ELL100: INTRODUCTION TO ELECTRICAL ENGG.

Lecture 22: Semiconductor Diode Circuits

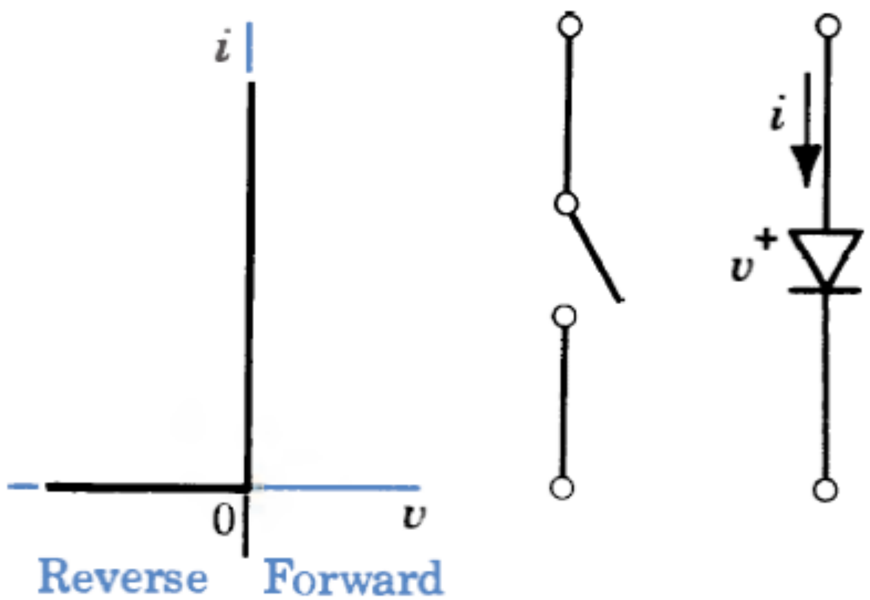
Instructor: Debanjan Bhowmik

Reference: Donald Neamen's 'Electronic Circuit Analysis'
Chapter 2 (Diode Circuits)

Ideal and Practical Diode

- An **ideal diode** has a infinite diffusion, and zero drift.
- Presents
  - Zero resistance in forward bias
  - Infinite resistance in reverse bias.

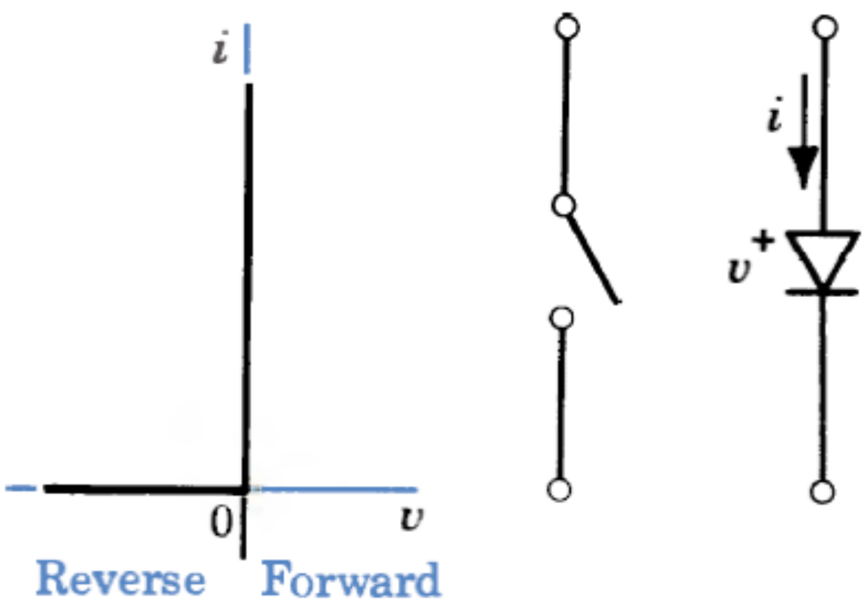
Like a switch



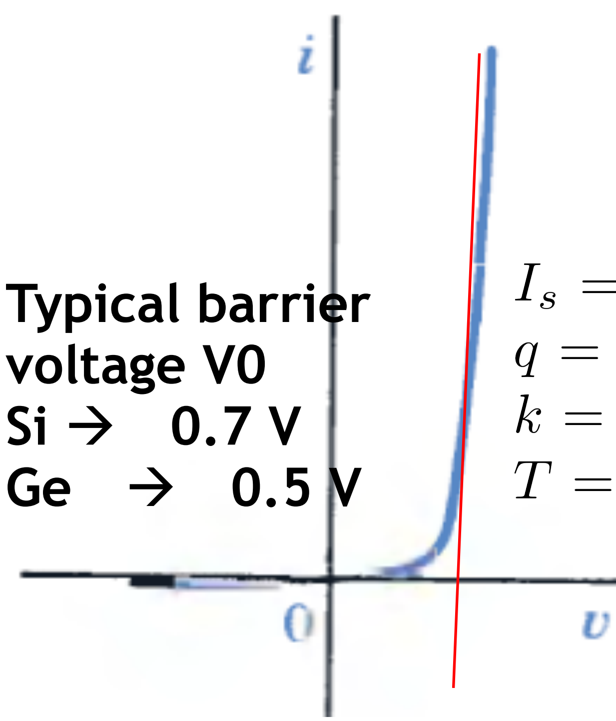
Ideal diode

Ideal and Practical Diode

- An **ideal diode** *acts like a switch*.
- A **practical diode** has a nonlinear I-V characteristics.
  - Current-voltage relations



