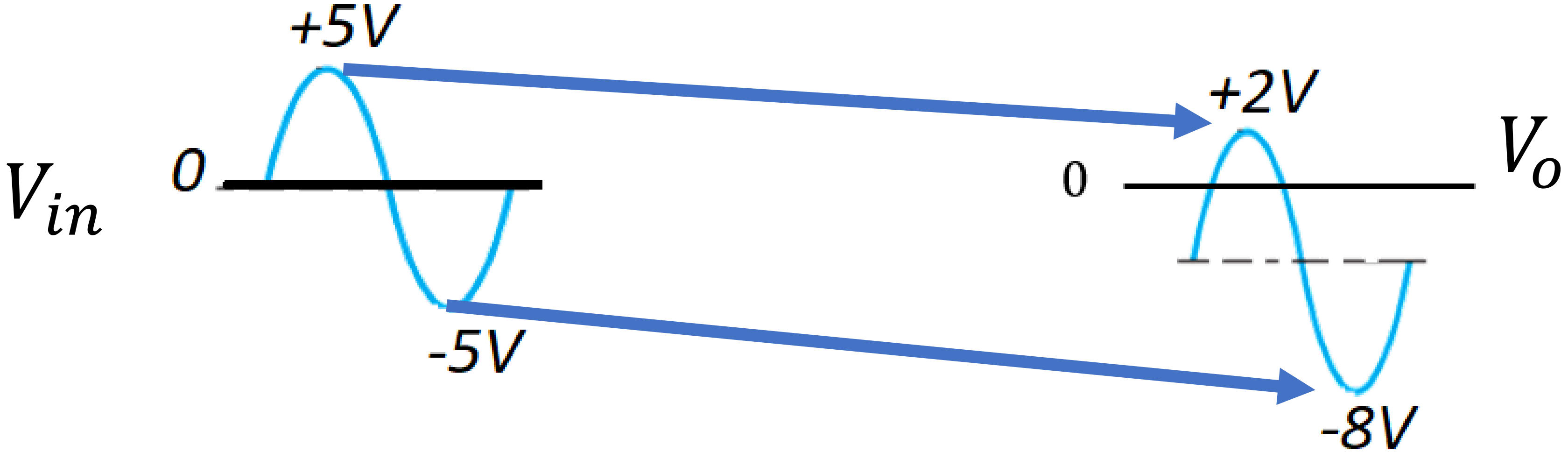
$$V_o = -2\,V_p + E$$



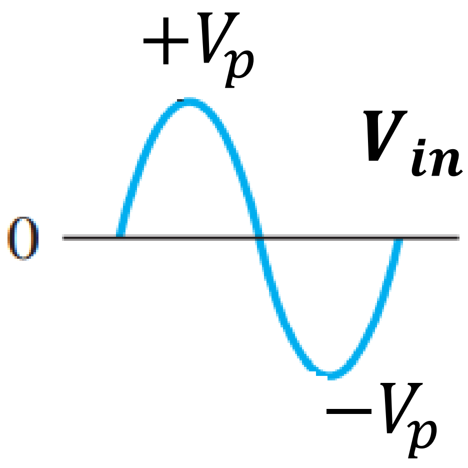
The output voltage waveform:

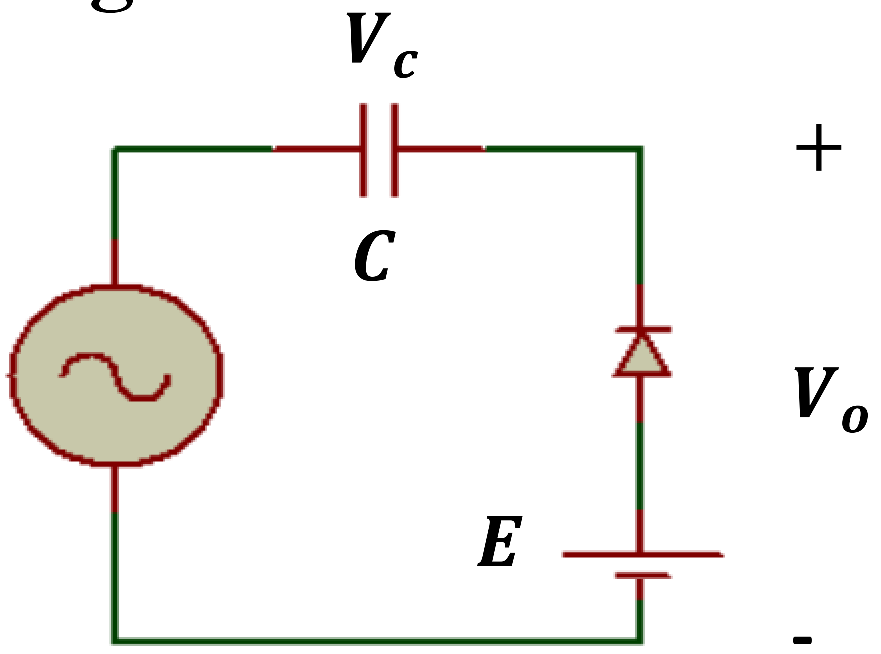


$If\ V_p = 5V$ and E= 2V



Sketch the output voltage waveform, assuming ideal diode and $\boldsymbol{V_{in} = 5\, sinwt}$.



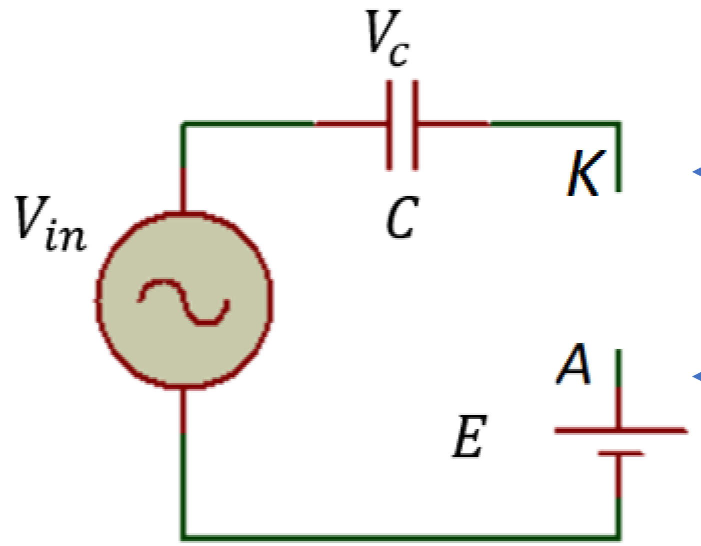


Diode is reverse and appears as open switch $(R_r = \infty)$ when:

$$V_A \leq V_K + V_B$$

$$E \leq V_{in} + 0$$

$$E \leq V_{in}$$



$V_c(intial) = 0$

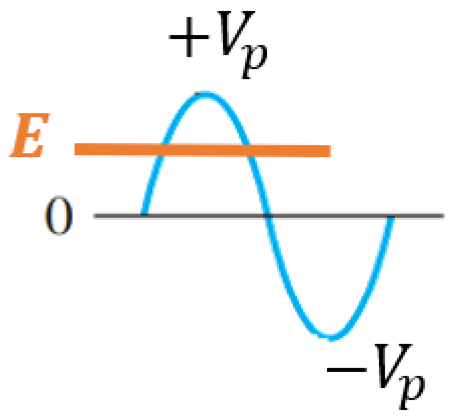
$V_K = V_{in}$

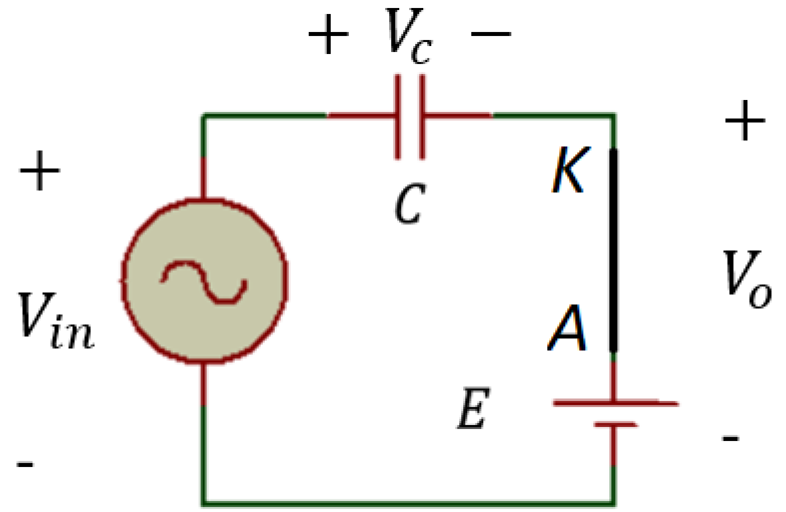
$V_A = E$

Diode is forward when:

$$V_{in} < E$$

Then, substitute the equivalent circuit of ideal diode in forward region (closed switch).





The output voltage: $V_o = E$

Capacitor will charge to maximum value of input voltage ($V_{in} = -V_p$)

$$V_{in} - V_c - V_o = 0$$

$$V_c = V_{in} - V_o$$

$$V_c = (-V_p) - (E)$$

Diode is reverse ($R_r = \infty$) when:

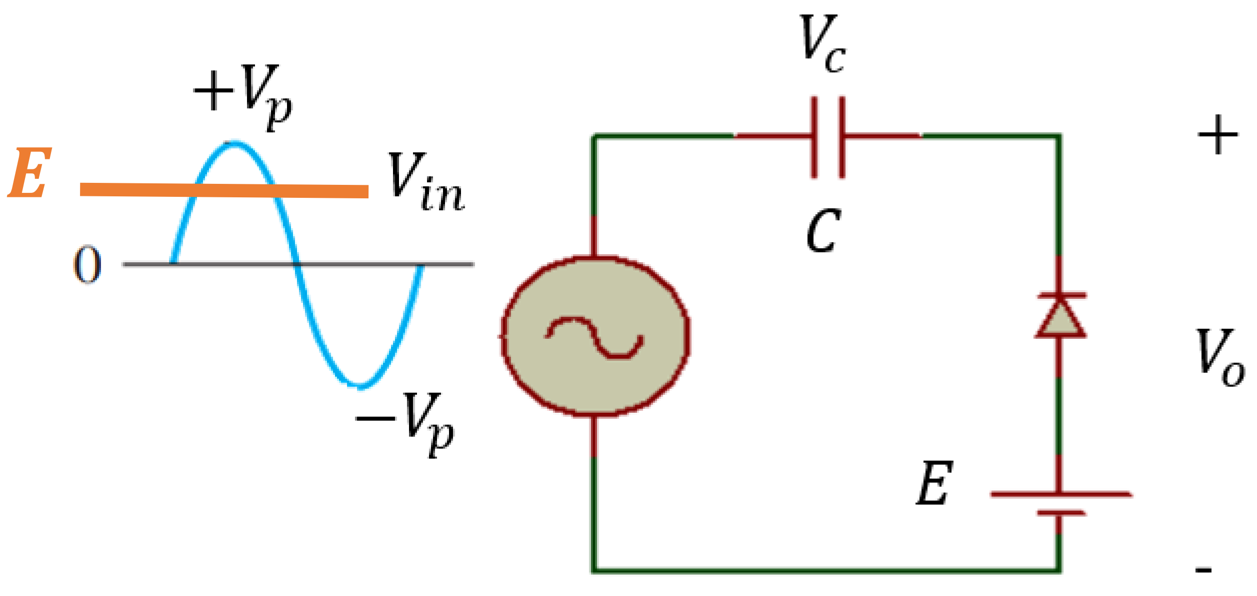
$$V_{in} \geq E$$

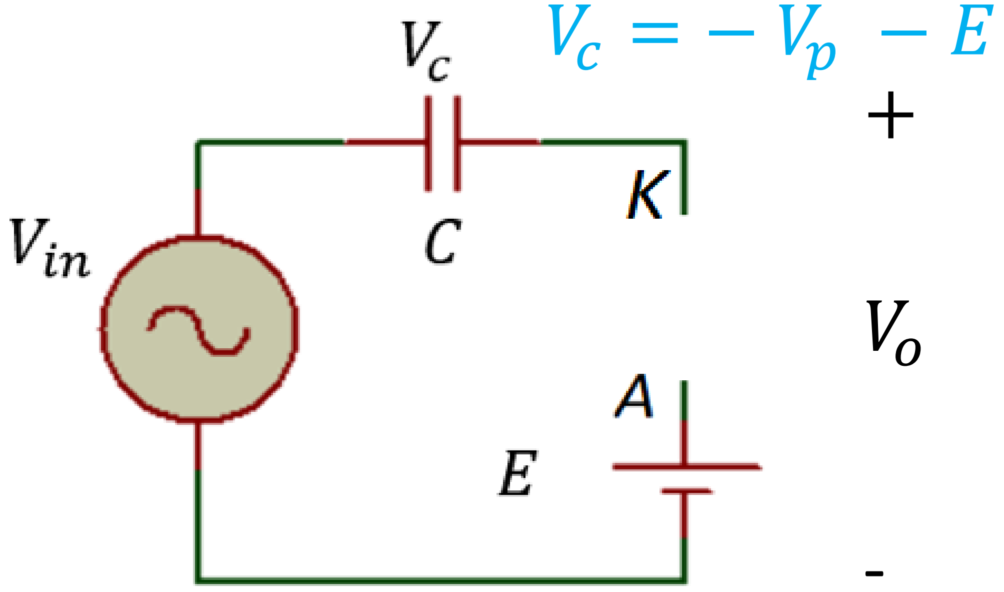
$$V_o = V_{in} - V_c$$

$$V_o = (+V_p) - (-V_p - E)$$

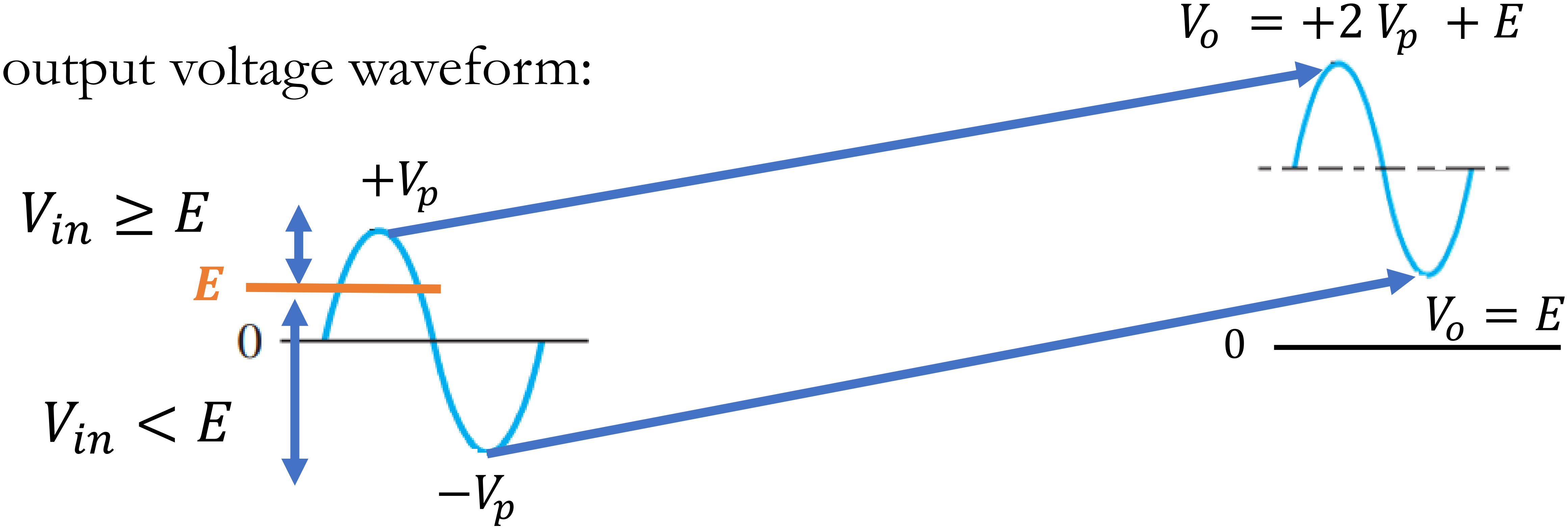
$$V_o = +V_p + V_p + E$$

$$V_o = +2\,V_p + E$$

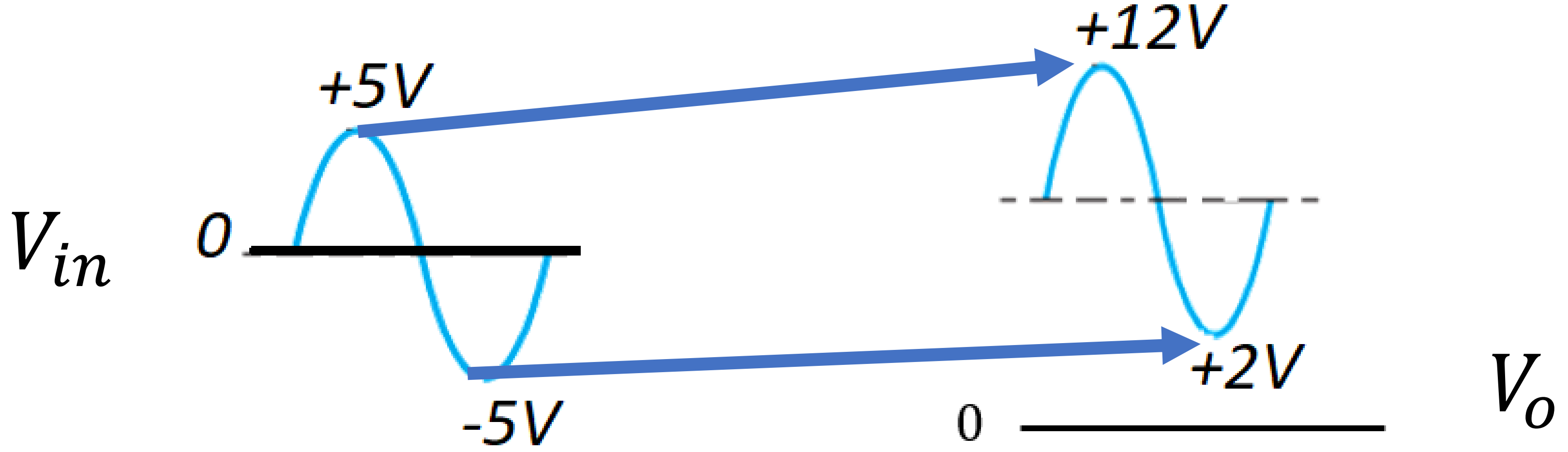




The output voltage waveform:

