Lecture 4

PRACTICAL APPLICATIONS OF DIODES

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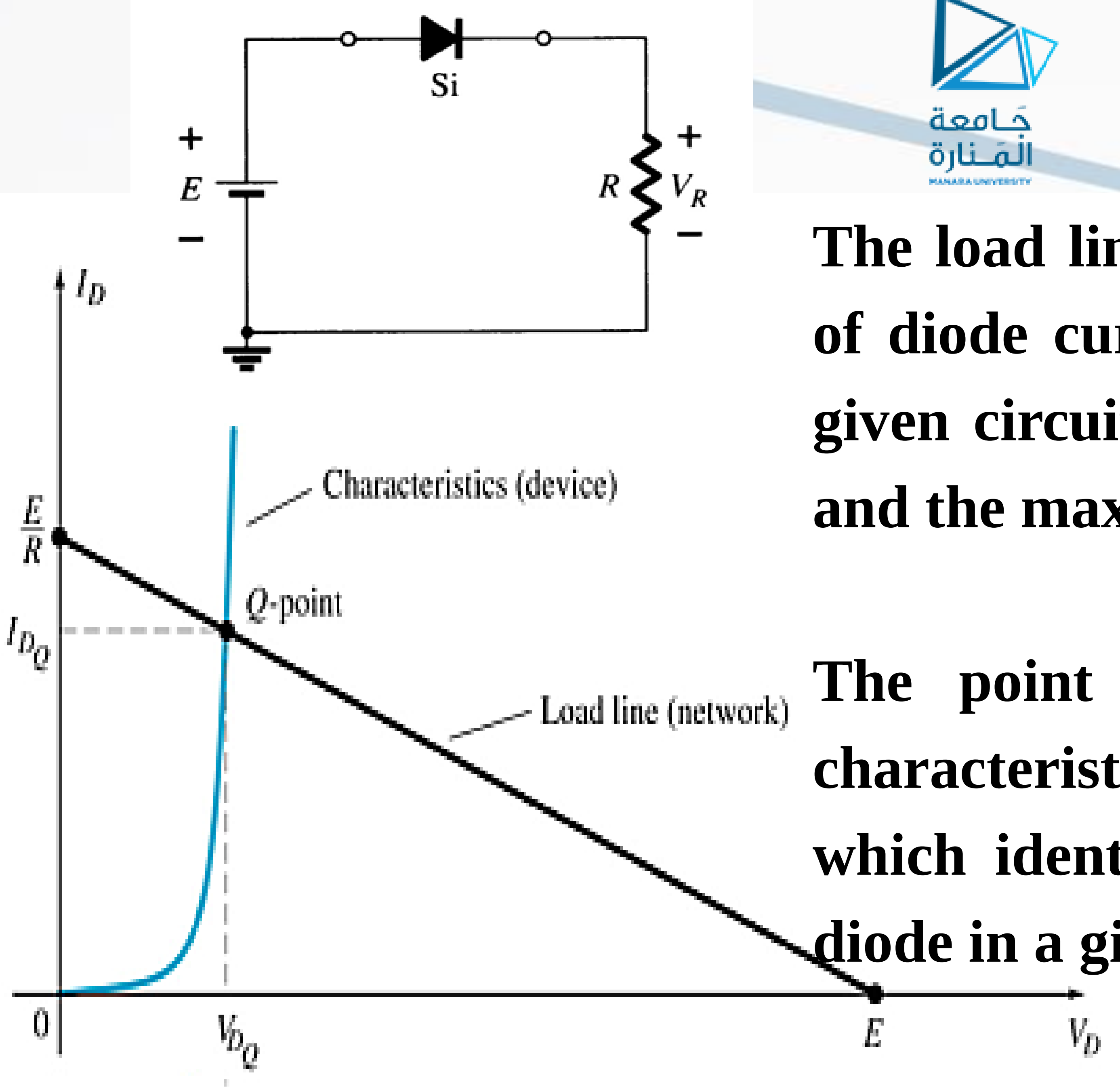
Practical Applications

- **Rectifier Circuits**
  - Conversions of AC to DC for DC operated circuits
  - Battery Charging Circuits
- **Simple Diode Circuits**
  - Protective Circuits against
  - Overcurrent
  - Polarity Reversal
  - Currents caused by an inductive kick in a relay circuit
- **Zener Circuits**
  - Overvoltage Protection
  - Setting Reference Voltages



Load-Line Analysis

The load line plots all possible combinations of diode current (*I_D*) and voltage (*V_D*) for a given circuit. The maximum *I_D* equals *E/R*, and the maximum *V_D* equals *E*.

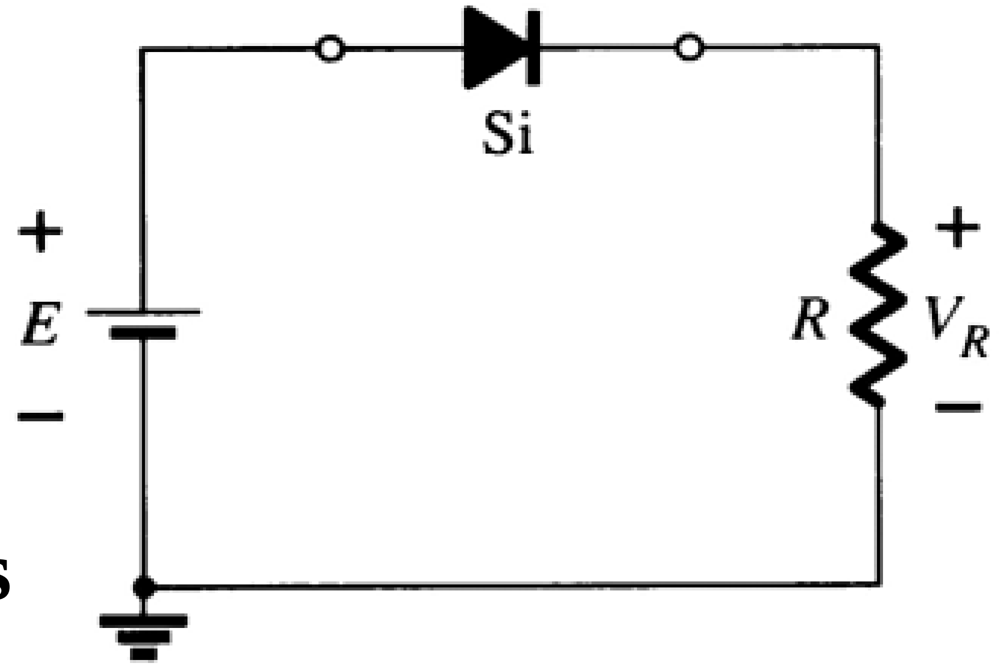
The point where the load line and the characteristic curve intersect is the Q-point, which identifies *I_D* and *V_D* for a particular diode in a given circuit.

Series Diode Configurations

Forward Bias

Analysis (for silicon)

- $V_D = 0.7\text{ V}$ (or $V_D = E$ if $E < 0.7\text{ V}$)
- $V_R = E - V_D$
- $I_D = I_R = I_T = V_R / R$



Reverse Bias

Diodes ideally behave as open circuits

Analysis

- $V_D = E$
- $V_R = 0\text{ V}$
- $I_D = 0\text{ A}$

Parallel Configurations

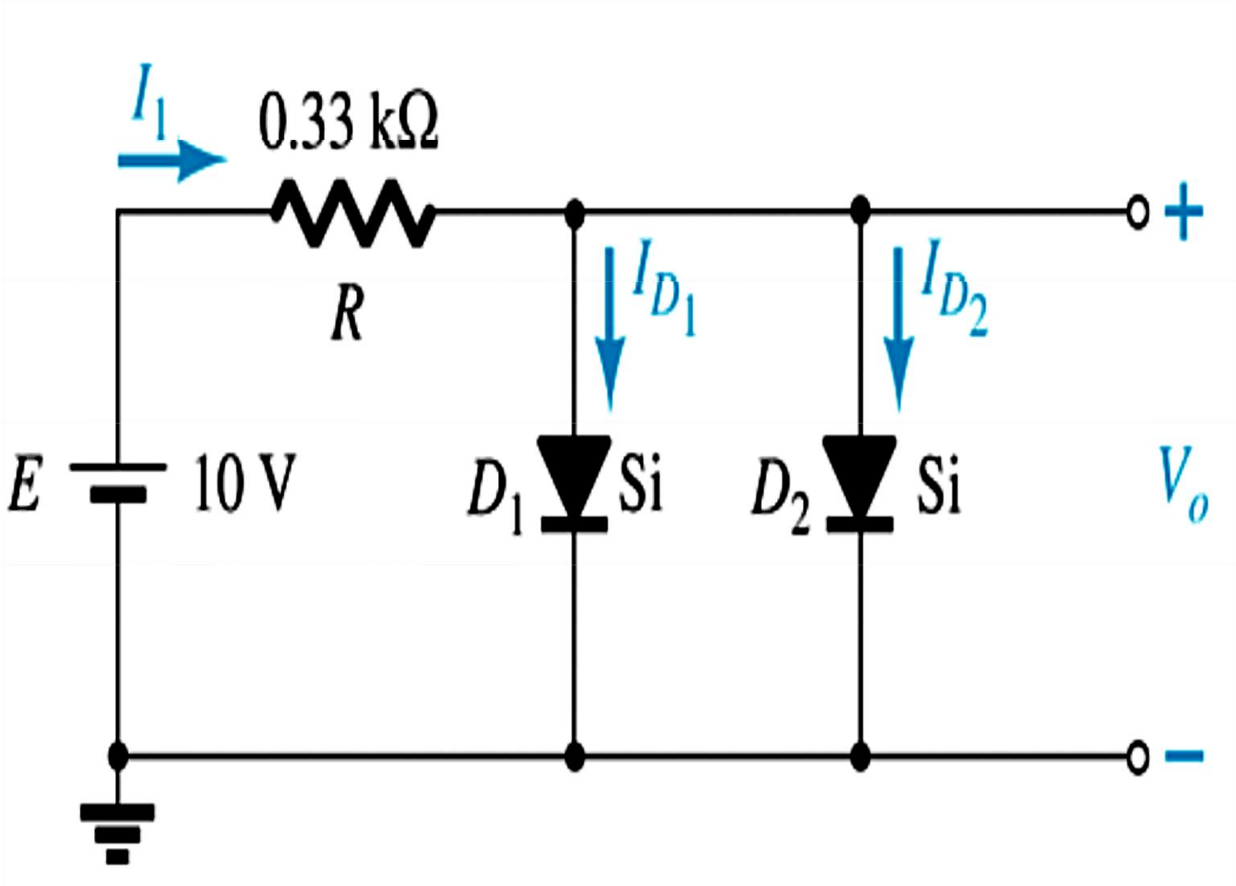
$$V_D = 0.7\ V$$

$$V_{D1} = V_{D2} = V_O = 0.7\ V$$

$$V_R = 9.3\ V$$

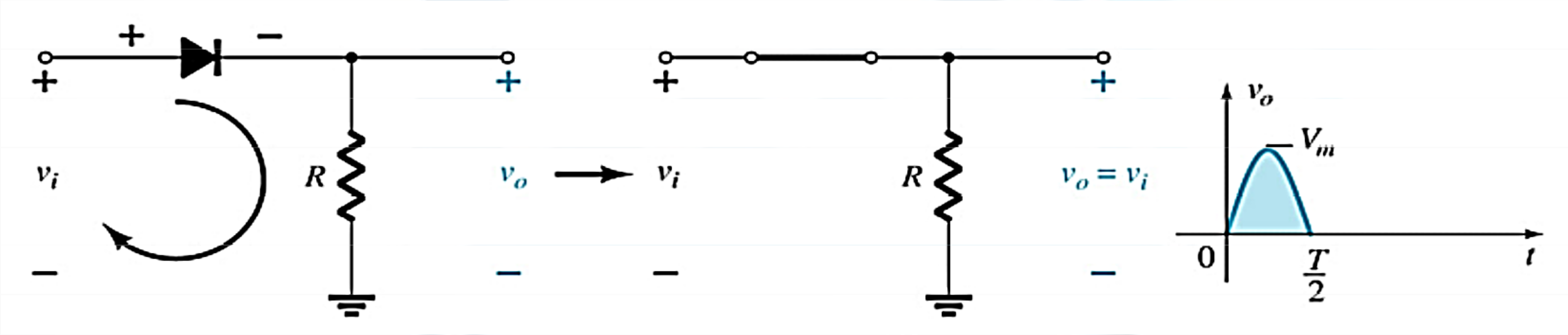
$$I_R = \frac{E - V_D}{R} = \frac{10\ V - .7\ V}{.33k\Omega} = 28\ mA$$

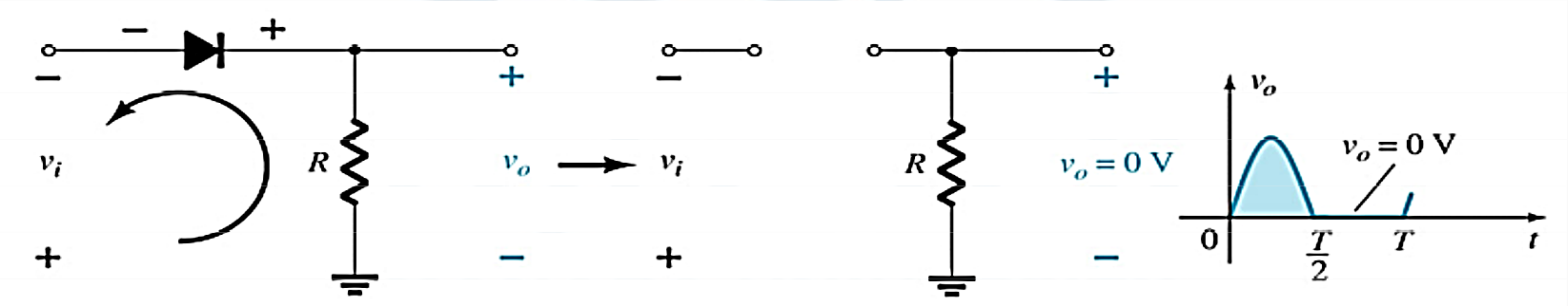
$$I_{D1} = I_{D2} = \frac{28\ mA}{2} = 14\ mA$$



Half-Wave Rectification

The diode only conducts when it is forward biased, therefore only half of the AC cycle passes through the diode to the output.





The DC output voltage is 0.318 V_m, where V_m = the peak AC voltage.

PIV (PRV)

Because the diode is only forward biased for one-half of the AC cycle, it is also reverse biased for one-half cycle.

It is important that the reverse breakdown voltage rating of the diode be high enough to withstand the peak, reverse-biasing AC voltage.