Ideal diode

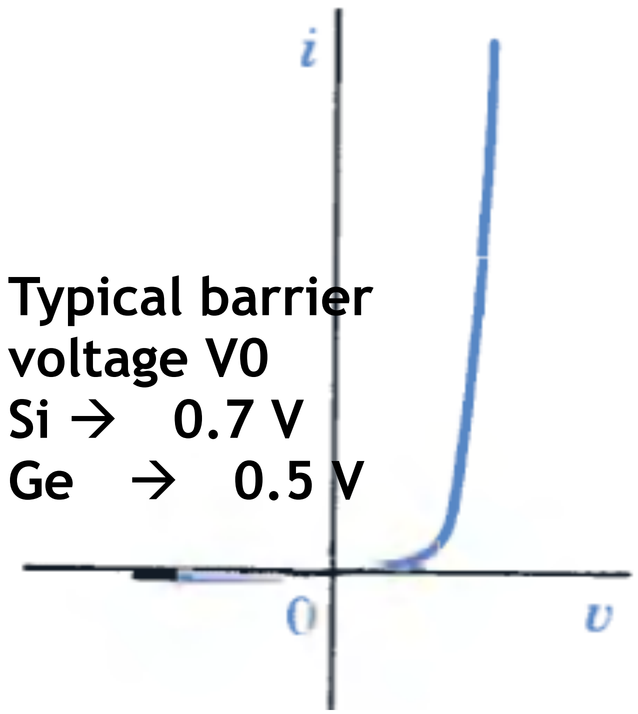


$$i = I_s\left(e^{\frac{qV}{kT}} - 1\right)$$

I_s = Reverse saturation current.
q = Charge of electron
k = Boltzmann Const.
T = Junction temperature in K

Practical Diode

Ideal and Practical Diode



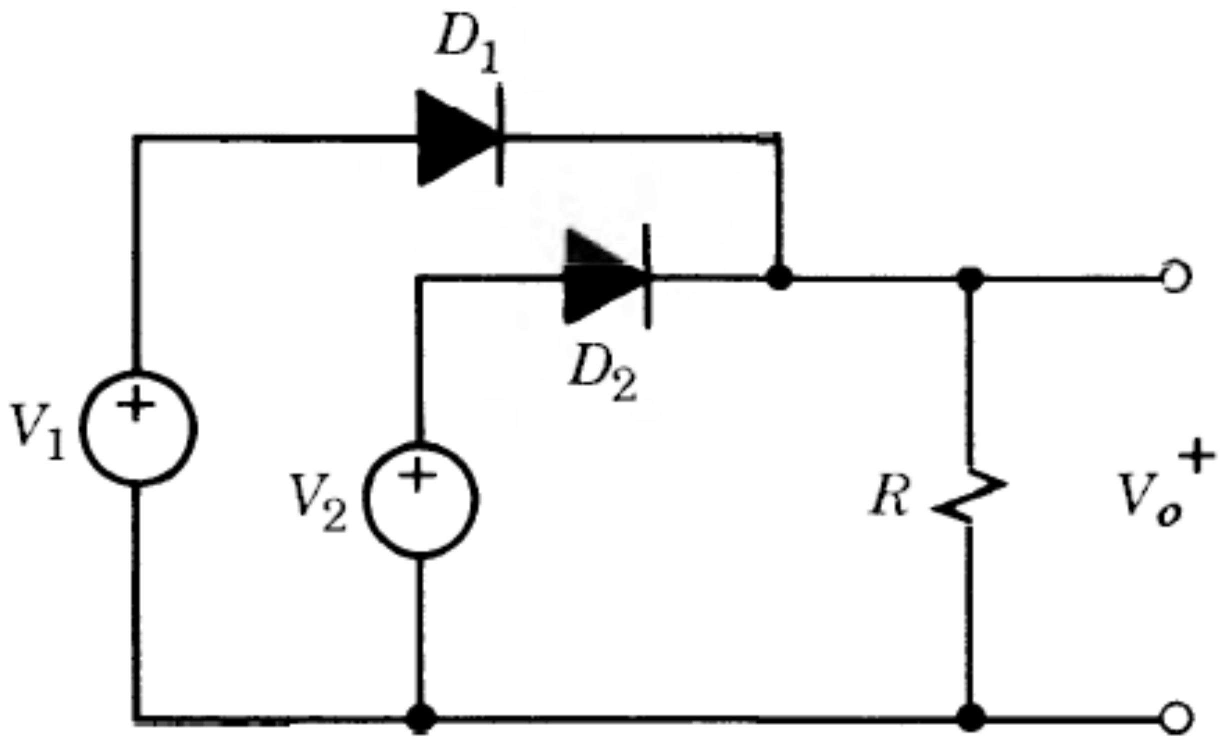
Practical Diode:

under forward bias: potential across it is almost 0.7 V (Si), current depends on the circuit.

under reverse bias: potential across it can be anything (negative quantity), current is almost 0

Example 1

- Consider the Si diode in the circuit. Let V1 = 5 V and V2 = 0 V. Determine Vo.



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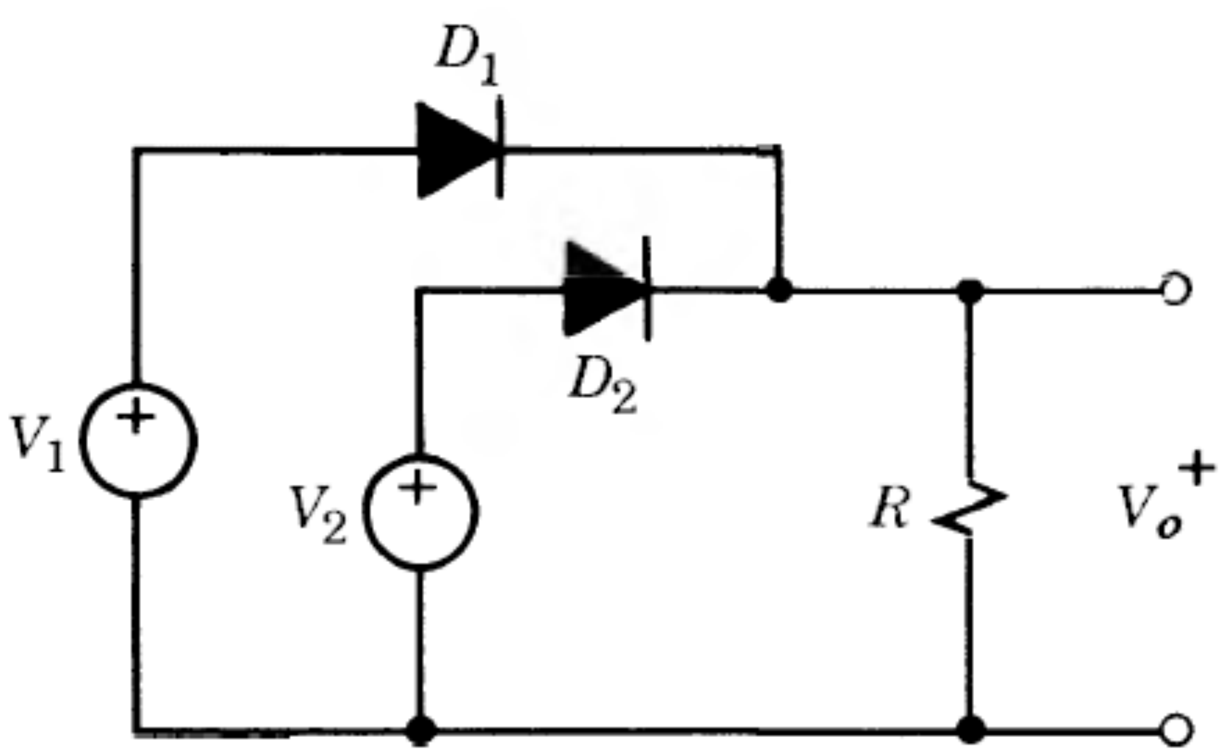