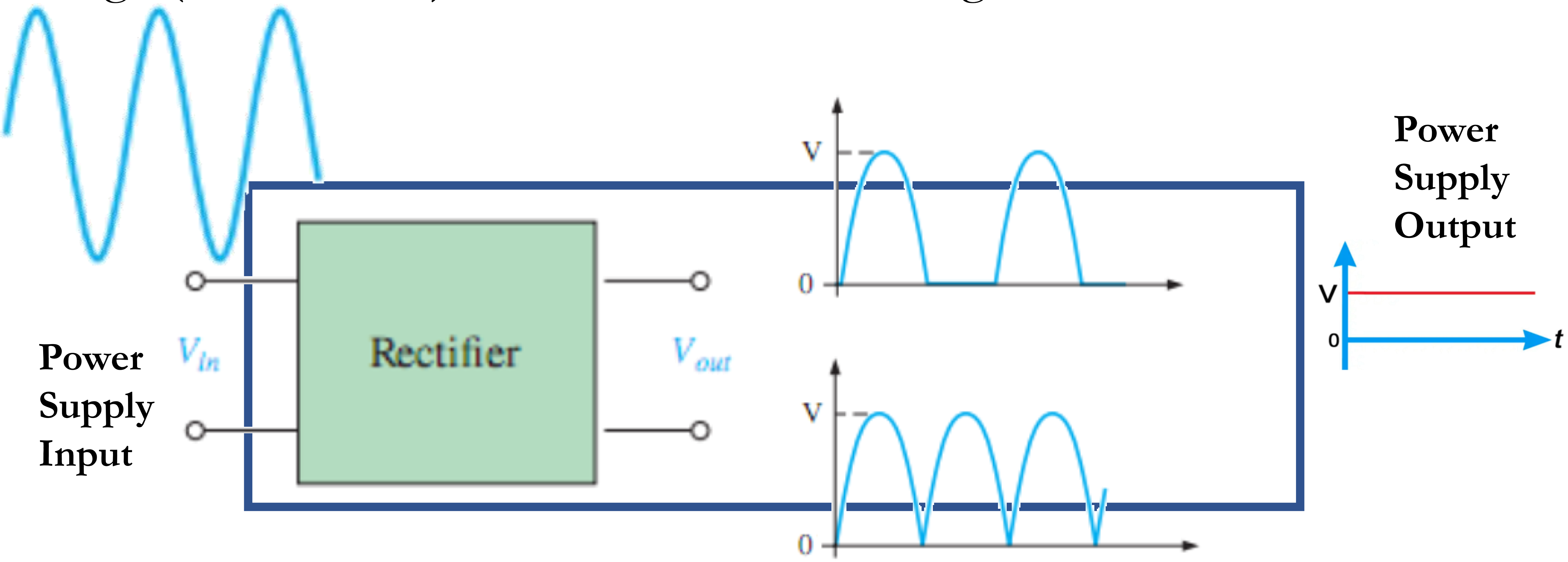


$If\ V_p = 5V$ and E= 2V

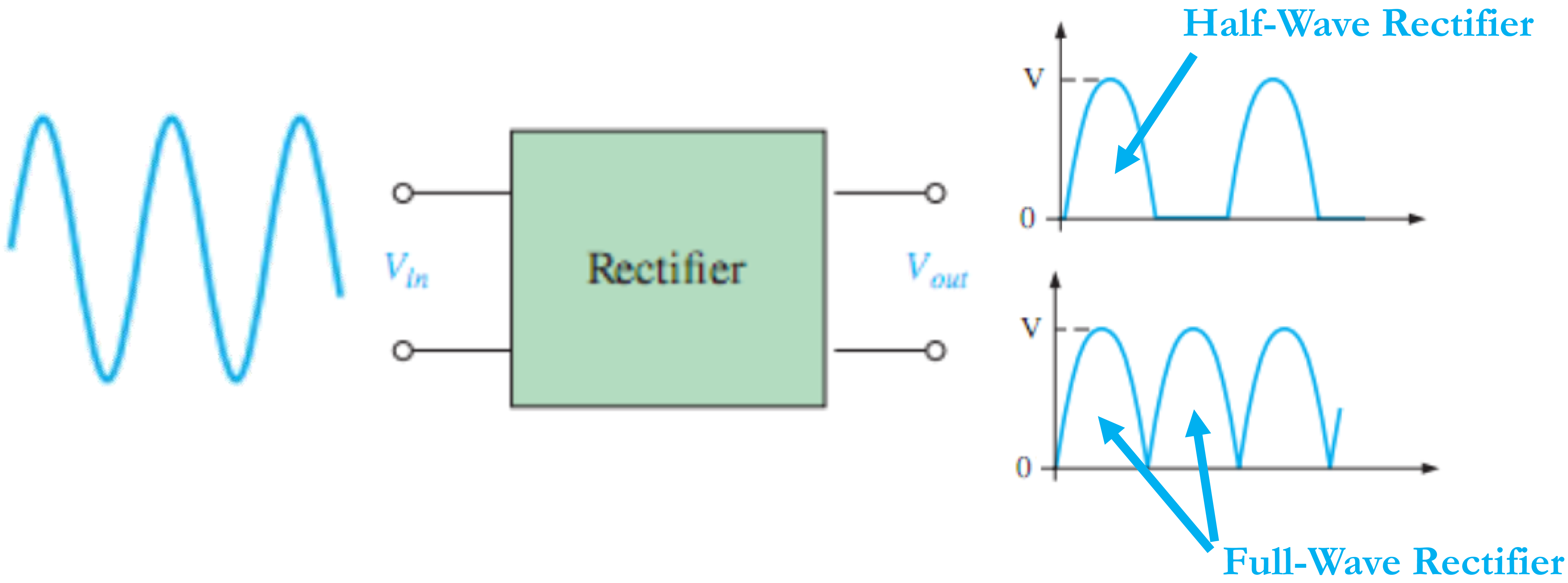


❑ Rectifier Circuits

Rectifier is found in all dc power supply. Power supply is an essential part in each electronic system. Power supplies convert the standard ac voltage (220V, 50Hz) into a constant dc voltage.

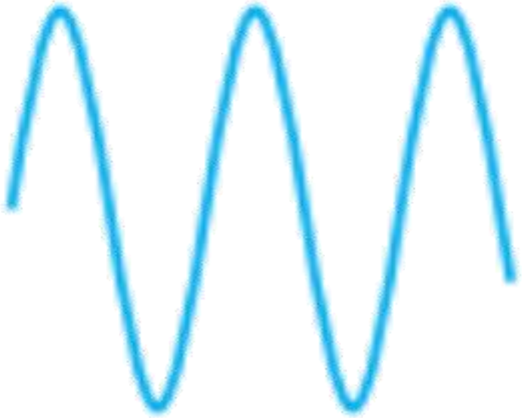


Rectifier circuits convert ac signal to unidirectional signal.



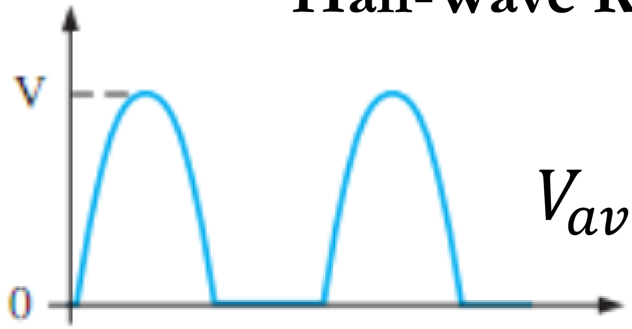
Rectifier can be either half-wave rectifier or full-wave rectifier.

In other words, **rectifier circuits** convert ac signal with zero average value to unidirectional signal with non-zero average value.



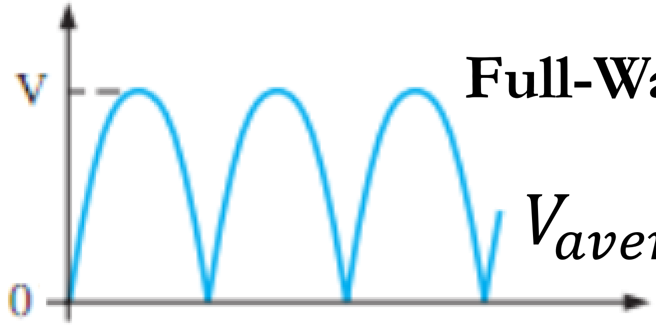
$$V_{average} = zero$$

Half-Wave Rectifier



$$V_{average} = \frac{V}{\pi}$$

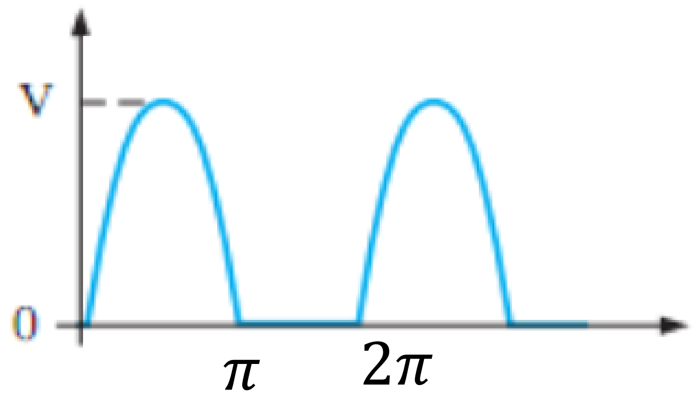
Full-Wave Rectifier



$$V_{average} = \frac{2V}{\pi}$$

Average value of half-wave rectified voltage is the value you would measure on a dc voltmeter. Mathematically, it is calculated by:

$$V_{average} = \frac{area\ under\ the\ curve\ over\ a\ full\ cycle}{full\ cycle}$$



$$V_{average} = \frac{\int_0^{\pi} V \sin\theta \, d\theta}{2\pi}$$

$$V_{average} = \frac{V\ [-cos\theta\ ]_0^{\pi}}{2\pi}$$

$$V_{average} = \frac{-V\ [cos\pi\ - cos0\ ]}{2\pi}$$

$$V_{average} = \frac{-V\ [(-1)\ - (1)\ ]}{2\pi} = \frac{-V\ [-2]}{2\pi} = \frac{V}{\pi}$$

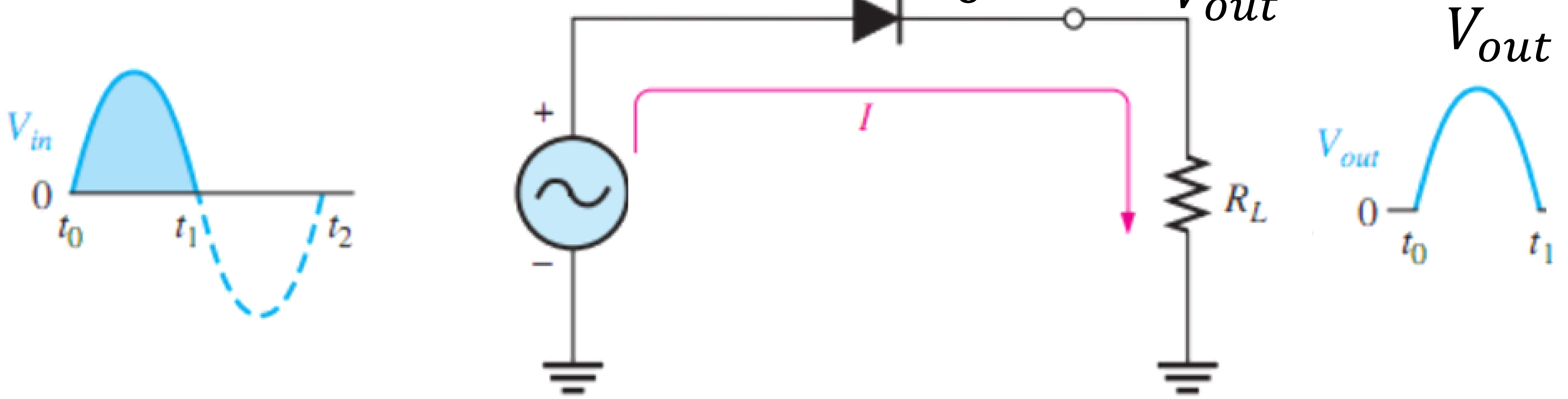
Half-Wave Rectifier Operation

A diode is connected to an ac source and to a resistor (R_L).

During the positive half cycle of the sinusoidal input voltage (V_{in}), the diode is forward-biased, acts as closed switch (ideal diode), and conducts current through the resistor.

The current produces an output voltage across the resistor, which has the same shape as the positive half-cycle of the input voltage.

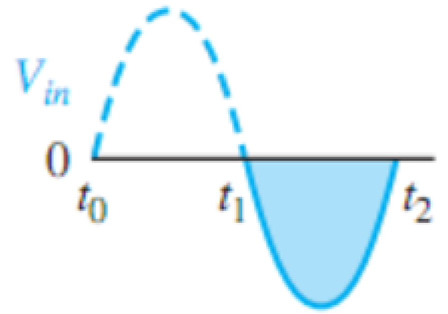
$+V_{p(in)}$ 0 V_{out}

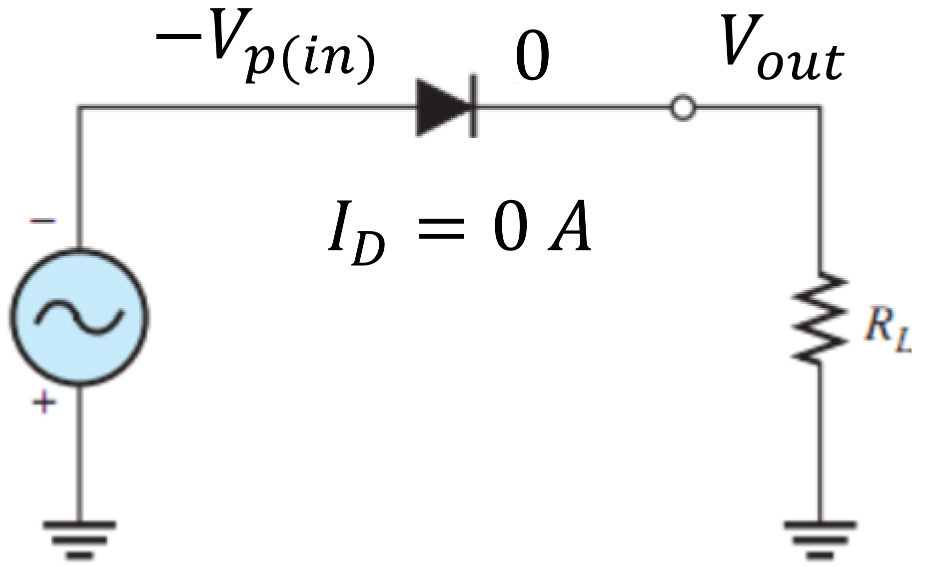


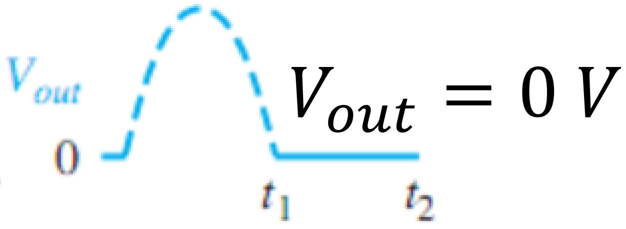
$$V_{out} = V_{in} = +V_{p(in)}$$

During the negative half cycle of the sinusoidal input voltage, the diode is reverse-biased and acts as open switch ($R_r = \infty$).

There is no current, so the output voltage across the resistor is 0 V.



