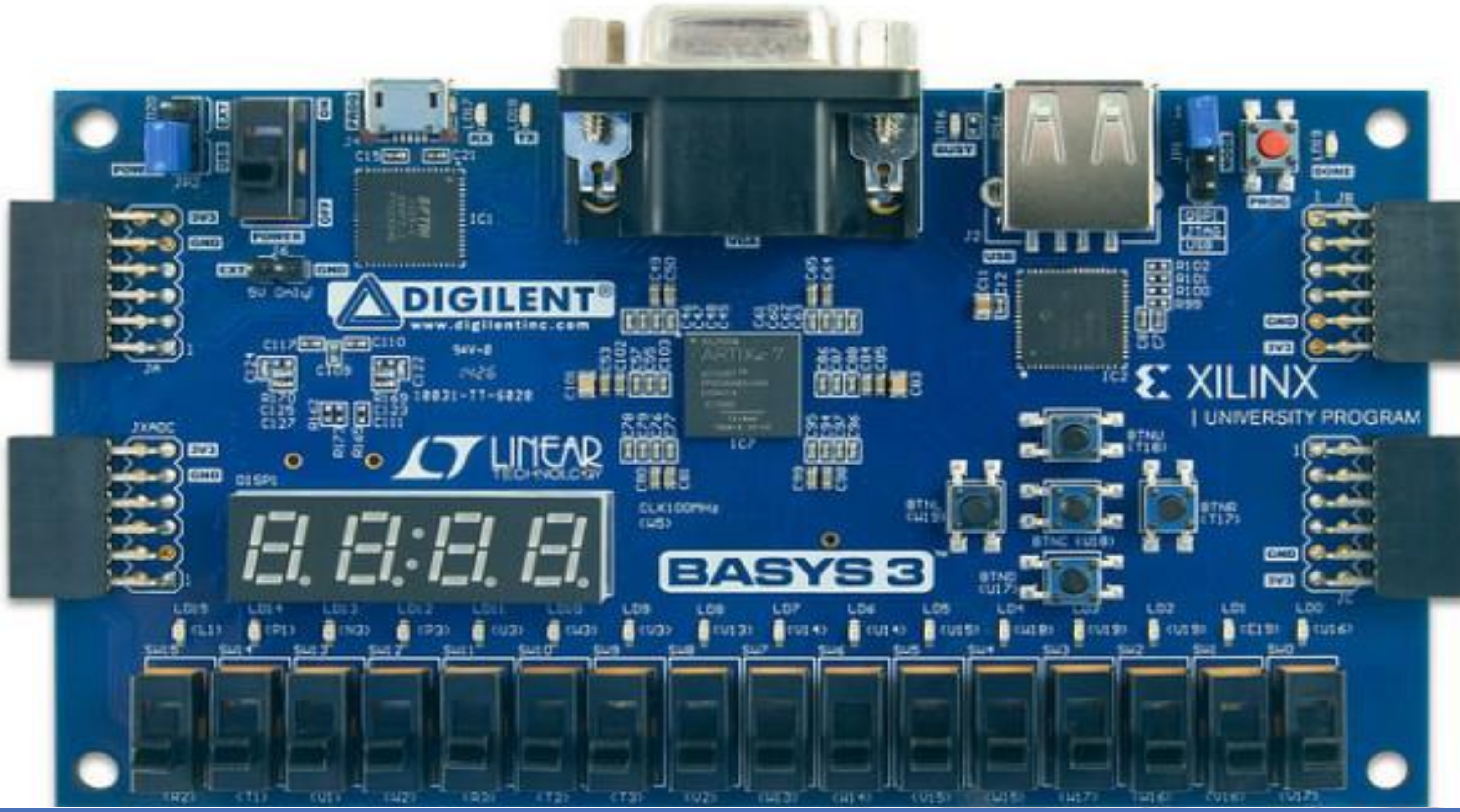


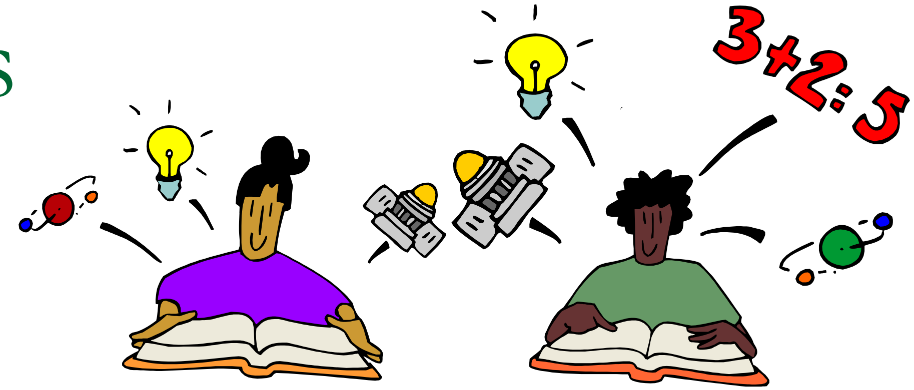
ECEG-2131 (AEI): Practical Diode Circuits

Addis Ababa Institute of Technology (AAIT) School of Electrical and Computer Engineering

Addis Ababa University
(Since 1950)

ADDIS ABABA UNIVERSITY

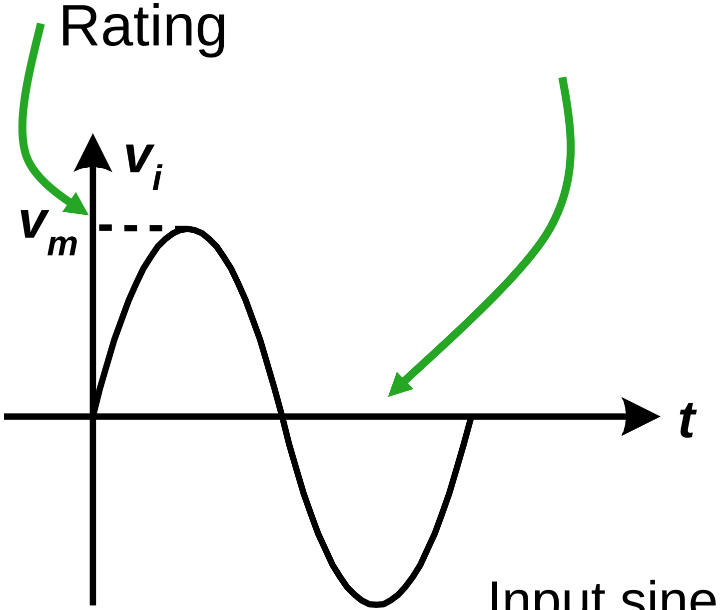
Learning Outcomes



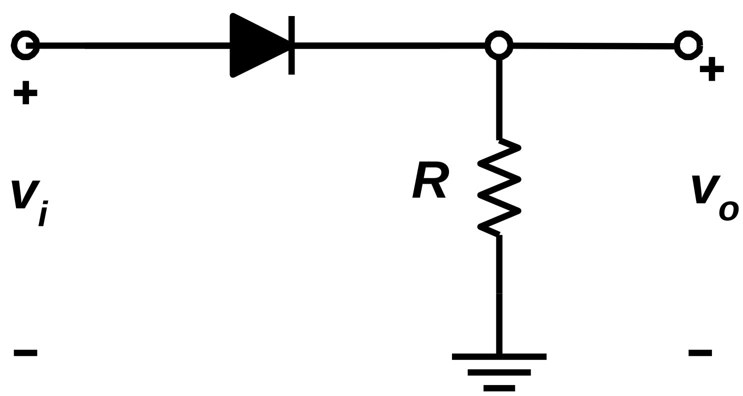
- At the end of the lecture, students should be able to know about:
  - Half-Wave and Full-Wave Rectifier.
  - Clipper.
  - Clamper.
  - Zener Regulation.

Sinusoidal Inputs: Half-Wave Rectification

- Used in ac-to-dc conversion circuit.
- The full wave sine wave will be rectified half, becomes a ½ wave rectification.
- Also known as Rectifier Diode with Higher Power & Current Rating



Input sine wave

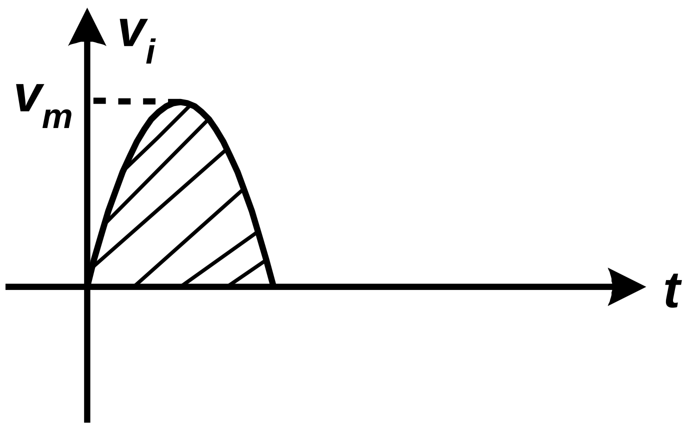


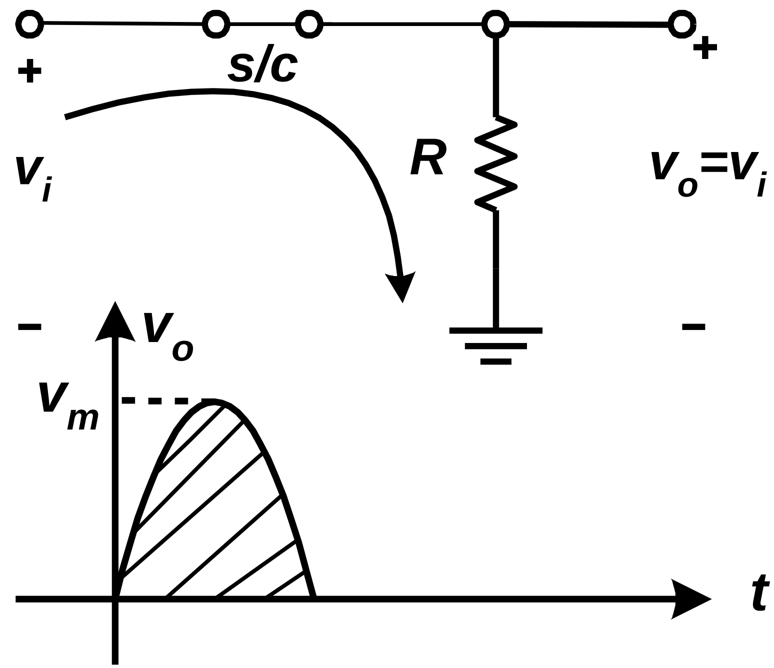
½ wave rectifier circuit

Half-Wave Rectification

- Assume Ideal Diode Model:

During + Cycle



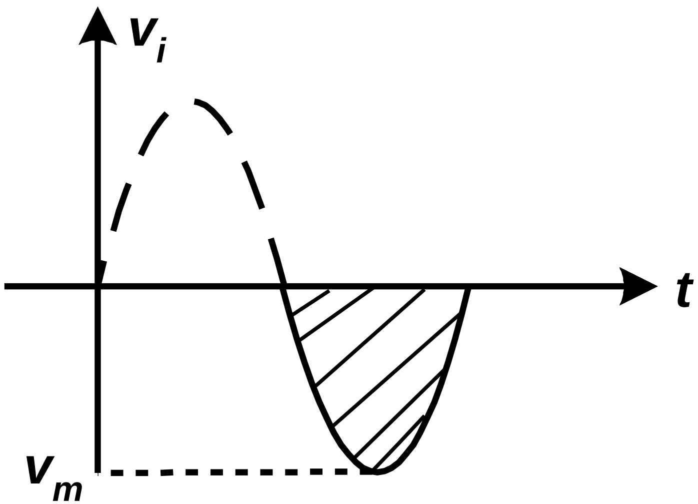


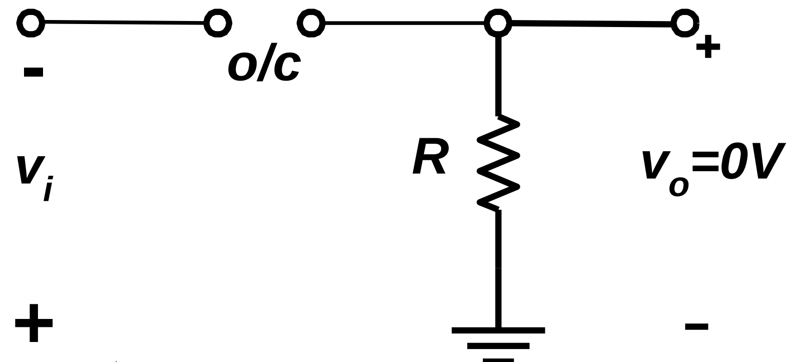
- Diode Forward-Bias
- Diode “ON”.
- Short-circuit.