Since it is a Silicon diode, barrier voltage is 0.7 V.
Now there are four situations corresponding to the forward/reverse biasing of the two diodes.
D1→FB, D2→RB (5>Vo>0) Possible
D1→RB, D2→RB (0<5<Vo) Possible
D1→FB, D2→FB (5>0>Vo) Possible
D1→RB, D2→FB (5<Vo<0) No

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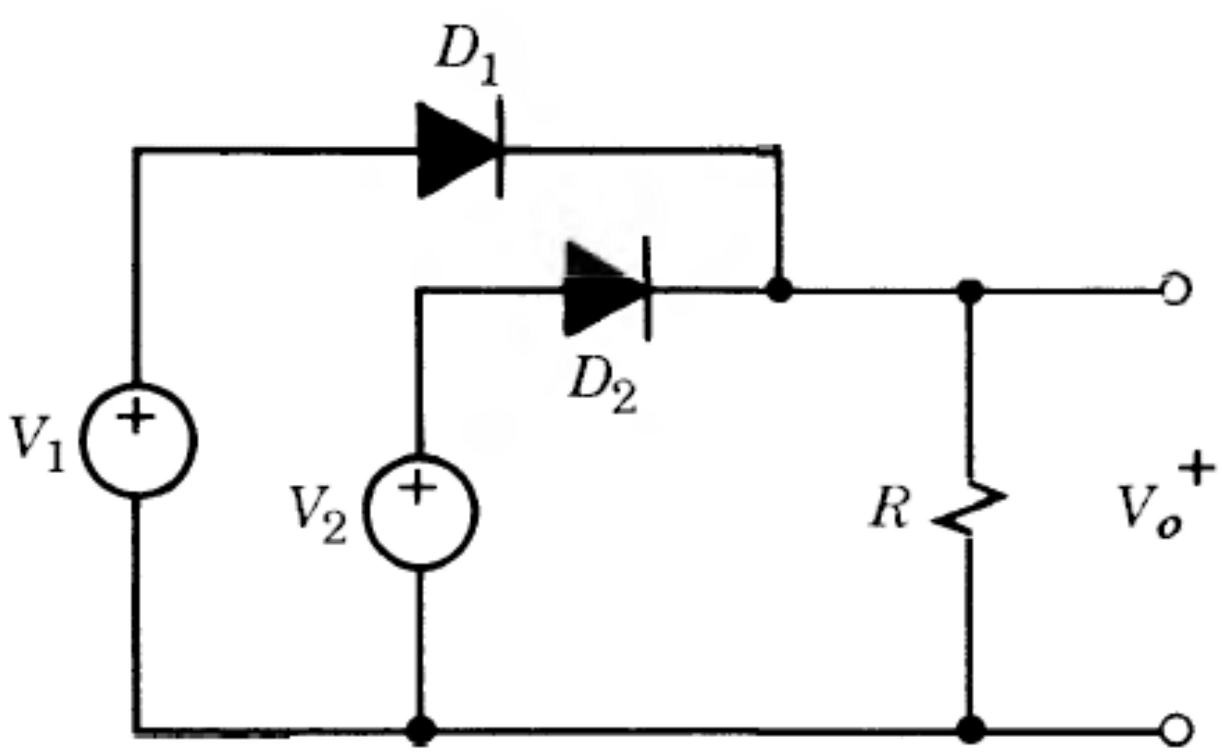

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D1→FB, D2→RB (5>Vo>0) Possible