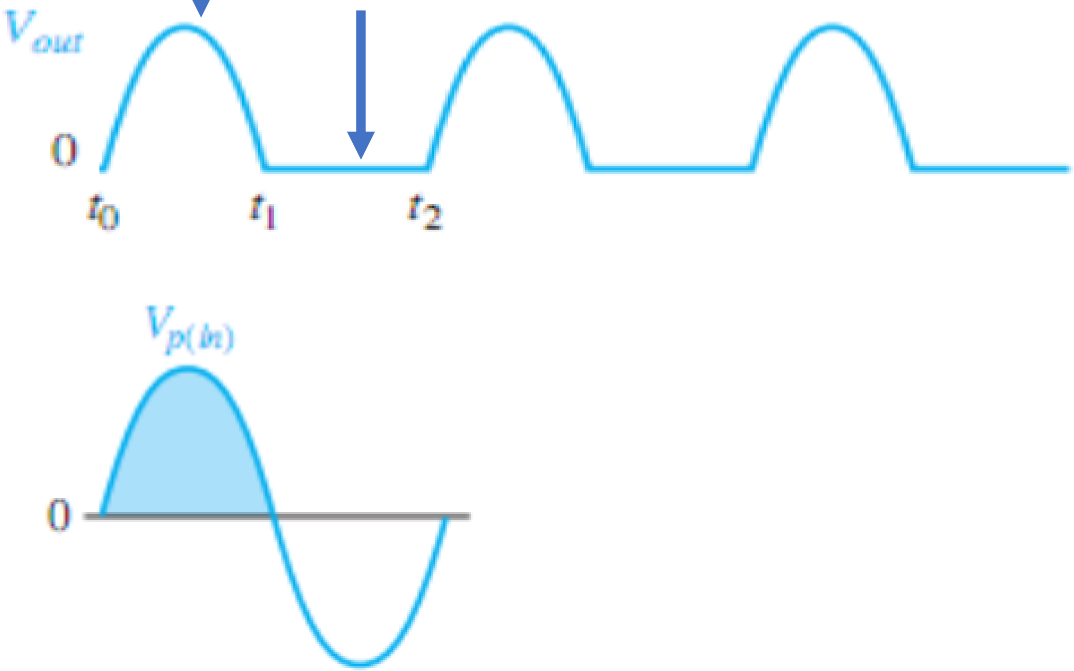




The output voltage waveform:

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

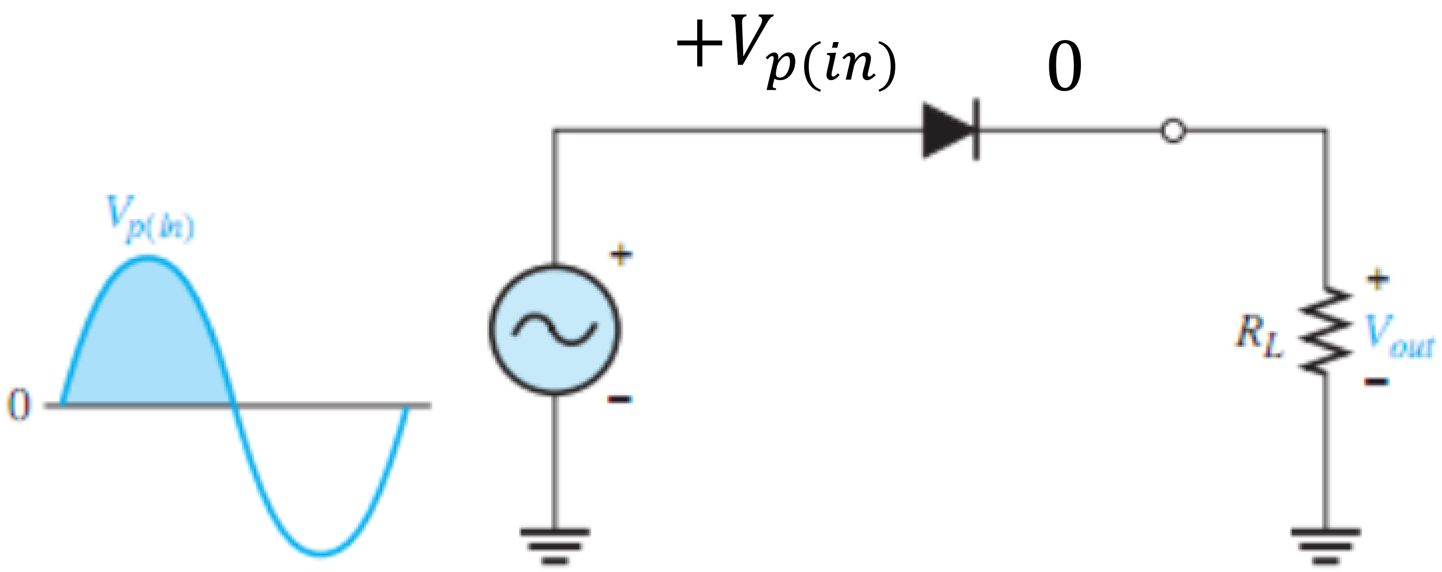
$$V_{out} = 0$$



Effect of Barrier Potential on Half-Wave Rectifier Output

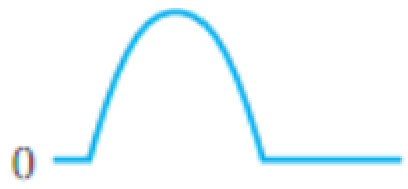
When practical diode model is used with the barrier potential of V_B.

During the positive half-cycle, the input voltage must overcome the barrier potential in order to the diode becomes forward-biased.

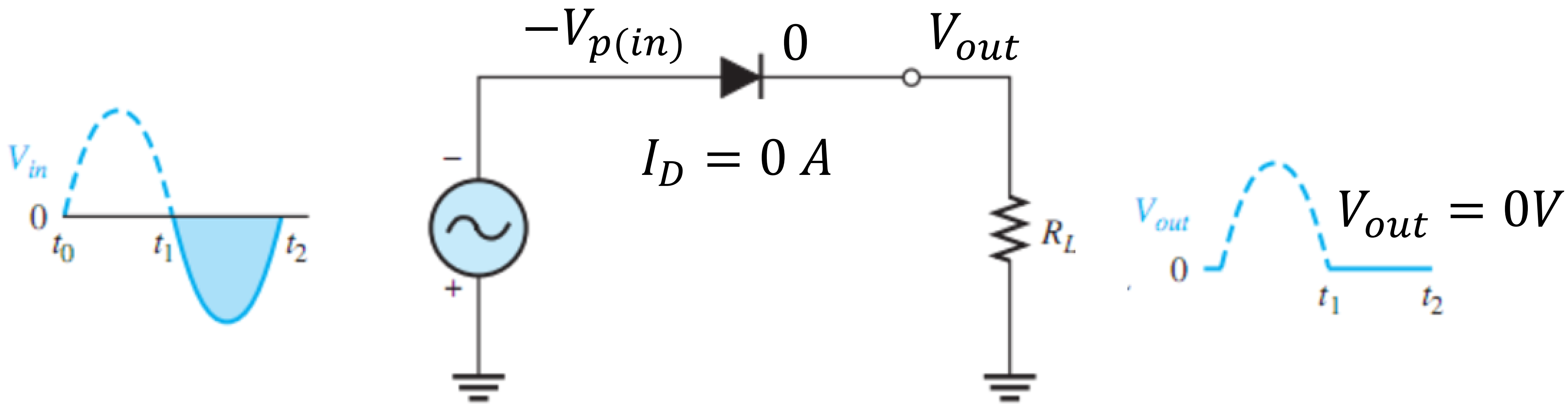


$$V_{out} = V_{in} - V_B$$

$$V_{out} = V_{p(in)} - V_B$$



During the negative half cycle of the sinusoidal input voltage, the diode is reverse-biased and acts as open switch ($R_r = \infty$).

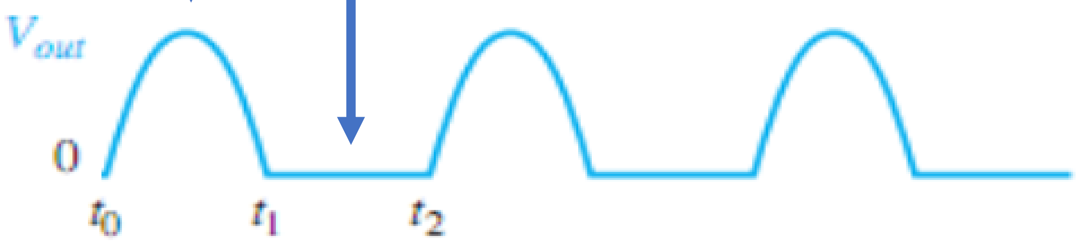


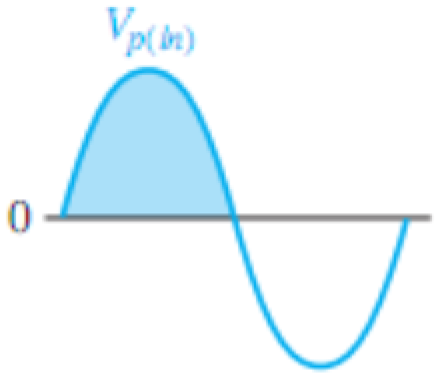
There is no current, so the output voltage across the resistor is 0V.

The output voltage waveform:

$$V_{out} = V_{p(in)} - V_B$$

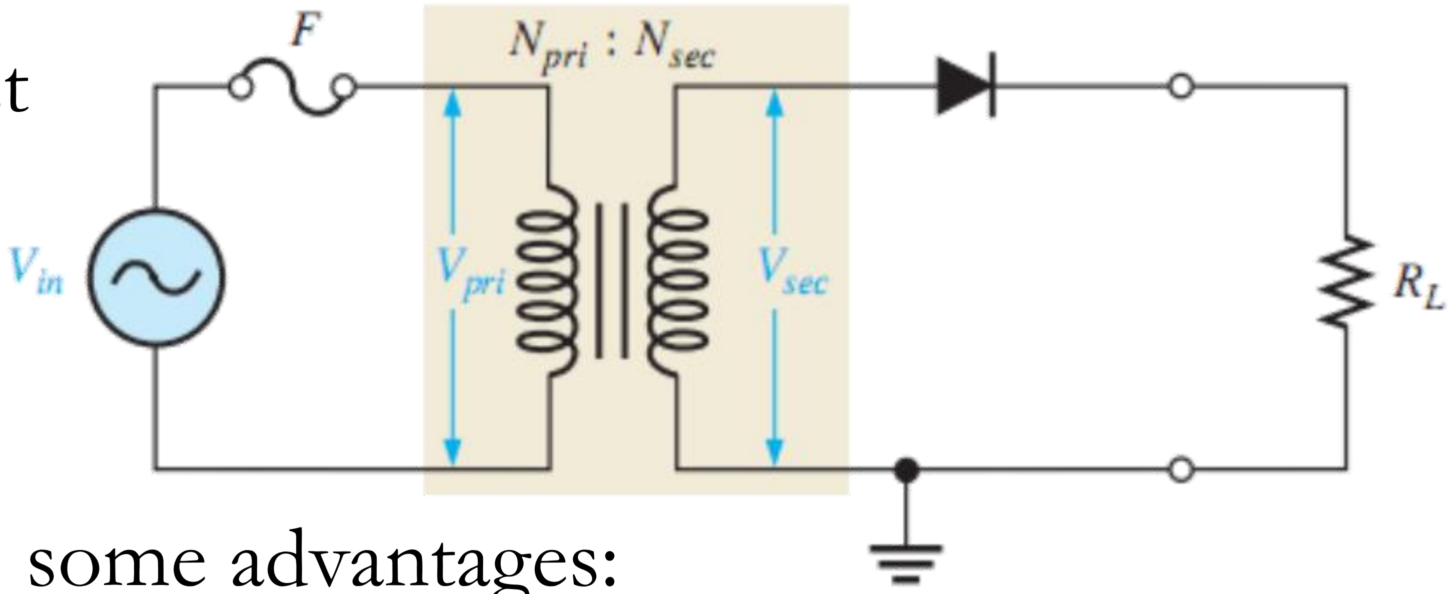
$$V_{out} = 0$$





Half-Wave Rectifier with Transformer

Transformer is used to connect ac input voltage source to the rectifier circuit.



Transformer coupling provides some advantages:

First, it allows input voltage source to be stepped up or down as needed.

$$V_{pri} = V_{in} \qquad and \qquad V_{sec} = \frac{N_{sec}}{N_{pri}} V_{pri} = \frac{N_{sec}}{N_{pri}} V_{in}$$

Second, the ac source is electrically isolated from the rectifier, thus avoiding a shock in the secondary circuit.

Operation of Half-Wave Rectifier with Transformer

During the positive half cycle of the sinusoidal input voltage (V_{in}), the diode is forward-biased.

$$V_{pri} = V_{in}$$

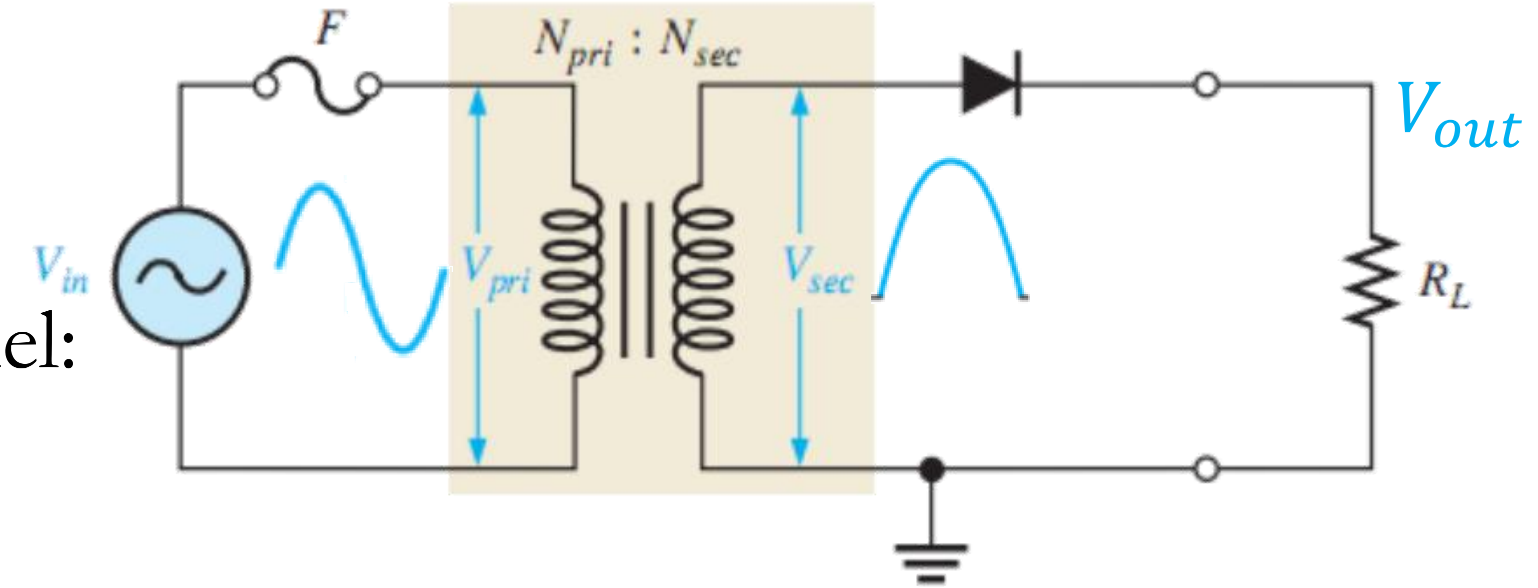
$$V_{sec} = \frac{N_{sec}}{N_{pri}} V_{pri} = \frac{N_{sec}}{N_{pri}} V_{in}$$

- ❑ Using diode ideal model:

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

- ❑ Using diode practical model:

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

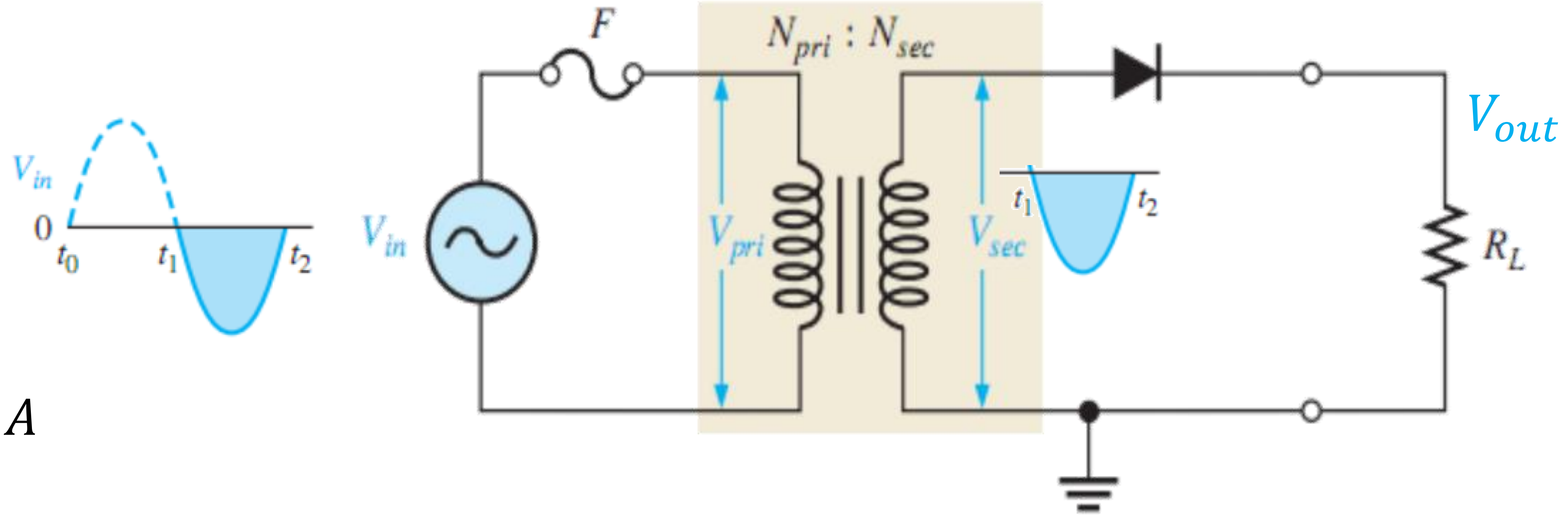


$$V_{p(sec)} = \frac{N_{sec}}{N_{pri}} V_{p(pri)} = \frac{N_{sec}}{N_{pri}} V_{p(in)}$$

During the negative half cycle of the sinusoidal input voltage (V_{in}),

Diode is reverse-biased and acts as open switch.