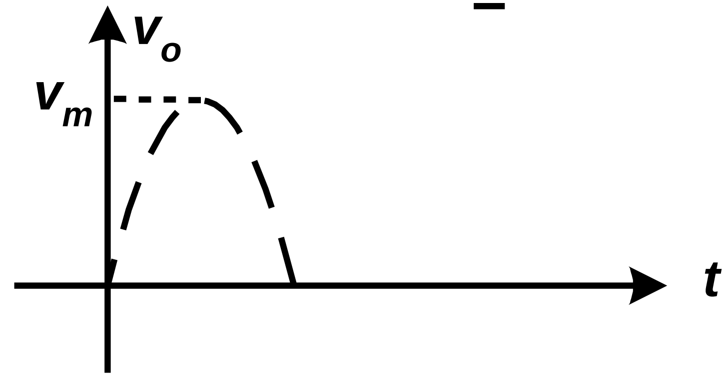
  Vo = Vi

Half-Wave Rectification

During – Cycle





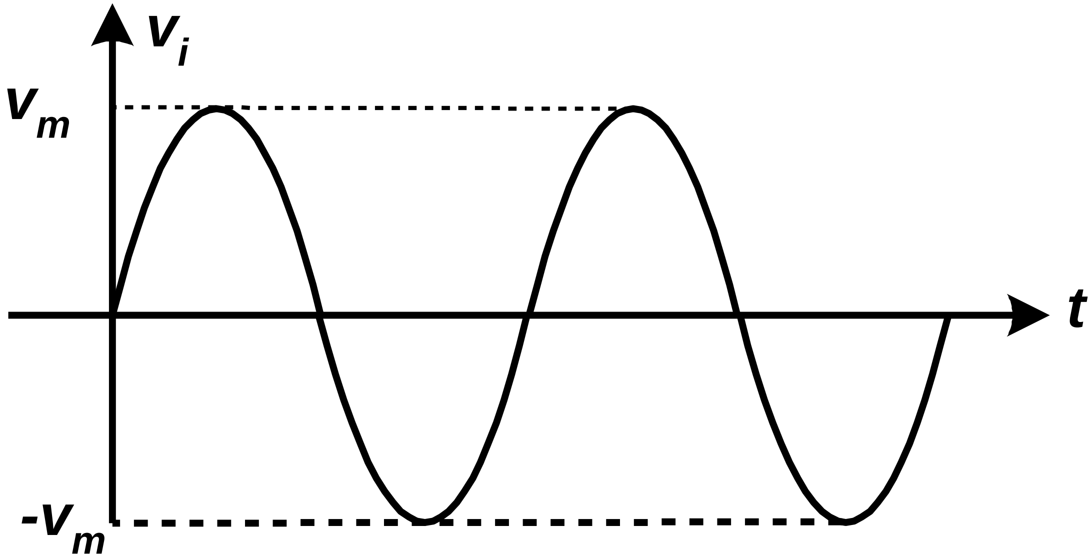


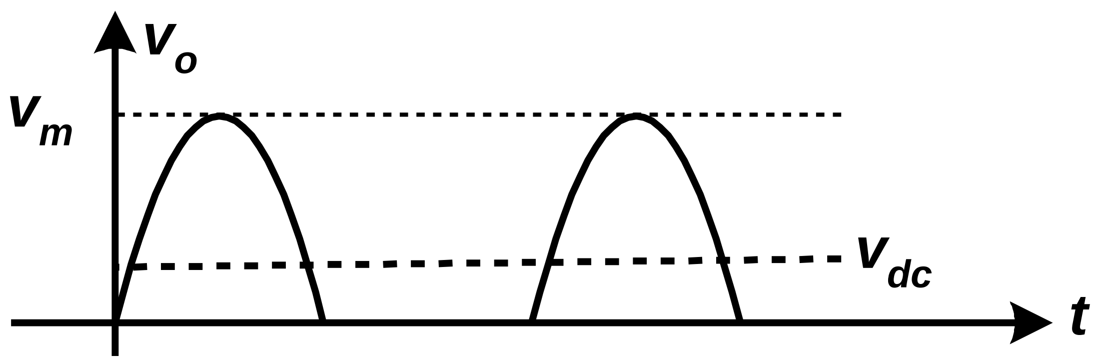
- Diode Reversed-Bias.
- Diode “OFF”.
- Open-circuit.

$v_o = 0V$

Half-Wave Rectification

Ideal Model

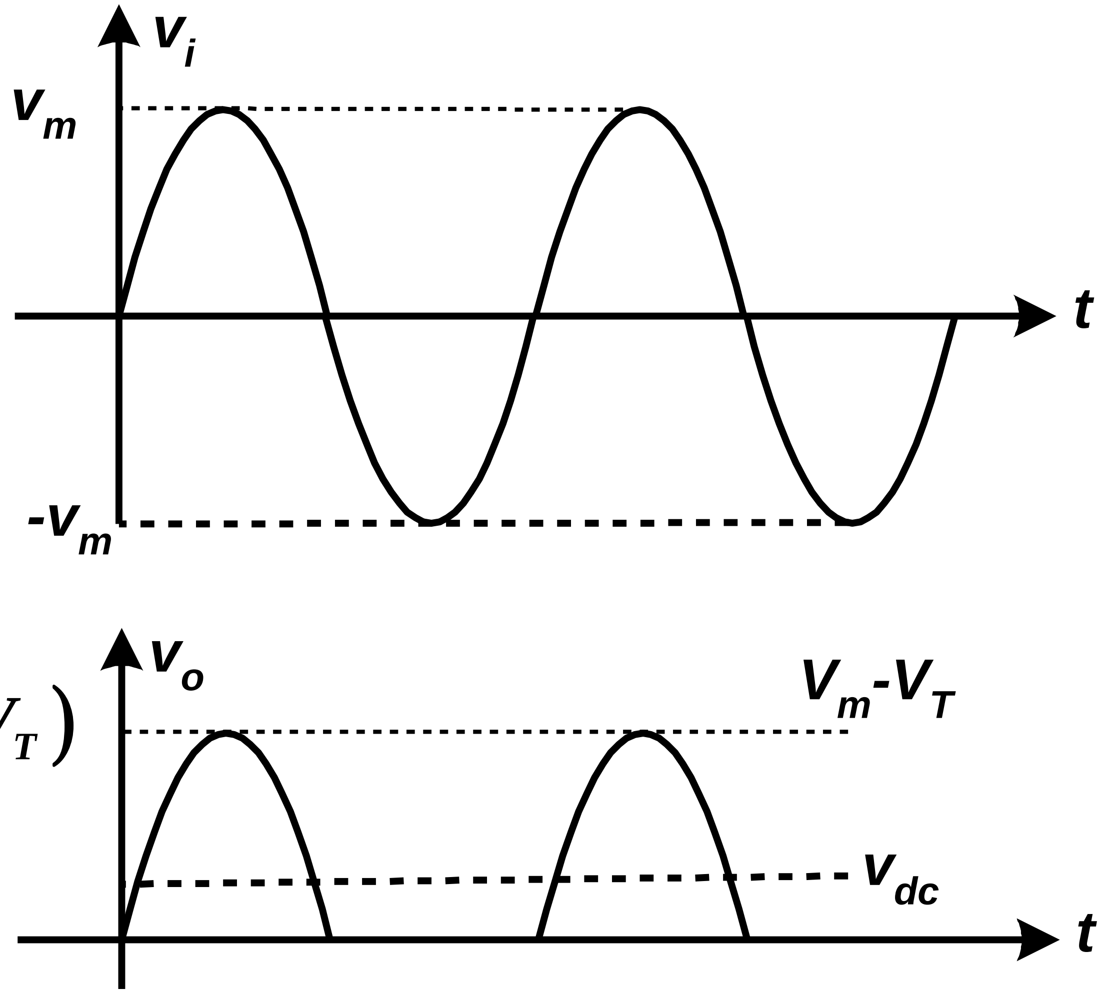




$$V_{dc} = 0.318 V_m$$

Half-Wave Rectification

Approx. Model

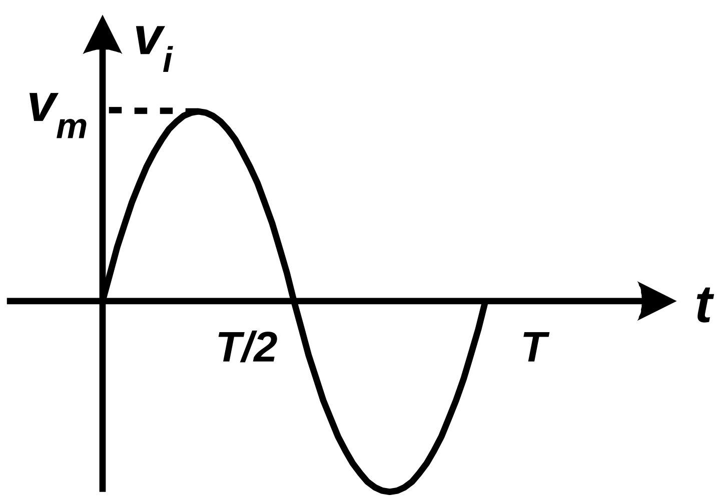


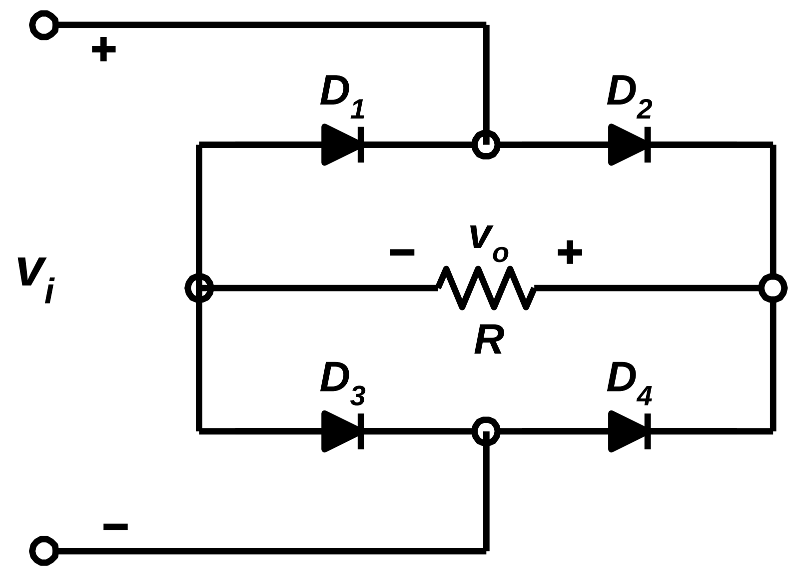
$$V_{dc} = 0.318\left(V_m - V_T\right)$$

Full-Wave Rectification

- Used in ac-to-dc conversion circuit.
- Improve 100% of the dc level obtained.
- 2 common configurations. Bridge & Centre-Tapped transformer

Bridge Network

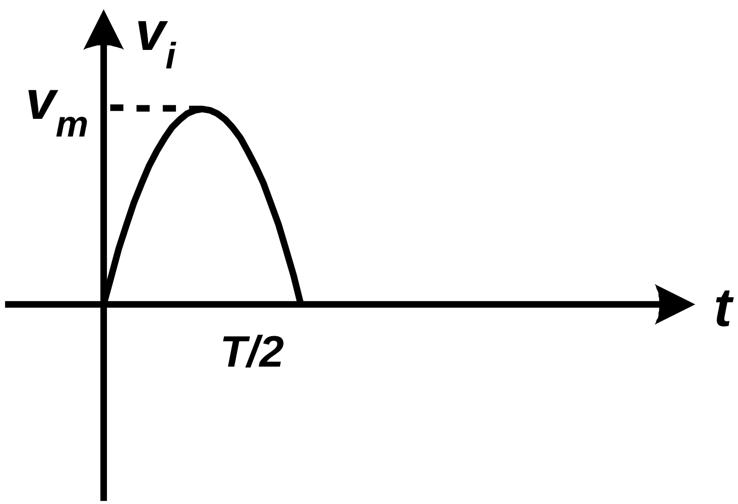


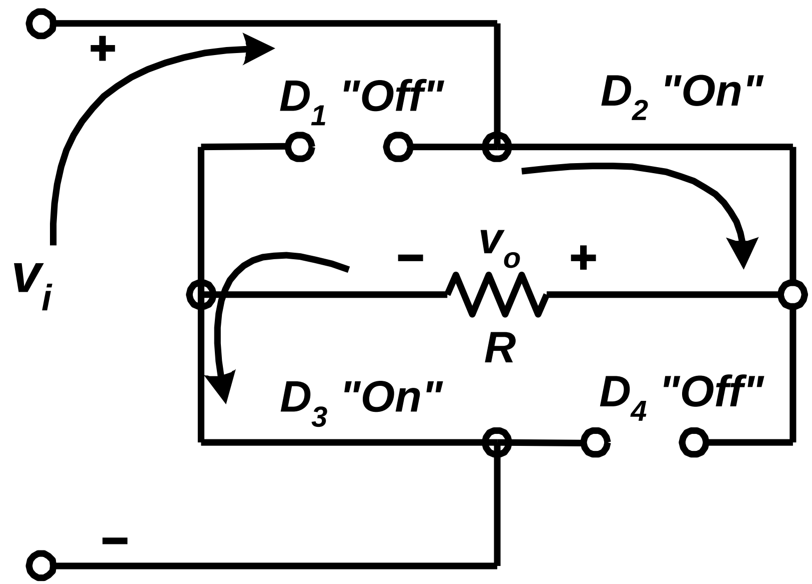


Full-Wave Rectification

- Assume Ideal Diode Model:

During + Cycle (t = 0 → T/2)



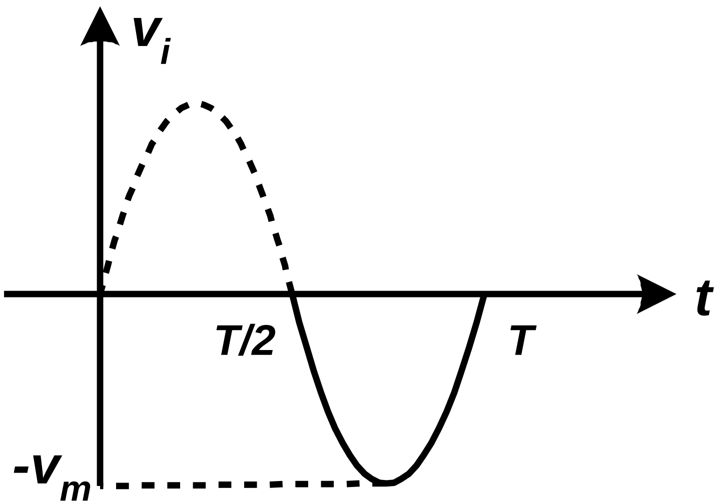


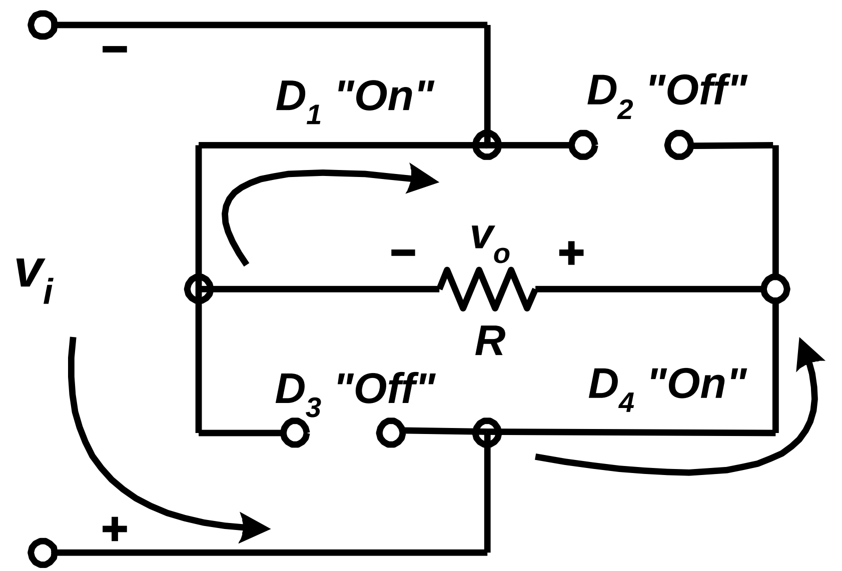
- Diode D_2 and D_3 “On”.
- Diode D_1 and D_4 “Off”.