Vo = 5-0.7 = 4.3 V

D1→RB, D2→RB (0<5<Vo) Possible

D1→FB, D2→FB (5>0>Vo) Possible

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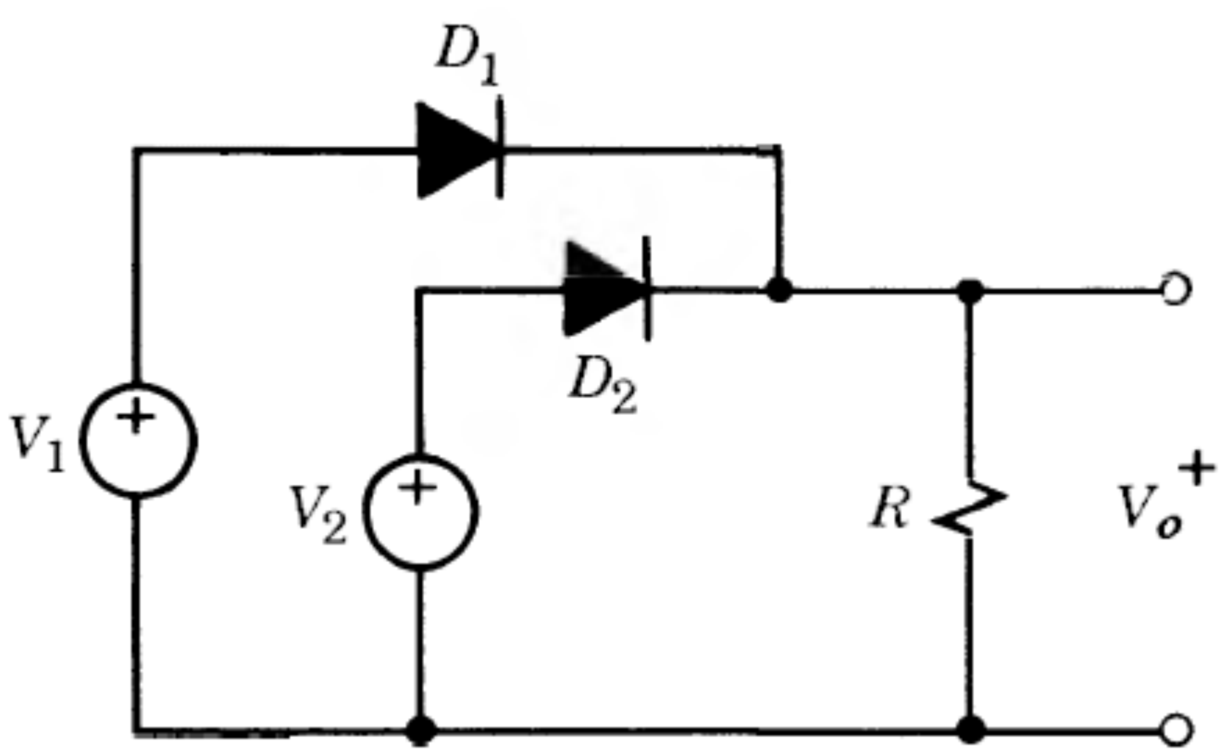

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D1→FB, D2→RB (5>Vo>0) Possible
Vo = 5-0.7 = 4.3 V

D1→RB, D2→RB (0<5<Vo) Possible
Vo = 0 and > 5 !!

D1→FB, D2→FB (5>0>Vo) Possible

~~D1→RB, D2→FB (5<Vo<0) No~~

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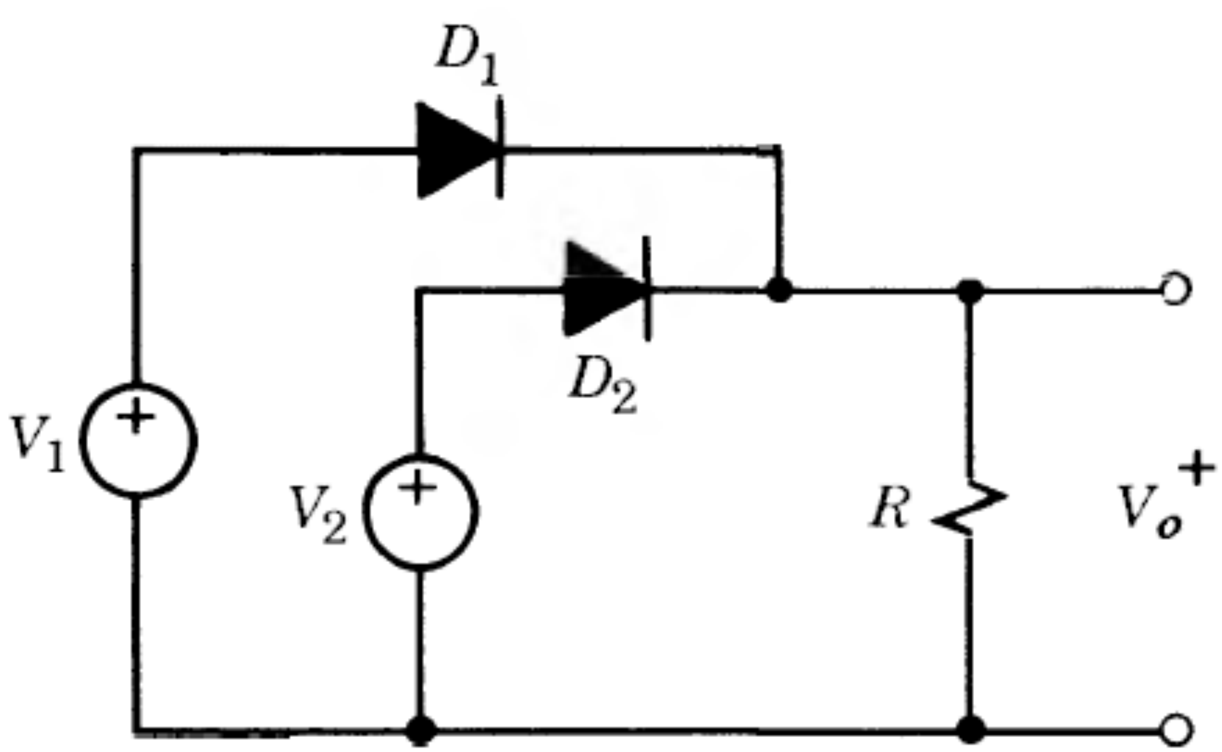

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~~D1→RB, D2→RB (0<5<Vo) Possible~~

D1→FB, D2→FB (5>0>Vo) Possible

Vo = 5+0.7; V=0+0.7 !!