PIV (or PRV) > V_m

- **PIV = Peak inverse voltage**
- **PRV = Peak reverse voltage**
- **V_m = Peak AC voltage**

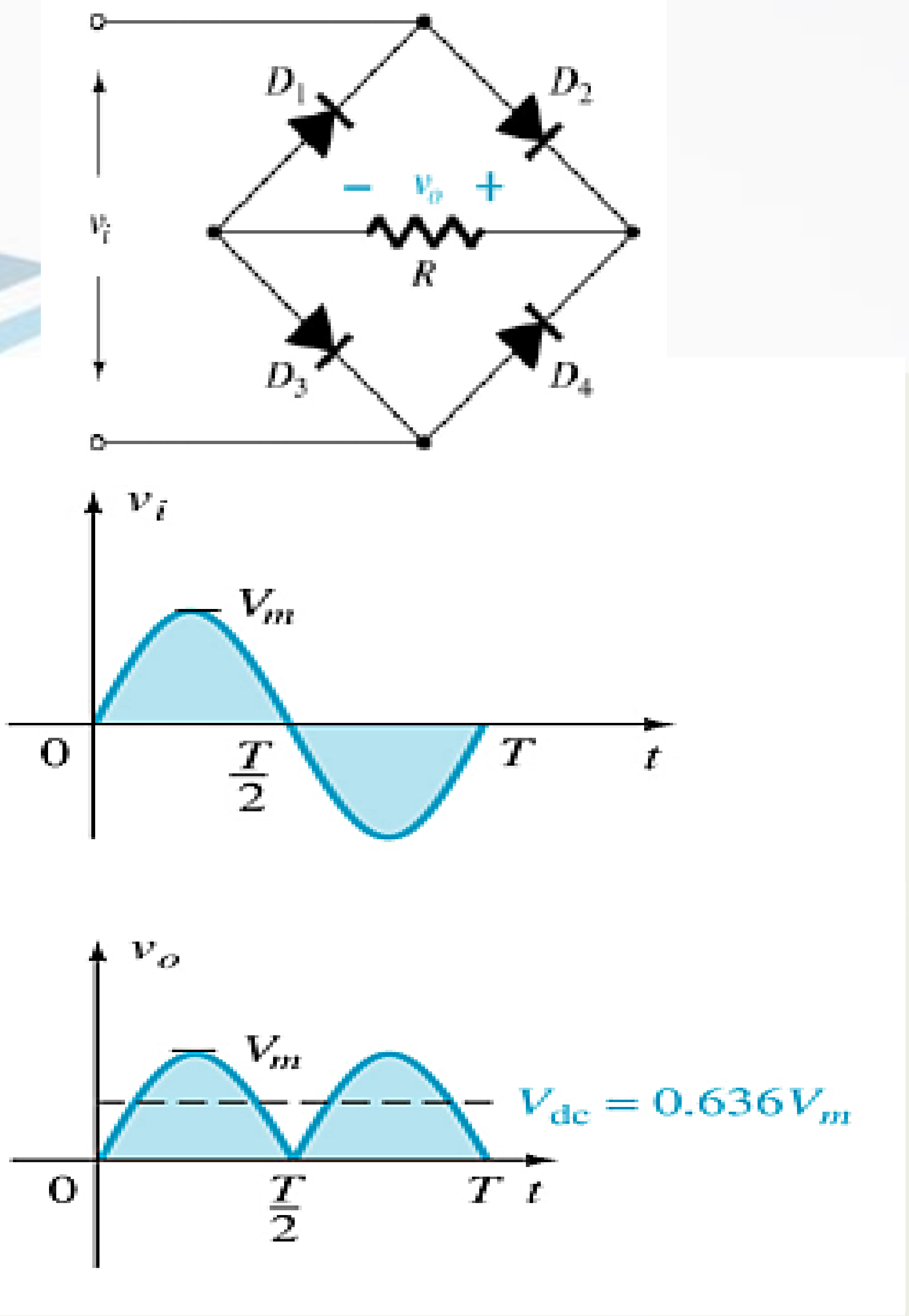
Full-Wave Rectification

The rectification process can be improved by using a full-wave rectifier circuit.

Full-wave rectification produces a greater DC output:

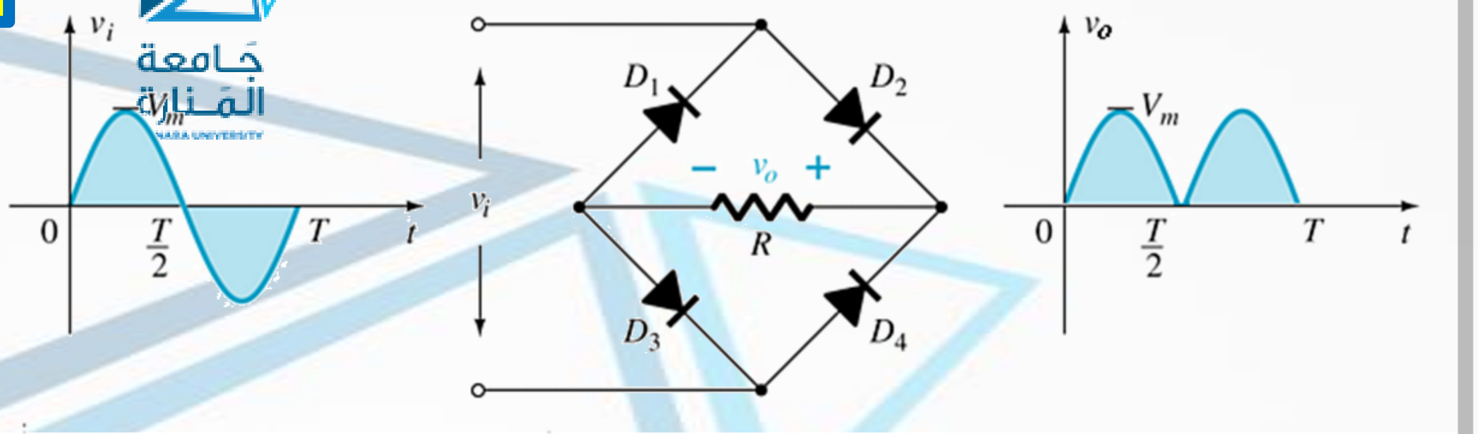
Half-wave: Vdc = 0.318Vm

Full-wave: Vdc = 0.636Vm

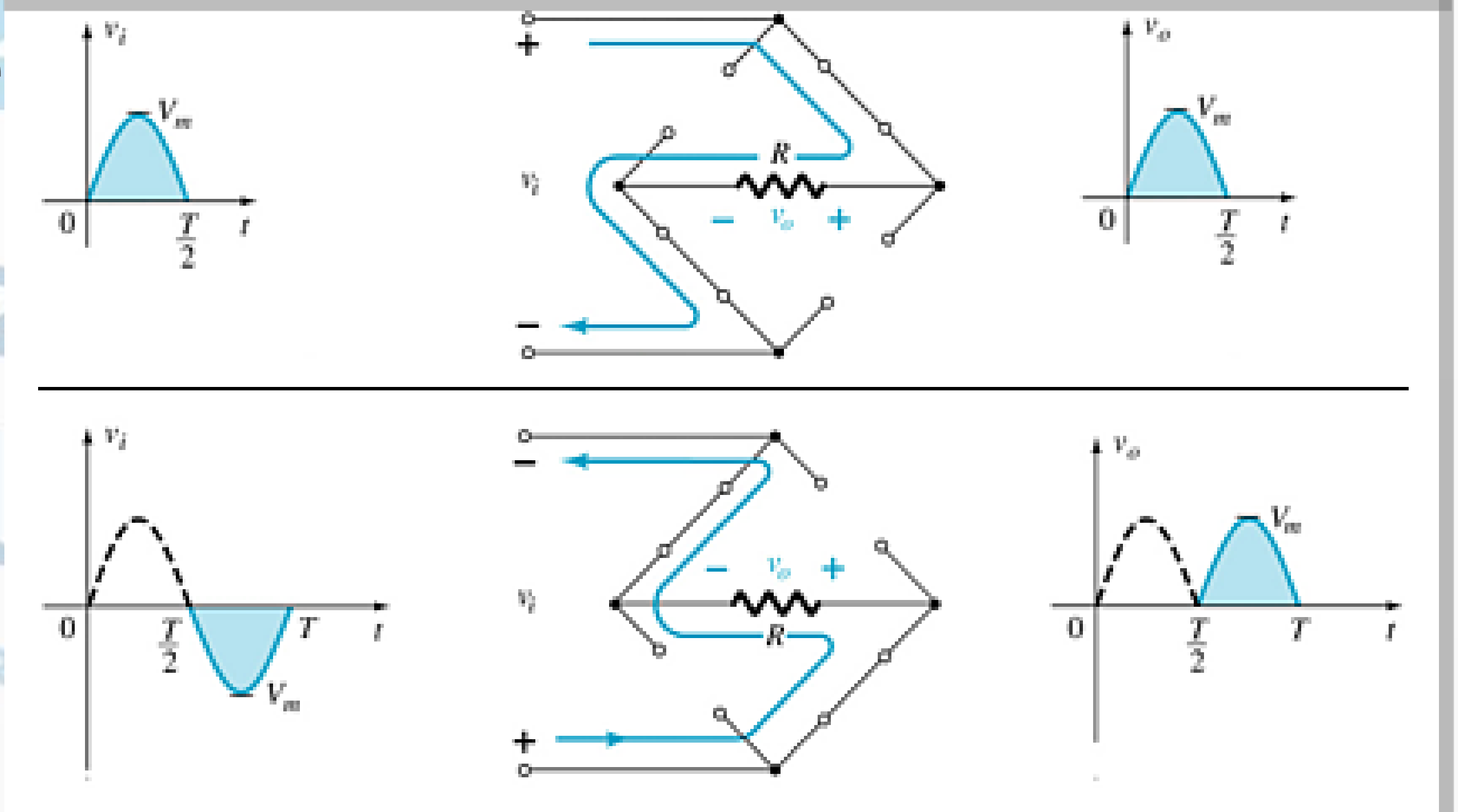


Full-Wave Rectification

Bridge Rectifier

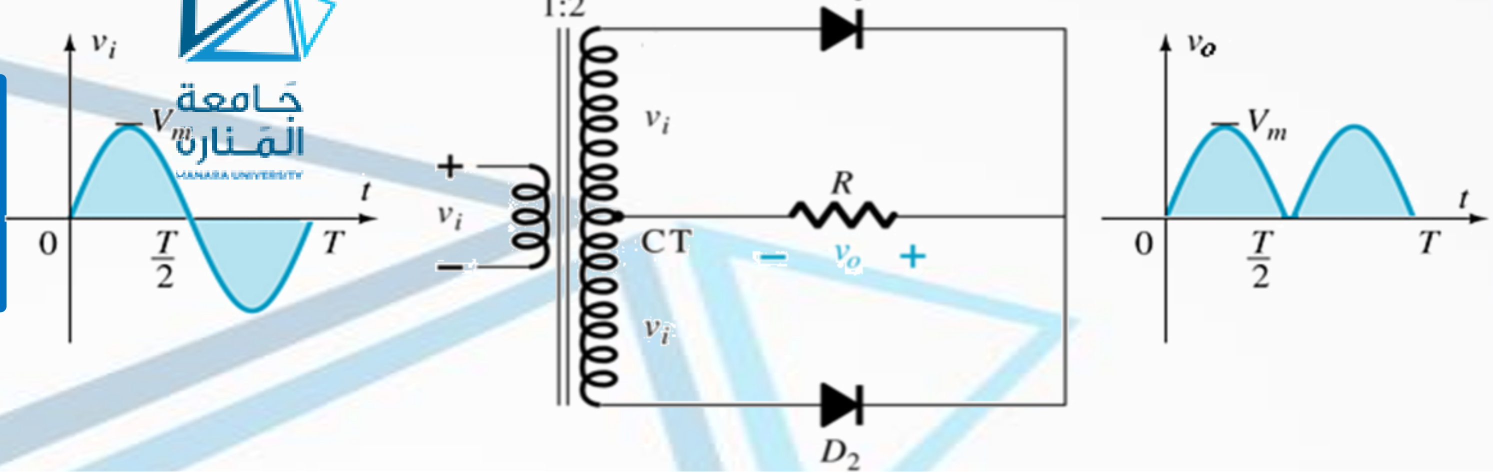


- Four diodes are connected in a bridge configuration
- $V_{DC} = 0.636\,V_m$



Full-Wave Rectification

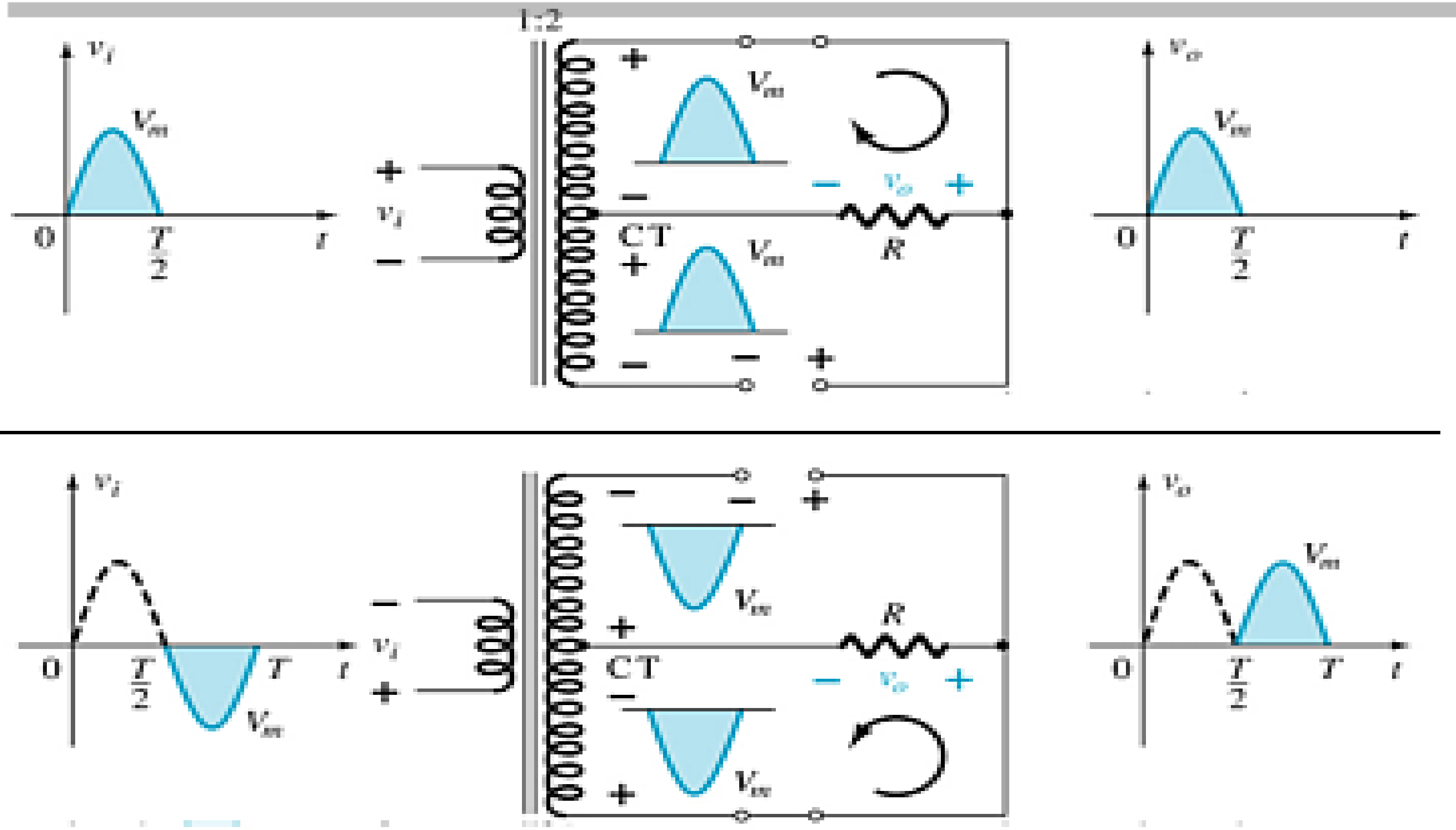
Center-Tapped Transformer Rectifier



Requires

- **Two diodes**
- **Center-tapped transformer**

$$V_{DC} = 0.636\, V_m$$



Summary of Rectifier Circuits

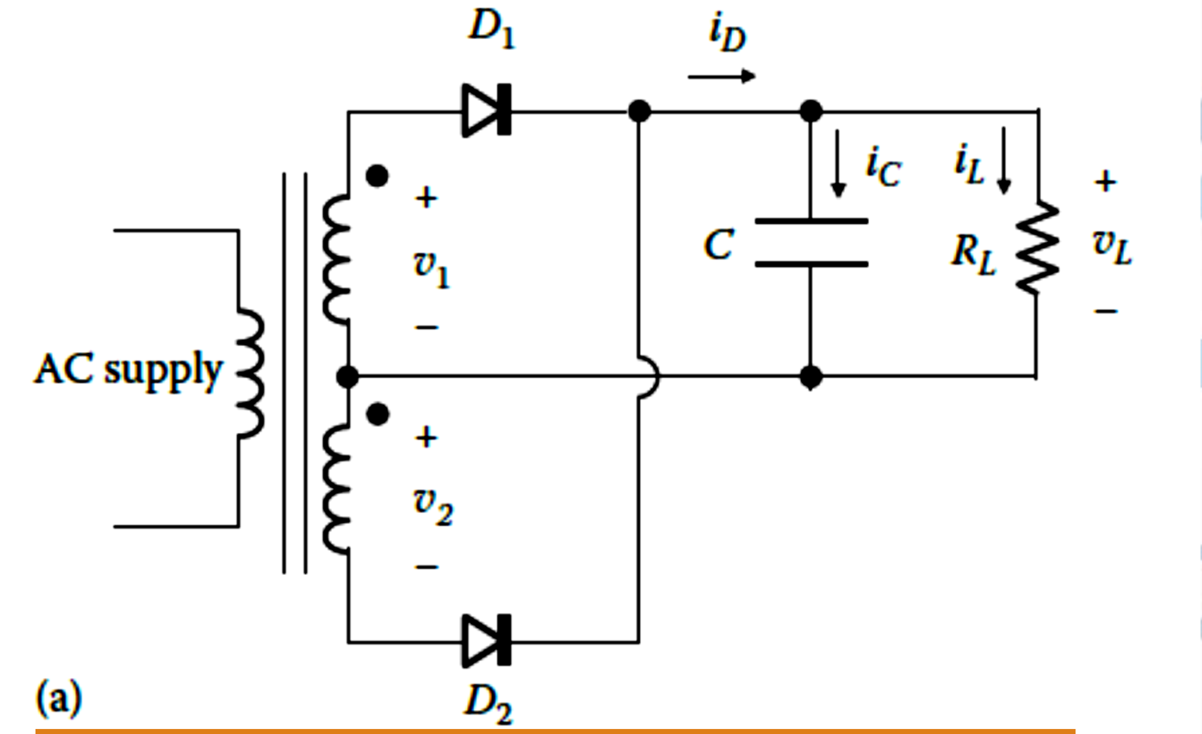
Rectifier	Ideal V_{DC}	Realistic V_{DC}
Half Wave Rectifier	$V_{DC} = 0.318\, V_m$	$V_{DC} = 0.318\, V_m - 0.7$
Bridge Rectifier	$V_{DC} = 0.636\, V_m$	$V_{DC} = 0.636\, V_m - 2(0.7\text{ V})$
Center-Tapped Transformer Rectifier	$V_{DC} = 0.636\, V_m$	$V_{DC} = 0.636\, V_m - 0.7\text{ V}$

V_m = peak of the AC voltage.

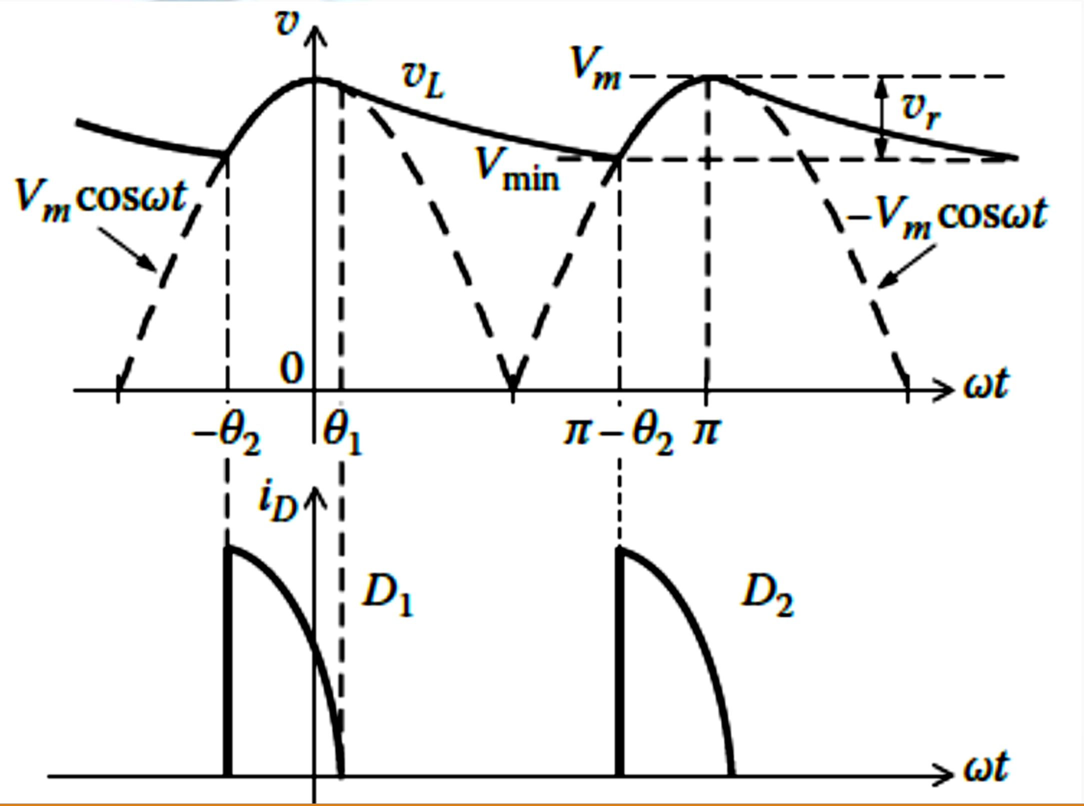
In the center tapped transformer rectifier circuit, the peak AC voltage is the transformer secondary voltage to the tap.

Smoothing of Output

full-wave rectifier circuit with a capacitor-input filter



(a) Full-wave rectifier with capacitor-input filter.



(b) Voltage and current waveforms.

During conduction, $i_D = i_L + i_C$, where $i_L = v_L/R_L$ and $i_C = C dv_L/dt$. This gives:

$$i_D = \frac{V_m}{R_L}\cos\omega t - \omega C V_m \sin\omega t, \quad -\theta_2 \le \omega t \le \theta_1$$

- When the diode stops conducting at $\omega t = \theta_1$; $iD = 0$.

$$\tan\theta_1 = \frac{1}{\omega C R_L}$$

- During the interval $\theta_1 \le \pi - \theta_2$, both diodes are nonconducting. C discharges exponentially through R_L, with a time constant $R_L C$ from an initial value $V_m cos\theta_1$ at $\omega t = \theta_1$
- Conduction resumes at $\pi - \theta_2$ when the decaying exponential intersects the rising negative half-cycle $v_L = -V_m cos\theta_1$. Substituting $-V_m cos\theta_2$

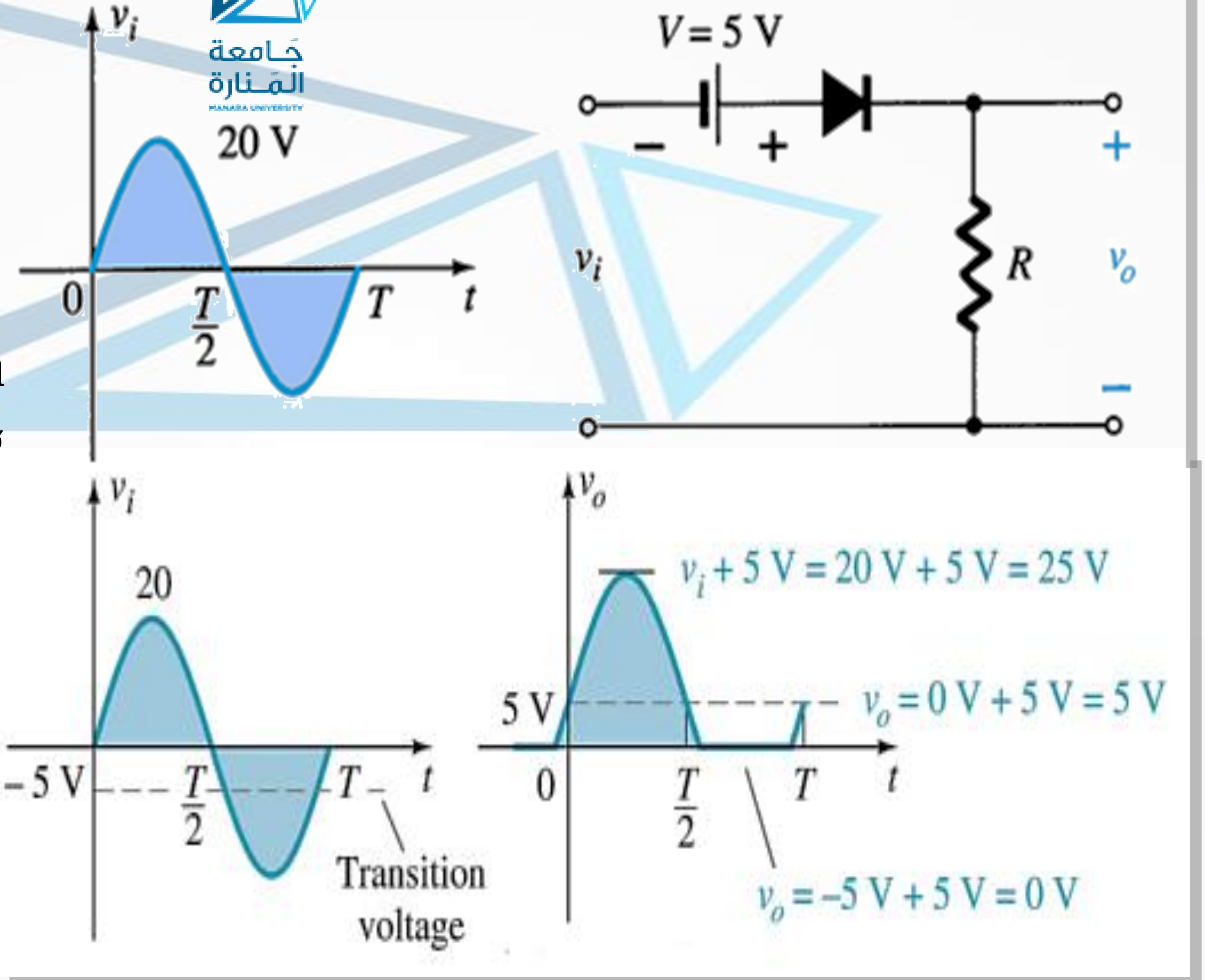
$$\cos\theta_2 = \cos\theta_1 e^{-[\pi-(\theta_1+\theta_2)]/\omega C R_L}$$

- average value of v_L is:

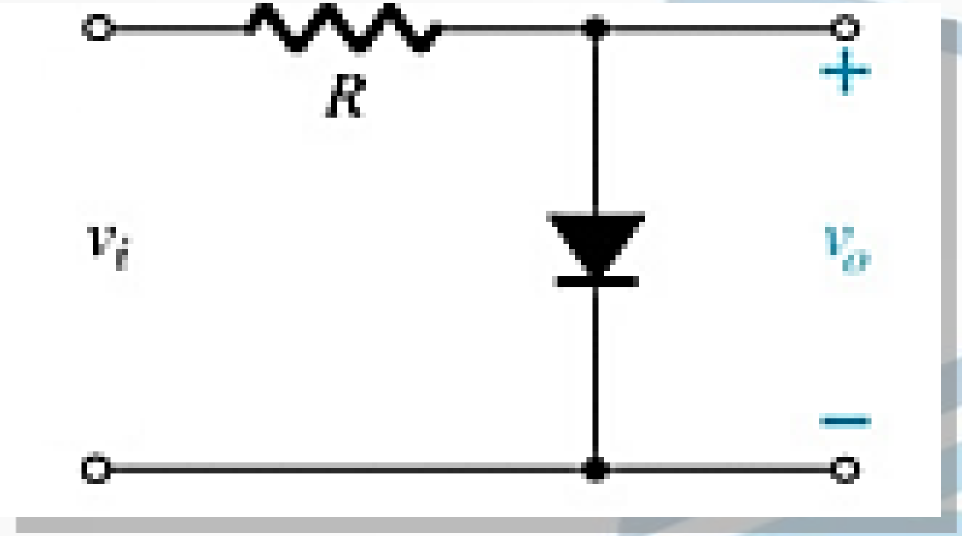
$$V_L = \frac{V_m}{\pi}\left[\int_{-\theta_2}^{\theta_1} \cos\omega t \, d(\omega t) + \int_{\theta_1}^{\pi-\theta_2} \cos\theta_1 e^{-(\omega t-\theta_1)/\omega C R_L} d(\omega t)\right]$$

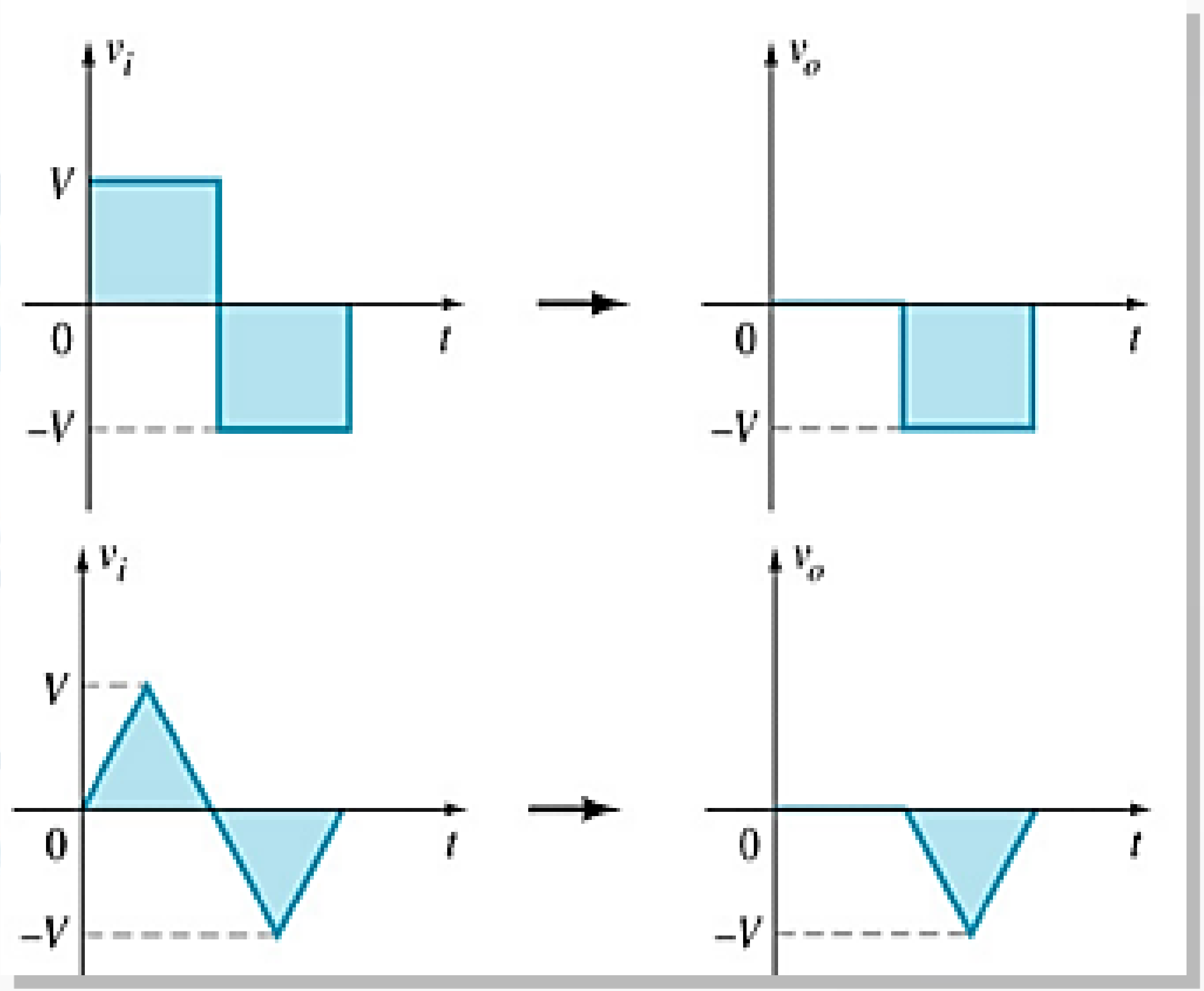
Biased Clippers

Adding a DC source in series with the clipping diode changes the effective forward bias of the diode.