$v_o = v_i$ (Ideal Diode)

Full-Wave Rectification

During - Cycle (t = T/2 → T)

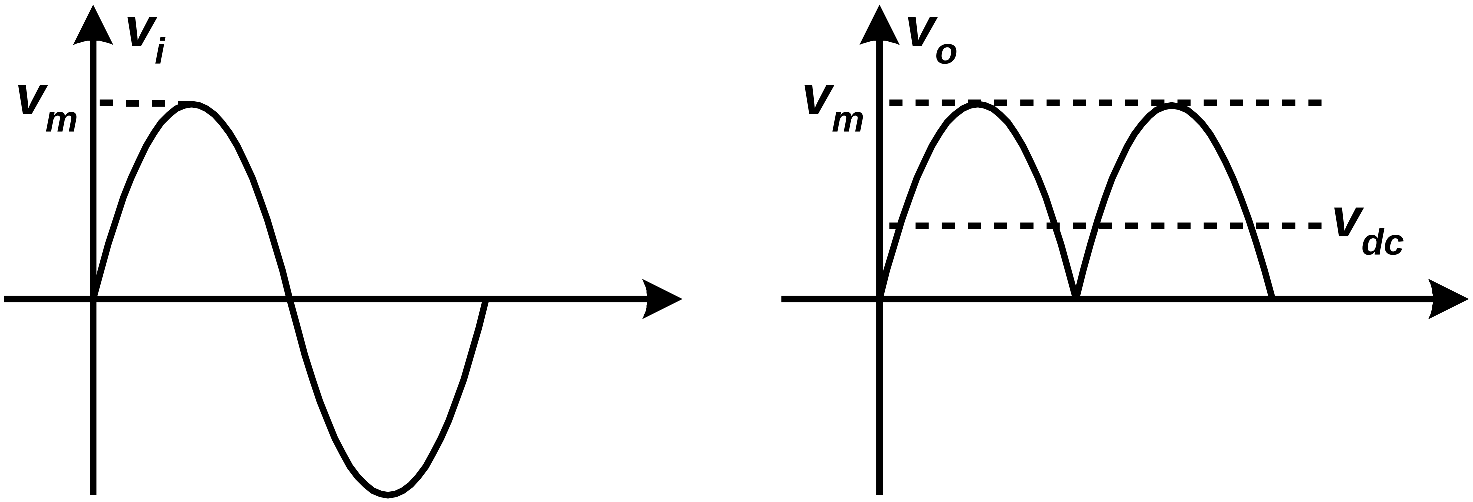




- Diode D_1 and D_4 "On".
- Diode D_2 and D_3 "Off".

$v_o = -v_i$ (Ideal Diode)

Full-Wave Rectification



- For the Full-wave rectifier, the dc level is doubled.

$$V_{dc} = 2(0.318V_m) = 0.636V_m$$

- If we use Silicon diode (Not ideal diode),

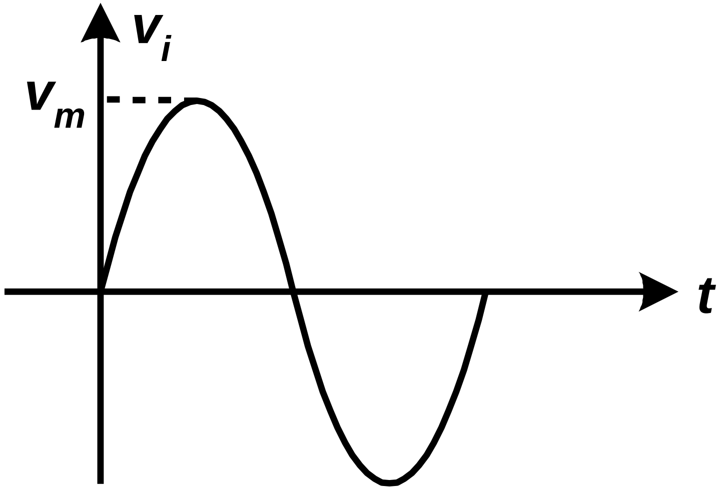
$$v_i - V_T - v_o - V_T = 0$$

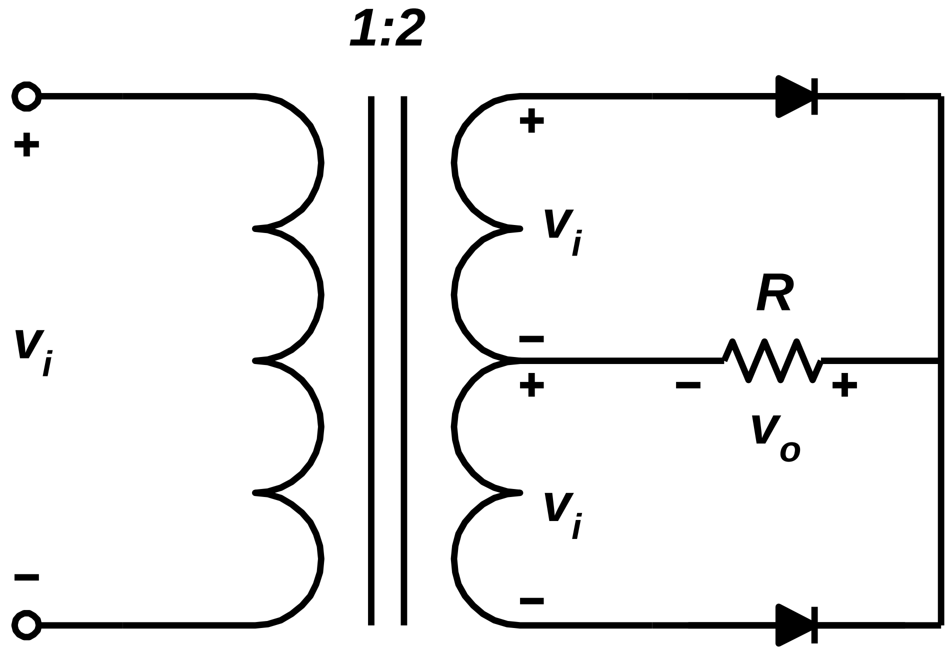
$$v_o = v_i - 2V_T \quad \text{and} \quad V_{dc} = 0.636(V_m - 2V_T)$$

Full-Wave Rectification

Center-Tapped Transformer

- Use two diodes with a Center-tapped transformer.

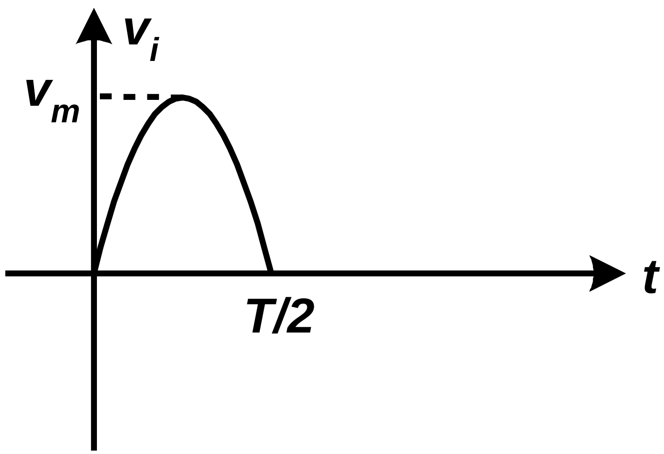


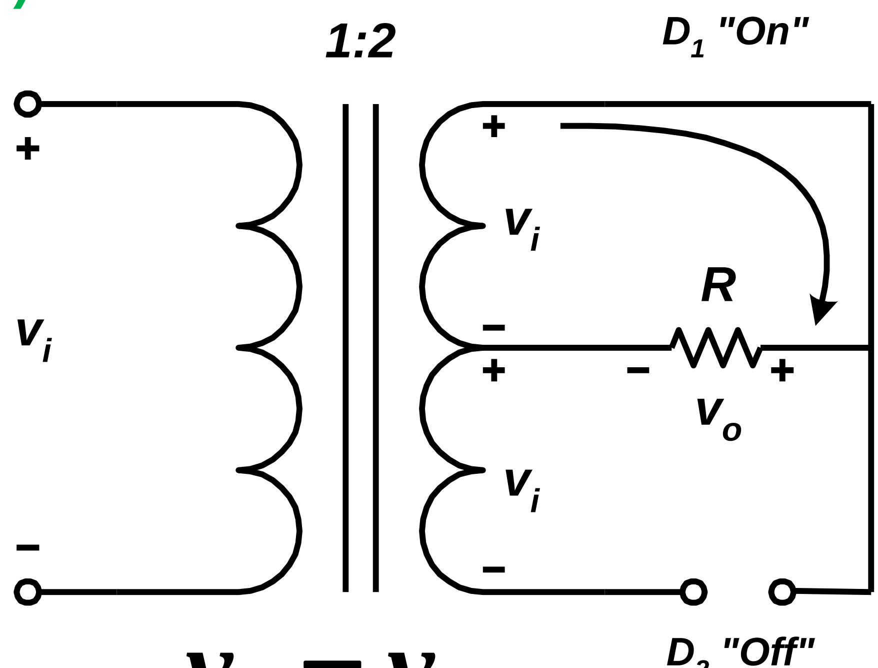


Full-Wave Rectification

Assume Ideal Diode Model:

During + Cycle (t = 0 → T/2)



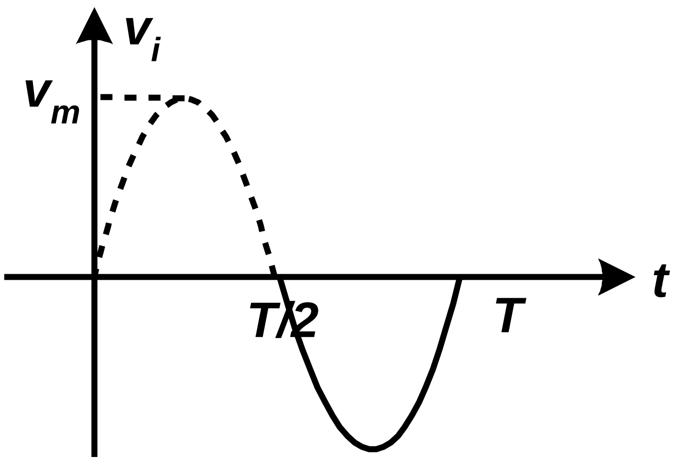


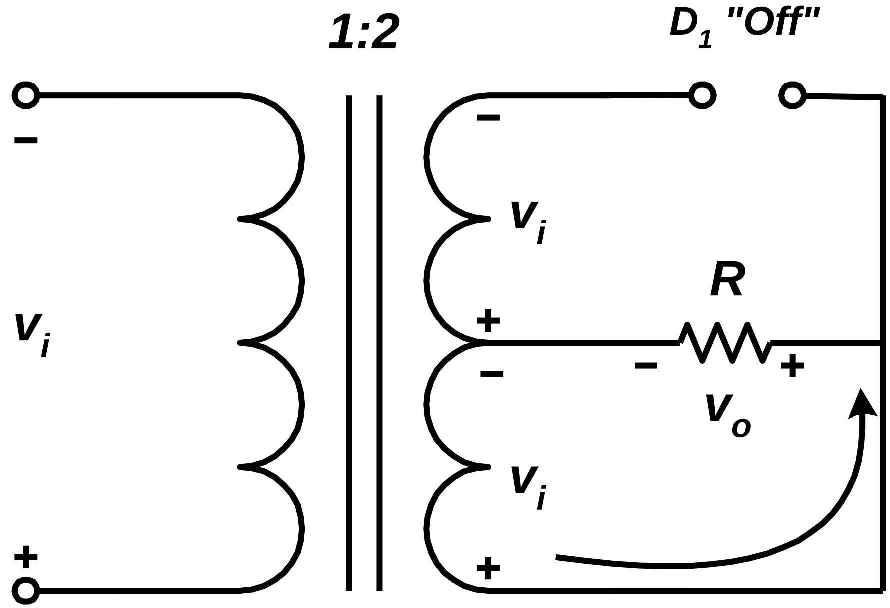
$$v_o = v_i$$

- Diode D_1 "On", D_2 "Off".

Full-Wave Rectification

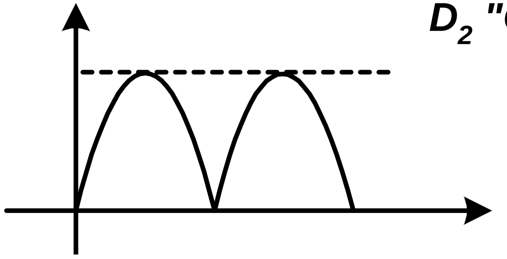
During – Cycle (t = T/2 → T)





Diode D_2 "On", D_1 "Off".