$V_{pri} = -V_{p(in)}$ $\quad$ $V_{p(sec)} = \frac{N_{sec}}{N_{pri}} V_{p(pri)} = -\frac{N_{sec}}{N_{pri}} V_{p(in)}$



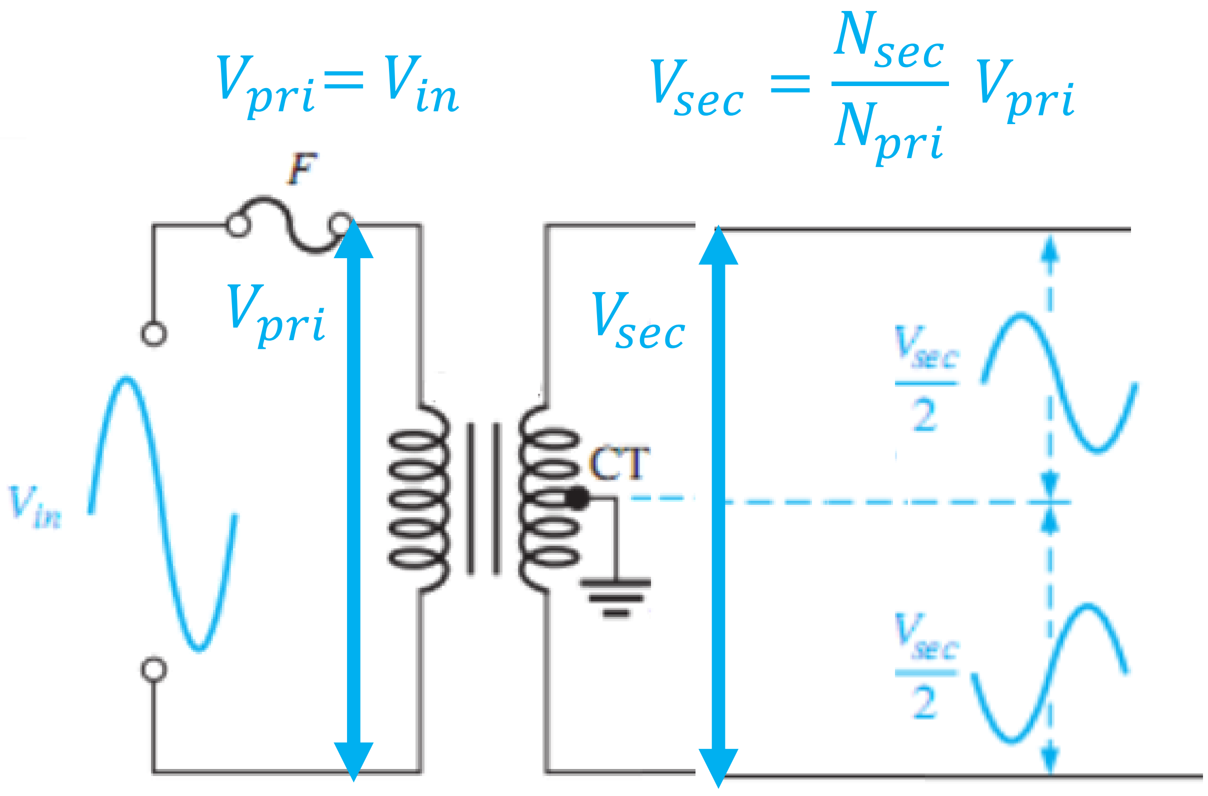
$I_D = 0\ A$

$V_{out} = 0\ V$

Full-Wave Rectifier Using Center-Tapped Transformer

In center-tapped transformer, the middle point of the secondary winding is connected to ground (zero volts).

This divides the secondary winding into two parts.

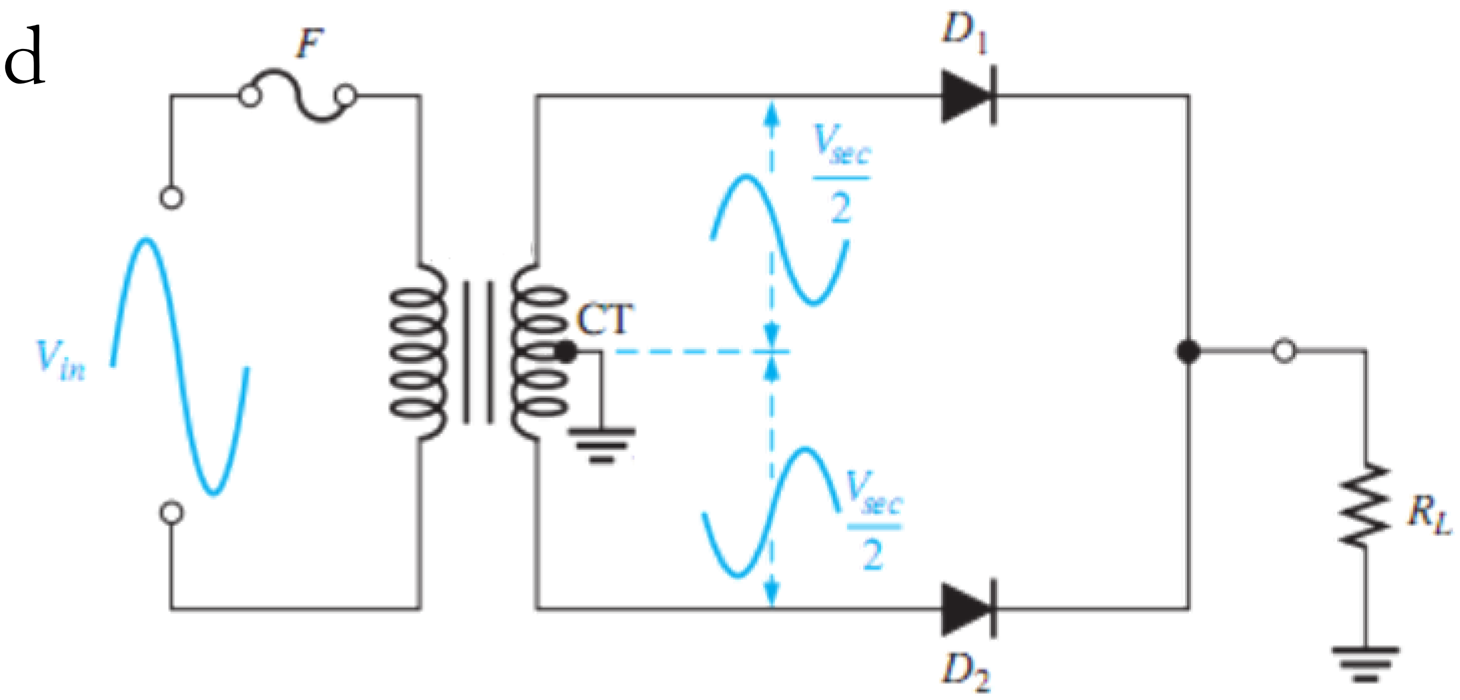


This allows the transformer to provide two separate signals which are equal in magnitude, but opposite in polarity, between the center and each end of the secondary winding.

Center-Tapped Full-Wave Rectifier Operation

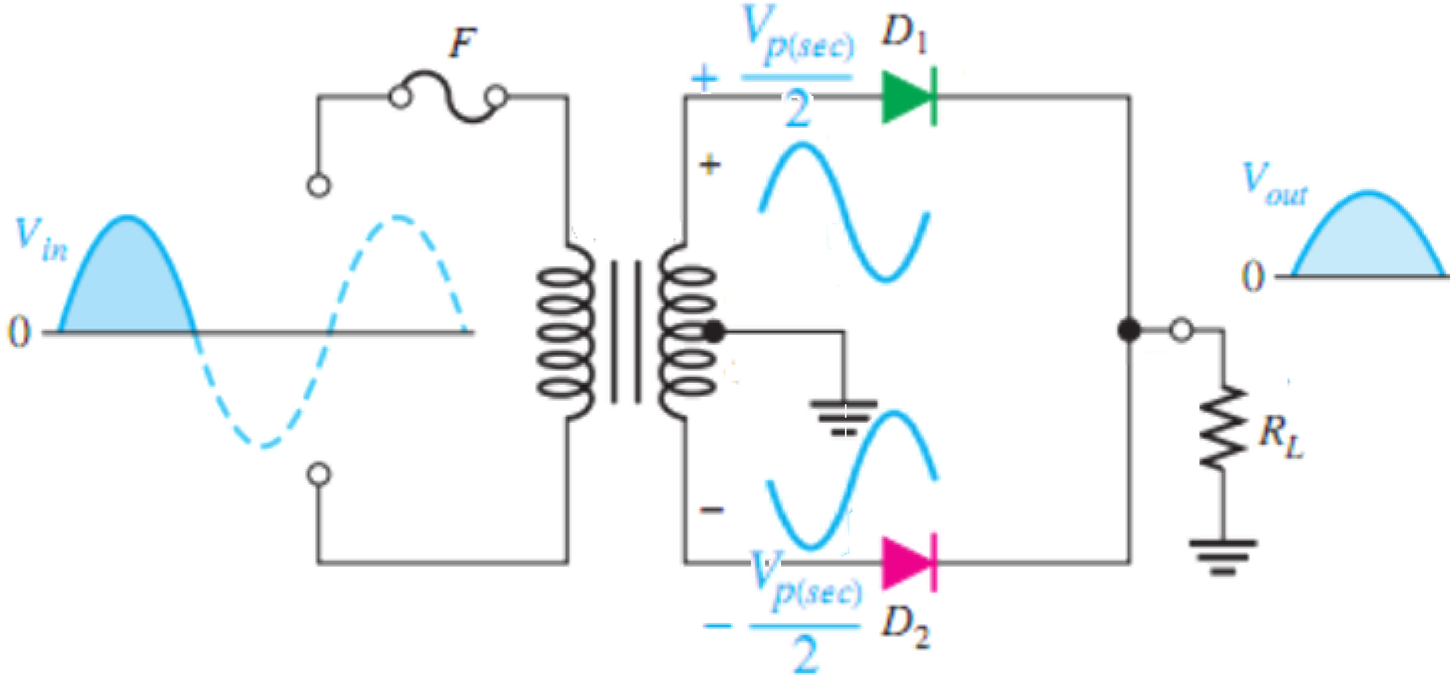
The input voltage is connected to the primary winding.

The center-tapped rectifier uses two diodes, connected to ends of the secondary winding.



The center-tapped transformer provides half of the secondary voltage, between the center and each end of the secondary winding, then to the anode of each diode.

During **positive** half-cycle of the input voltage (V_{in}):

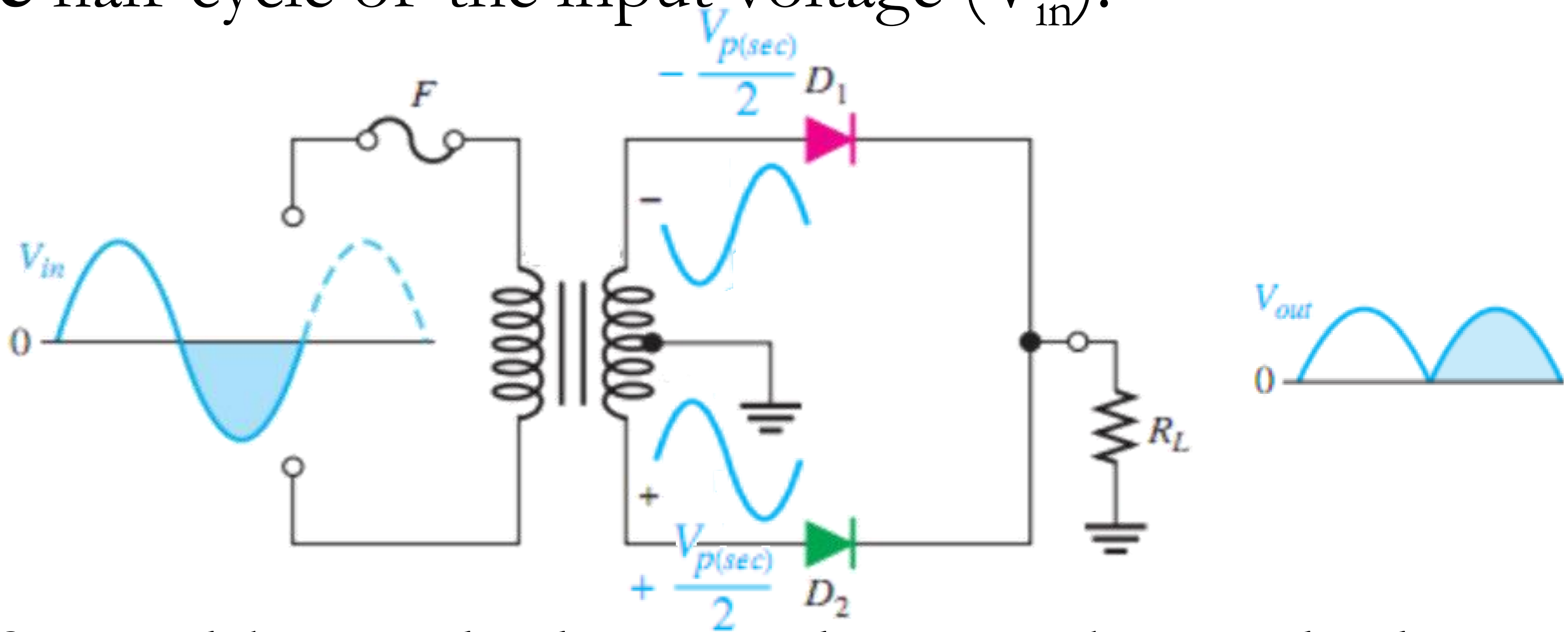


This condition forward-biases diode D_1 and reverse-biases diode D_2. The current flow through D_1 and the resistor.

The output voltage across the resistor is:

$$V_{out} = \frac{V_{p(sec)}}{2} \quad \text{(Ideal Diode)} \qquad or \qquad V_{out} = \frac{V_{p(sec)}}{2} - V_B \quad \text{(Practical Diode)}$$

During **negative** half-cycle of the input voltage (V_{in}):



This condition forward-biases diode D_2 and reverse-biases diode D_1. The current flow through D_2 and the resistor.

The output voltage across the resistor is:

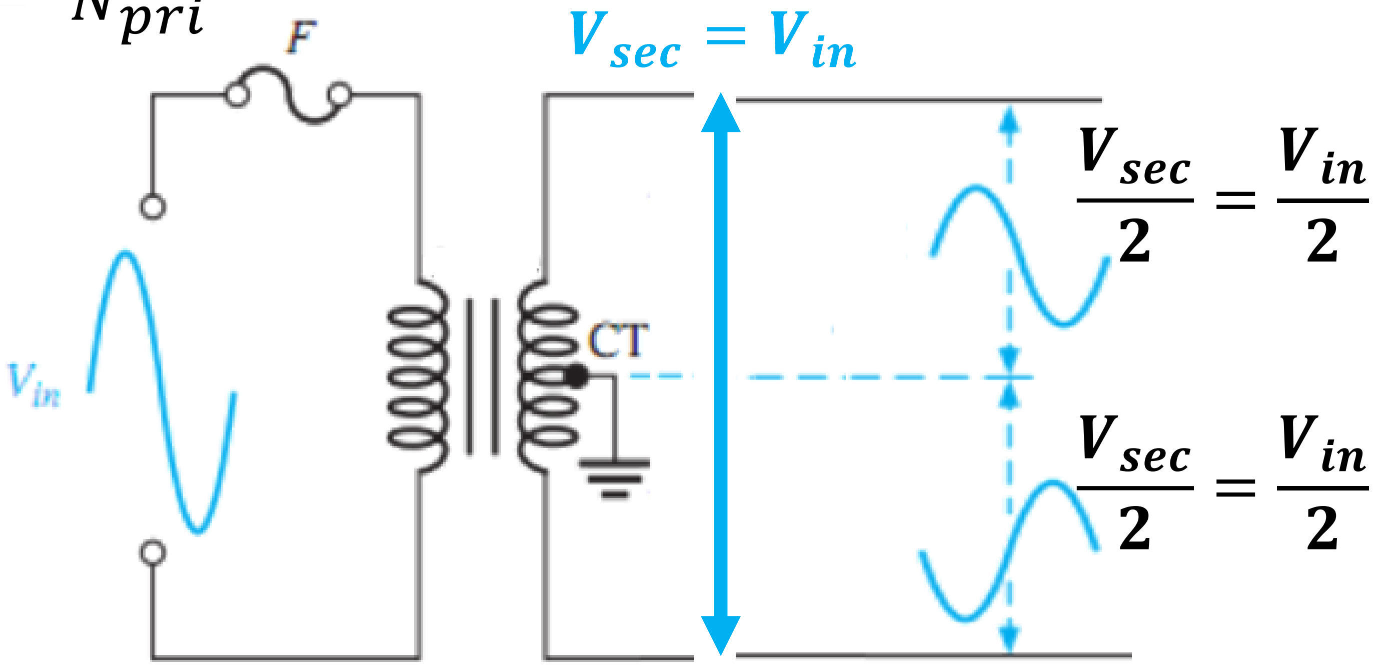
$$V_{out} = \frac{V_{p(sec)}}{2} \qquad or \qquad V_{out} = \frac{V_{p(sec)}}{2} - V_B$$

(Ideal Diode) (Practical Diode)

If transformer with turns ratio of $\frac{N_{sec}}{N_{pri}} = 1.$

$$V_{in} = V_{pri}$$

$$V_{sec} = \frac{N_{sec}}{N_{pri}} V_{pri} = V_{pri} = V_{in}$$



The output voltage across the resistor is:

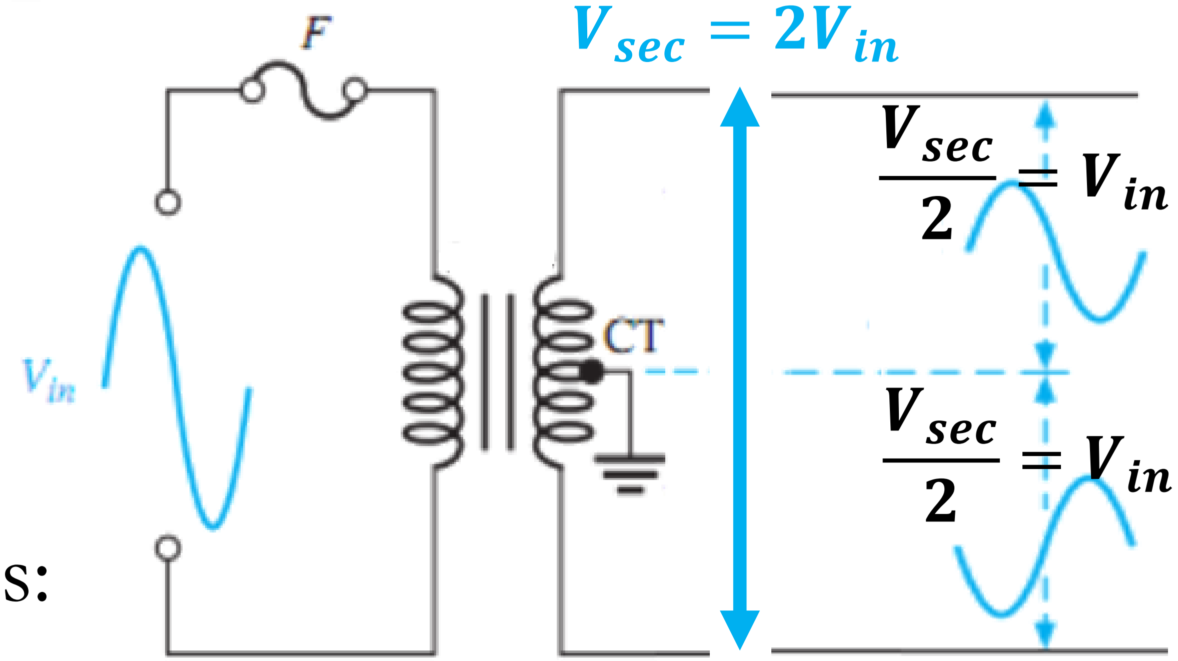
$$V_{out} = \frac{V_{p(sec)}}{2} = \frac{V_{p(in)}}{2} \qquad \text{(Ideal Diode)}$$

$$V_{out} = \frac{V_{p(sec)}}{2} - V_B = \frac{V_{p(in)}}{2} - V_B \qquad \text{(Practical Diode)}$$