Parallel Clippers

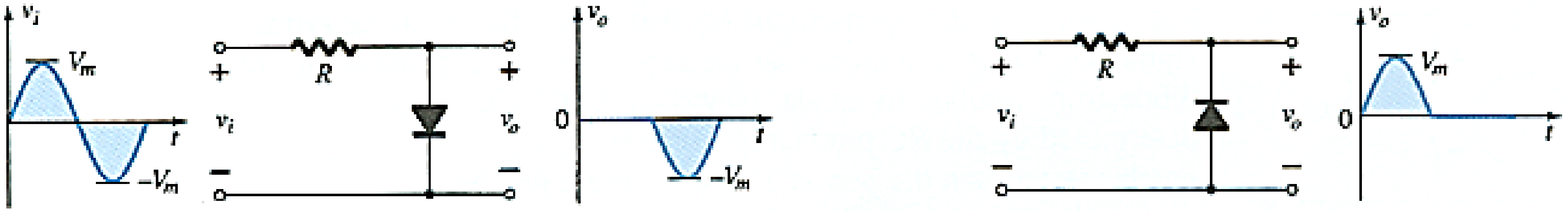




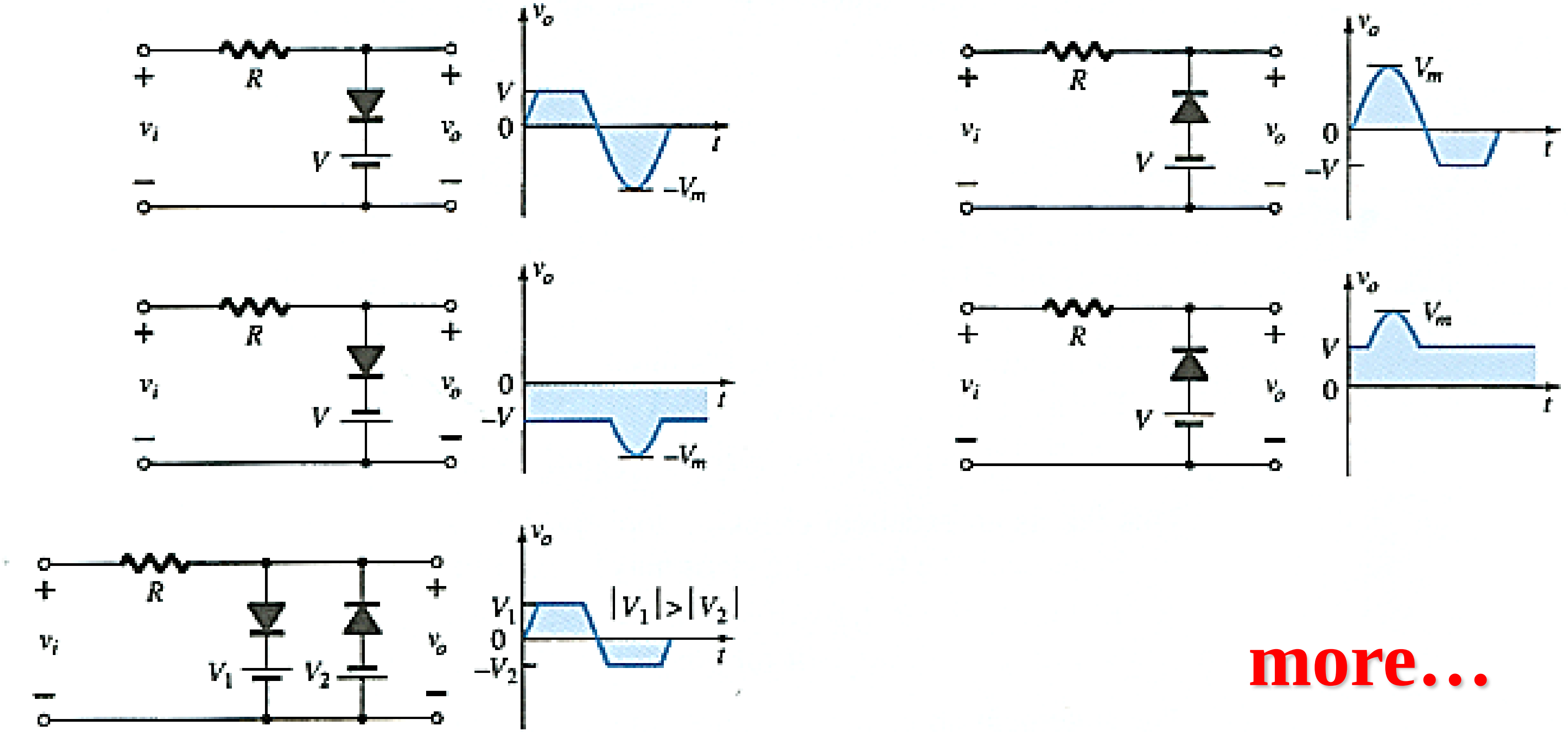
The diode in a **parallel clipper** circuit "clips" any voltage that forward bias it. DC biasing can be added in series with the diode to change the clipping level.

Summary of Clipper Circuits

Simple Parallel Clippers (Ideal Diodes)



Biased Parallel Clippers (Ideal Diodes)



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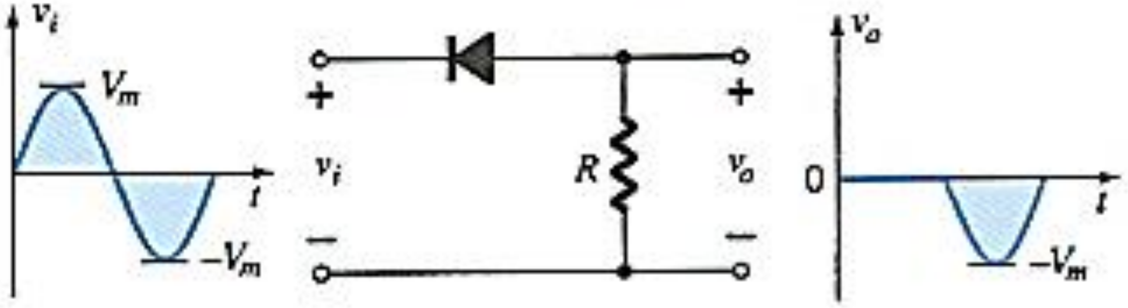
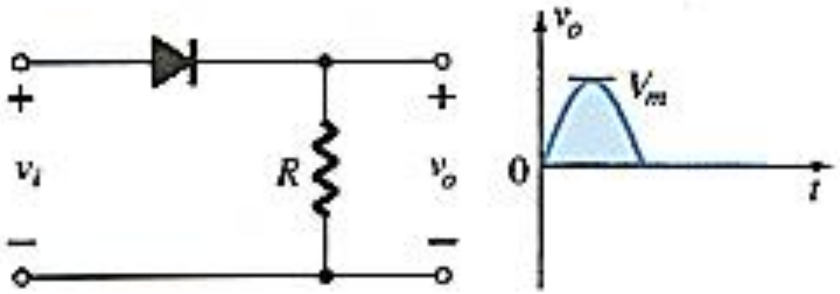
Simple Series Clippers (Ideal Diodes)

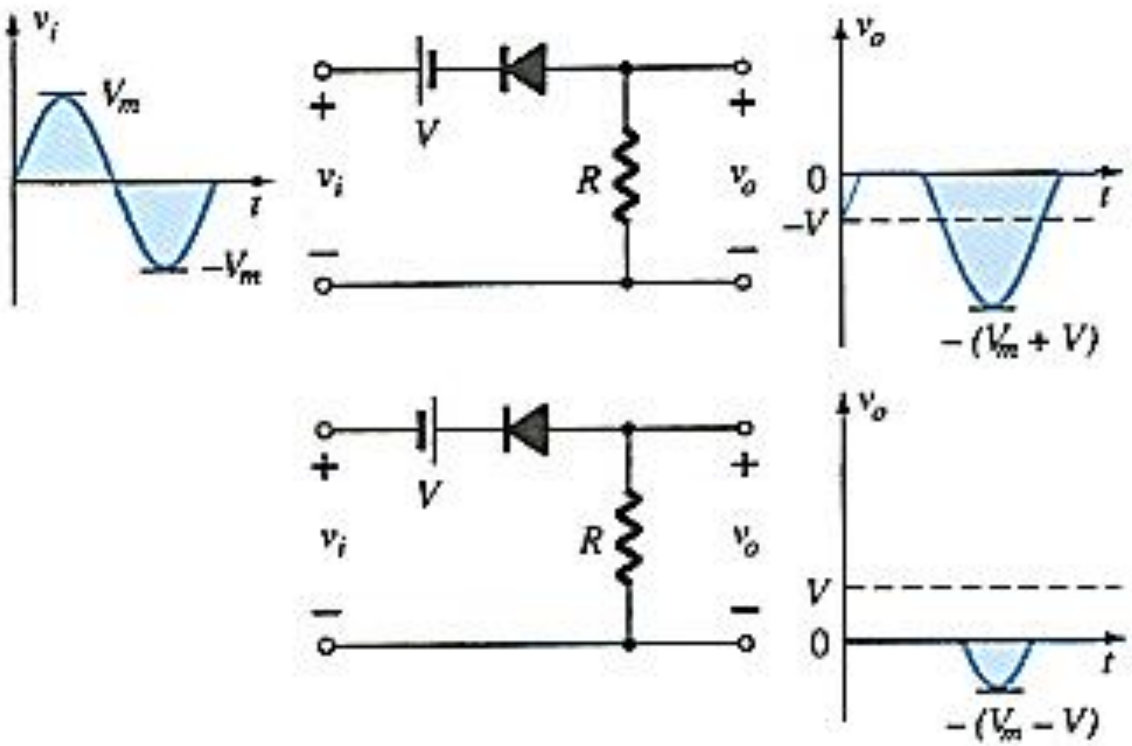
POSITIVE

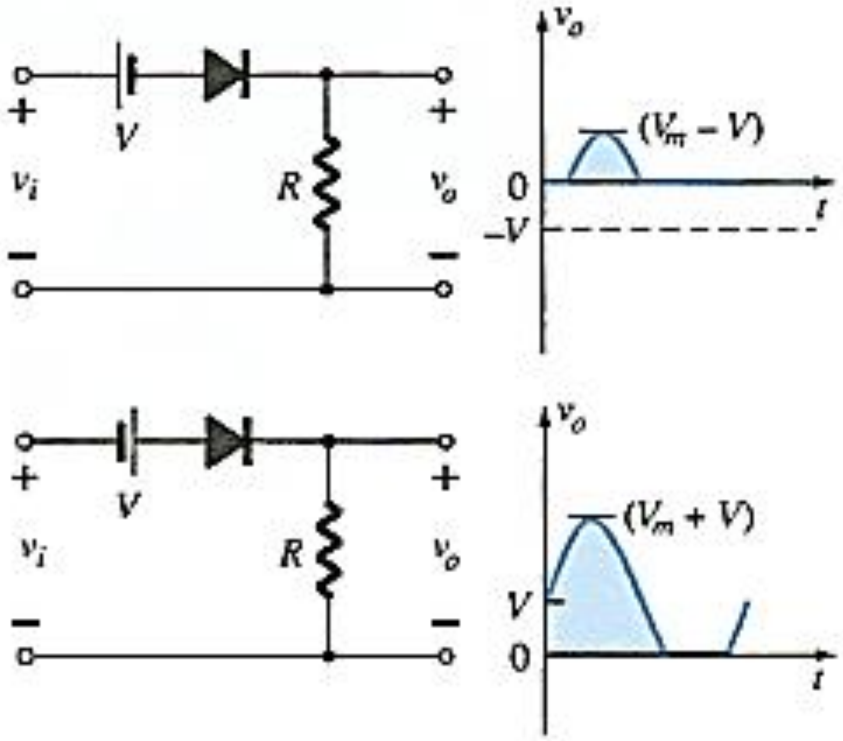


NEGATIVE

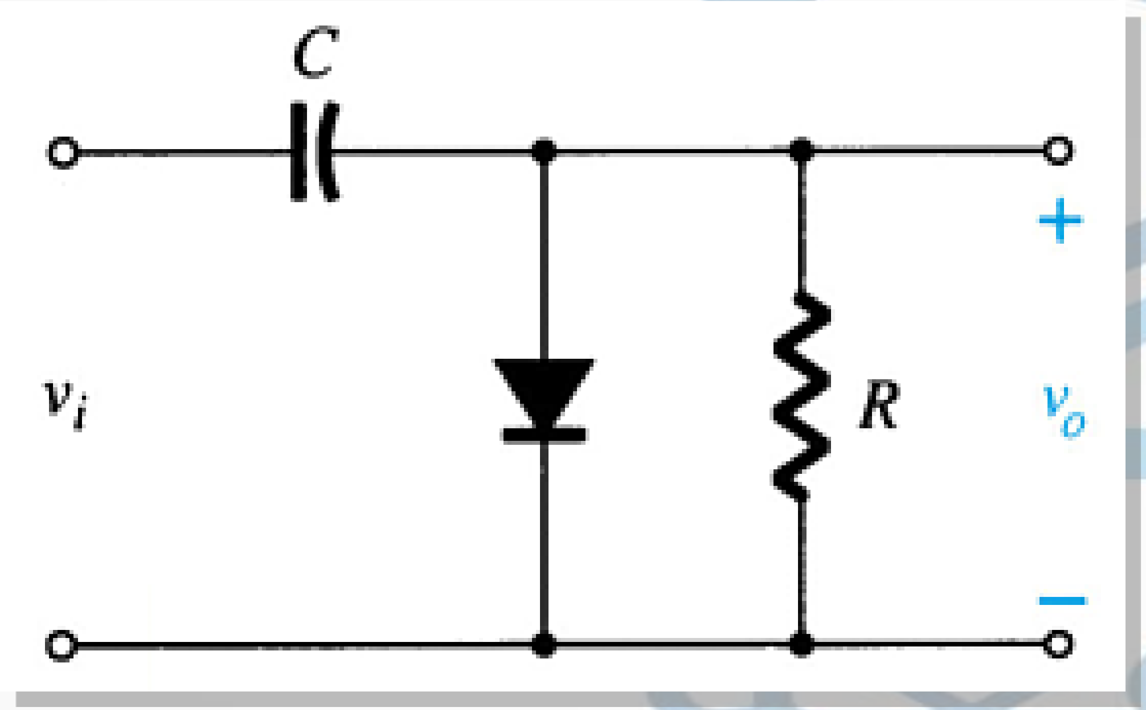


Biased Series Clippers (Ideal Diodes)