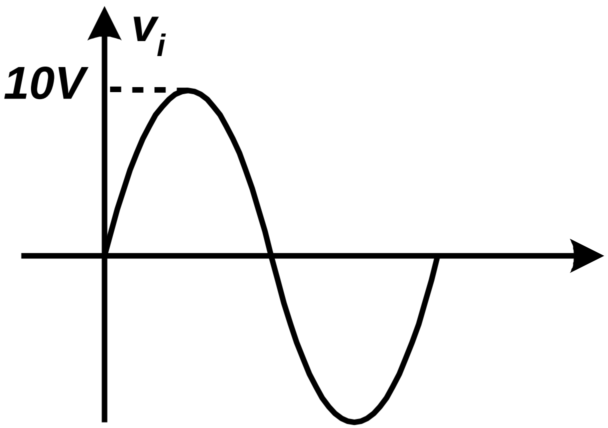
$$v_o = v_i$$

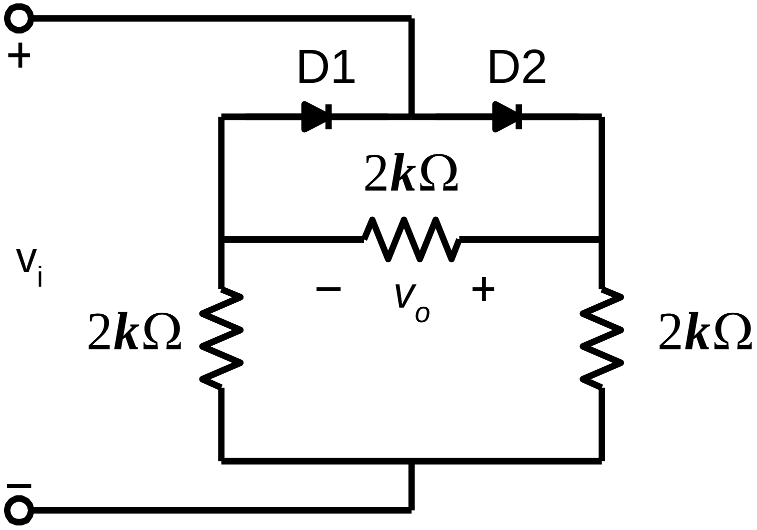


Full-Wave Rectification

Example 1: (*Boylestad)*

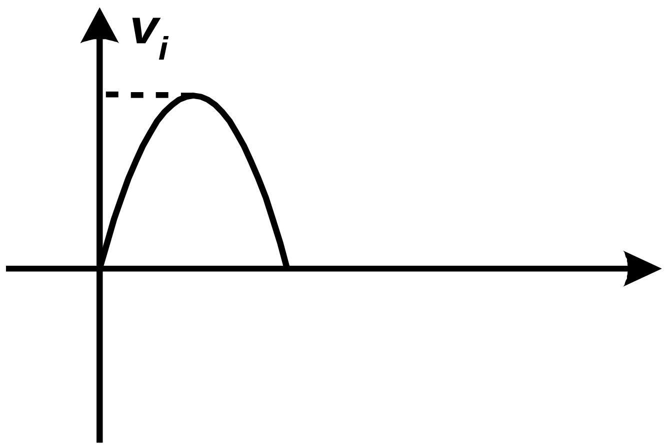
- Determine and sketch the output waveform for the network below. Use ideal diode model.

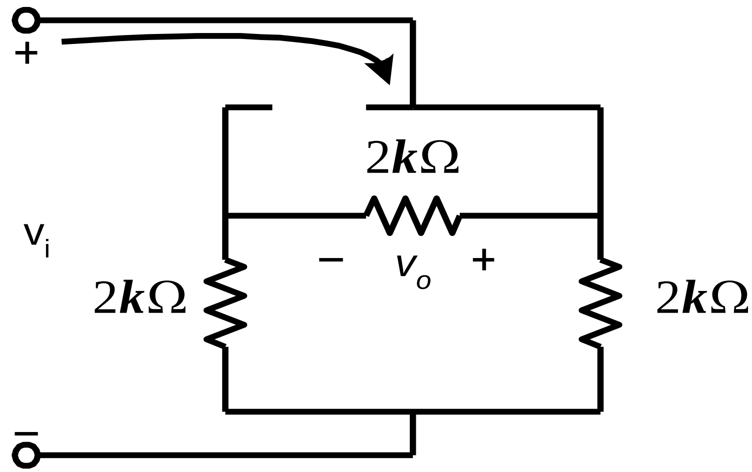


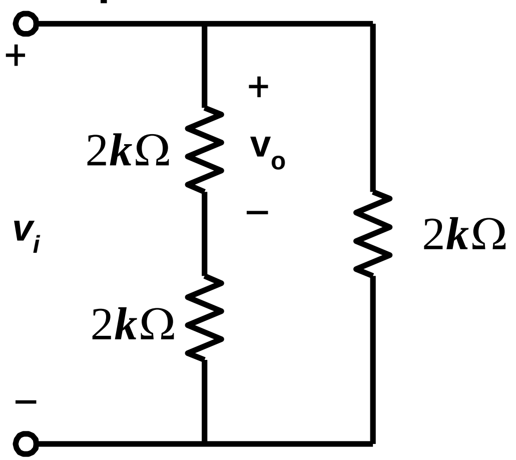


Full-Wave Rectification

During + Cycle (t = 0 → T/2)







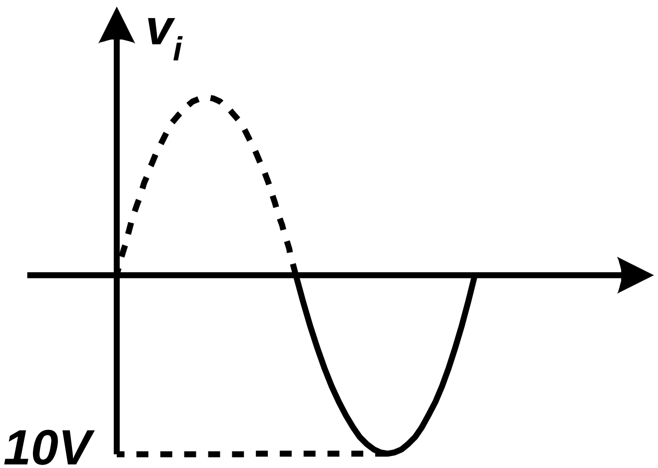
$$v_o = \frac{1}{2} v_i = 5V$$

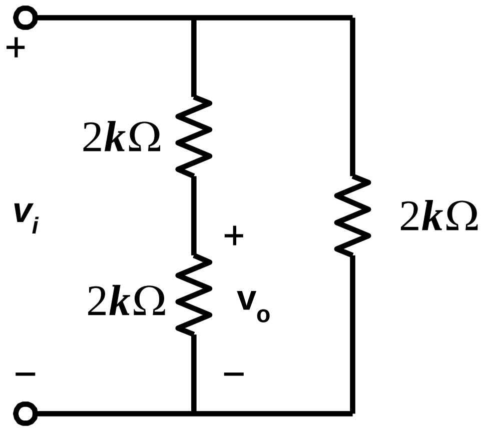
$$V_{dc} = 0.636 V_m = 0.636(5) = 3.18V$$

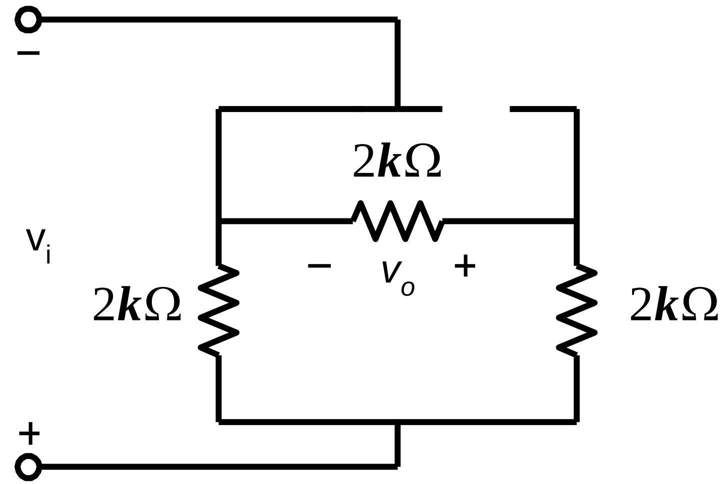
→Effect of removing two diodes.

Full-Wave Rectification

During - Cycle (t = T/2 → T)



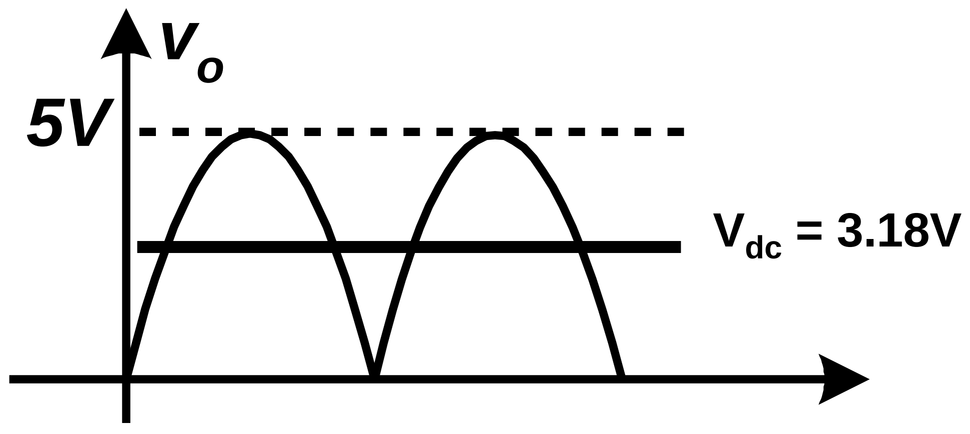




$$v_o = \frac{1}{2} v_i = 5V$$

$$V_{dc} = 0.636 V_m = 0.636(5) = 3.18V$$

Full-Wave Rectification

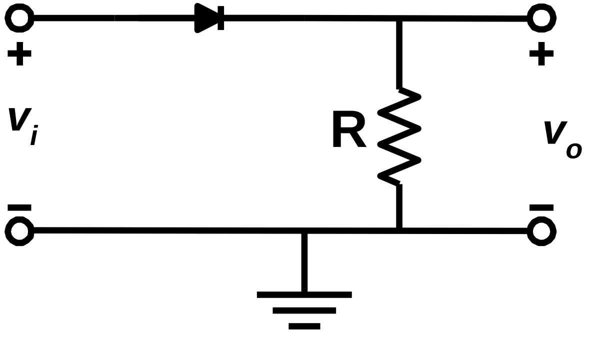


Clippers (Wave Shaping)

- Clippers circuit is used to “clip” off or chunk off a portion of the input signal.
- There are series and parallel clippers.

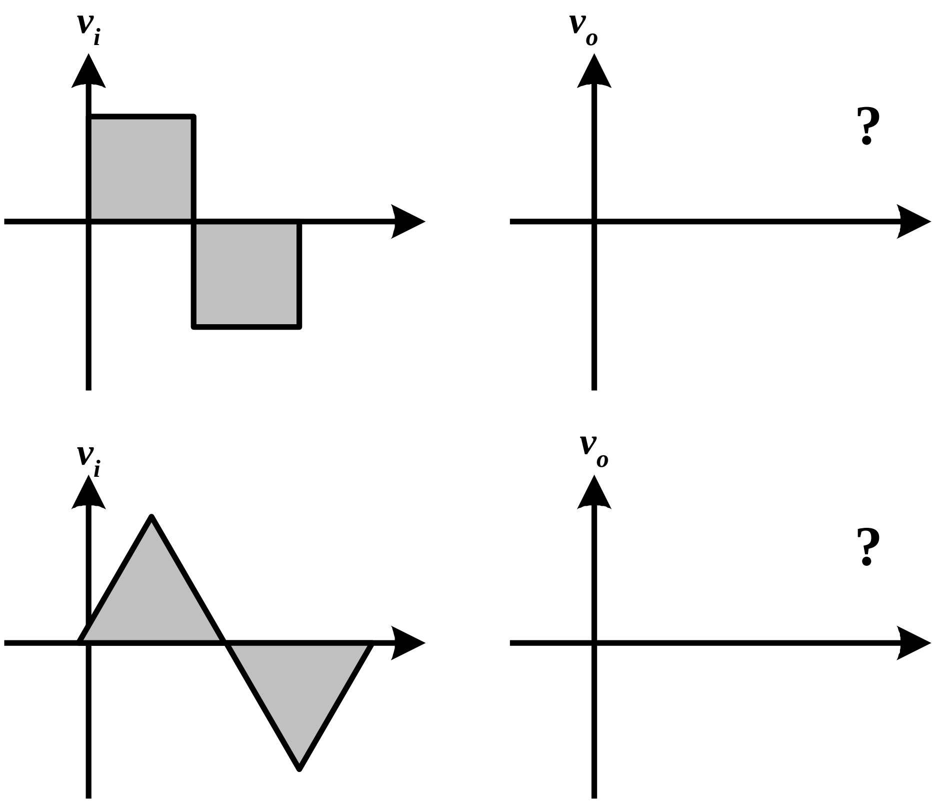
Series Clipper Circuit

- Diode in series with the load.