~~D1→RB, D2→FB (5<Vo<0) No~~

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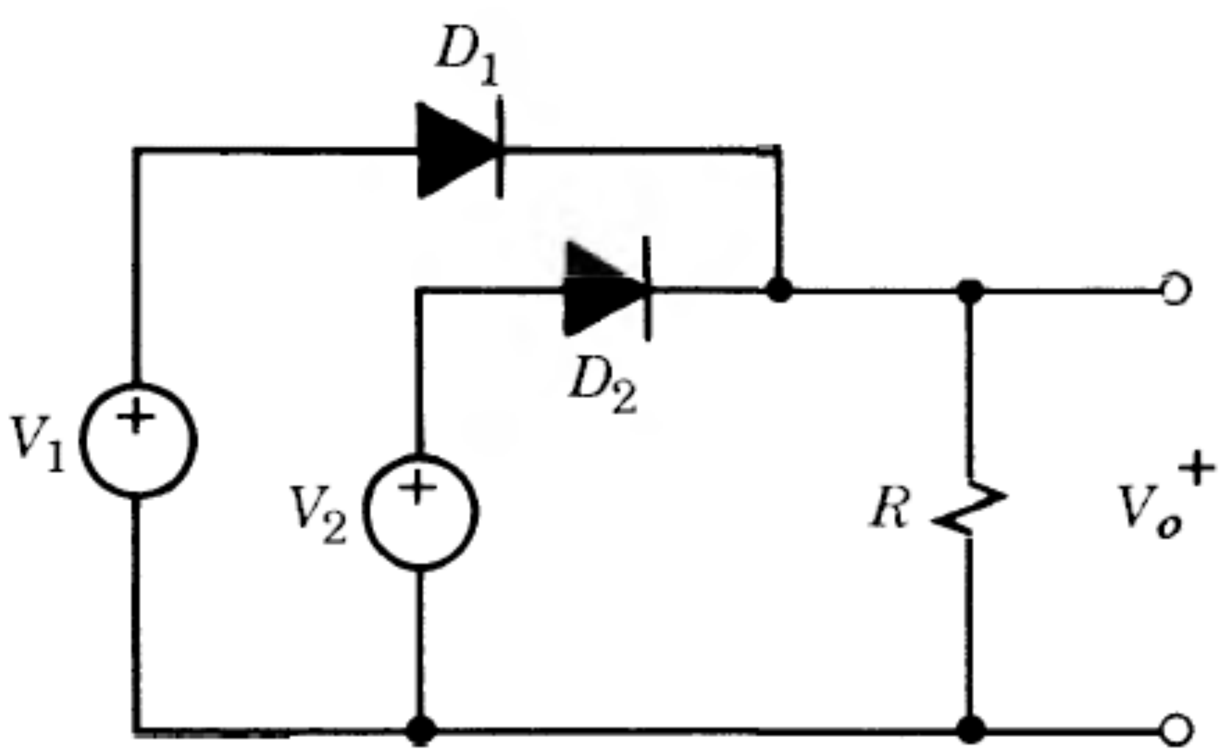

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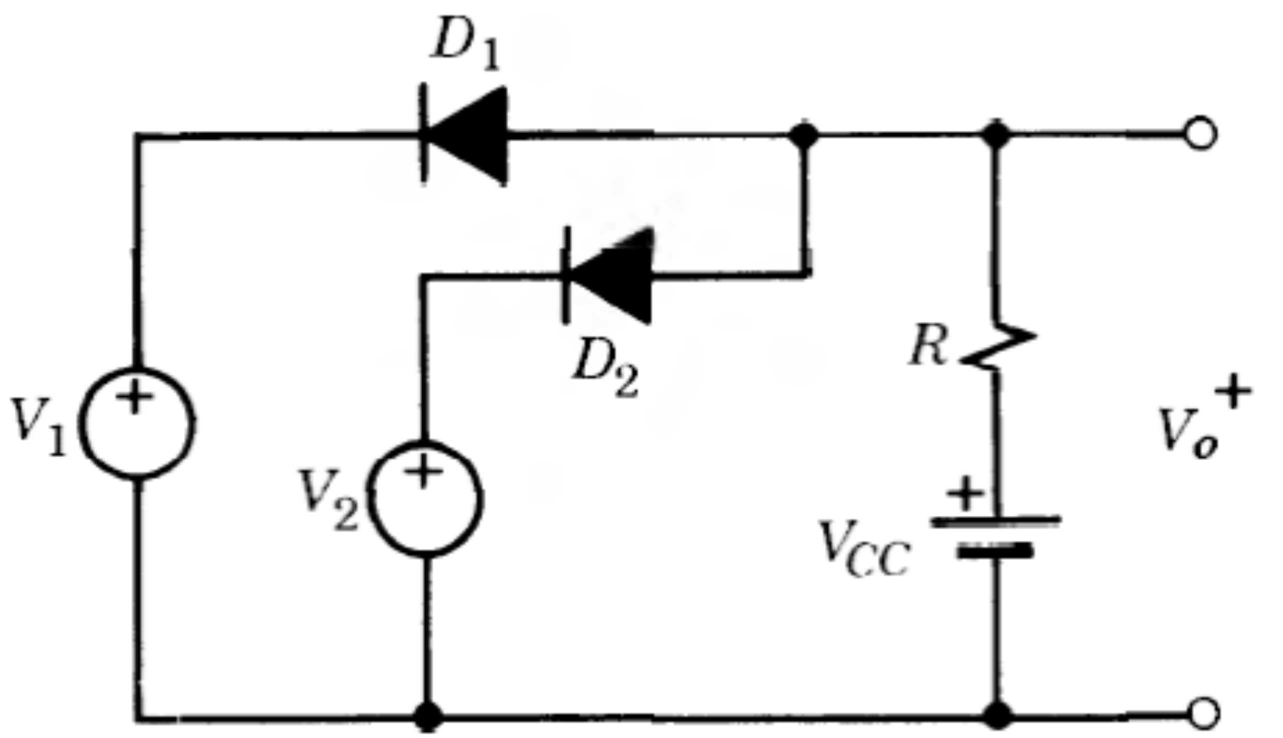
~~D1→RB, D2→RB (0<5<Vo) Possible~~

~~D1→FB, D2→FB (5>0>Vo) Possible~~

~~D1→RB, D2→FB (5<Vo<0) No~~

Example 2

- Consider the Si diode in the circuit. Let V1 = 5 V and V2 = 0 V and Vcc=6 V Determine Vo.