In order to obtain output voltage with a peak equal to input peak, a transformer with turns ratio of $\frac{N_{sec}}{N_{pri}} = 2$, must be used.

$$V_{in} = V_{pri}$$

$$V_{sec} = \frac{N_{sec}}{N_{pri}} V_{pri} = 2V_{pri} = 2\,V_{in}$$



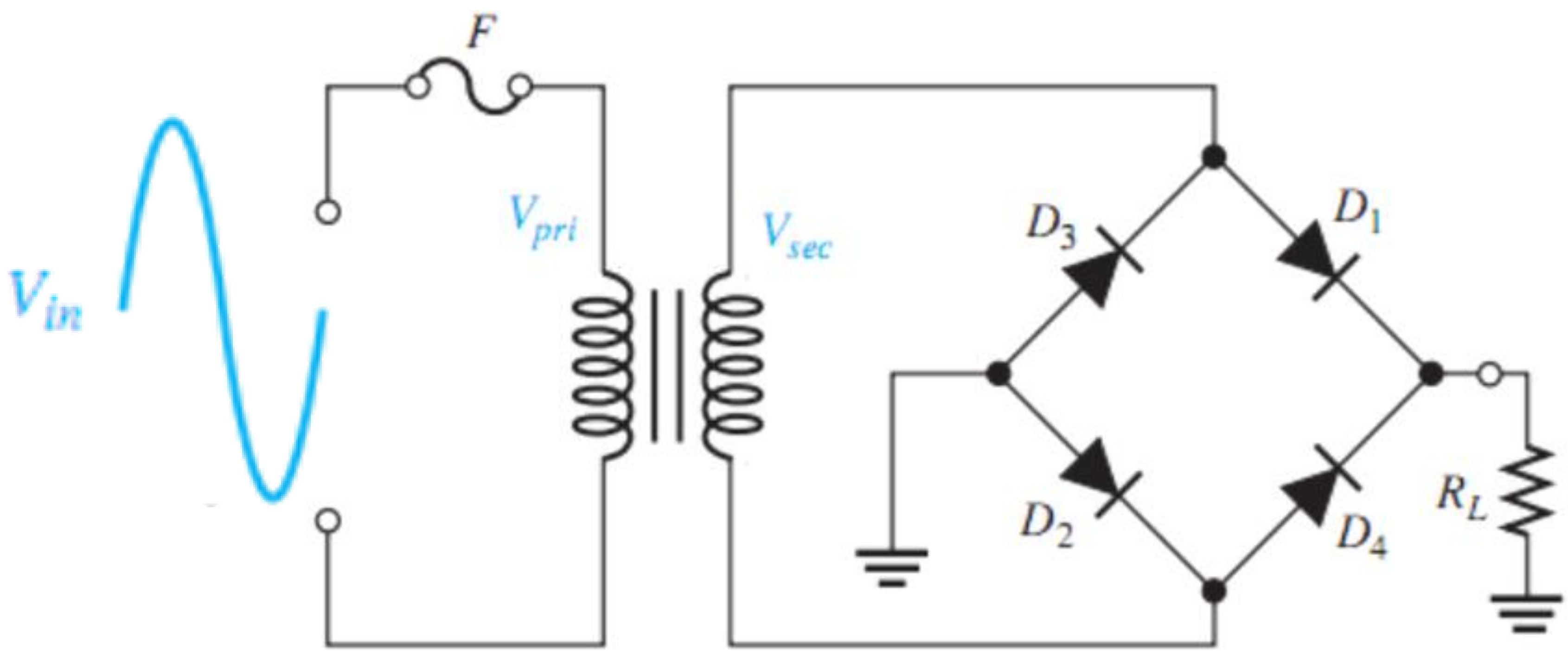
The output voltage across the resistor is:

$$V_{out} = \frac{V_{p(sec)}}{2} = V_{p(in)} \qquad \text{(Ideal Diode)}$$

$$V_{out} = \frac{V_{p(sec)}}{2} - V_B = V_{p(in)} - V_B \qquad \text{(Practical Diode)}$$

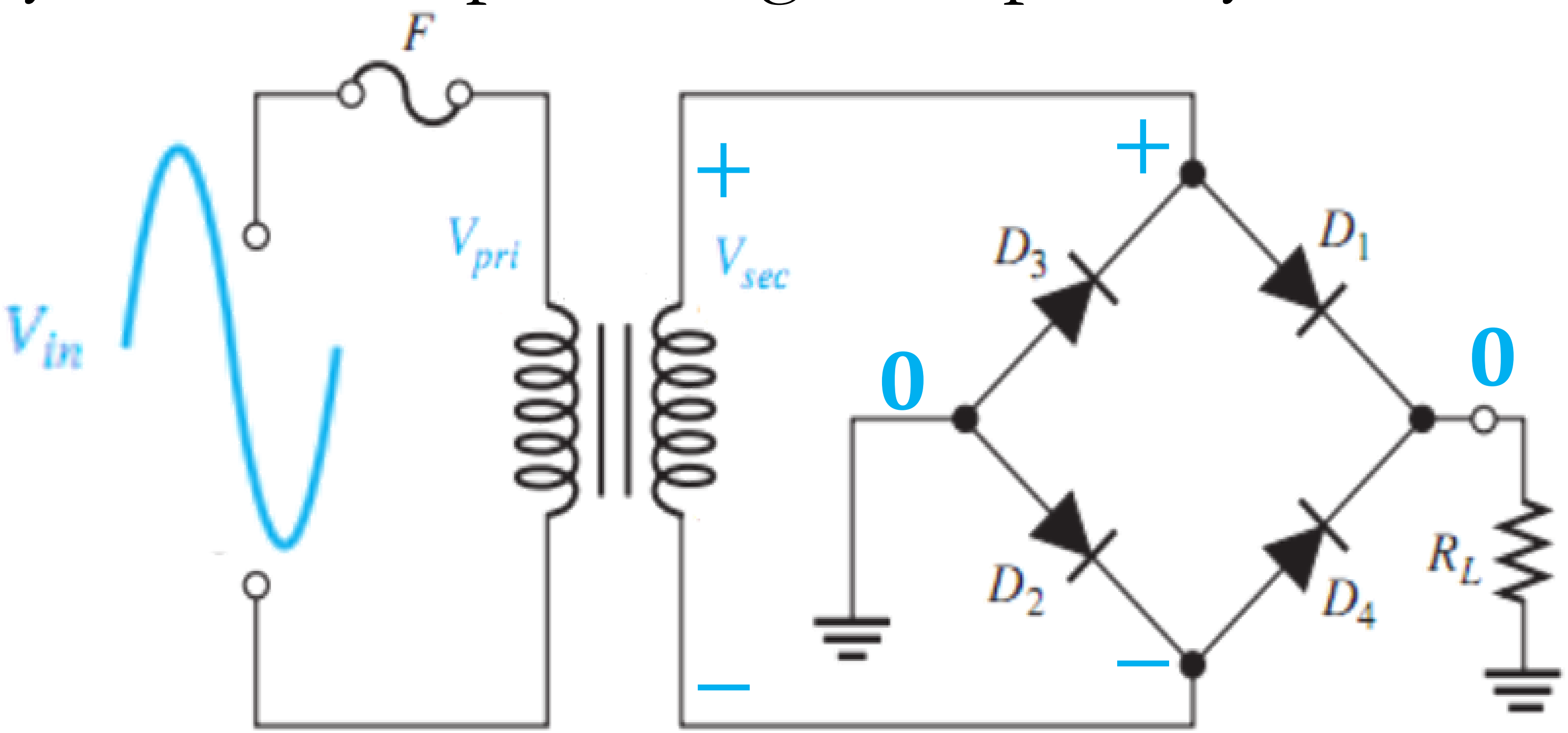
Bridge Full-Wave Rectifier Operation

The input voltage is connected to the primary winding.



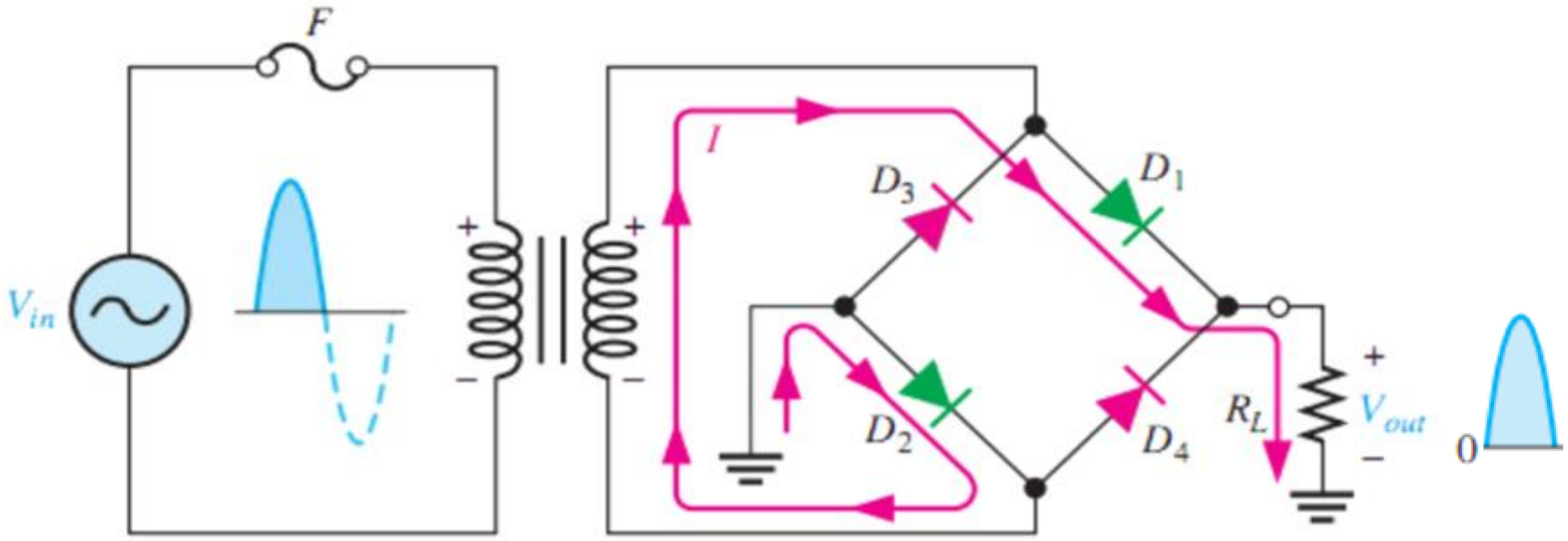
The bridge rectifier uses four diodes connected to the ends of the secondary winding.

During positive half-cycle of the input voltage, the polarity of the secondary voltage is:



Diodes D_1 and D_2 are forward-biased.
Diodes D_3 and D_4 are reverse-biased.

The current flow through D_1 and D_2 then to the resistor.

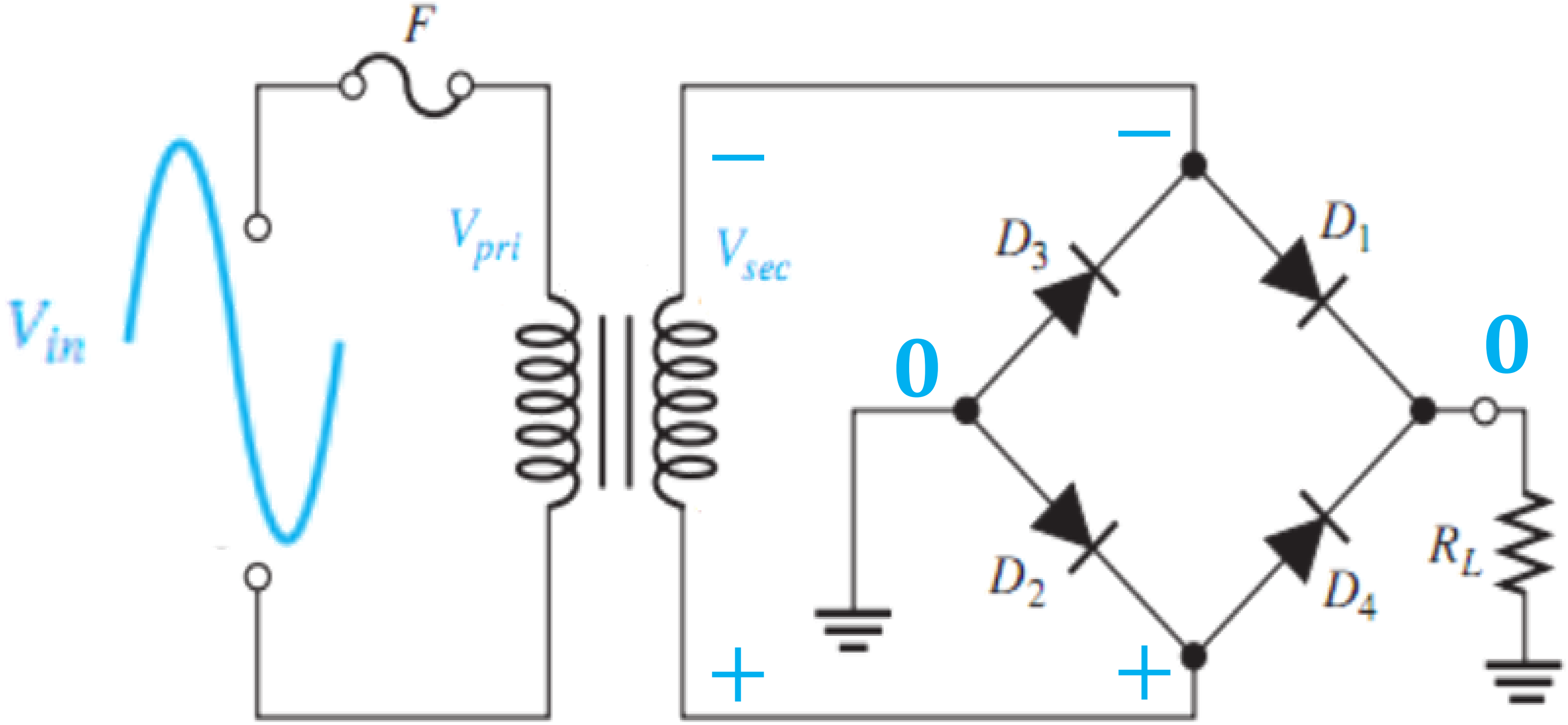


The output voltage across the resistor is:

$$V_{out} = V_{p(sec)} \qquad \text{(Ideal Diode)}$$

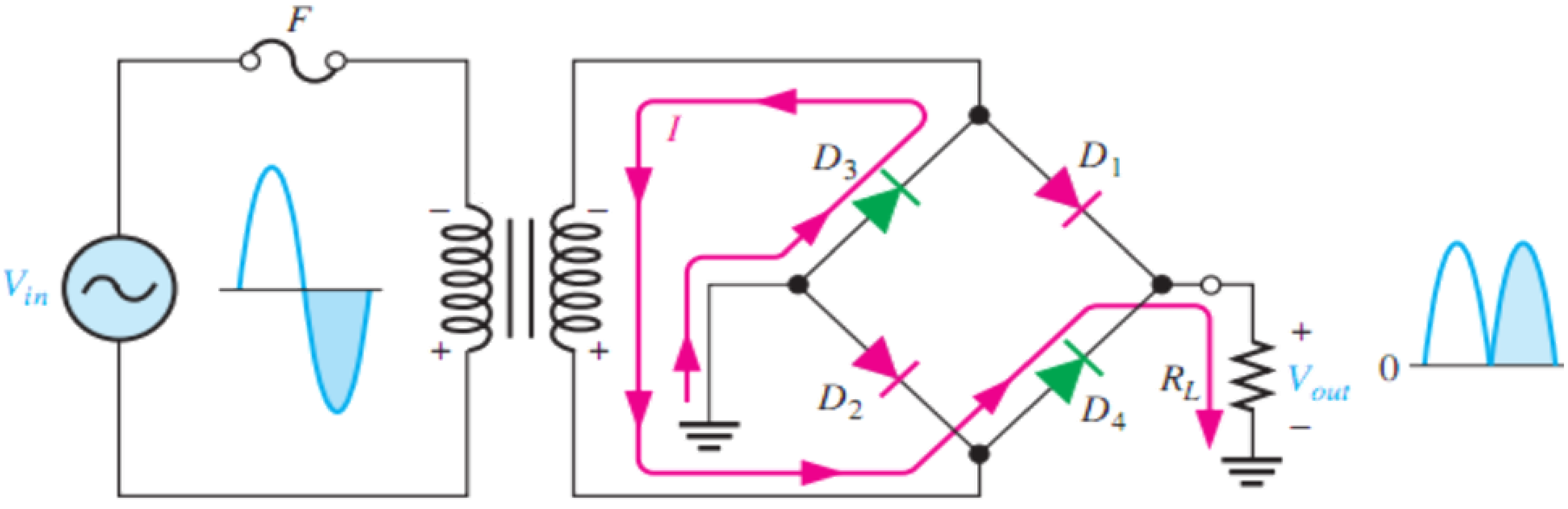
$$V_{out} = V_{p(sec)} - 2\,V_B \qquad \text{(Practical Diode)}$$

During negative half-cycle of the input voltage, the polarity of the secondary voltage is:



Diodes D_1 and D_2 are reverse-biased.
Diodes D_3 and D_4 are forward-biased.