Clippers

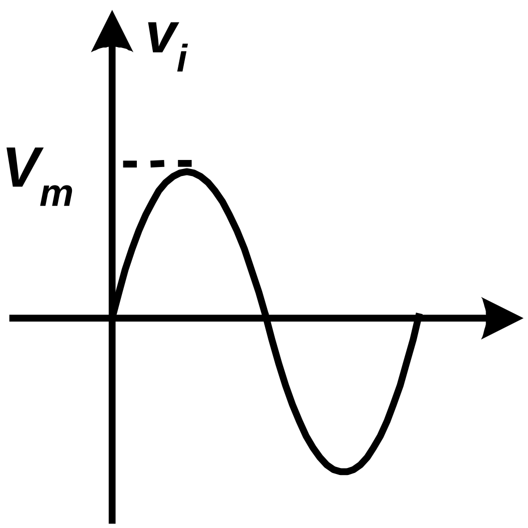
- Consider an Ideal diode
- Try to analyze the following waveform
- Use the series clipper circuit before

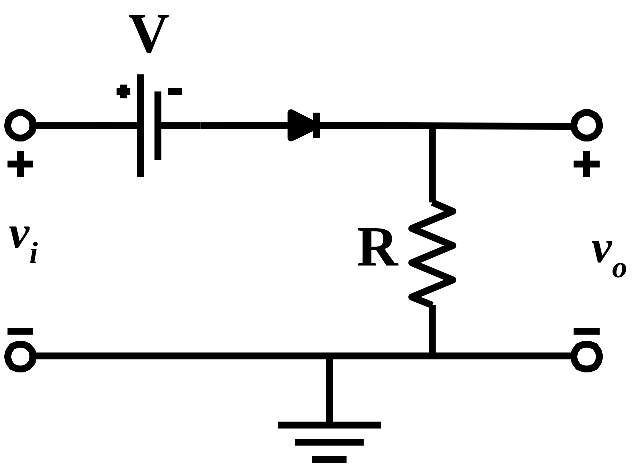


Clippers

- Consider Ideal diode for simplification.

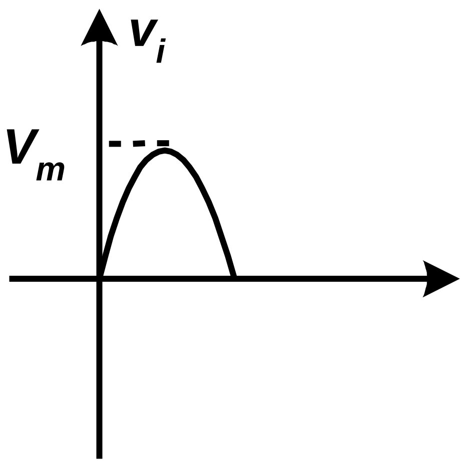
Series Clipper With a dc supply

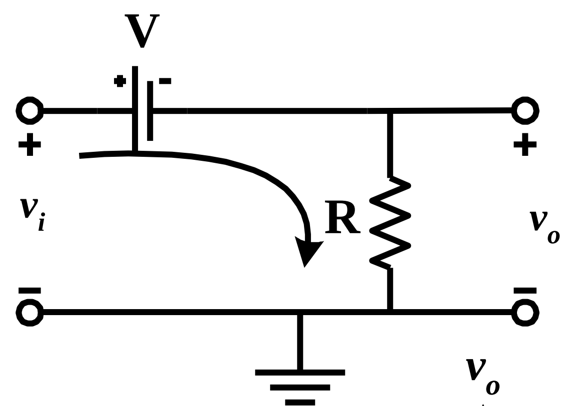




Clippers

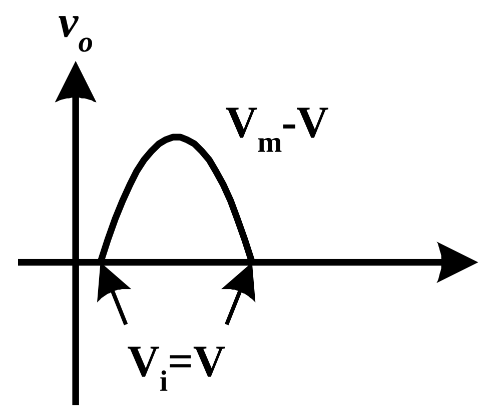
During + Cycle (t = 0 → T/2)





- Assume diode to be short circuit “On”.
- Use KVL to obtain i/p and o/p relation.

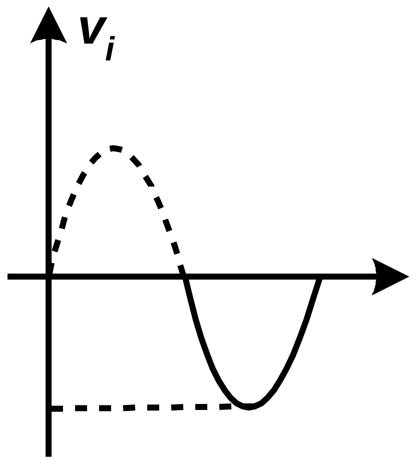
$$-v_i + V + v_o = 0 \qquad v_o = v_i - V$$

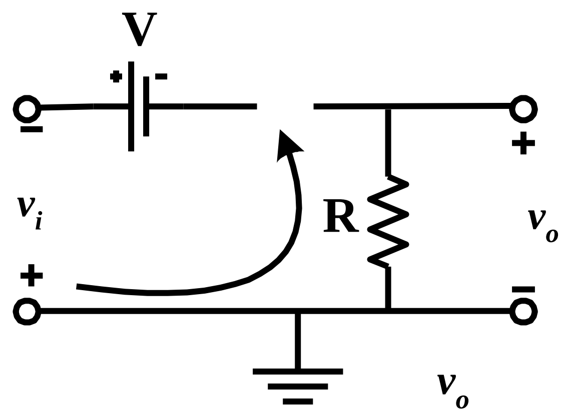


  - vo, will be positive only when vi ≥V.
  - When vi <V, diode is open circuit.

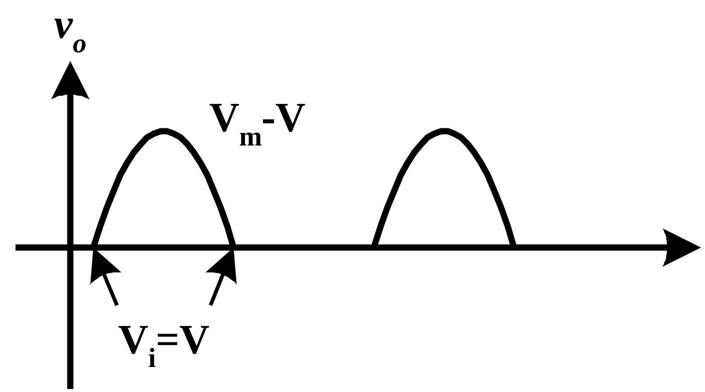
Clippers

During - Cycle (t = T/2 → T)





$$v_o = 0$$

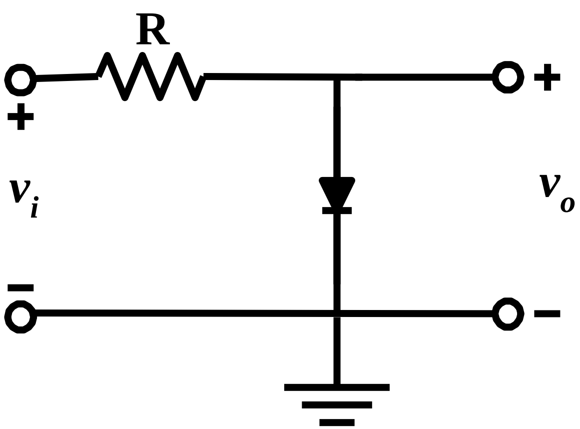


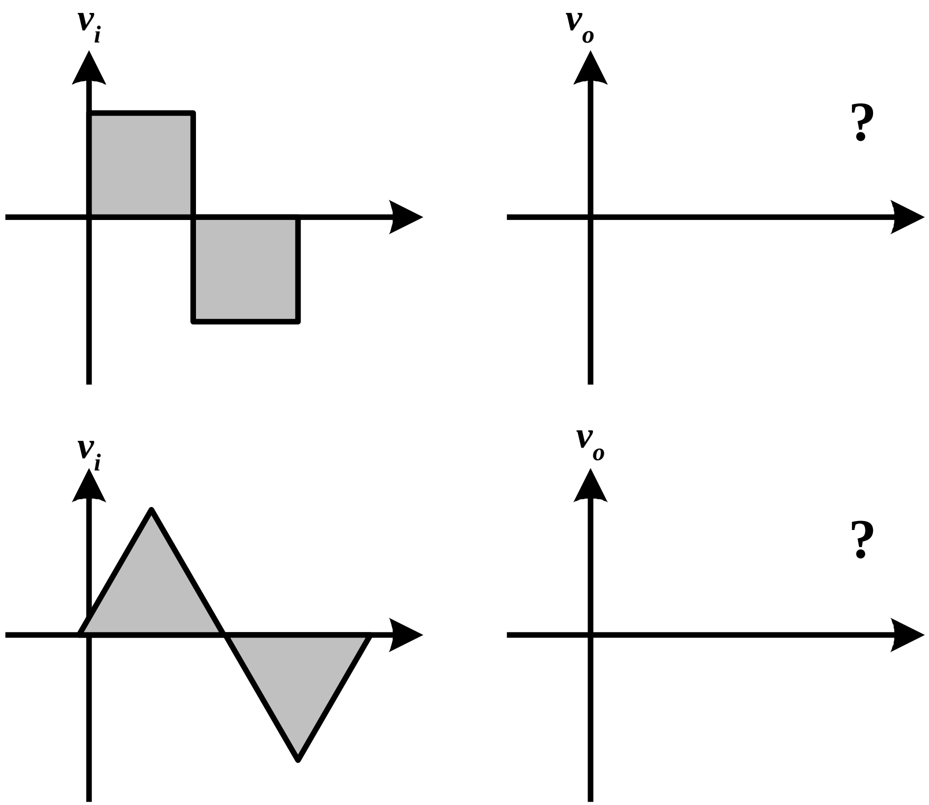
- Diode is open circuit “Off”.

Clippers

Parallel Clipper Circuit

- Diode in parallel with the load.

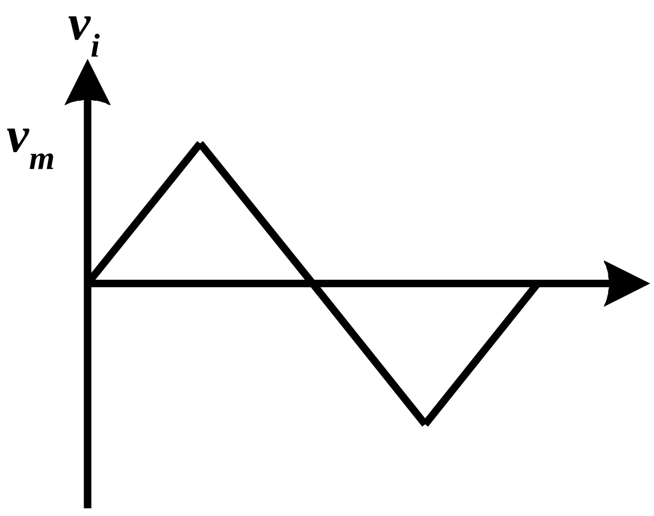


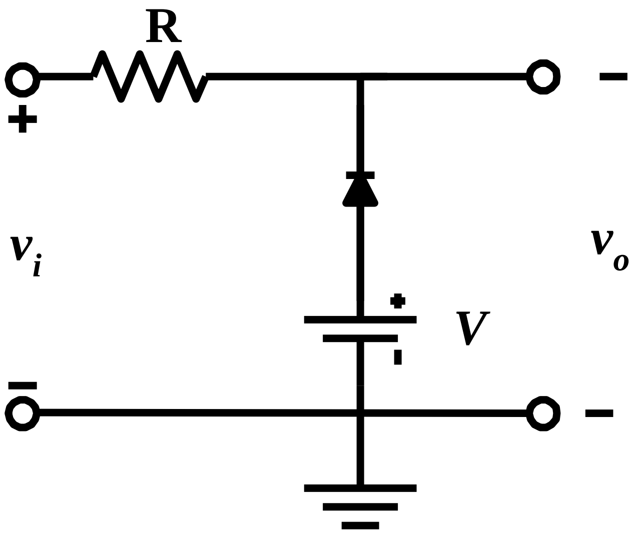


- Consider an Ideal diode.
- Observe for each cycle.

Clippers

Parallel Clipper With a dc supply





During + Cycle (t = 0 → T/2)

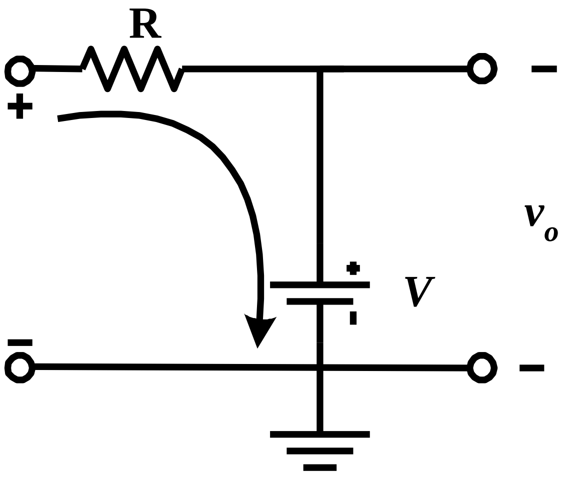
- Assume diode to be short circuit.
- Apply KVL.
- Assume v_m > V.