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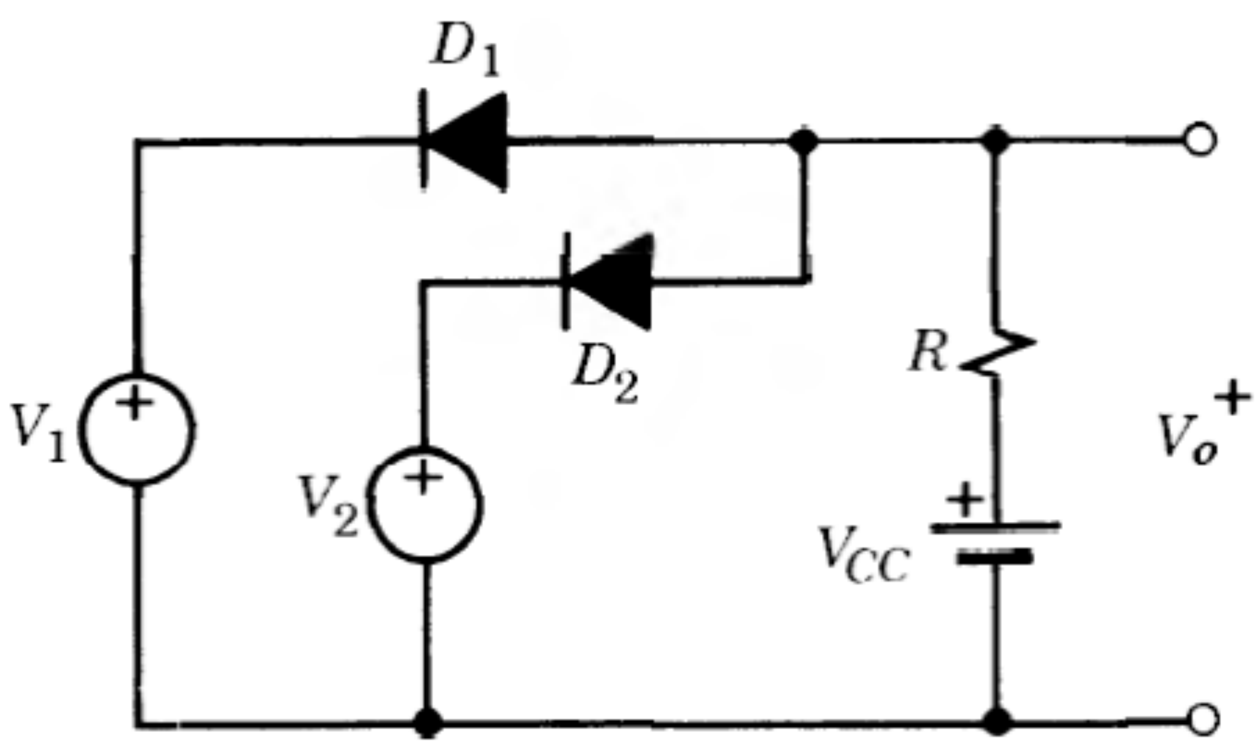

Since it is a Silicon diode, barrier voltage is 0.7 V.
D1, D2 → FB 6>Vo>(5,0)
But then there is conflict of Vo=5-0.7 or 0-0.7.
D1,D2 → RB 6<Vo<(5,0) NOT Possible

Example 2

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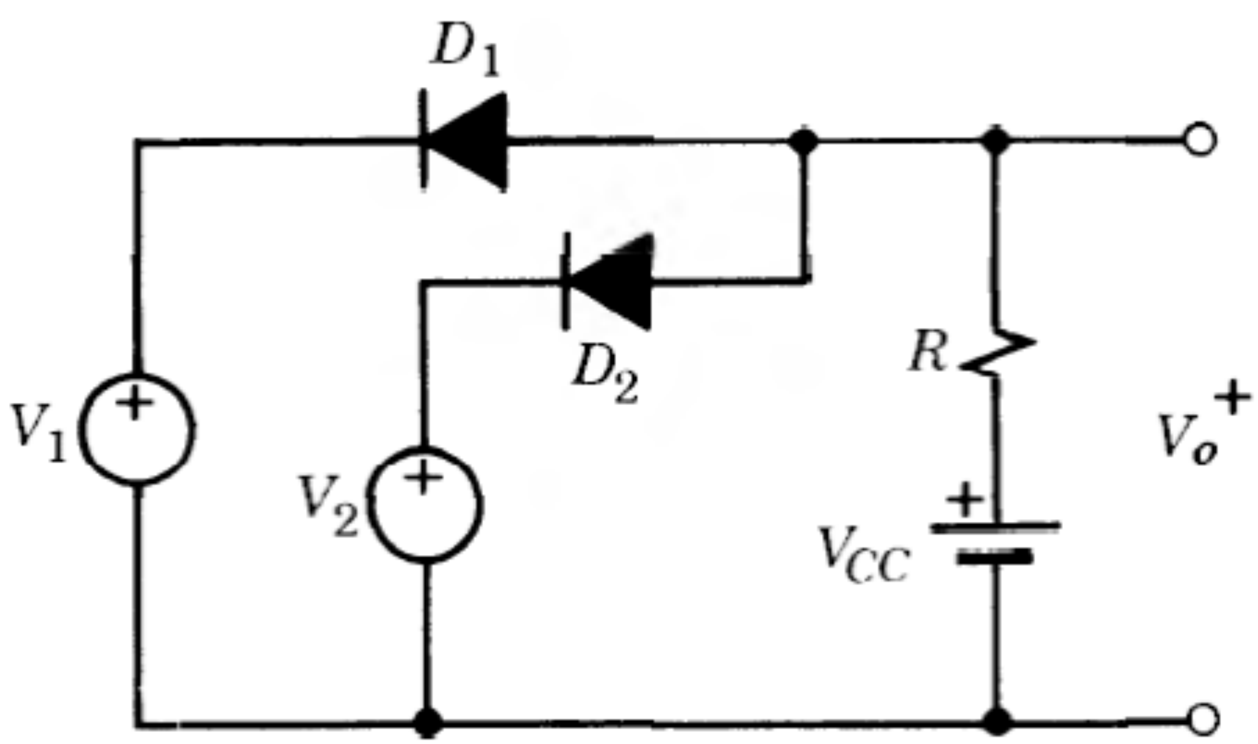