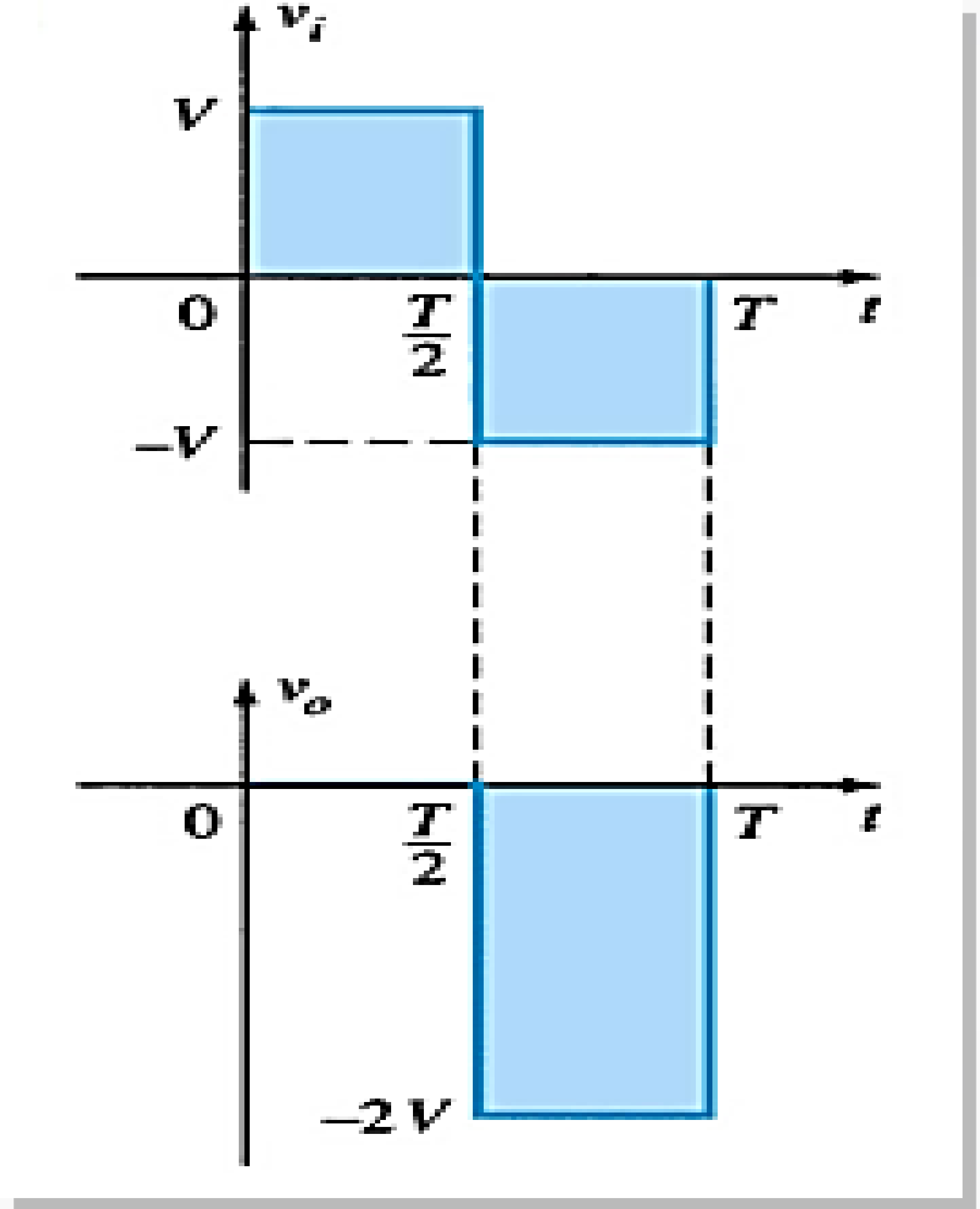




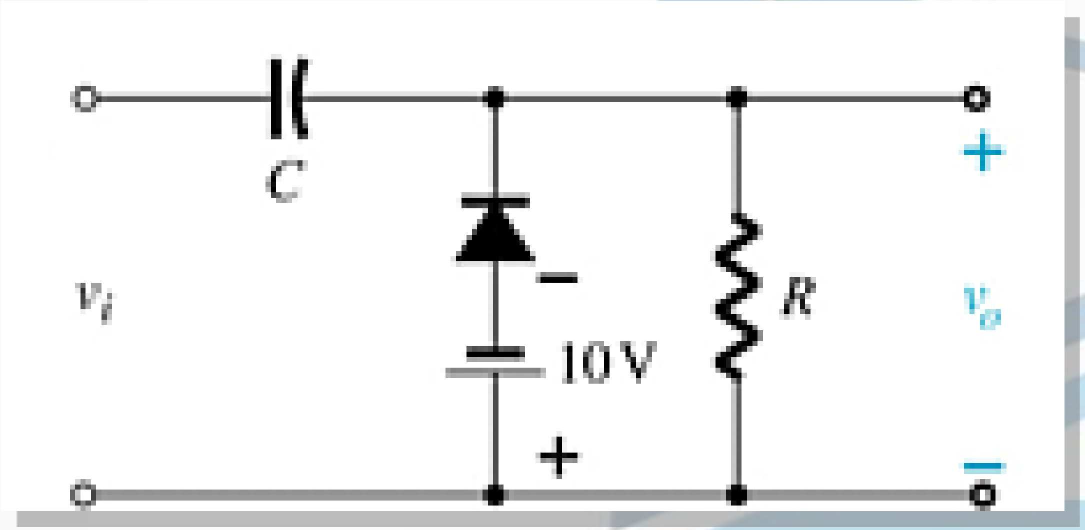
Clampers

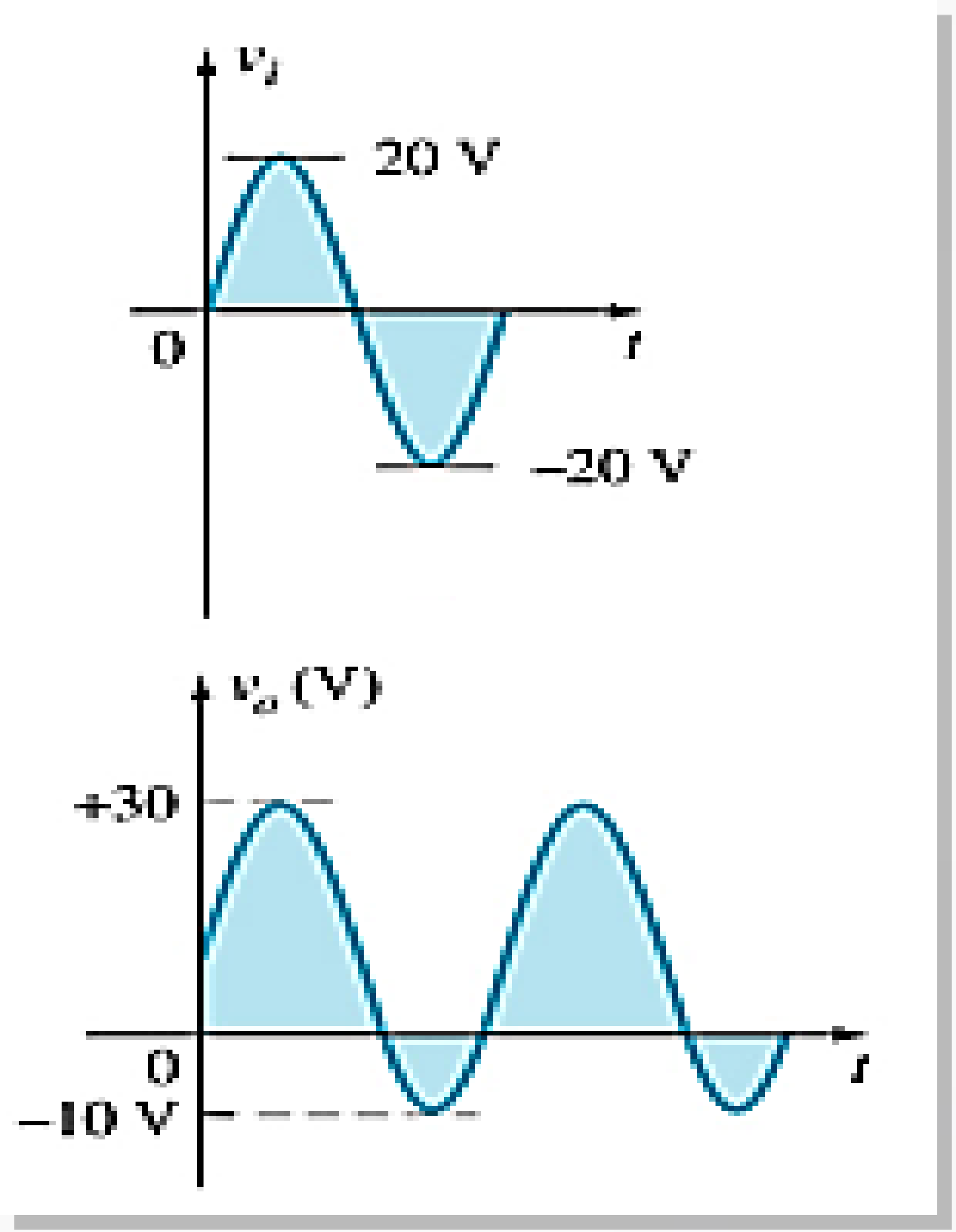


A diode and capacitor can be combined to "clamp" an AC signal to a specific DC level.



Biased Clamper Circuits

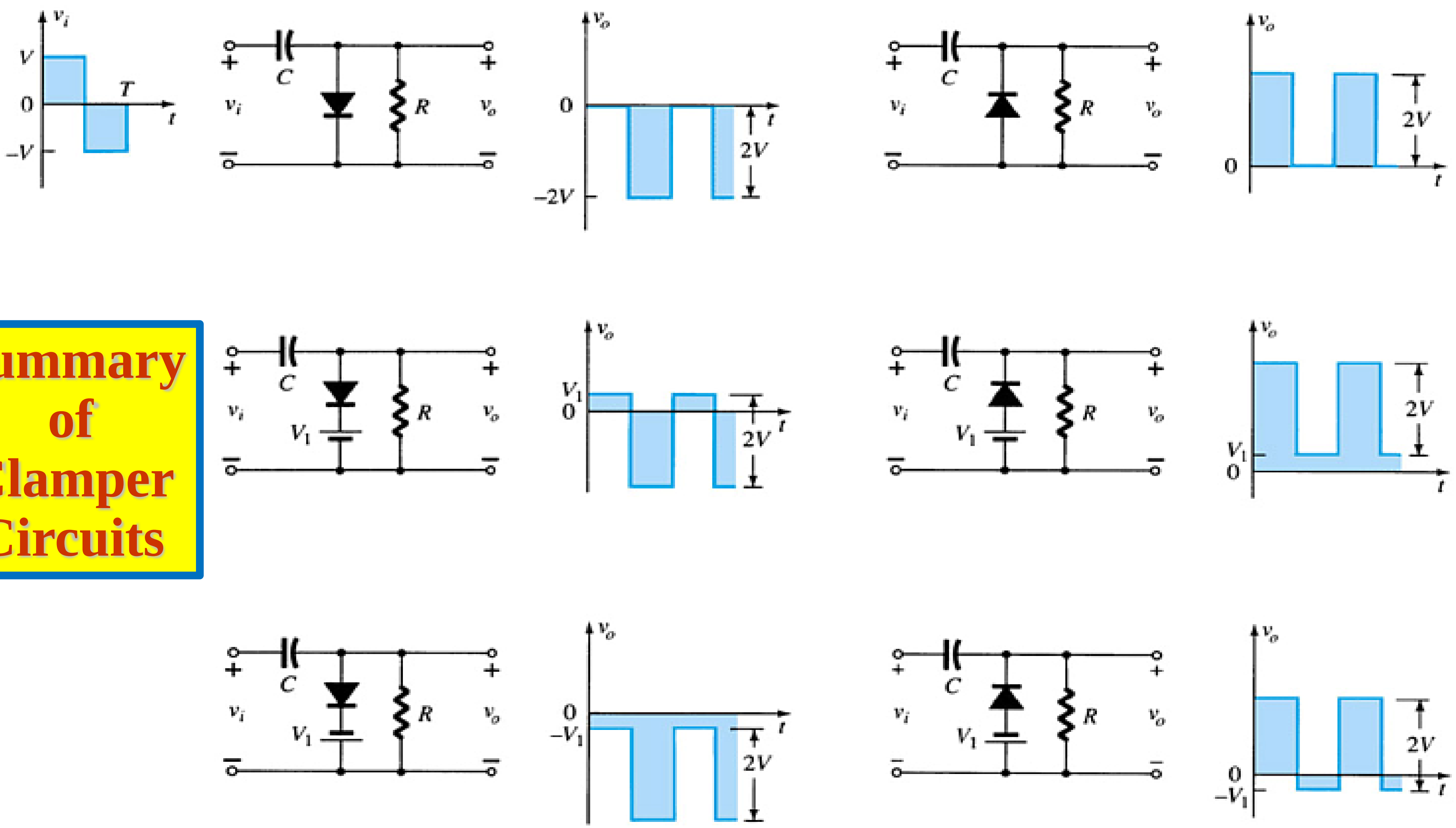




- **The input signal can be any type of waveform such as sine, square, and triangle waves.**

- **The DC source lets you adjust the DC camping level.**

Clamping Networks

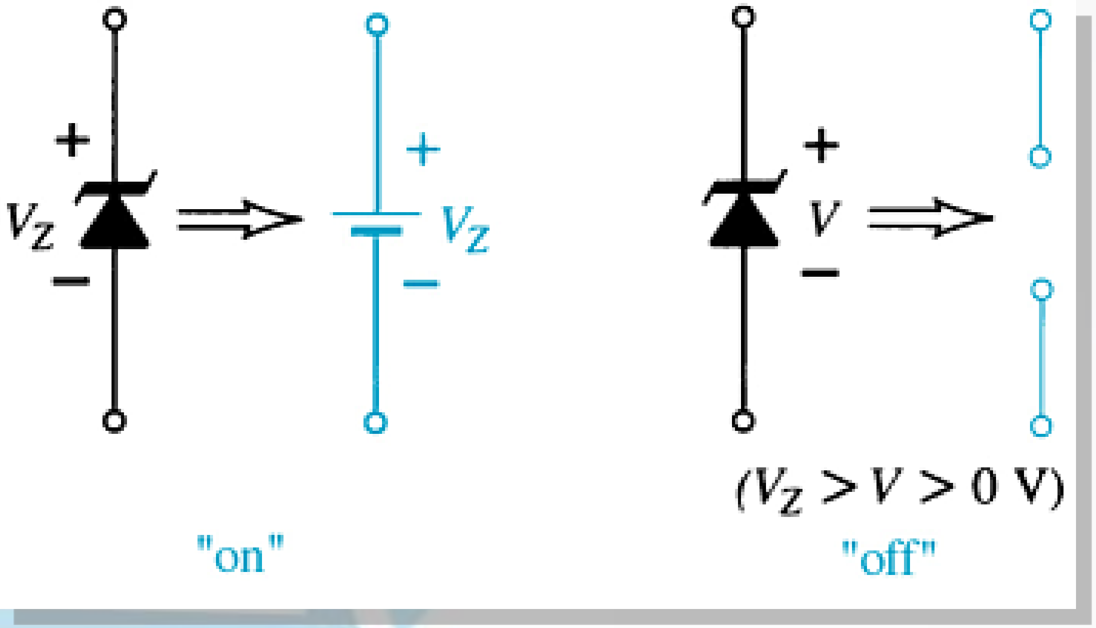


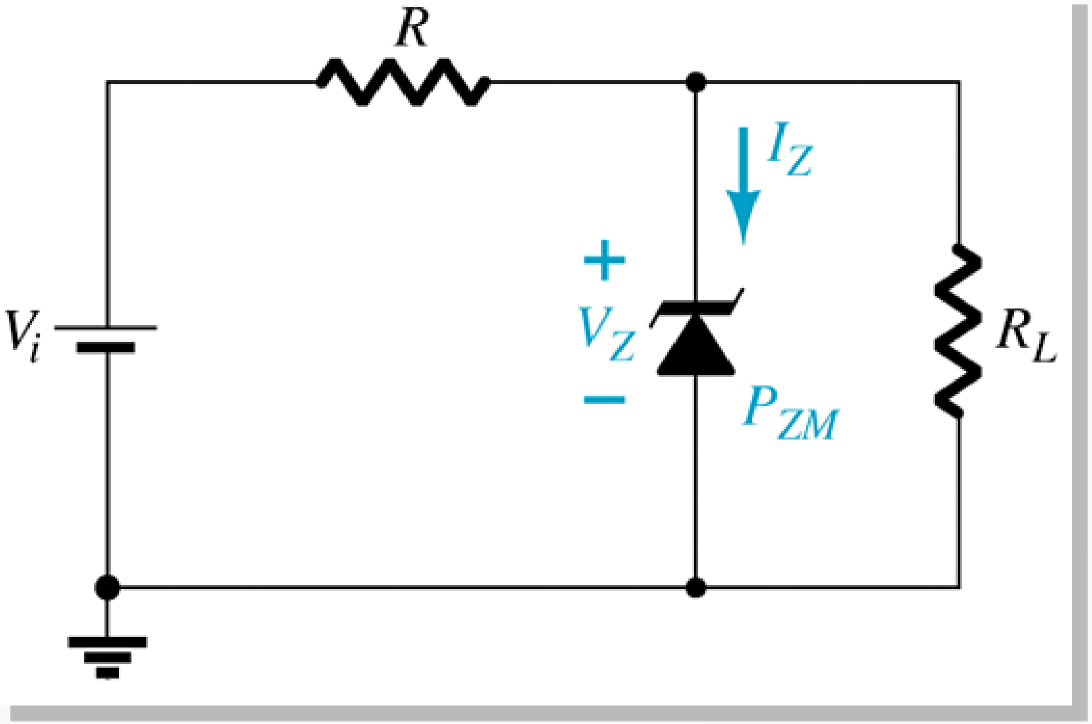
Summary of Clamper Circuits

Zener Diodes

The Zener is a diode operated in reverse bias at the Zener Voltage (V_z).