Clippers

$$v_o = V$$

- Only true when vi < V.
- When vi > V, diode open cct.

$$v_o = v_i$$

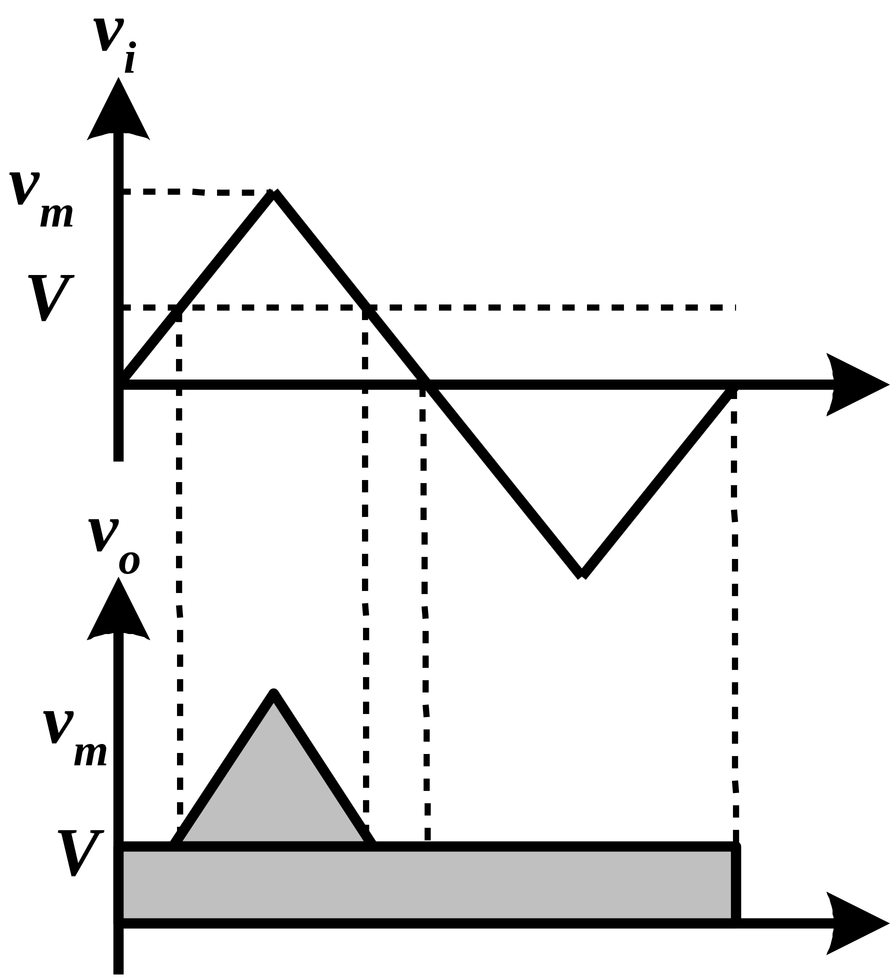


During - Cycle (t = T/2 → T)

- Diode is always short circuit, “On”.

$$v_o = V$$

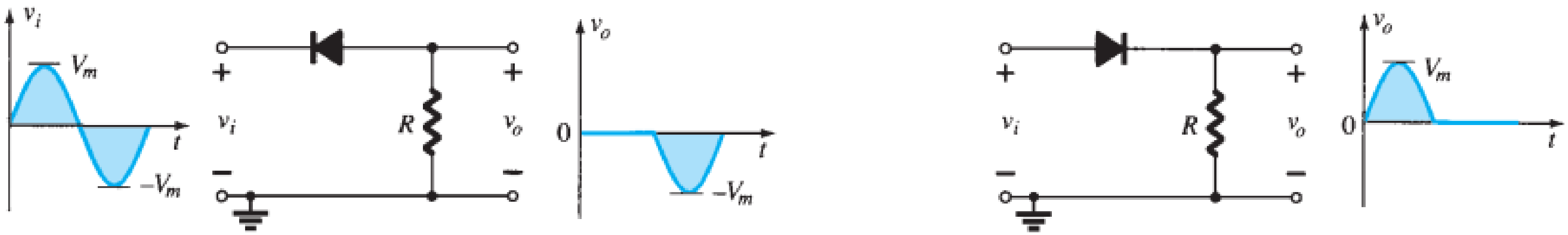
Clippers



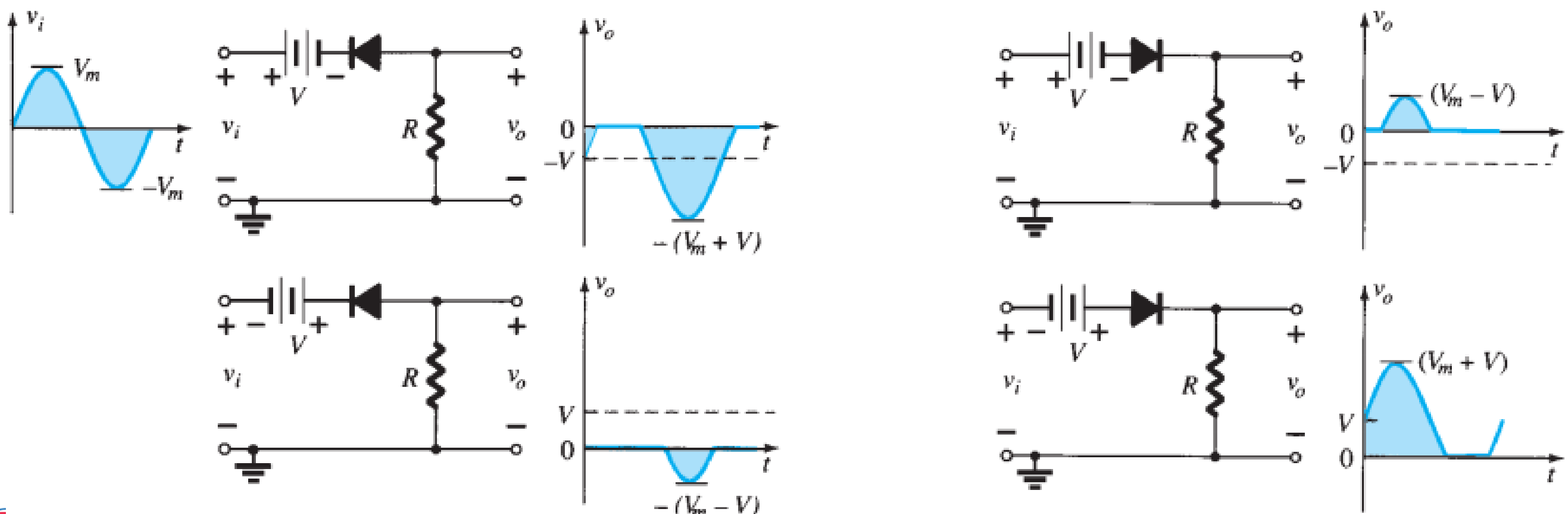
Series Clipping Circuits

Simple Series Clippers (Ideal Diodes)

POSITIVE | NEGATIVE

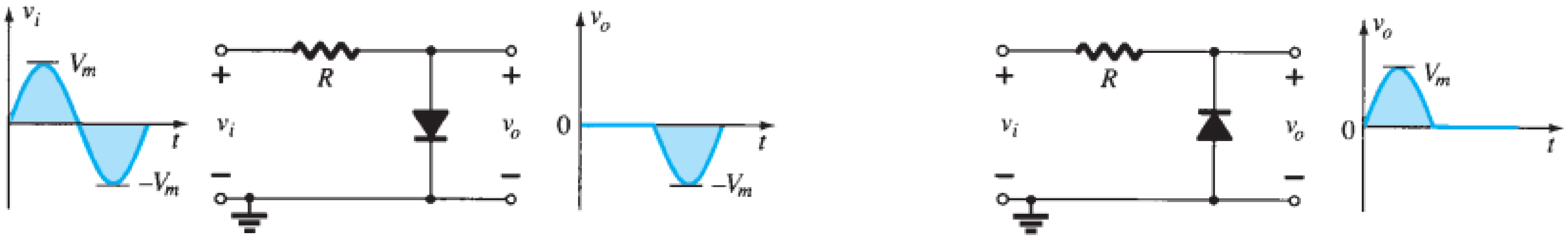


Biased Series Clippers (Ideal Diodes)

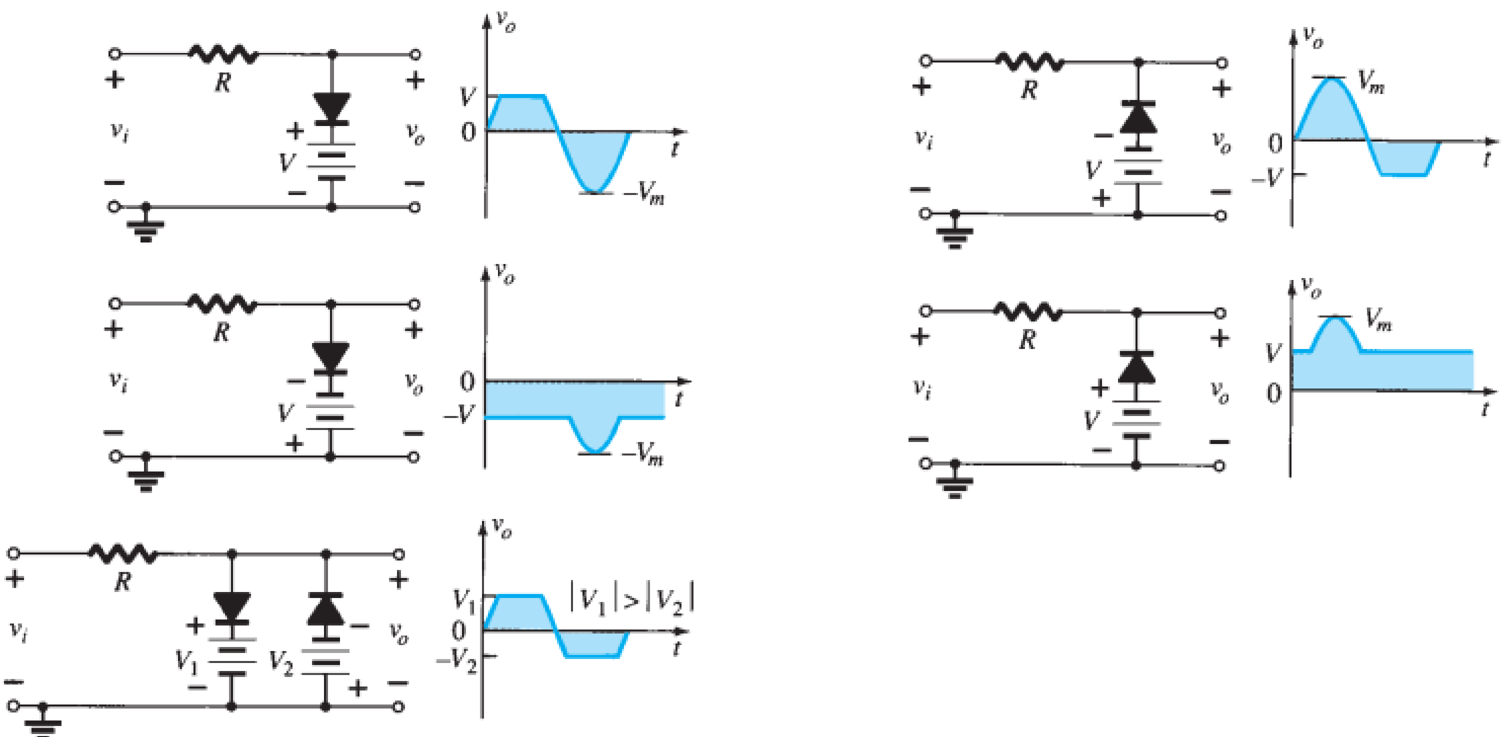


Parallel Clipping Circuits

Simple Parallel Clippers (Ideal Diodes)

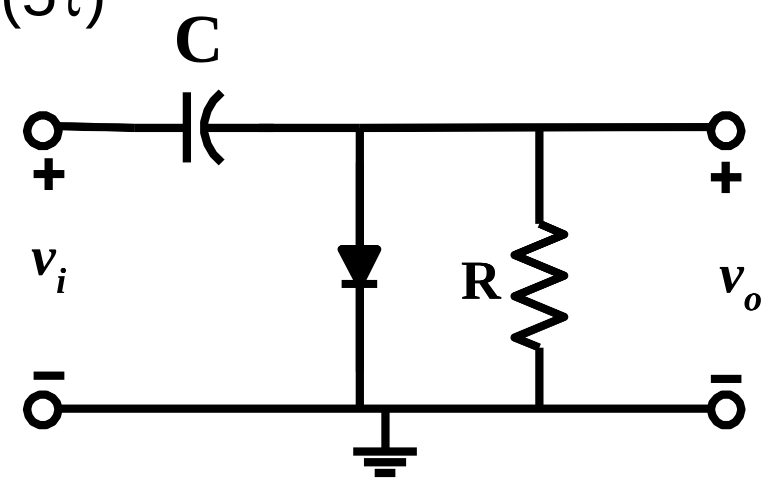


Biased Parallel Clippers (Ideal Diodes)



Clampers (Wave Shaping)

- Used to "clamp" or attach a signal to a different dc level.
- Circuit usually has a capacitor, diode and a resistor
- τ = RC is chosen to be large enough to avoid discharging process
- Assumption: capacitor will fully discharge and charge in five time constant (5τ)



Clampers (Wave Shaping)

Steps for Analyzing Clampers Circuit

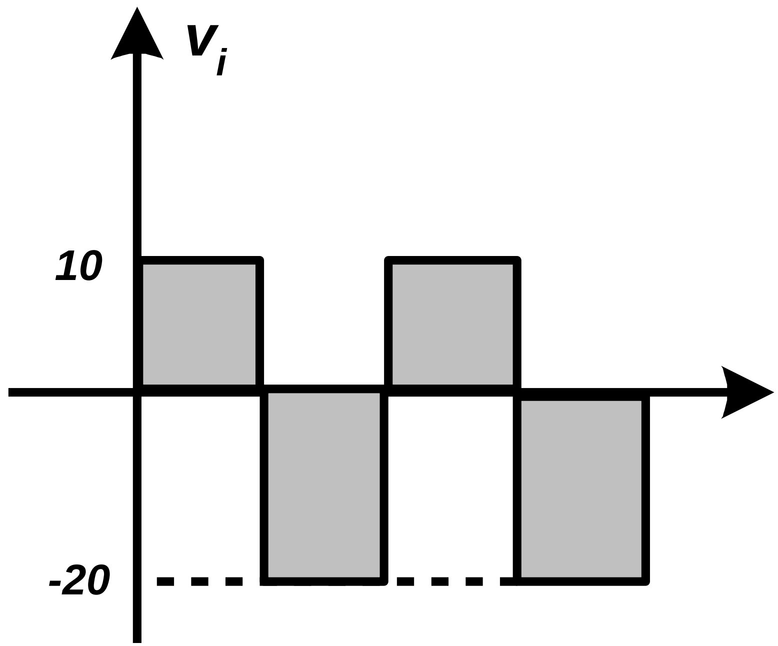
1. Start the analysis by considering the signal which forward biases the diode
2. During the period the diode is in the ‘on’ state, assume C will charge up instantaneously to a voltage level set by the surrounding network
3. During the period the diode is in the ‘off’ state, assume C holds on to its established voltage level
4. Throughout the analysis, be aware of the location and polarity for Vo
5. Check that the total swing of the output matches that of the input

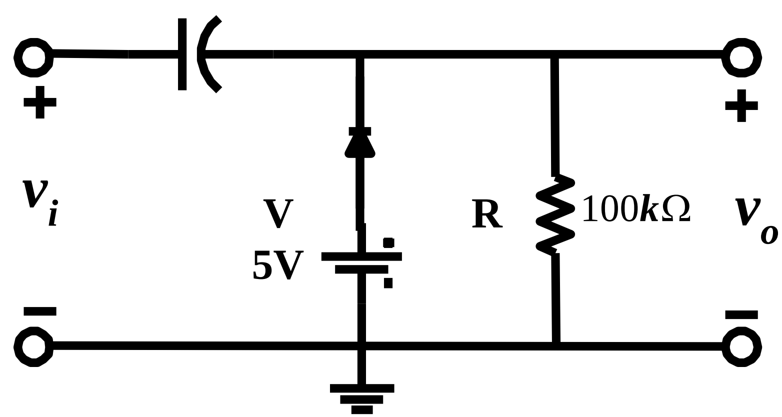
Clampers

Example 2: (*Boylestad 9th ed.)*

Example : Determine v_o.

$$f = 1000\,Hz$$





- For clamping circuit, start the analysis when the diode is forward-bias.