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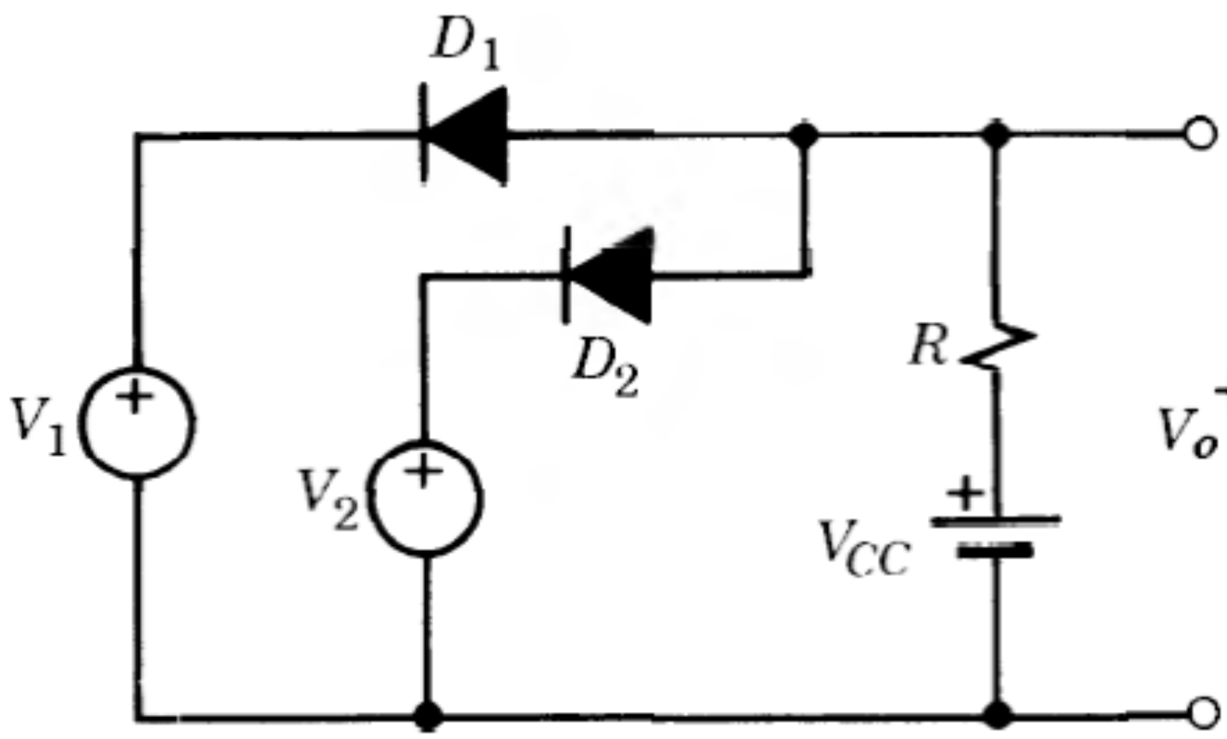

Since it is a Silicon diode, barrier voltage is 0.7 V.

~~D1, D2 → FB 6>Vo>(5,0)~~

~~D1,D2 → RB 6<Vo<(5,0) NOT Possible~~

D1→FB, D2→RB 0>Vo>5 NOT Possible

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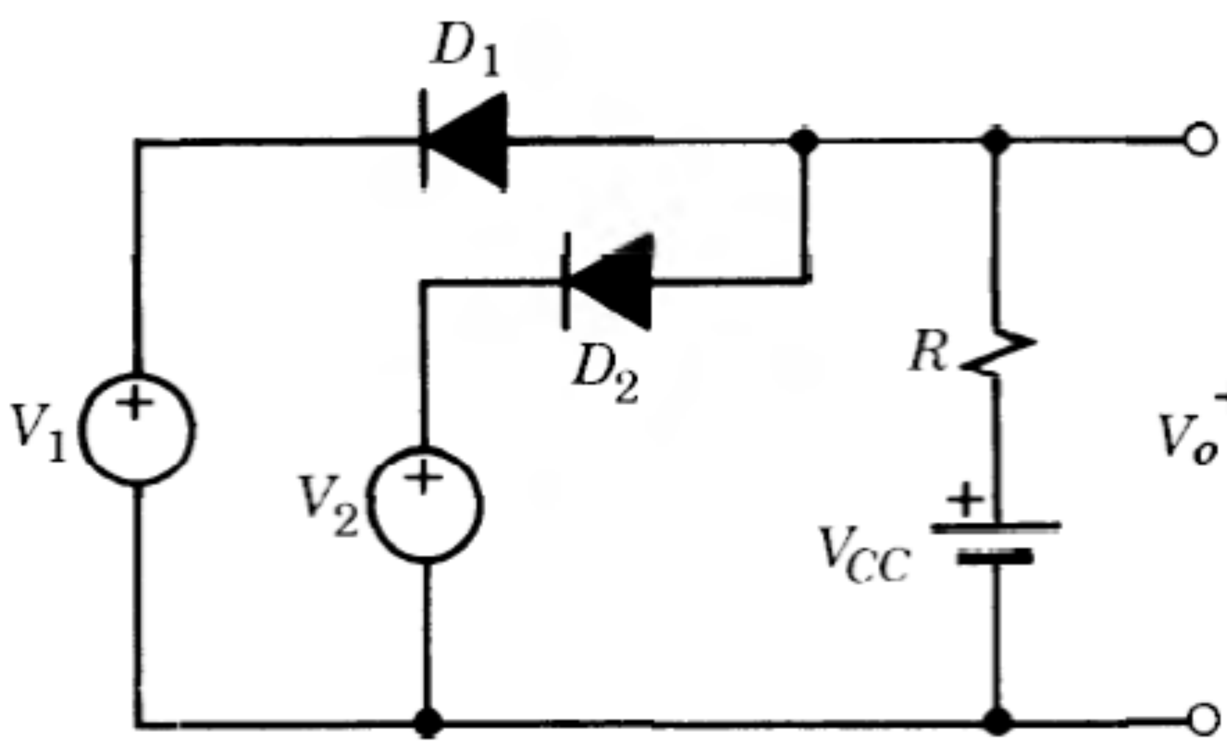


Since it is a Silicon diode, barrier voltage is 0.7 V.