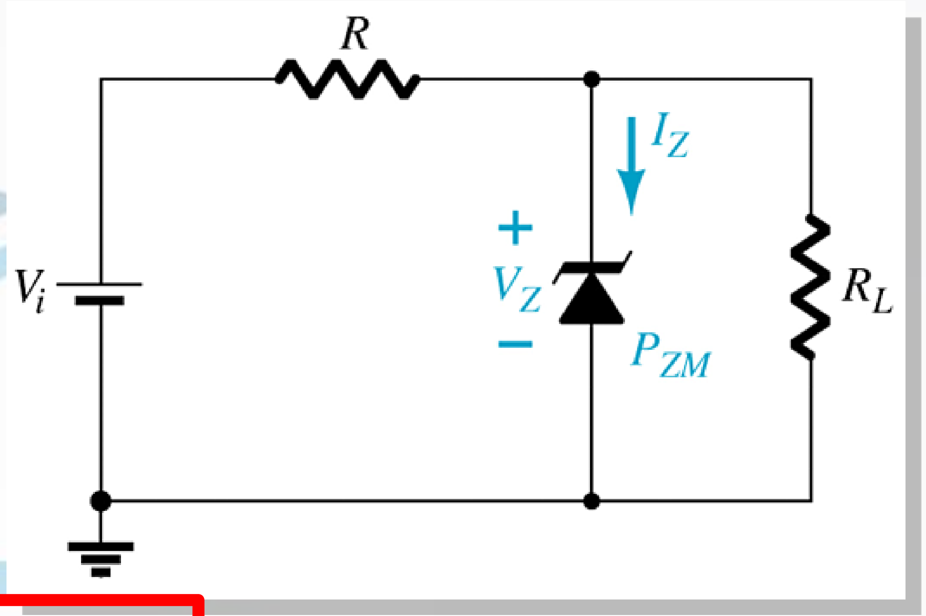
- When $V_i \geq V_Z$
  - The Zener is on
  - Voltage across the Zener is V_Z
  - Zener current: $I_Z = I_R - I_{RL}$
  - The Zener Power: $P_Z = V_Z I_Z$
- When $V_i < V_Z$
  - The Zener is off
  - The Zener acts as an open circuit





Zener Resistor Values

If R is too large, the Zener diode cannot conduct because the available amount of current is less than the minimum current rating, I_{ZK}. The minimum current is given by:



$$I_{L\min} = I_R - I_{ZK}$$

The maximum value of resistance is:

$$R_{L\max} = \frac{V_Z}{I_{L\min}}$$

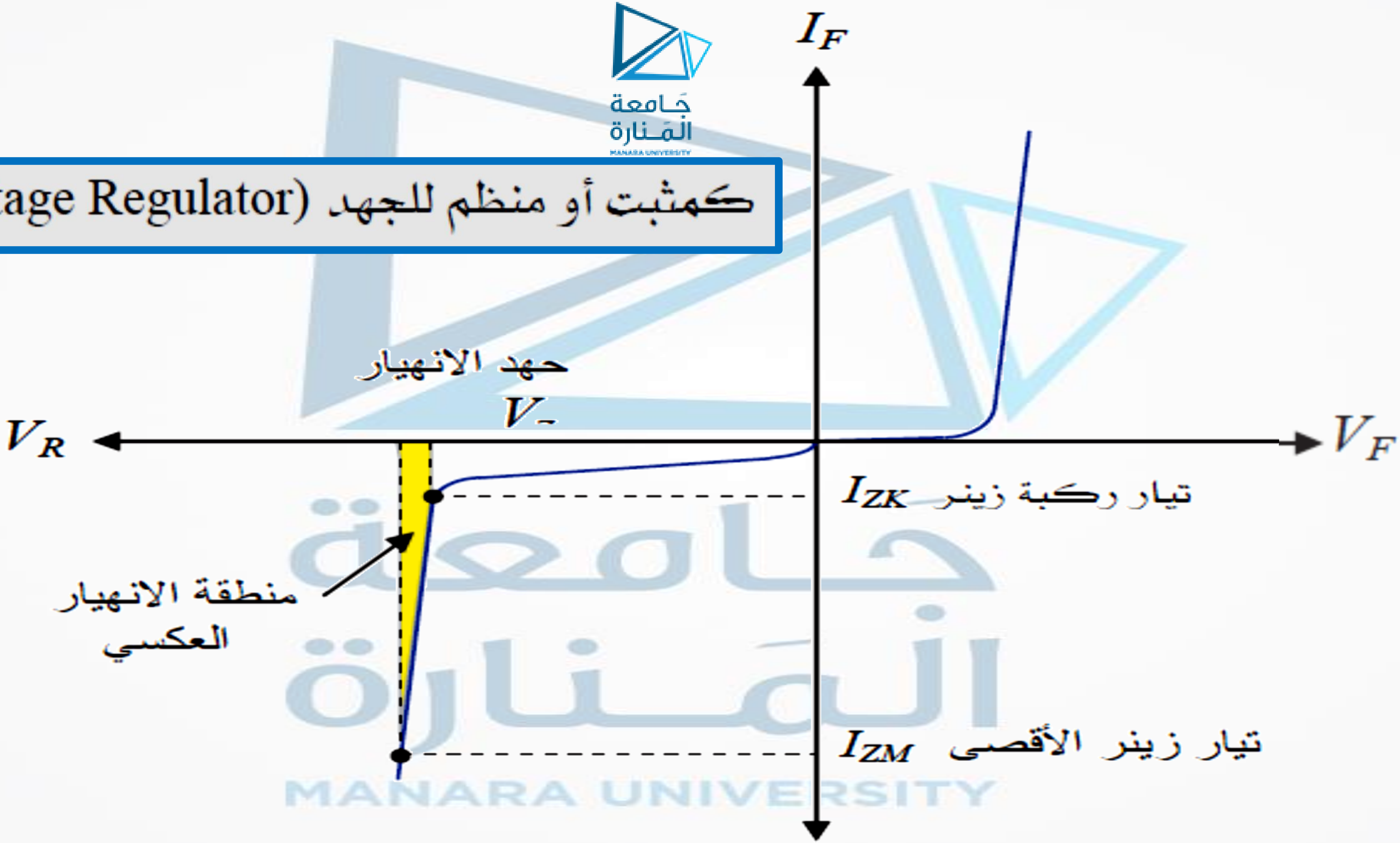
If R is too small, the Zener current exceeds the maximum current rating, I_{ZM} . The maximum current for the circuit is given by:

$$I_{L\max} = \frac{V_L}{R_L} = \frac{V_Z}{R_{L\min}}$$

The minimum value of resistance is:

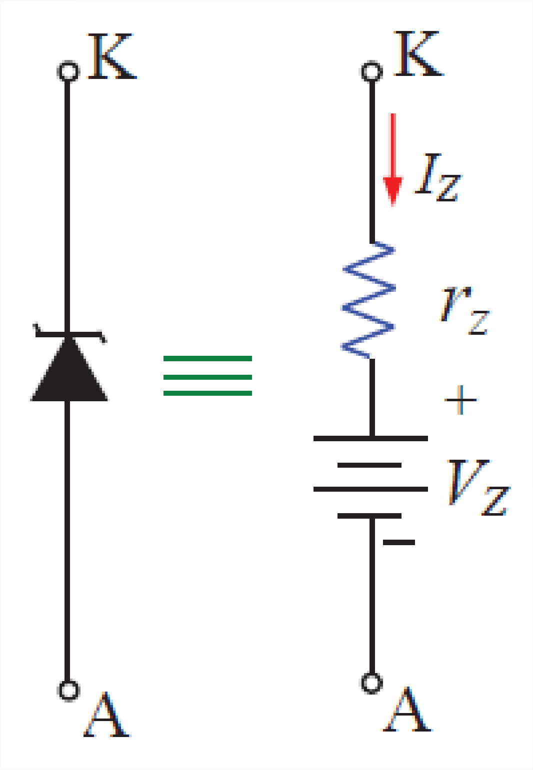
$$R_{L\min} = \frac{RV_Z}{V_i - V_Z}$$

كمثبت أو منظم للجهد (Voltage Regulator).