Clampers

From t_1-t_2 :

$$v_o = 5V$$

Apply KVL,

$$-20V + V_C - 5V = 0$$

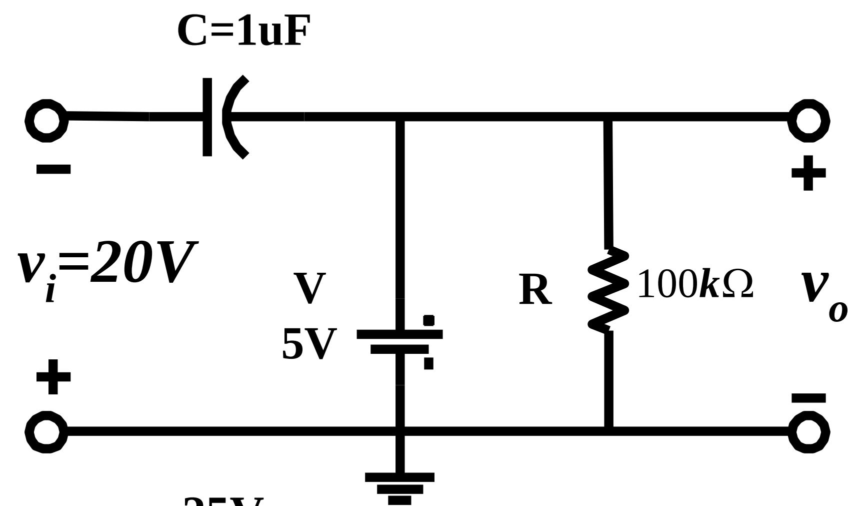
$$V_C = 25V$$

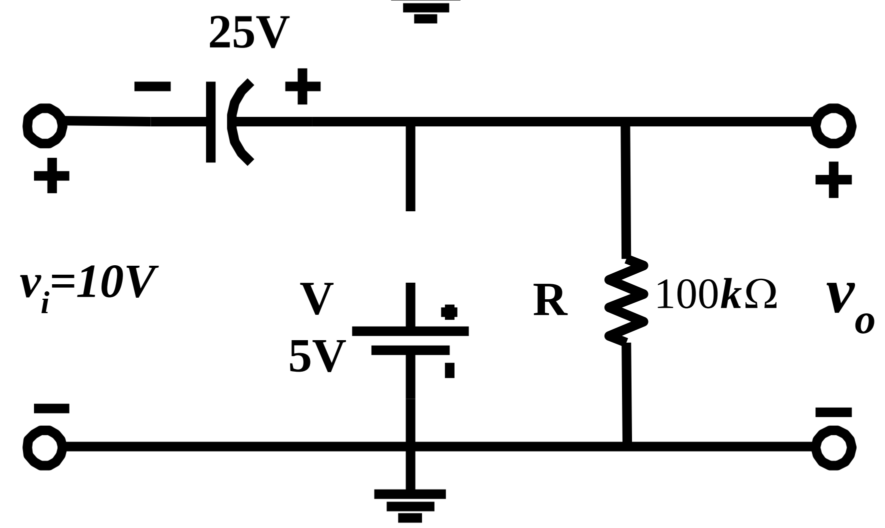
From t_2-t_3 :

Apply KVL, outside loop

$$10V + 25V - v_o = 0$$

$$v_o = 35V$$





Clampers

Calculate discharging time,

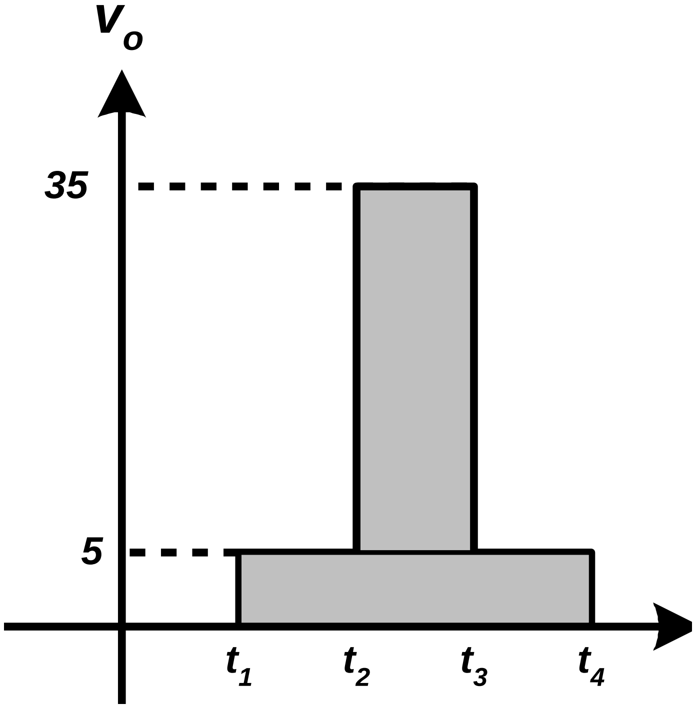
$$\tau = RC = (100k\Omega)(0.1\mu F) = 10ms$$
$$5\tau = 5(10ms) = 50ms$$

Given,

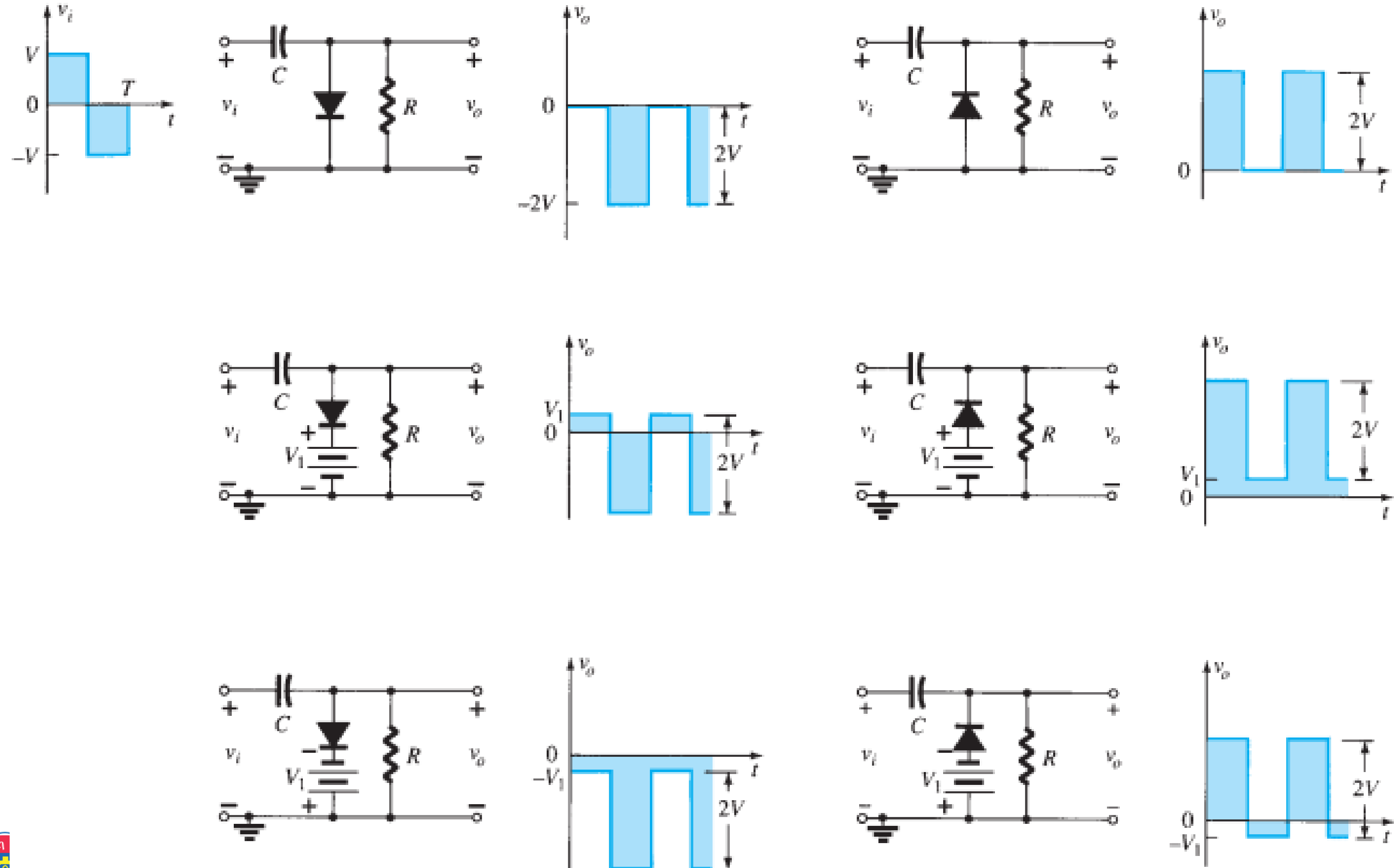
$$f = 1000Hz; T = 1ms$$

1/2T= t_2-t_3 =0.5ms

* Since 1/2T < 5τ, therefore capacitor will not have enough time to discharge.

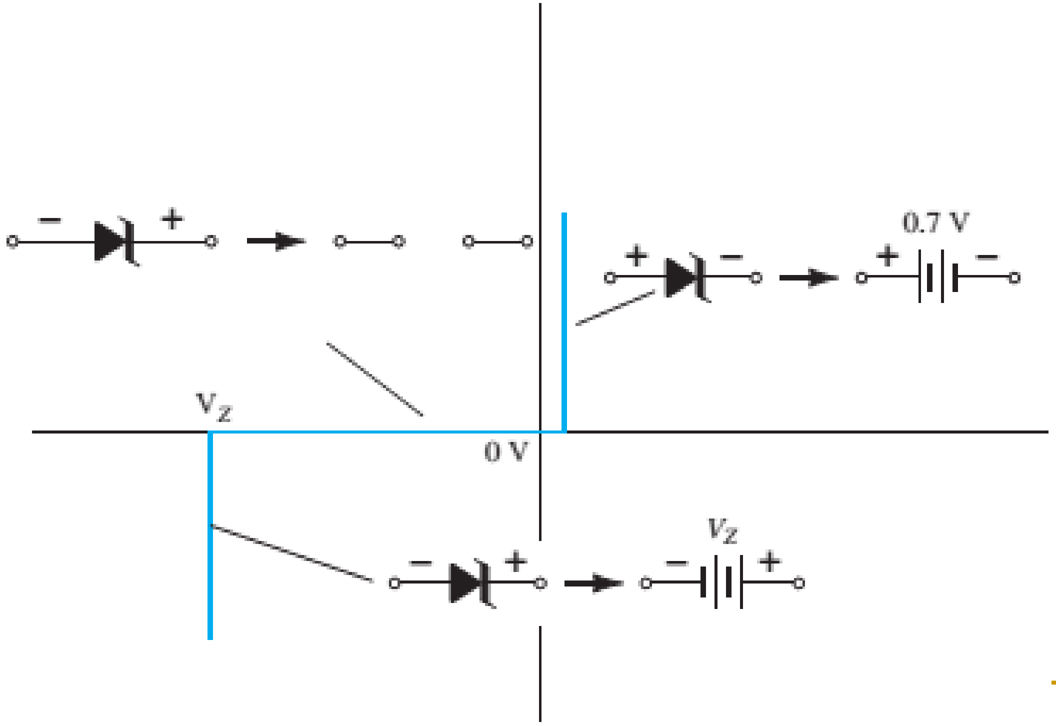


Clamping circuits with ideal diodes



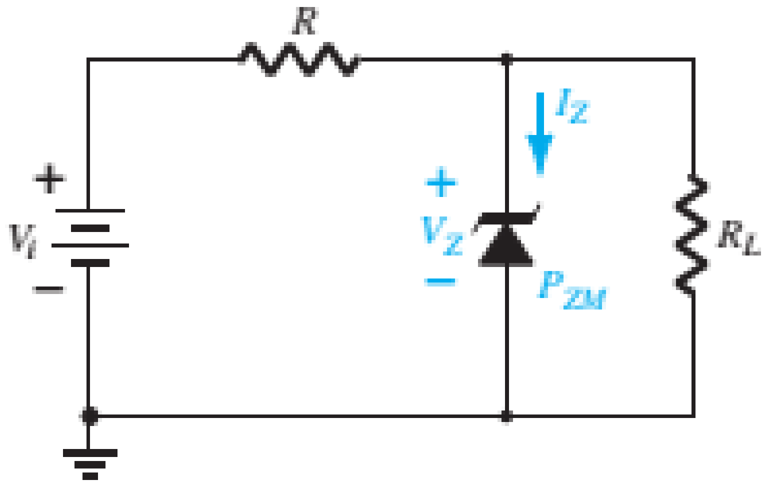
Zener Regulation

- Analysis of networks employing Zener diodes is quite similar to the analysis of semiconductor diodes in previous sections.
- First the state of the diode must be determined, then substituting the appropriate model and determining the other unknown quantities of the network.