The current flow through D_3 and D_4 then to the resistor.



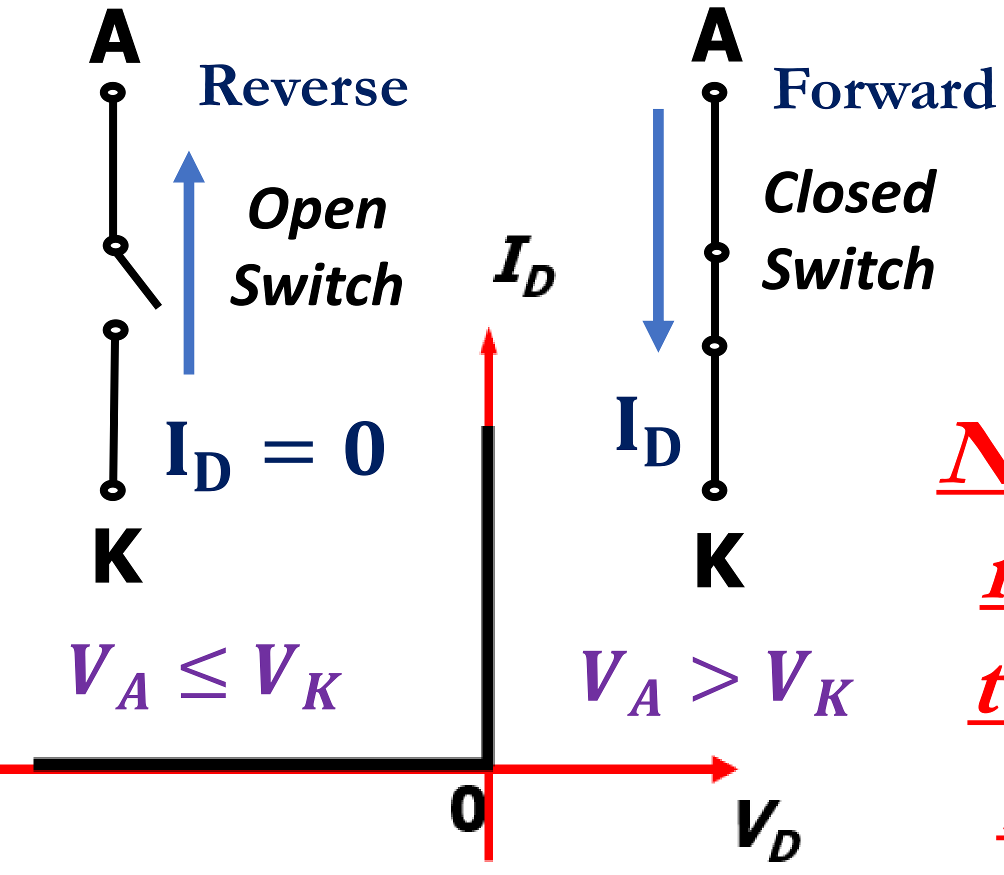
The output voltage across the resistor is:

$$V_{out} = V_{p(sec)} \qquad \text{(Ideal Diode)}$$

$$V_{out} = V_{p(sec)} - 2\,V_B \qquad \text{(Practical Diode)}$$

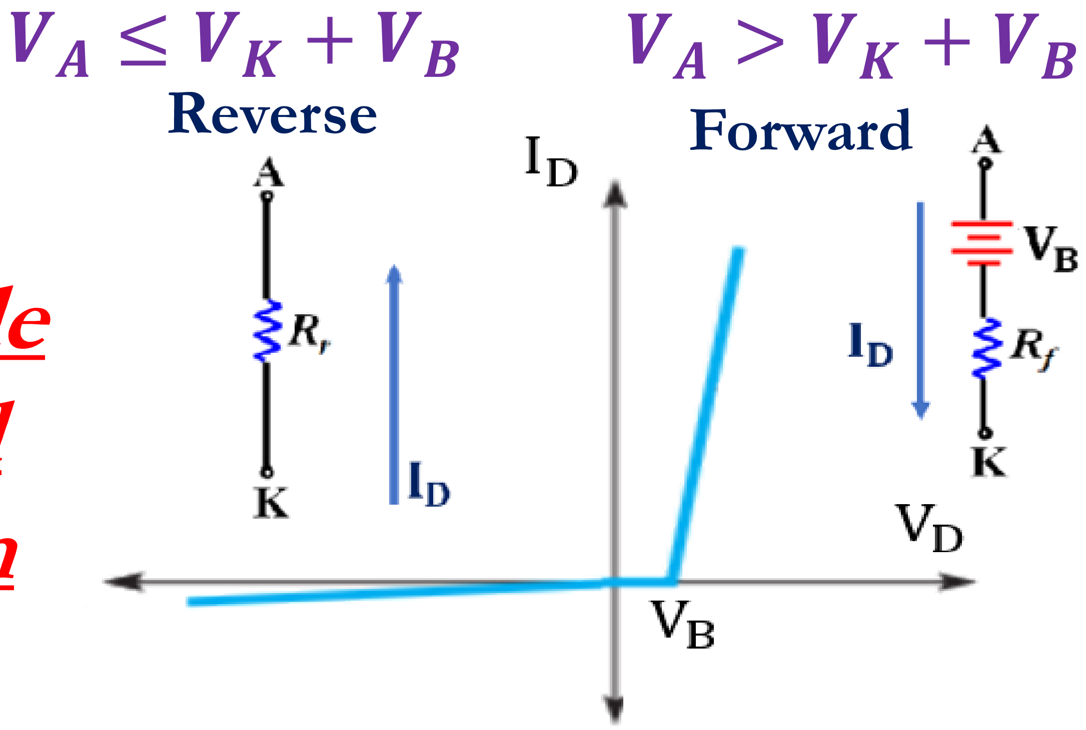
Normal Diode

The **normal diode** in any application may be **ideal or practical** and operates in only two regions (**forward & reverse**).



Normal Ideal Diode

Normal diode not deigned to operate in breakdown region.

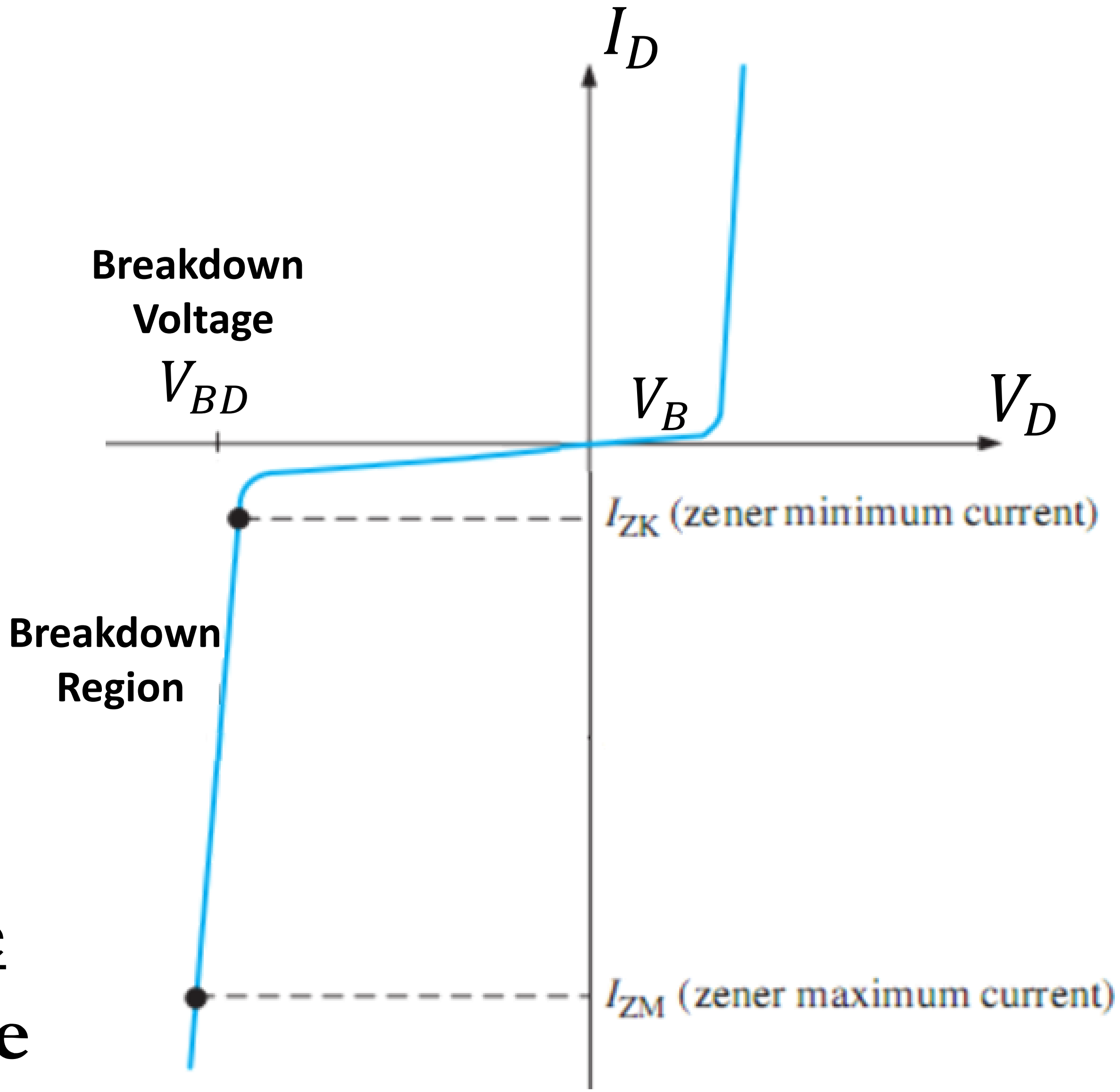


Normal Practical Diode

Zener Diode

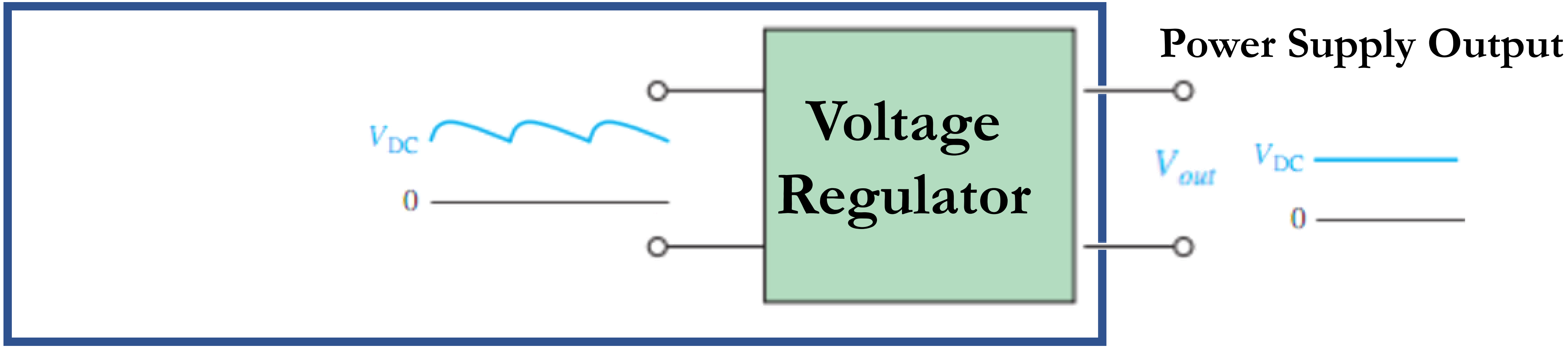
<u>Zener diode</u> is <u>designed for operation in breakdown region</u>.

Zener diode symbol



In breakdown region, <u>zener diode maintains a constant voltage</u> while producing a <u>large increase in current</u>.

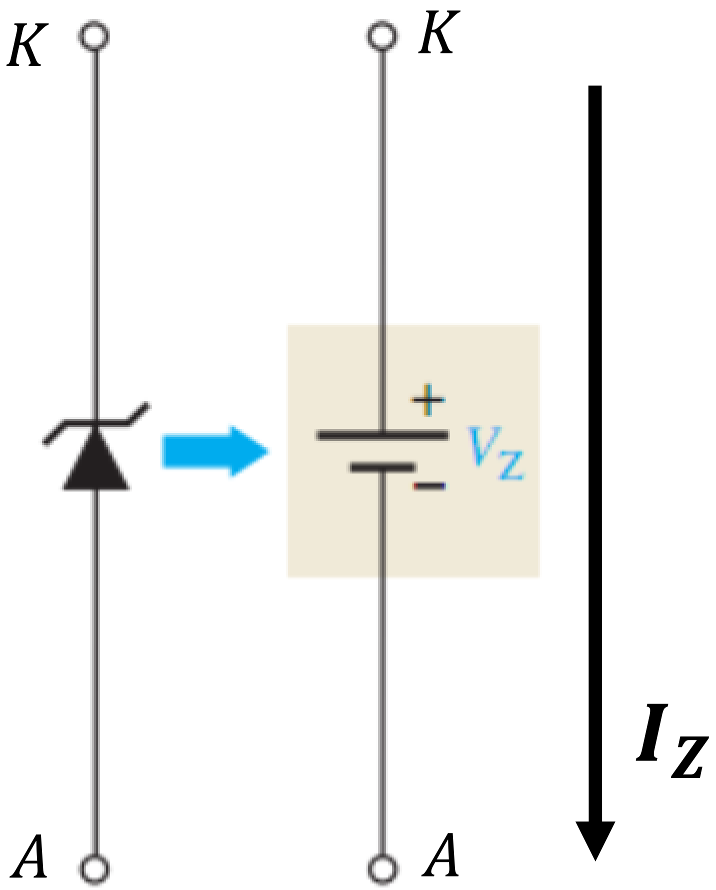
In breakdown region, **<u>zener diode acts as a voltage regulator</u>**.



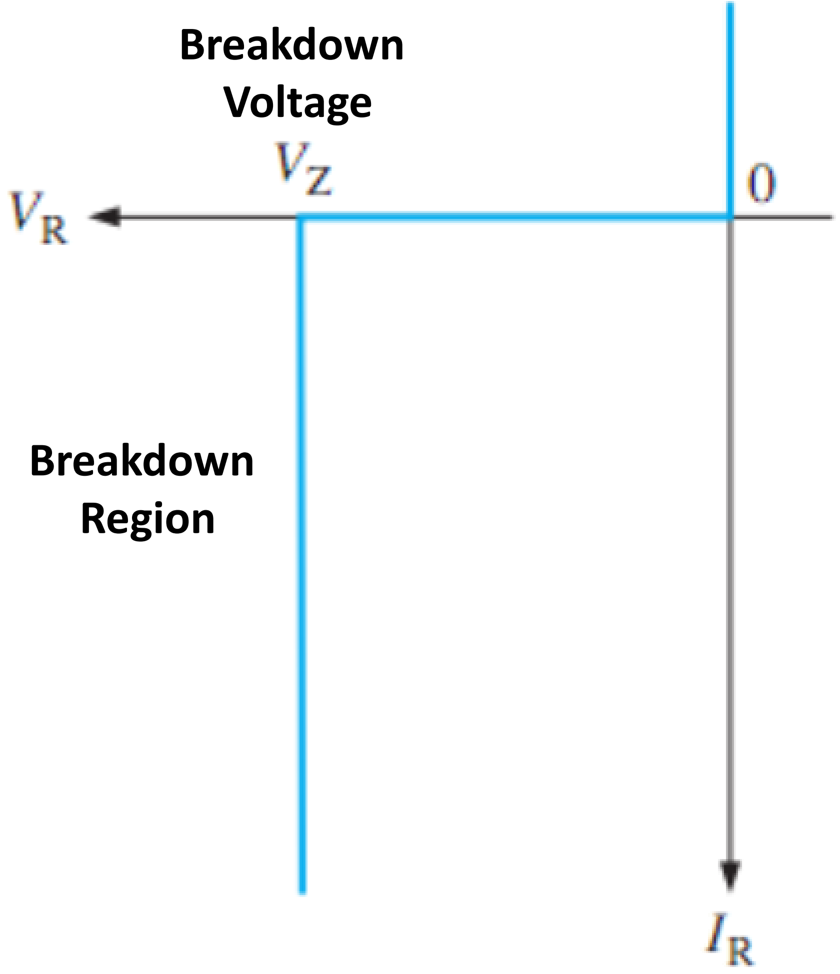
The **<u>voltage regulator</u>** circuit is the last stage in power supply and used to provides constant voltage at its output.

<u>Voltage Regulator</u> is a circuit that **<u>provides a constant output voltage</u>** even if there is variations in the input voltage.