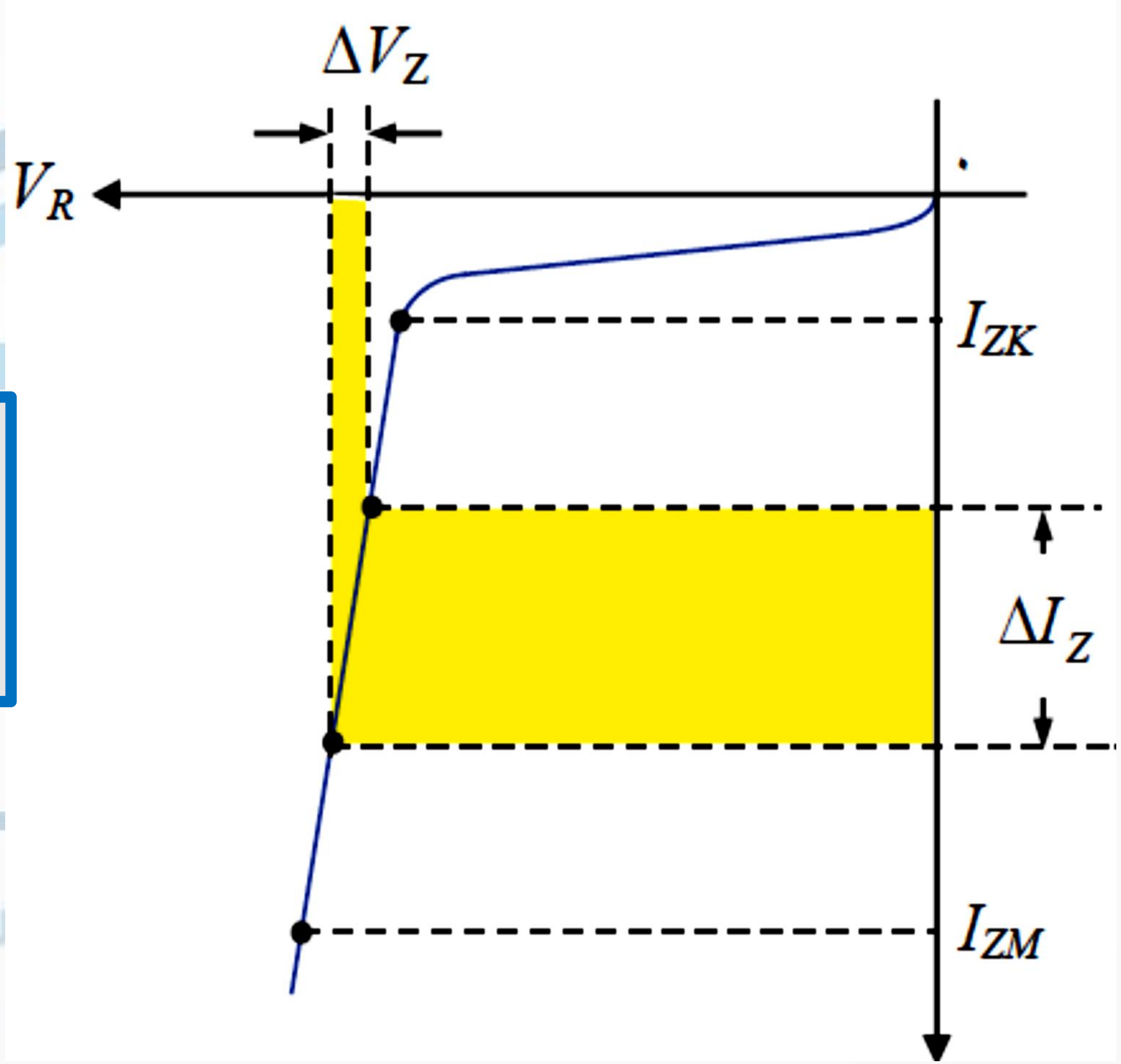


(أ) منحنى الخواص

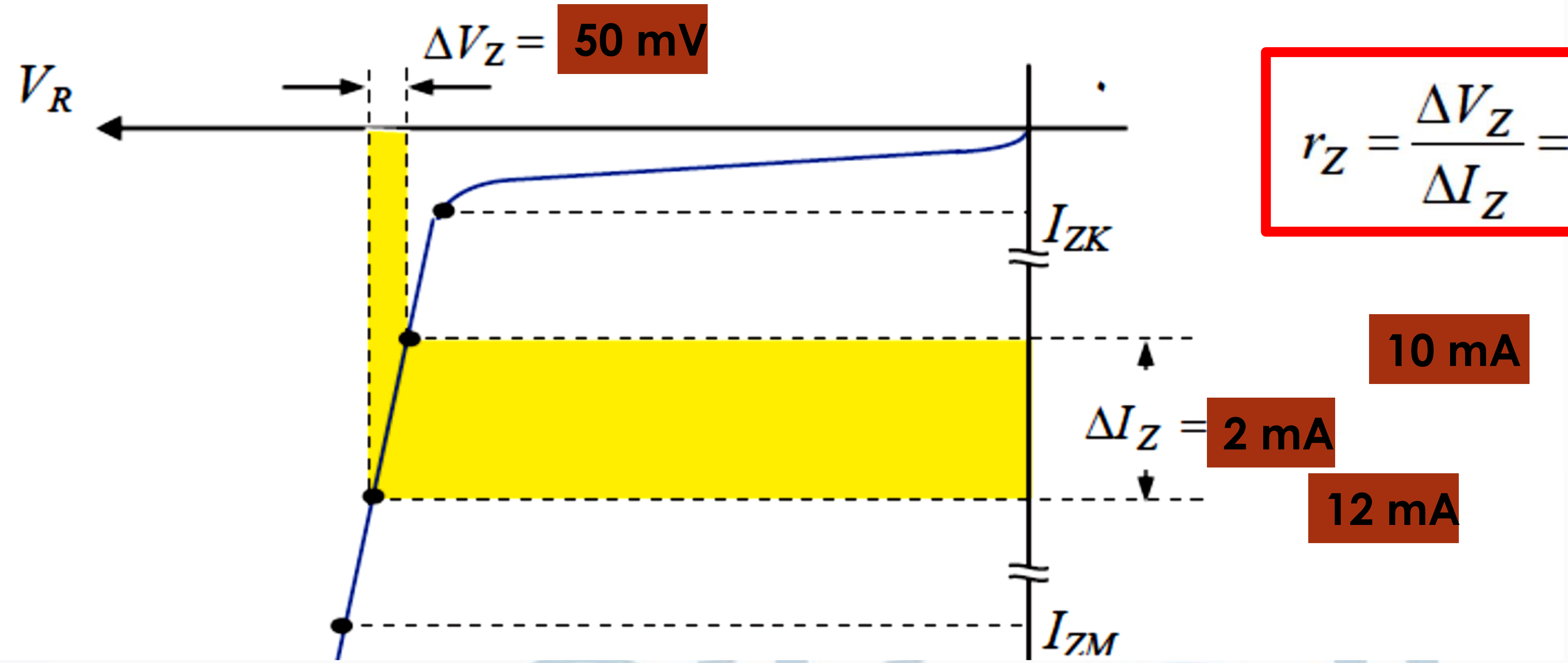
Zener diode equivalent circuit



$$r_Z = \frac{\Delta V_Z}{\Delta I_Z}$$



أوجد المقاومة r_Z لثنائي زينر

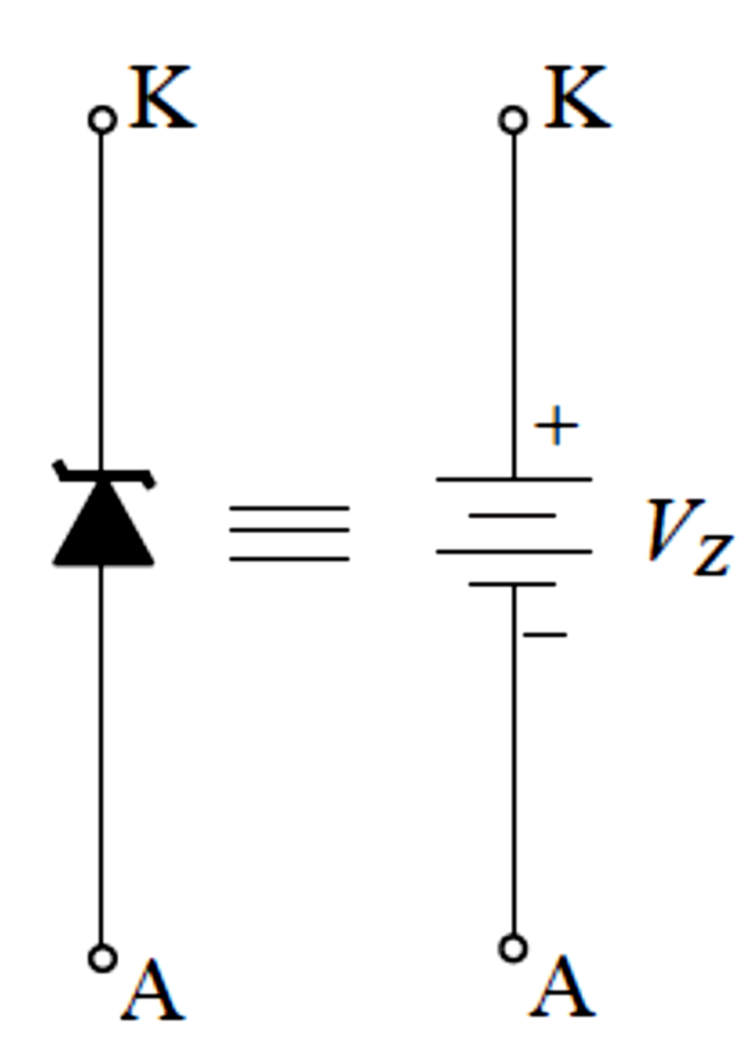


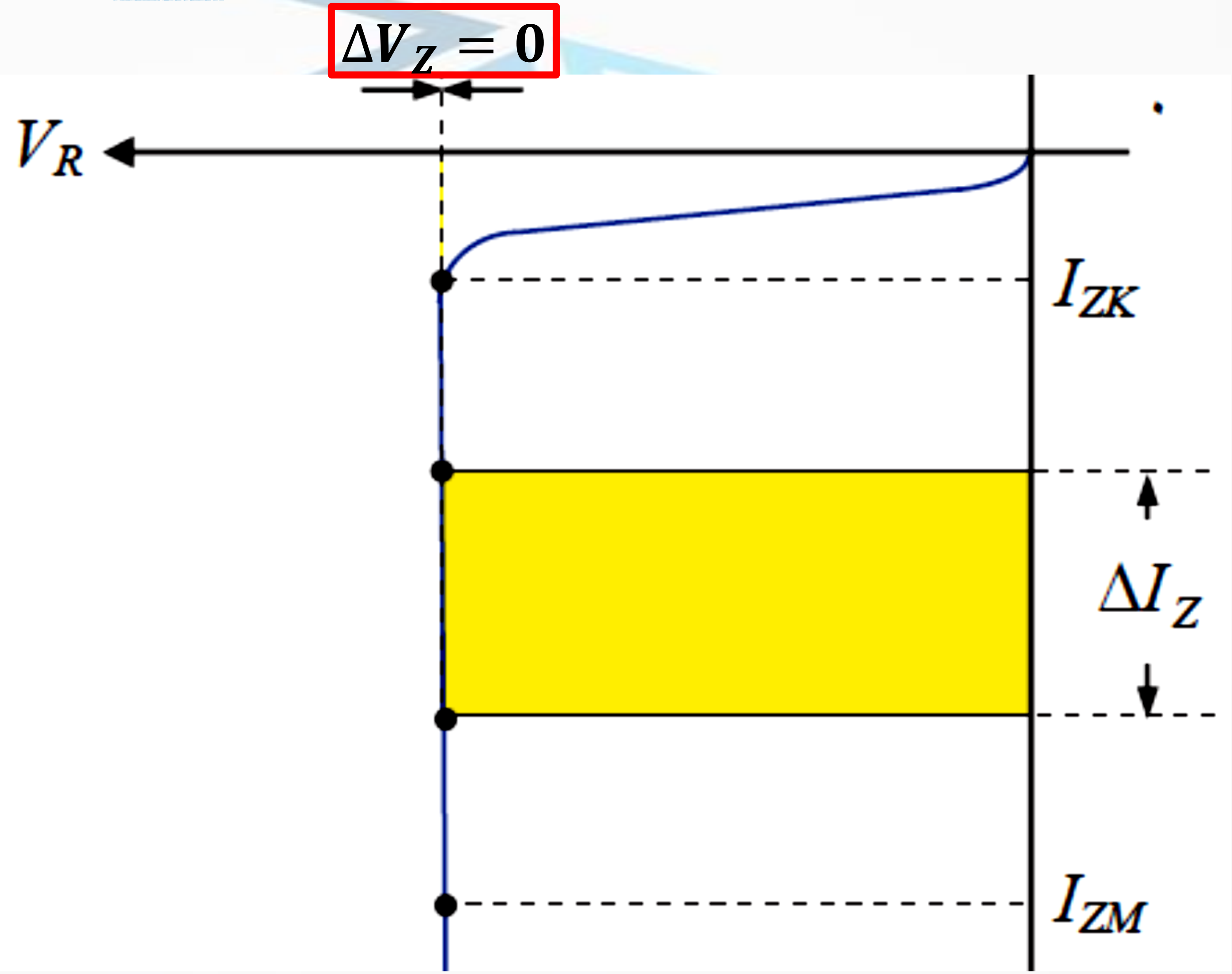
$$r_Z = \frac{\Delta V_Z}{\Delta I_Z} = \frac{50mV}{2mA} = 25\Omega$$

اذا كانت rz=5 Ω و Vz=6.8 V فما هي قيمة الجهد على طرفي ثنائي زينر V_{zD} عند مرور تيار مقداره 20 mA.

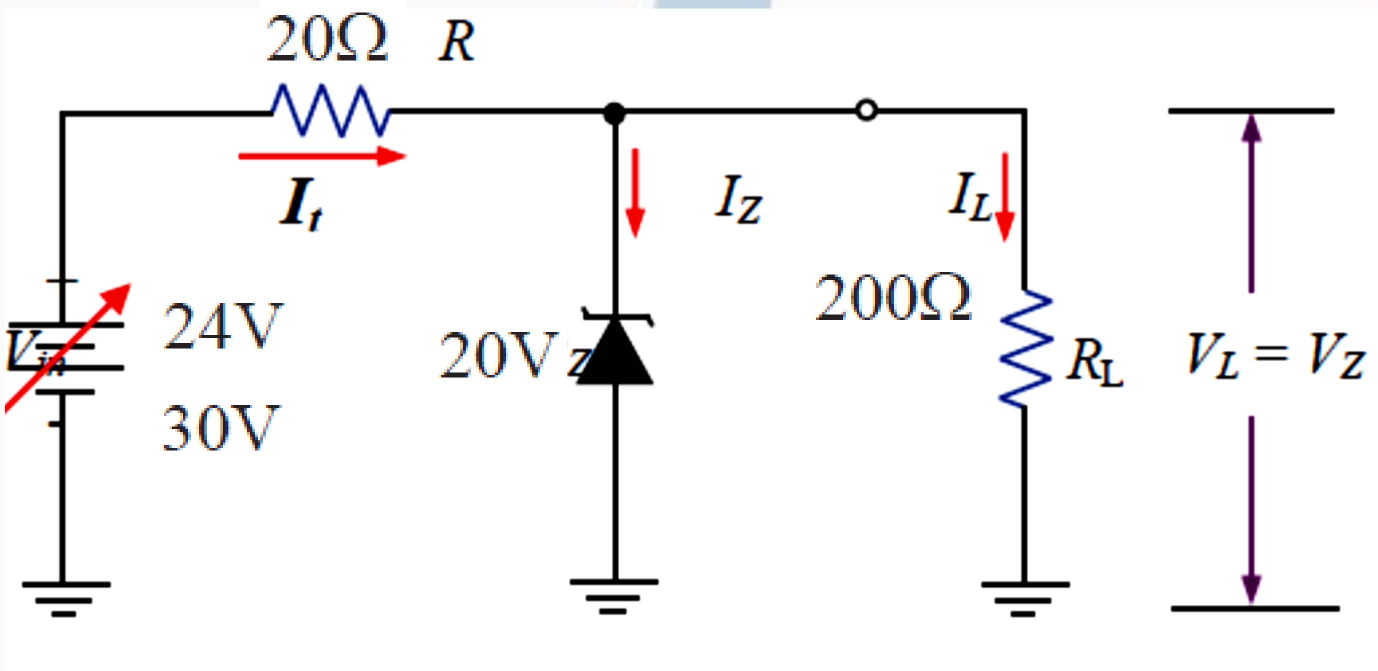
$V_{zD} = V_z + I_z$ rz = 6.8 V+ 20 mA. 5 Ω=6.9 V

الدارة المكافئة لزينر المثالي





Zener Regulation with a Varying Input Voltage



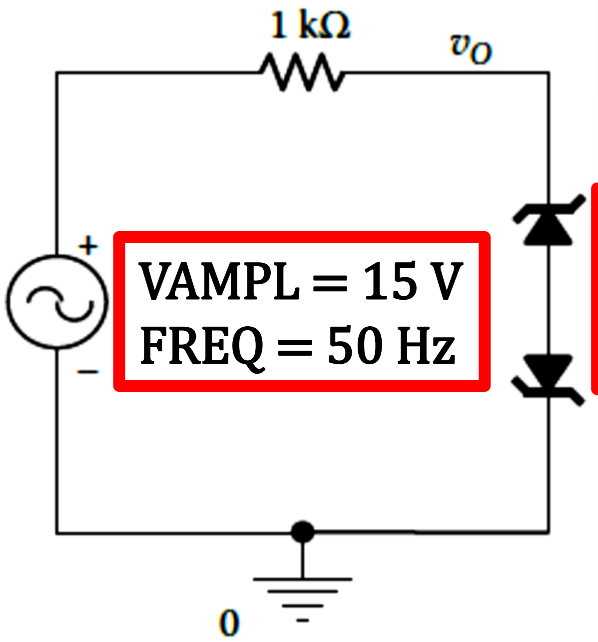
$$I_{t(\min)} = \frac{24V - 20V}{20\Omega} = 0.2A$$

$$I_{t(\max)} = \frac{30V - 20V}{20\Omega} = 0.5A$$

$$I_{Z(\min)} = I_{t(\min)} - I_L = 0.2A - 0.1A = 0.1A$$

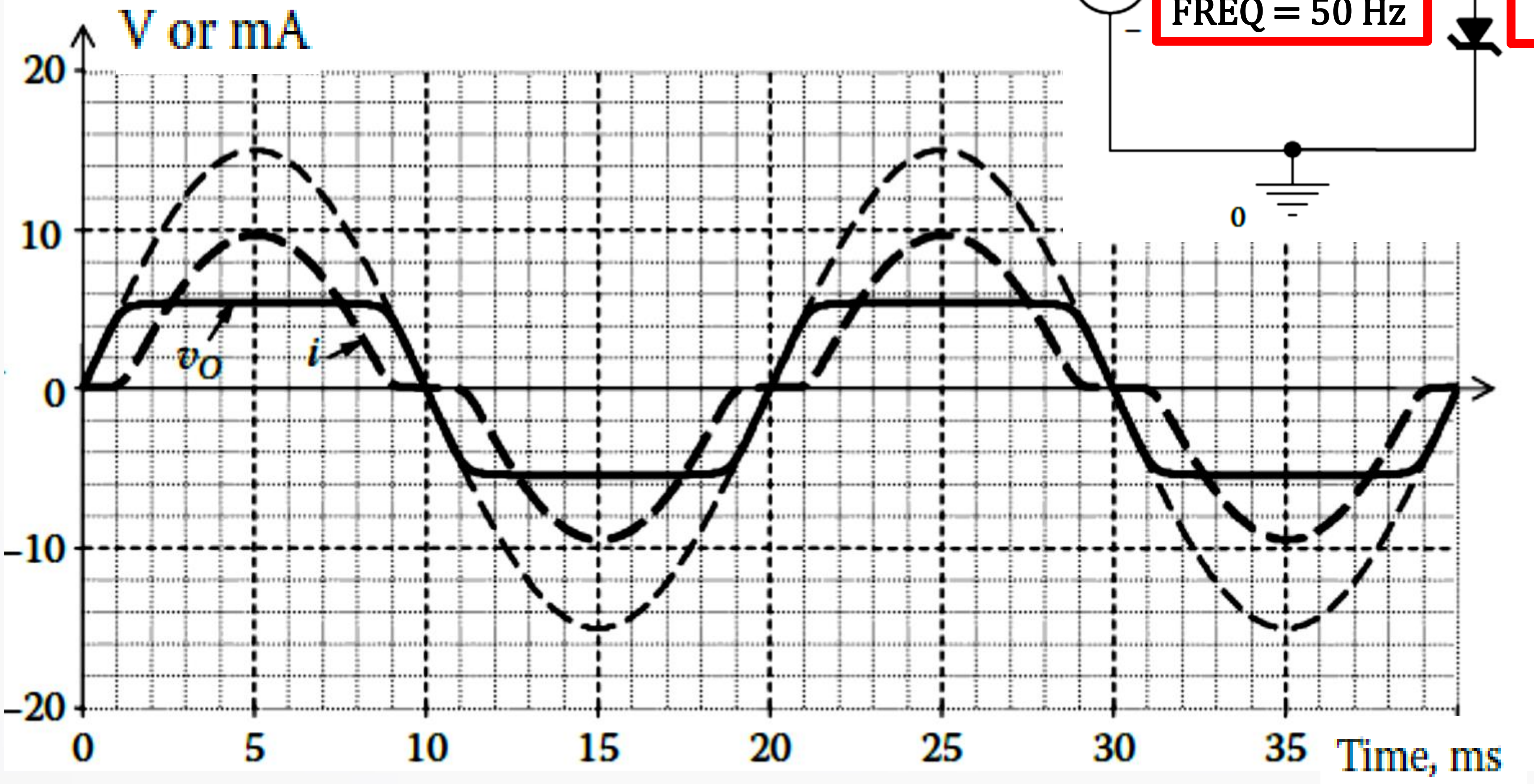
$$I_{Z(\max)} = I_{t(\max)} - I_L = 0.5A - 0.1A = 0.4A$$