Zener Regulation

- The use of the Zener diode as a regulator is so common that three conditions surrounding the analysis of the basic Zener regulator are considered.
- The analysis is first for **fixed quantities**, followed by a **fixed supply voltage and a variable load**, and finally a **fixed load and a variable supply.**

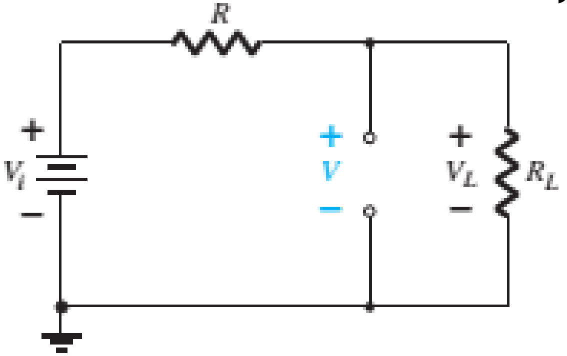


V_i and R_L fixed

- The analysis can fundamentally be broken down into 2 steps:

1. ***Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.***

$$\boxed{V = V_L = \frac{R_L V_i}{R + R_L}}$$

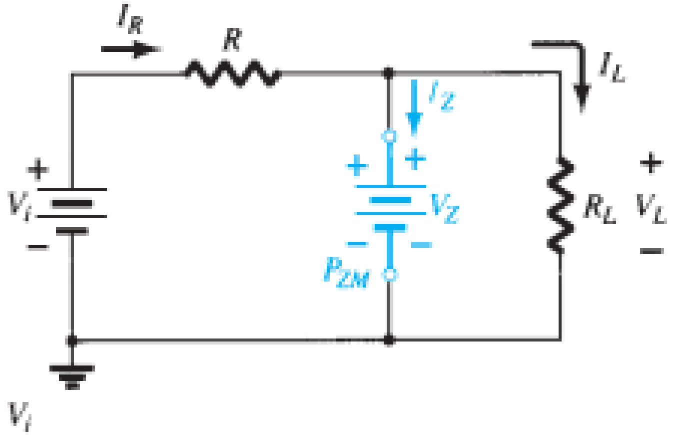


2. ***Substitute the appropriate equivalent circuit and solve for unknowns.***

$$\boxed{V_L = V_Z}$$

$$\boxed{I_Z = I_R - I_L}$$

$$\boxed{P_Z = V_Z I_Z}$$



Fixed V_i variable R_L

- If R is too small, the Zener current exceeds the maximum current rating, I_{ZM}. The maximum current for the circuit is then given by: $$I_{L_{\max}} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L_{\min}}}$$
- The corresponding minimum load resistance can be calculated by taking V_L=V_Z. That is, $V_L = V_Z = \dfrac{R_L V_i}{R_L + R}$ $\Rightarrow$ $$R_{L_{\min}} = \frac{RV_Z}{V_i - V_Z}$$
- Once the diode is "on", the voltage across R remains fixed at

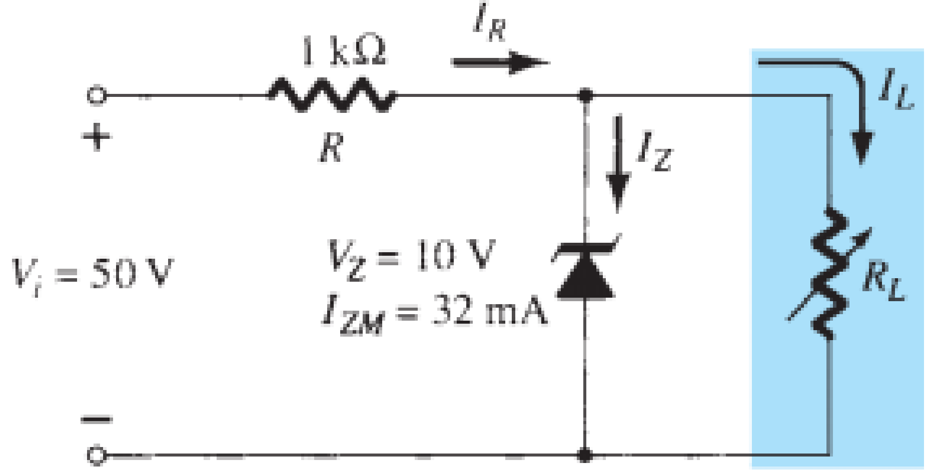
$$V_R = V_i - V_Z \Rightarrow I_R = \frac{V_R}{R} \Rightarrow I_Z = I_R - I_L$$

- But I_Z is limited to I_{ZM} as provided on the data sheet. Replacing I_{ZM} for I_Z establishes the minimum I_L as:

$$I_{L_{\min}} = I_R - I_{ZM} \Rightarrow R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}}$$

Example (Boylestad)

- For the network of Figure below, determine the range of R_L and I_L that will result in V_{RL} being maintained at 10 V. Determine the maximum wattage rating of the diode.



- To determine the value of *RL* that will turn the Zener diode on,

$$R_{L_{\min}} = \frac{RV_Z}{V_i - V_Z} = \frac{(1\text{ k}\Omega)(10\text{ V})}{50\text{ V} - 10\text{ V}} = \frac{10\text{ k}\Omega}{40} = \mathbf{250\ \Omega}$$

Example

- The voltage across the resistor *R* is then determined

$$V_R = V_i - V_Z = 50\text{ V} - 10\text{ V} = \mathbf{40\text{ V}}$$

- The magnitude of I_R:

$$I_R = \frac{V_R}{R} = \frac{40\text{ V}}{1\text{ k}\Omega} = \mathbf{40\text{ mA}}$$

- The minimum level of I_L is then,

$$I_{L_{\min}} = I_R - I_{ZM} = 40\text{ mA} - 32\text{ mA} = \mathbf{8\text{ mA}}$$

- Determining the maximum value of R_L:

$$R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}} = \frac{10\text{ V}}{8\text{ mA}} = \mathbf{1.25\text{ k}\Omega}$$

- The maximum power rating will then be given by:

$$P_{max} = V_Z I_{ZM} = (10V)(32mA) = 320mW$$

Fixed R_L variable V_i

- For fixed values of R_L, the voltage V_i must be sufficiently large to turn on the Zener diode. The minimum turn on voltage is determined by: $$V_L = V_Z = \frac{R_L V_i}{R_L + R} \Rightarrow V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L}$$
- The maximum value of Vi is limited by the maximum Zener current I_{ZM}. Since $I_{ZM} = I_R - I_L$.

$$I_{R_{\max}} = I_{ZM} + I_L$$

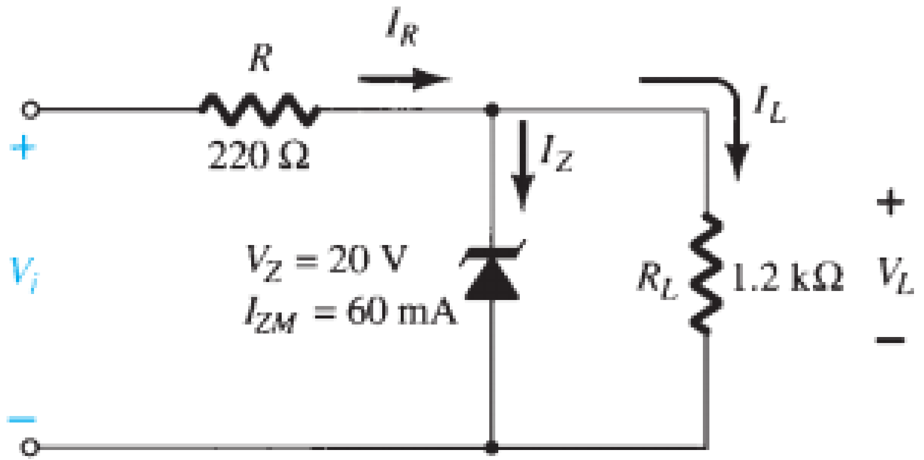
- Since I_L is fixed and I_{ZM} is the maximum value of I_Z, the maximum I_Z is defined by:

$$V_{i_{\max}} = V_{R_{\max}} + V_Z$$

$$V_{i_{\max}} = I_{R_{\max}} R + V_Z$$

Example (Boylestad)

- Determine the range of values of V_i that will maintain the Zener diode in the "on" state



$$V_{i_{\min}} = \frac{(R_L + R)V_Z}{R_L} = \frac{(1200\ \Omega + 220\ \Omega)(20\ \text{V})}{1200\ \Omega} = \mathbf{23.67\ V}$$

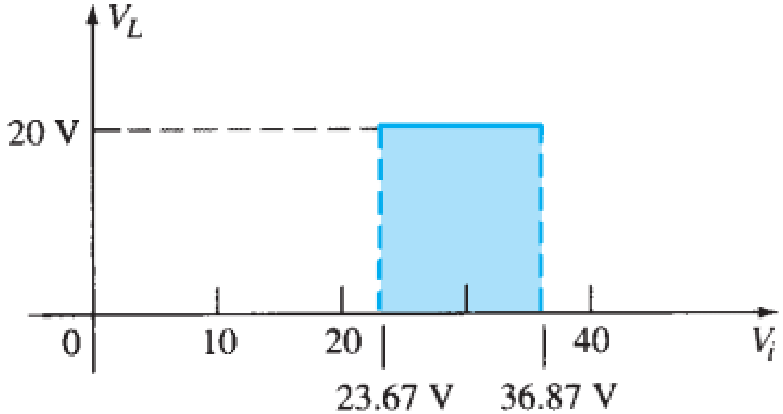
$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20\ \text{V}}{1.2\ \text{k}\Omega} = 16.67\ \text{mA}$$

Example

$$I_{R_{max}} = I_{ZM} + I_L = 60\text{ mA} + 16.67\text{ mA} = 76.67\text{ mA}$$

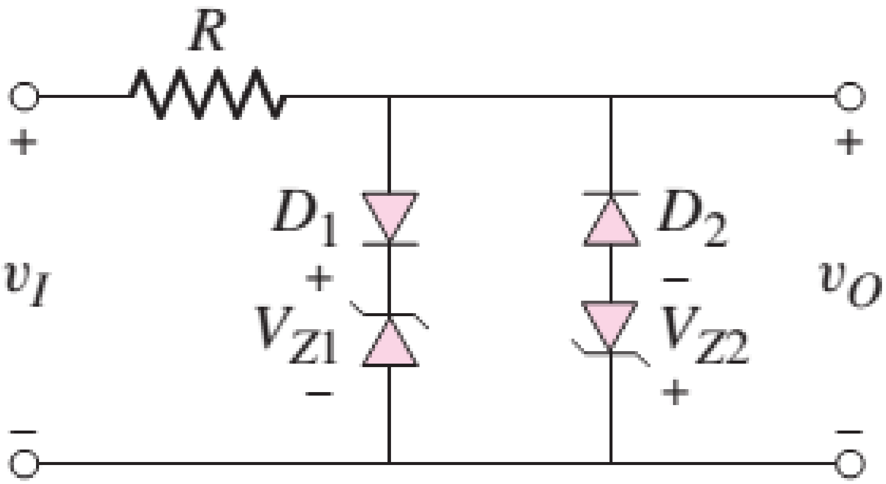
$$V_{i_{max}} = I_{R_{max}}R + V_Z$$

$$= (76.67\text{ mA})(0.22\text{ k}\Omega) + 20\text{ V} = \mathbf{36.87\text{ V}}$$

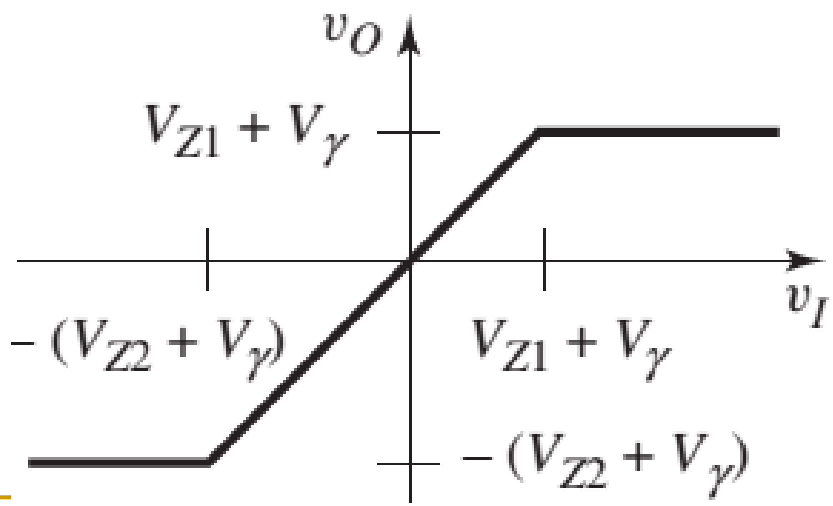


A Plot of V_L Versus V_i

Zener Limiting (Regulation)



- Its Corresponding input-output characteristic



What to Do This Week?

- Reading Assignment
  - Voltage Multipliers and other practical application circuits of Diodes.
- For Next class read:
  - BJT (Bipolar Junction Transistors).