Ideal Zener Diode Equivalent Circuit

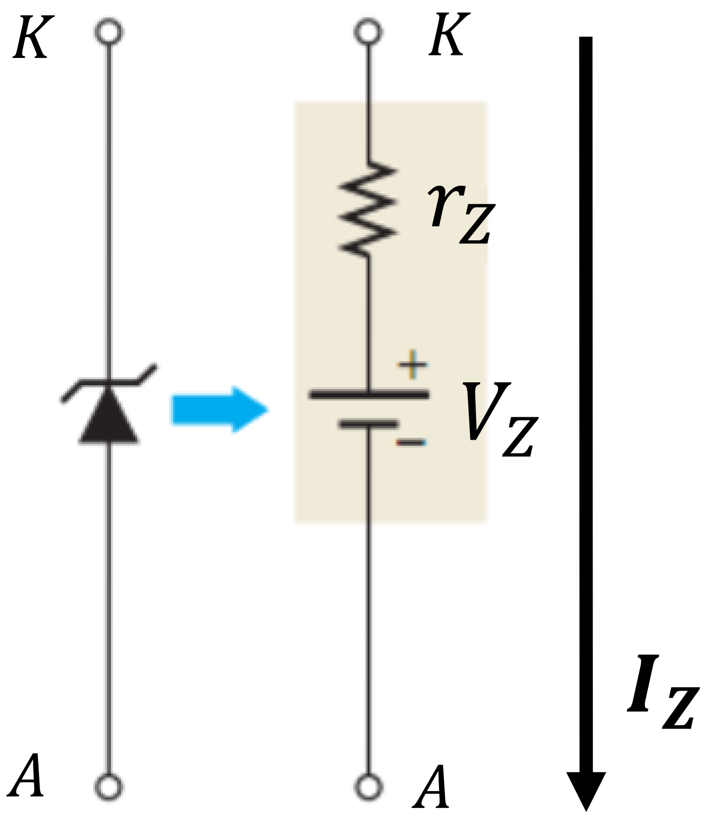


Ideal Zener Model

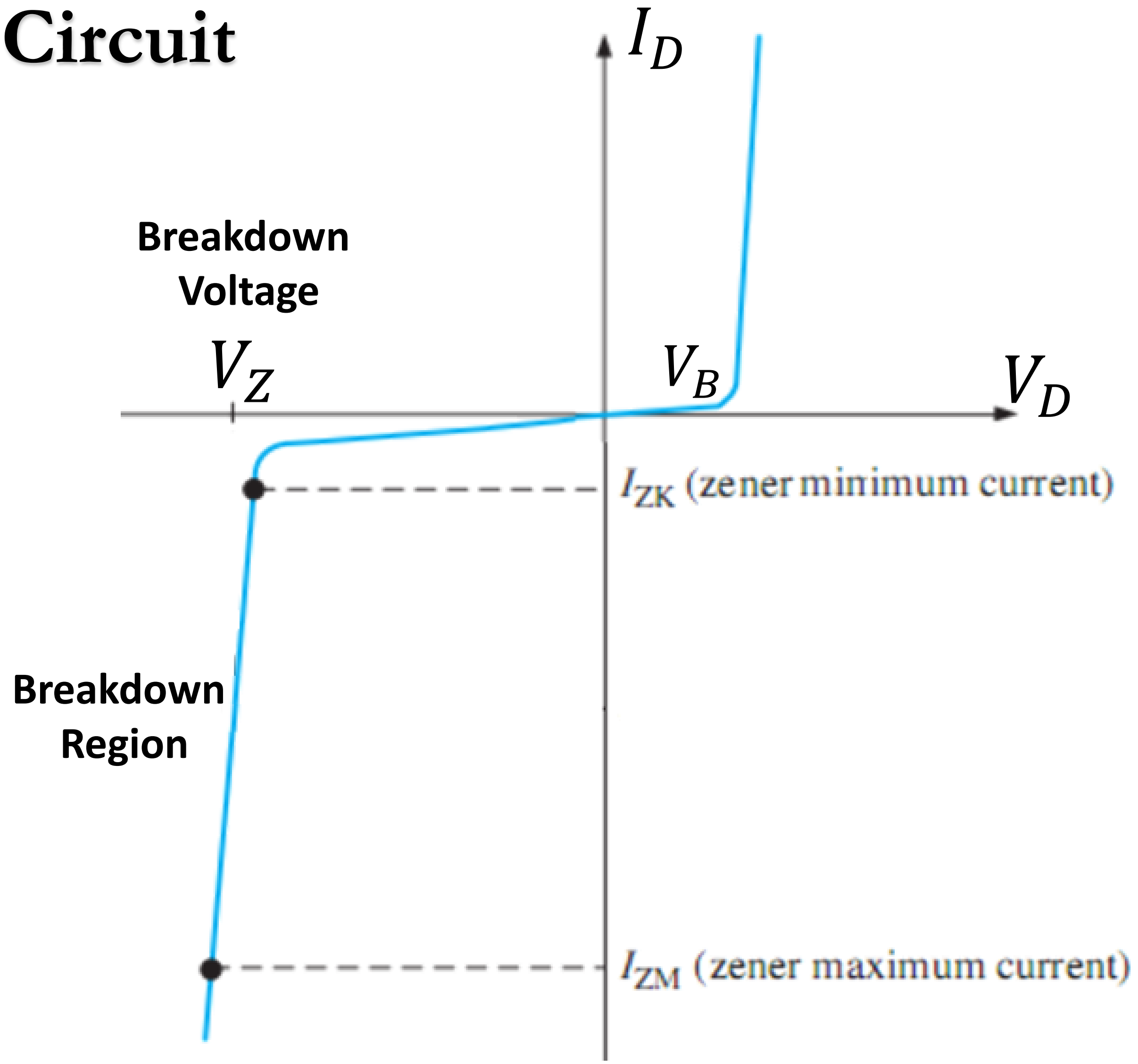


Ideal Zener Characteristic Curve

Practical Zener Diode Equivalent Circuit



Practical Zener Model



Practical Zener Characteristic Curve

(I) For the zener diode network, determine:

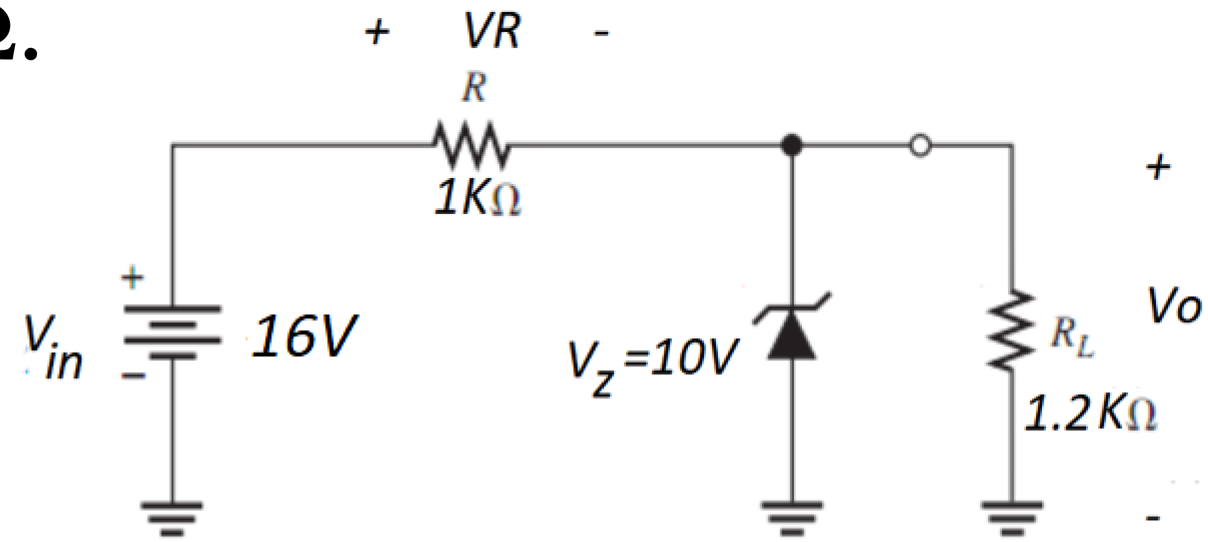
(a) The output voltage (V_o) across R_L.

(b) The voltage (V_R) across R.

(c) The current through the zener diode (I_Z).

(d) The zener power (P_Z).

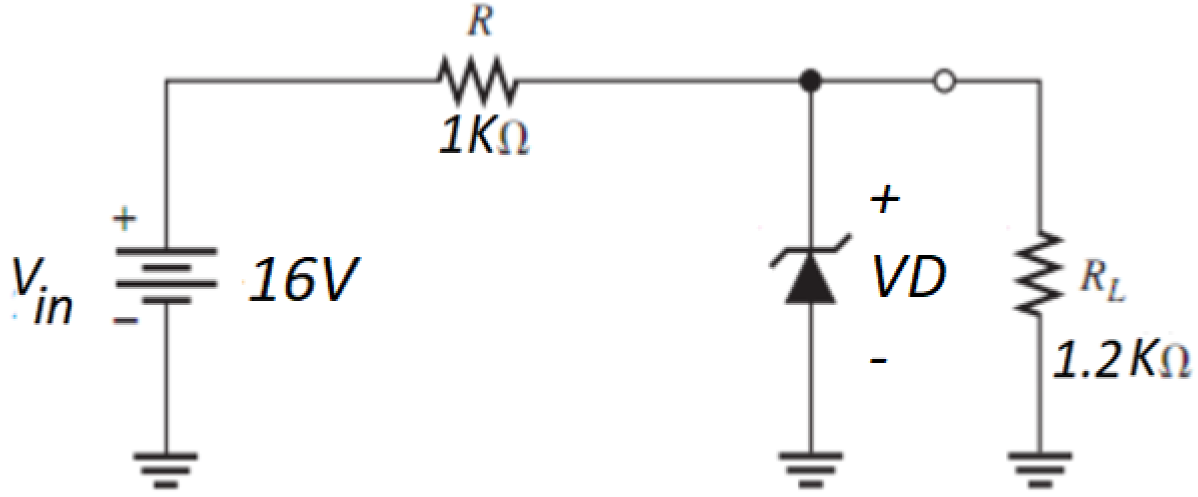
(II) Repeat part (I) with R_L= 3kΩ.



Part (I):

First, <u>determine state of zener diode,</u> by calculating voltage across it.

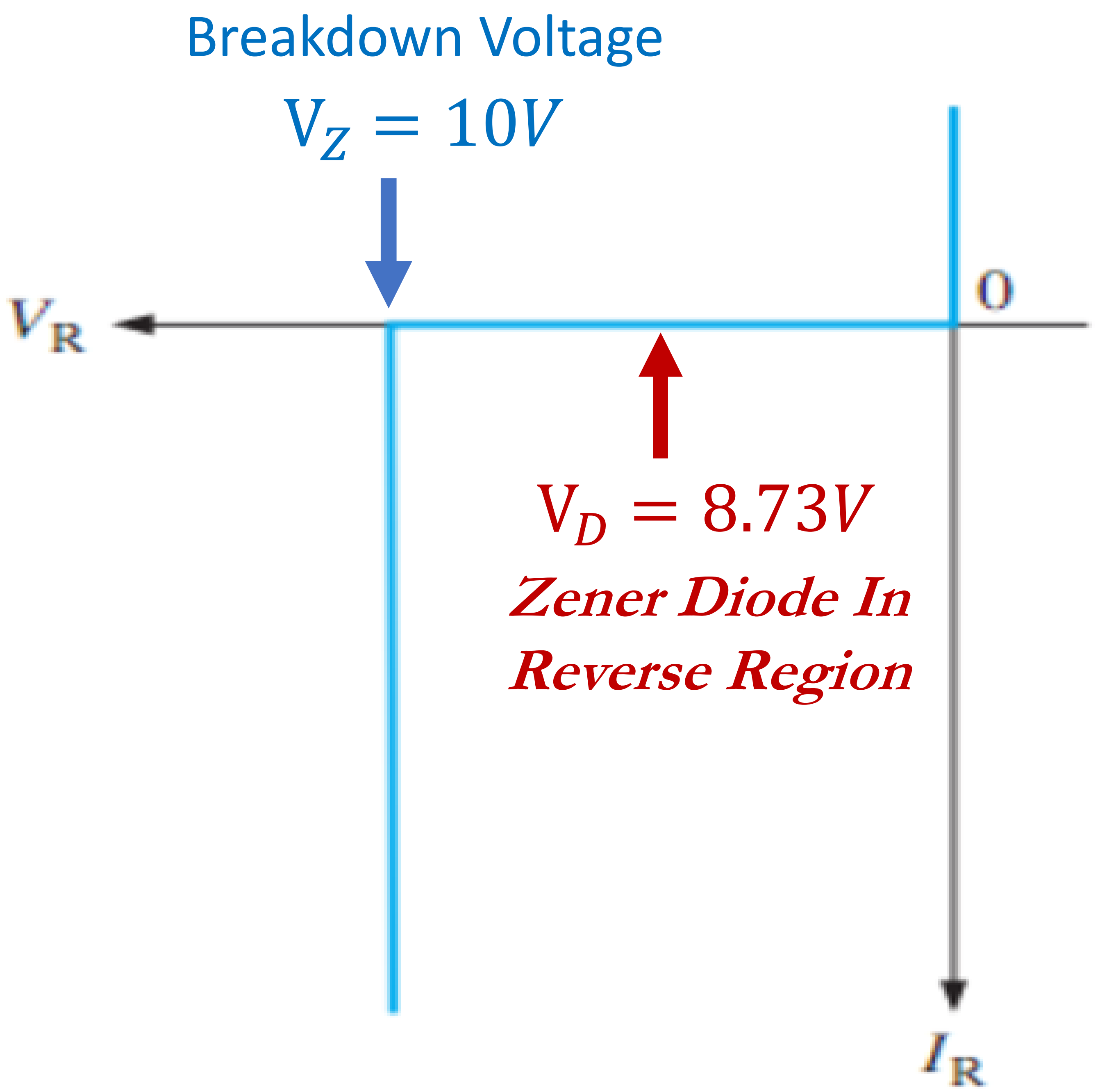
By using the <u>voltage divider rule</u>, the voltage across the zener diode (V_D) can be determined by:



$$V_D = \frac{V_{in}\, R_L}{R_L + R} = \frac{16 * (1.2K)}{(1.2K) + (1K)} = 8.73V$$

Since $\boldsymbol{V_D = 8.73V}$ is less than $\boldsymbol{V_Z = 10V}$

<u>Zener diode is in reverse region</u>.

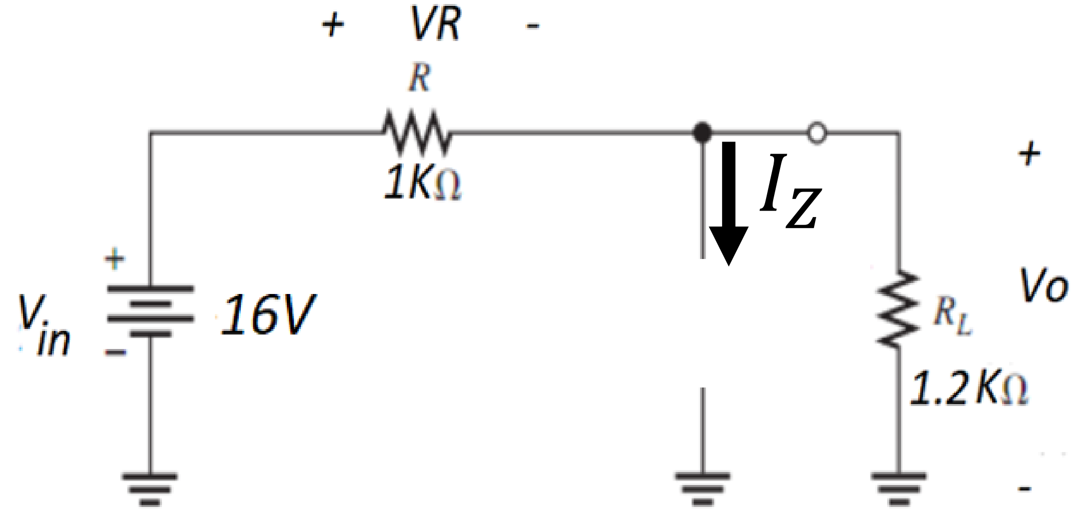

Breakdown Voltage
$V_Z = 10V$
V_R
0
$V_D = 8.73V$
Zener Diode In
Reverse Region
I_R

Since $V_D = 8.73V$ is less than $V_Z = 10V$.

1- Zener diode is in the reverse region.

2- Substitute the equivalent circuit of zener diode in reverse region which is an open switch ($R_r = \infty$).

3- Solve for the desired unknowns.



$$V_o = \frac{V_{in} R_L}{R_L + R} = \frac{16 * (1.2K)}{(1.2K) + (1K)} = 8.73V$$

$$V_R = V_{in} - V_o = 16 - 8.73 = 7.27V$$

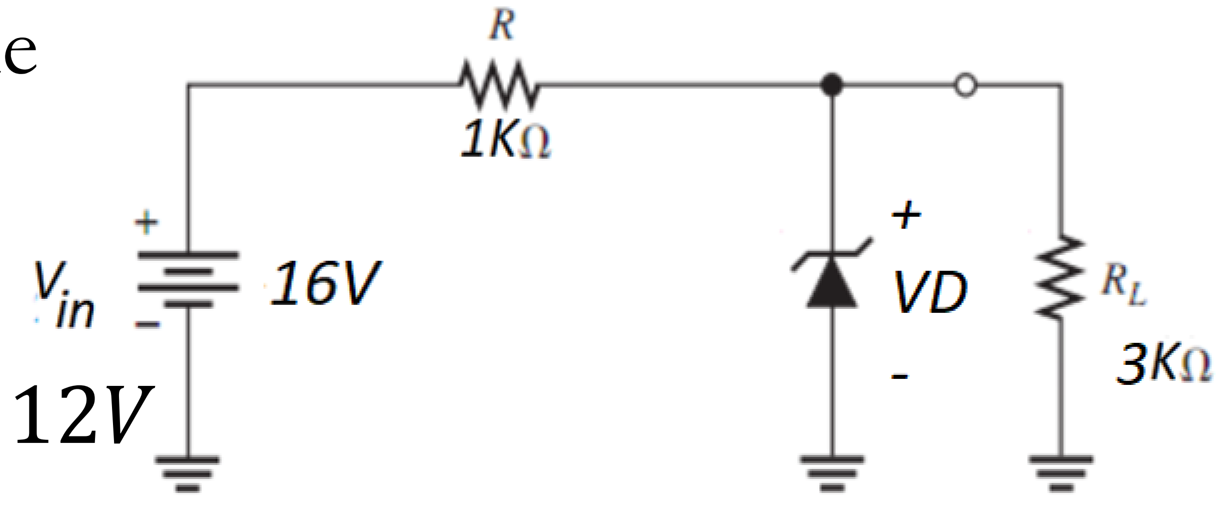
$$I_Z = 0A$$

$$P_Z = I_Z V_Z = 0W$$

(II) Repeat with RL= 3kΩ:

<u>Determine state of zener diode,</u> by calculating voltage across it.