$$P_{Z(\max)} = V_Z I_{Z(\max)} = 0.4A\ \ 20V$$ **=8W**



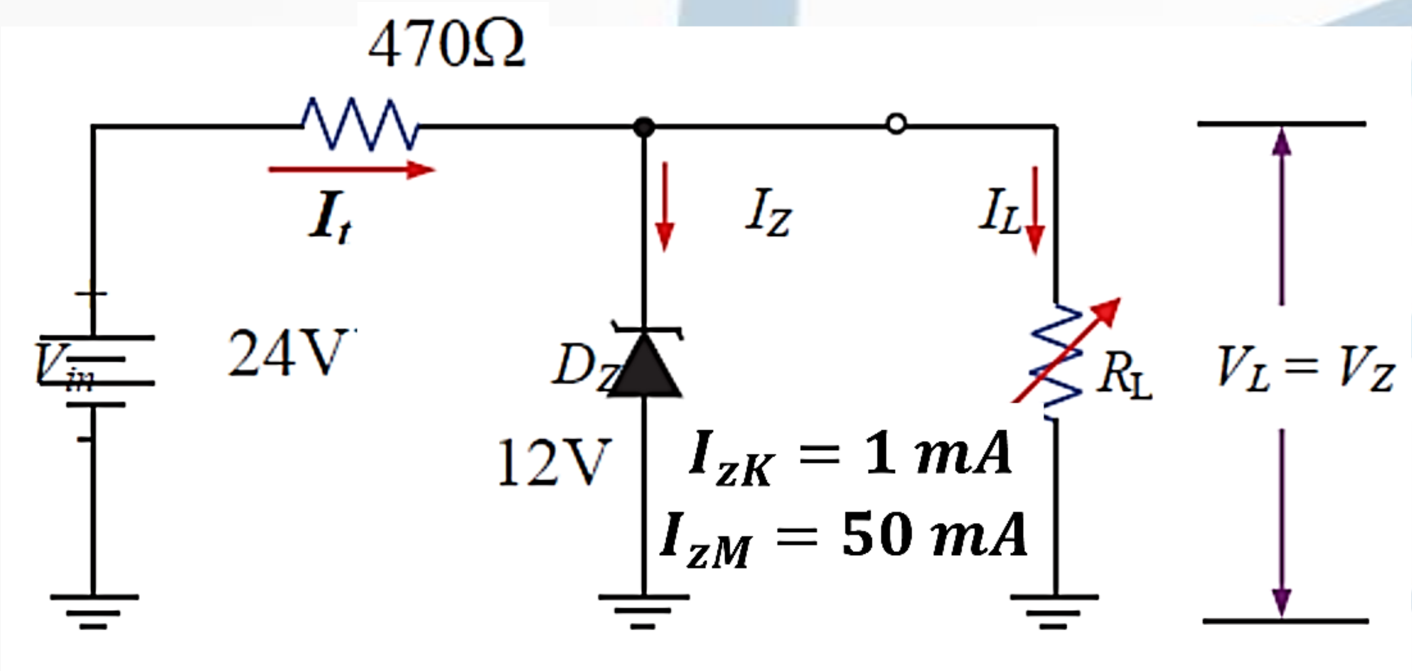
VAMPL = 15 V
FREQ = 50 Hz

V_{D0}=0.7 V ;
V_{Z0}=9.1 V



Zener Regulation with a Variable Load

أوجد قيم $I_{L(max)}$، $I_{L(min)}$ و $R_{L(min)}$



$$I_{Z(\max)} = I_t = \frac{V_{in} - V_Z}{R} = \frac{24\text{V} - 12\text{V}}{470\Omega} = 25.5\text{mA}$$

$$I_R = \frac{24 - 12}{470} = 25.5\ mA$$

$$I_{L(max)} = 25.5\ mA - 1 = 24.5\ mA$$

$$R_{L(\min)} = \frac{V_Z}{I_{L(\max)}} = 490\Omega$$

$$R_{L(min)} = \frac{12}{24.5} = 490\ \Omega$$

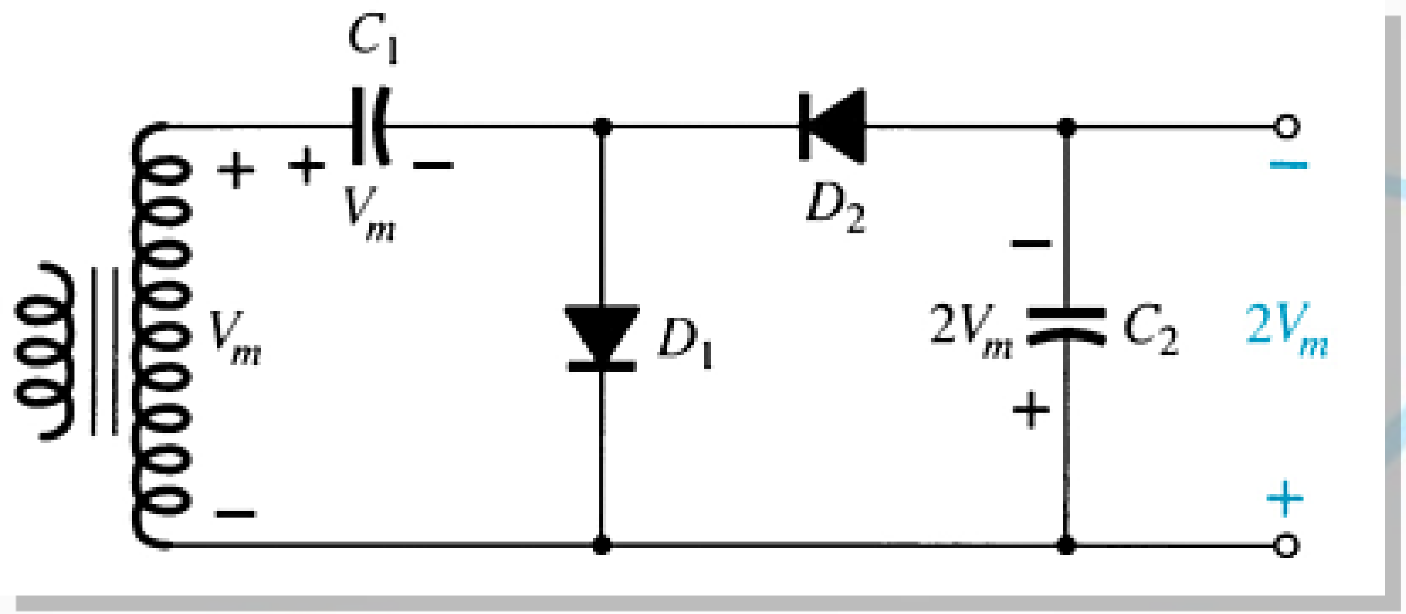
$$R_{L(max)} = \infty$$

Voltage-Multiplier Circuits

Voltage multiplier circuits use a combination of diodes and capacitors to step up the output voltage of rectifier circuits.

- **Voltage Doubler**
- **Voltage Tripler**
- **Voltage Quadrupler**

Voltage Doubler

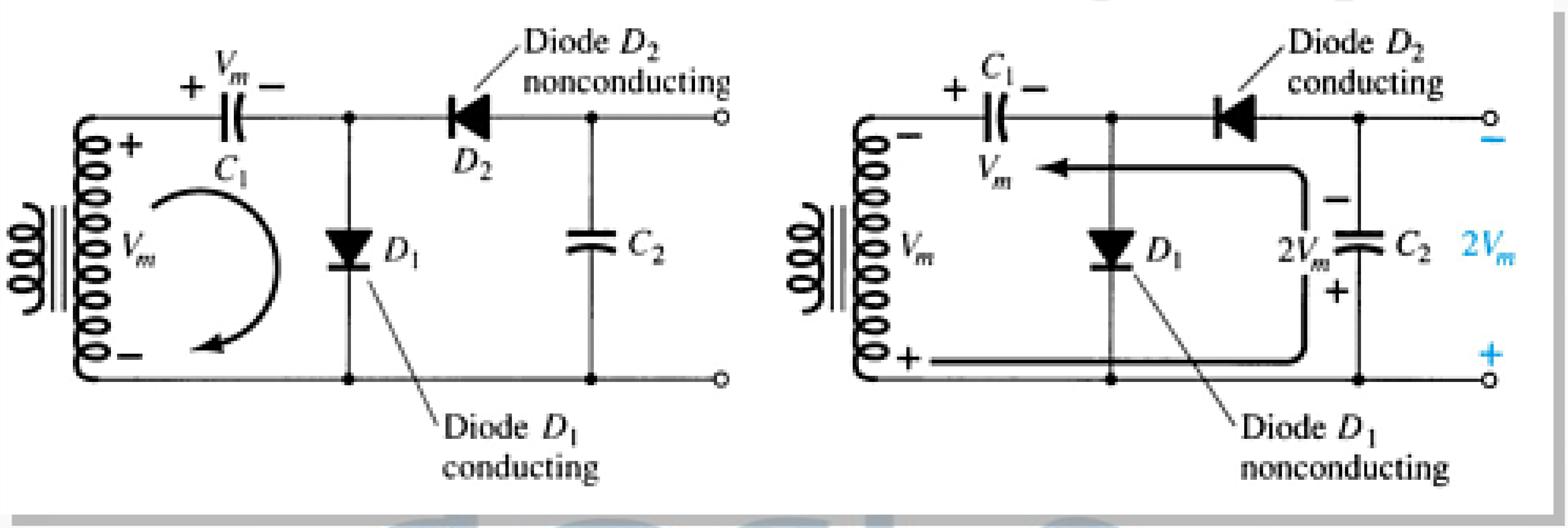


This half-wave voltage doubler's output can be calculated by:

$$V_{out} = V_{C2} = 2V_m$$

where V_m = peak secondary voltage of the transformer

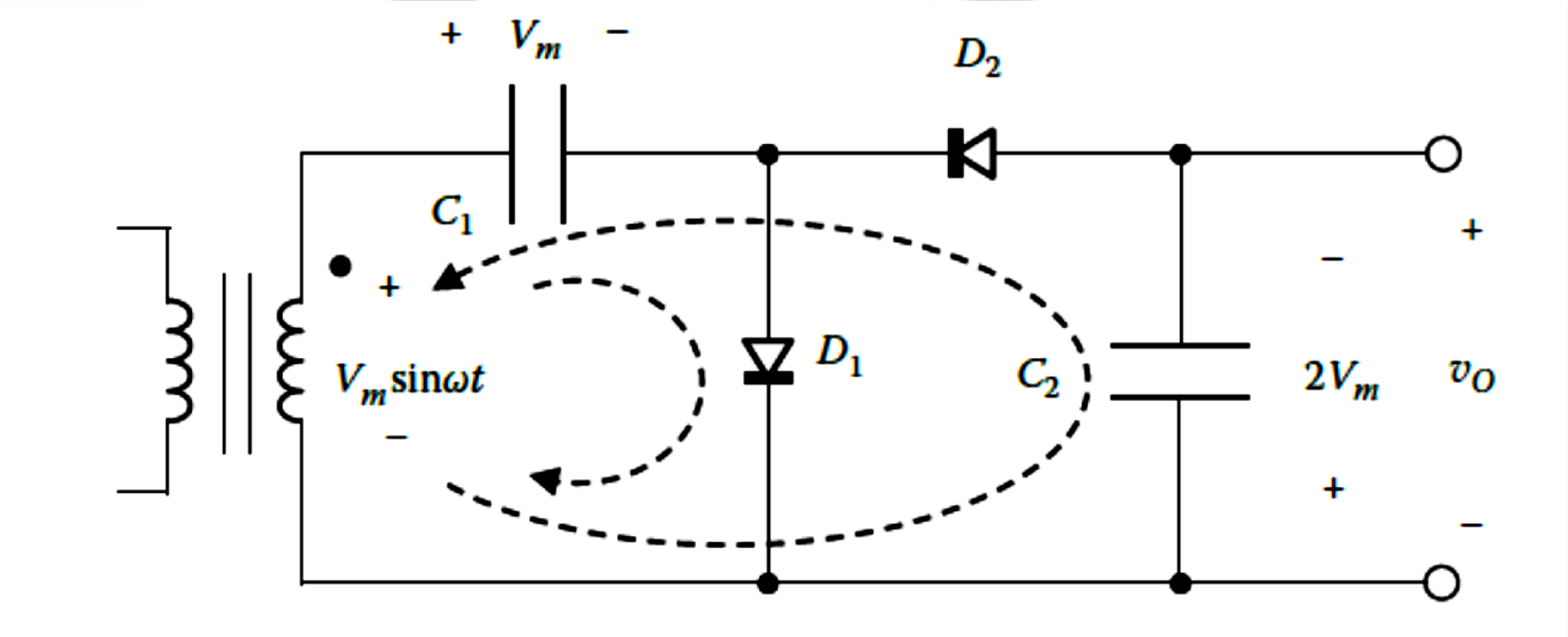
Voltage Doubler — Voltage Multiplication



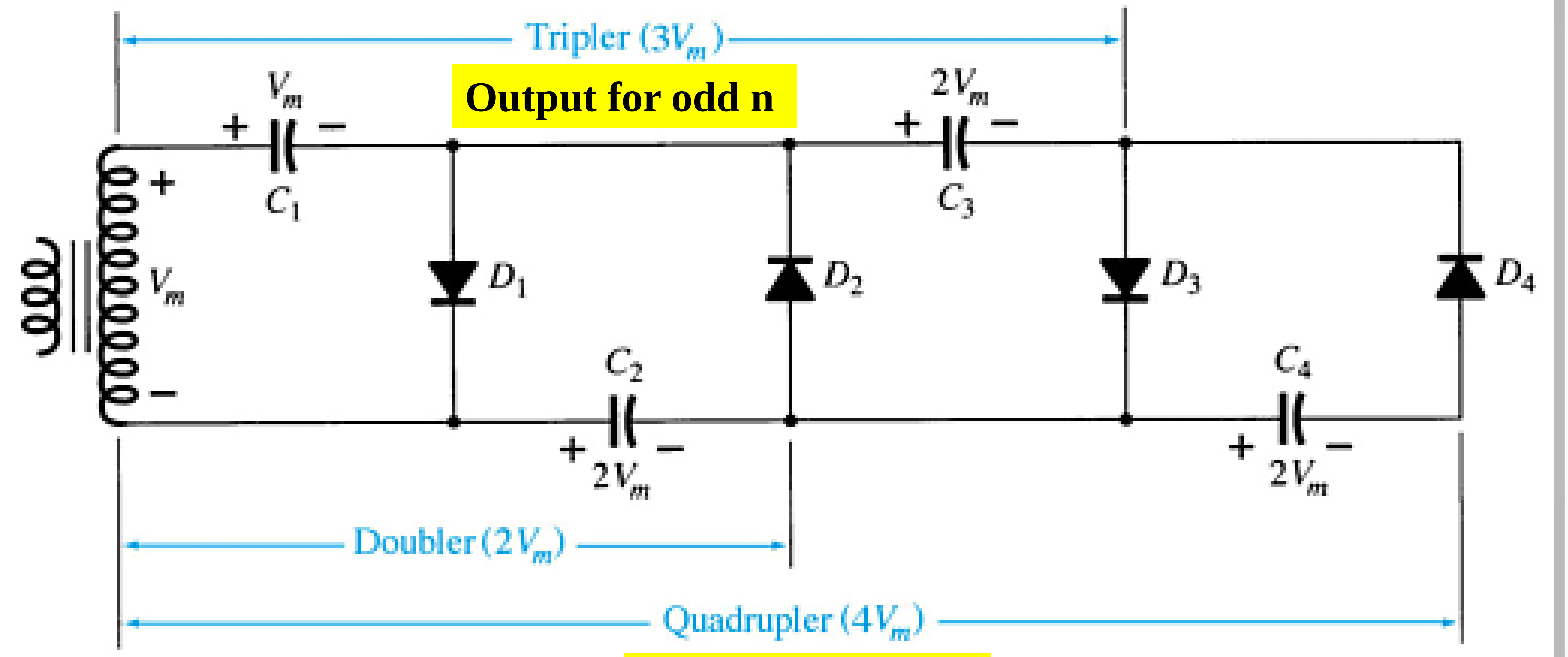
- **Positive Half-Cycle**
  - **D_1 conducts**
  - **D_2 is switched off**
  - **Capacitor C_1 charges to V_m**
- **Negative Half-Cycle**
  - **D_1 is switched off**
  - **D_2 conducts**
  - **Capacitor C_2 charges to V_m**

$$V_{out} = V_{C2} = 2V_m$$

Voltage Multiplication



Voltage Tripler and Quadrupler



Output for odd n

Output for even n