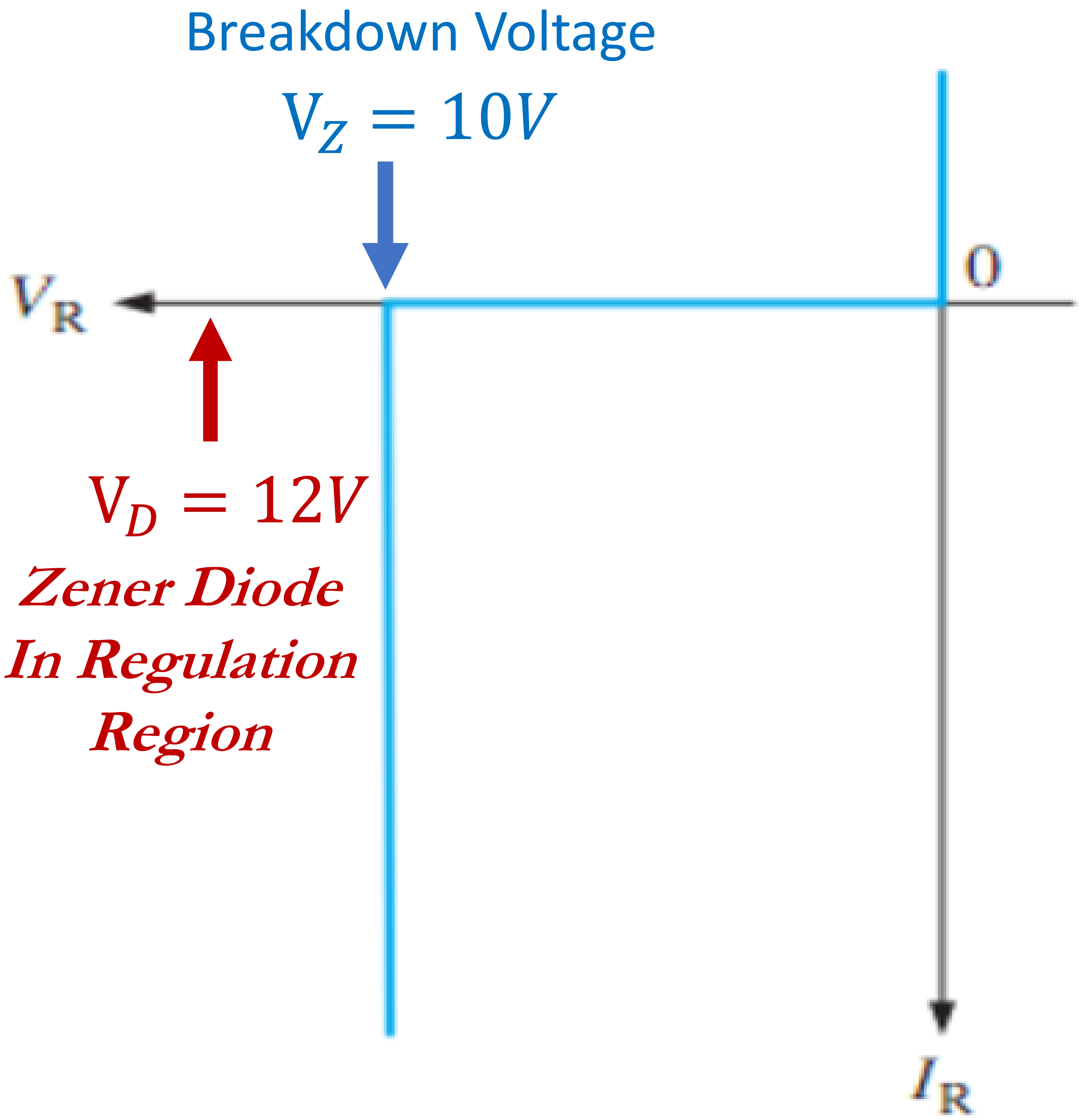
By using the <u>voltage divider rule,</u> the voltage across the zener diode (V_D) can be determined by:



$$V_D = \frac{V_{in}\,R_L}{R_L + R} = \frac{16 * (3K)}{(3K) + (1K)} = 12V$$

Since $V_D = 12V$ is greater than $V_Z = 10V$

<u>**Zener diode is in regulation region (breakdown region)**</u>**.**

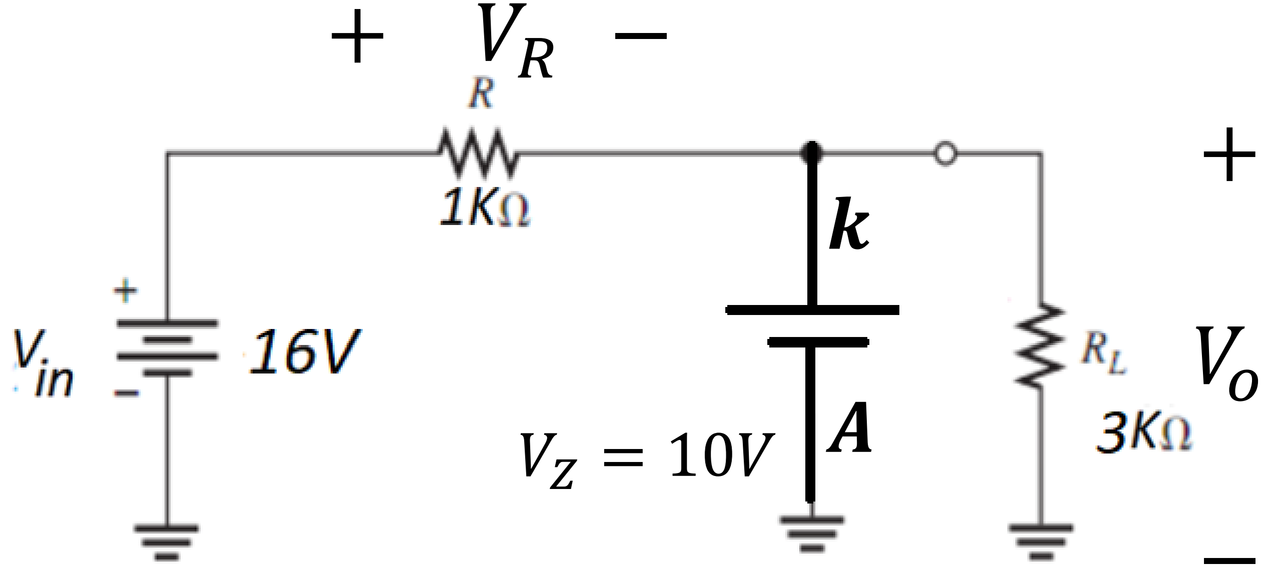

Breakdown Voltage
$V_Z = 10V$
V_R
0
$V_D = 12V$
Zener Diode In Regulation Region
I_R

Since $V_D = 12V$ is greater than $V_Z = 10V$.

1- Zener diode is in the regulation region.

2- Substitute the equivalent circuit of zener diode in regulation region which is a constant voltage equals $V_Z = 10V$.

3- Solve for the desired unknowns.



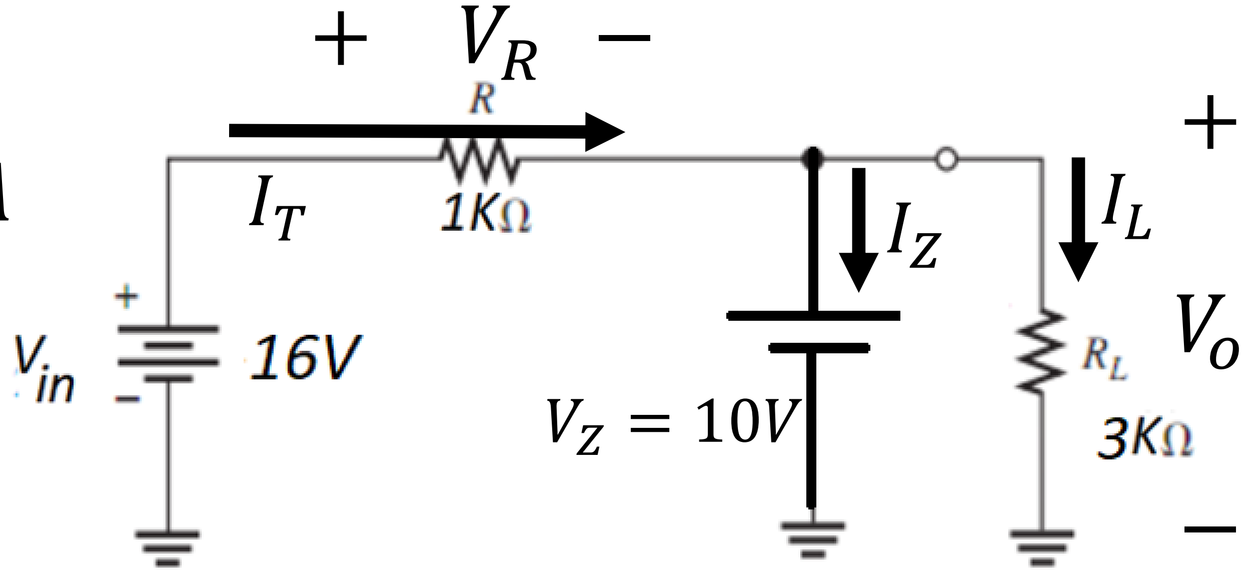
$$V_o = V_Z = 10V$$

$$V_R = V_{in} - V_o = 16 - 10 = 6V$$

$$I_L = \frac{V_o}{R_L} = \frac{V_Z}{R_L} = \frac{10V}{3k} = 3.33mA$$

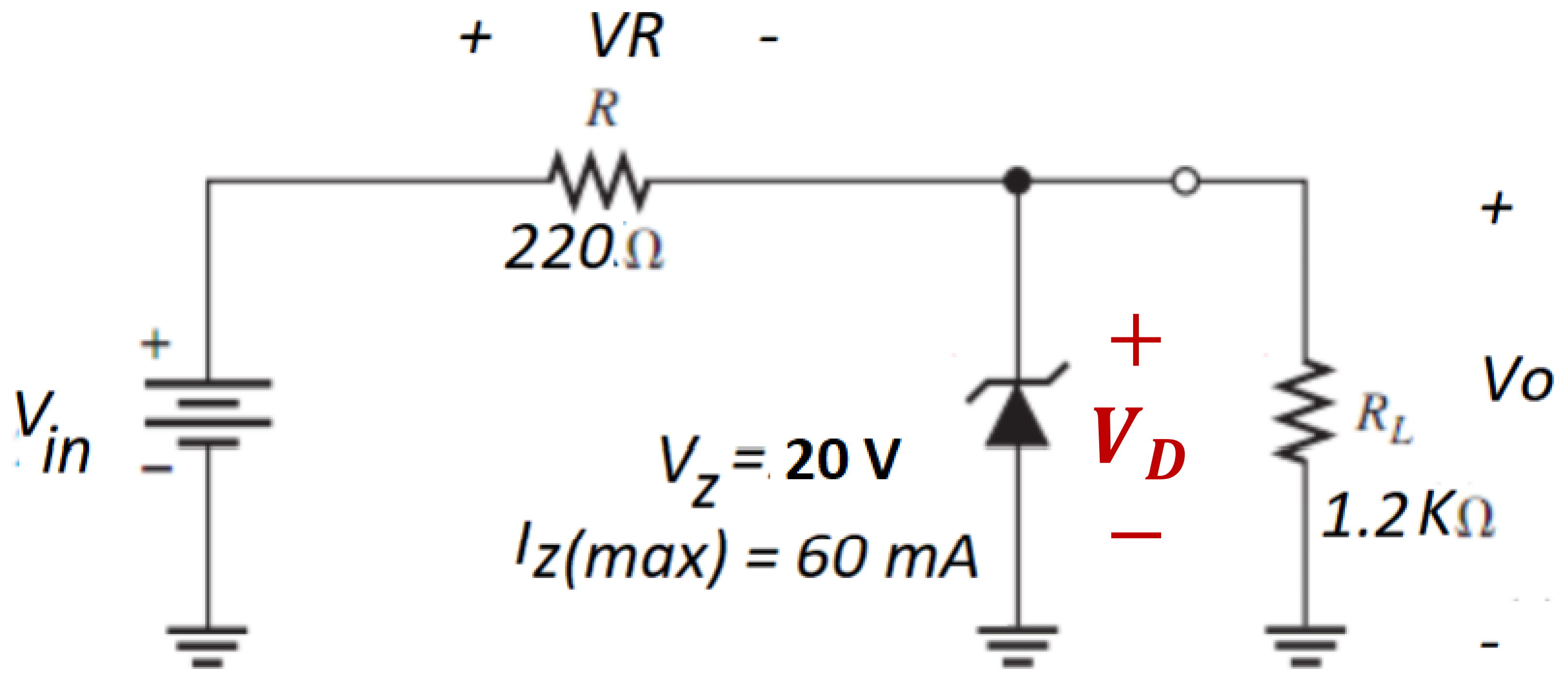
$$I_T = \frac{V_R}{R} = \frac{6V}{1k} = 6mA$$

$$I_Z = I_T - I_L = 6 - 3.33 = 2.67mA$$



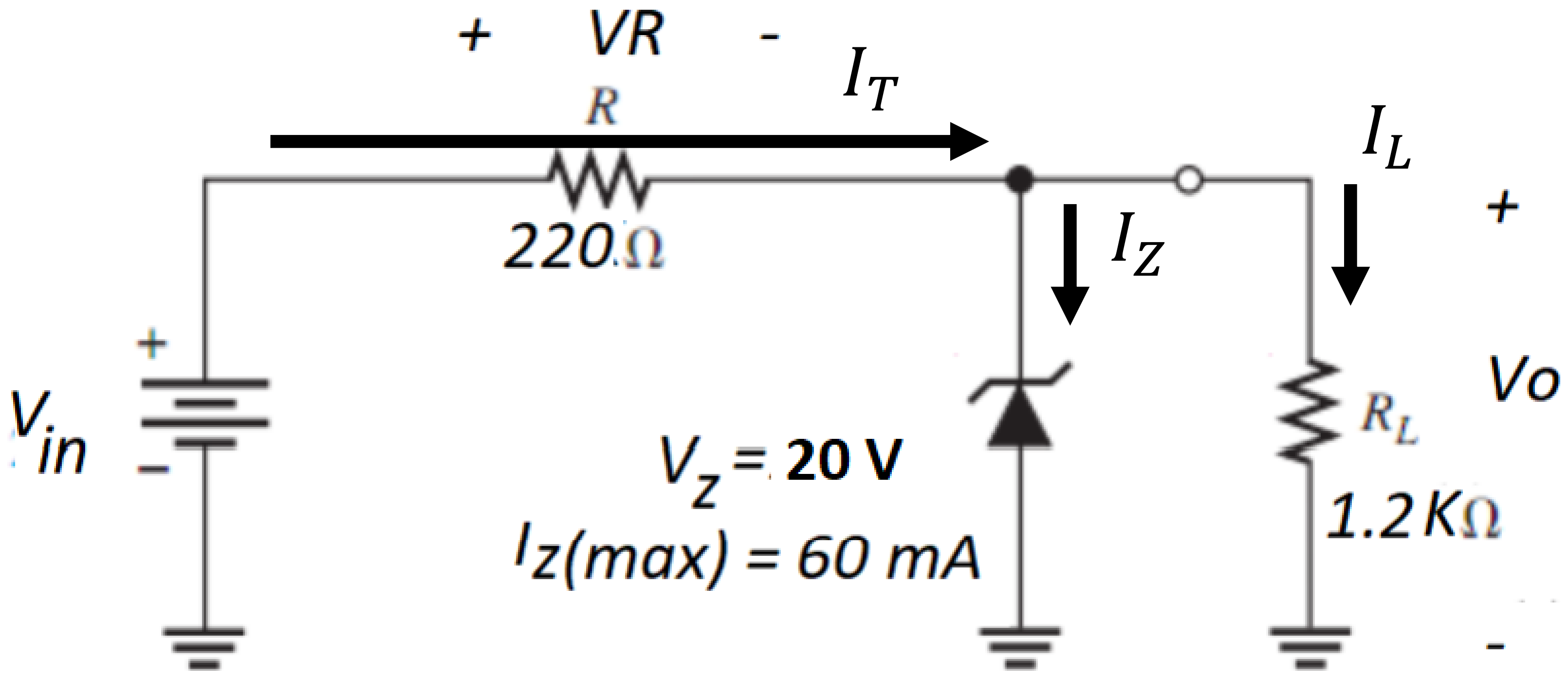
$$P_Z = I_Z V_Z = (2.67mA)(10V) = 26.7mW$$

Determine the range of values for V_{in} that will maintain zener diode in the regulation state.



By using the voltage divider rule, the voltage across the zener diode (V_D) is related to the input voltage (V_{in}) by:

$$V_D = \frac{V_{in}\, R_L}{R_L + R} = V_Z = \frac{V_{in}\,(1.2K)}{(1.2K) + (220)} = 20V \Rightarrow V_{in} = 23.67V$$



$$I_L = \frac{V_o}{R_L} = \frac{V_Z}{R_L} = \frac{20V}{1.2k} = 16.67\ mA$$

$$I_T = I_Z + I_L = 60 + 16.67 = 76.67\ mA$$

$$V_{in} = I_T R + V_Z = 76.67x10^{-3}x220 + 20 = 36.87\ V$$

The range of values for V_{in} that will maintain zener diode in the regulation state is:

$$36.87V \geq V_{in} \geq 23.67V$$