~~D1, D2 → FB 6>Vo>(5,0)~~

~~D1,D2 → RB 6<Vo<(5,0) NOT Possible~~

~~D1→FB, D2→RB 0>Vo>5 NOT Possible~~

D1→RB, D2→FB 0<Vo<5

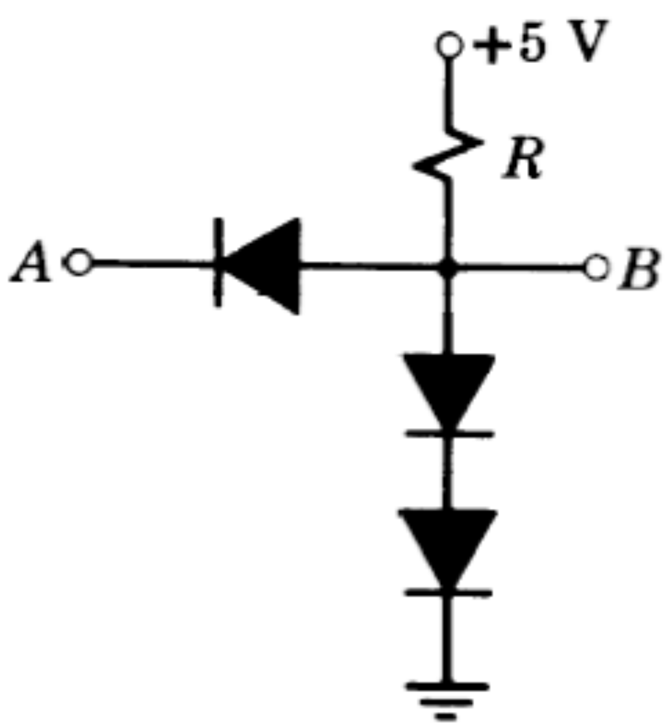
Vo = 0+0.7 = 0.7 V

Current flowing through D1= 0

Current flowing through D2 = (Vcc – Vo)/ R

Example 3

- Consider the circuit with silicon diodes. Determine V_B, when V_A = 2 V, 1 V, 0 V, -1. V



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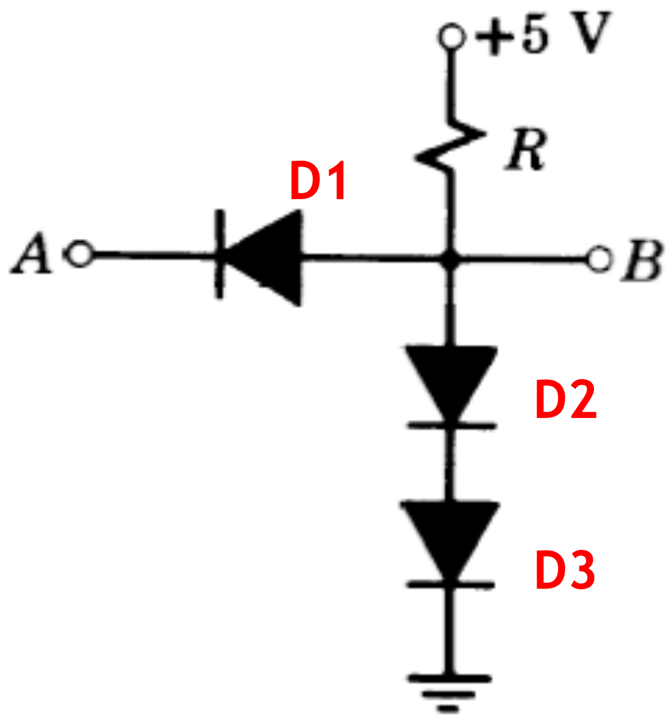

	D2,D3→FB	D2,D3→RB
D1→RB		Vb<min(Va,0) Vb = ???
D1→FB		

Example 3

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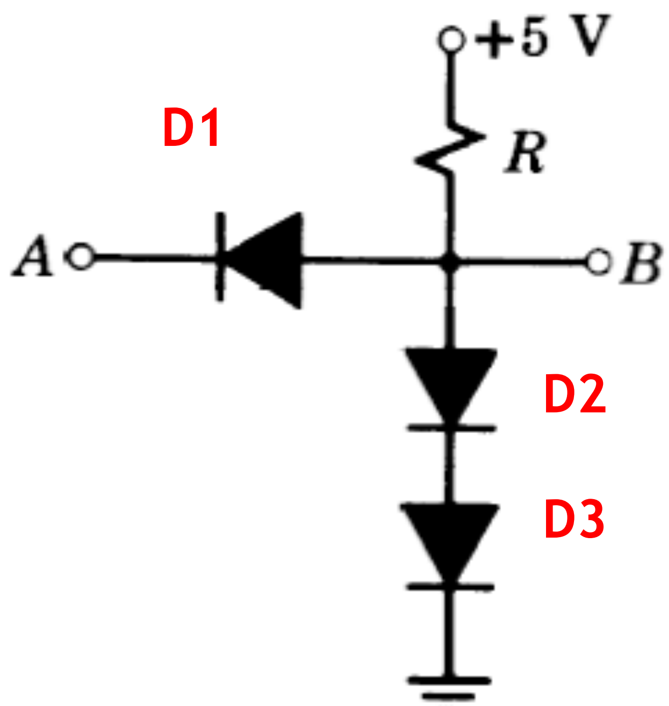

	D2,D3→FB	D2,D3→RB
D1→RB	Va>Vb>0 Vb = 0+2*0.7 = 1.4V	Vb<min(Va,0) Vb = ???
D1→FB		

Va = 2 V, Vb = 1.4 V

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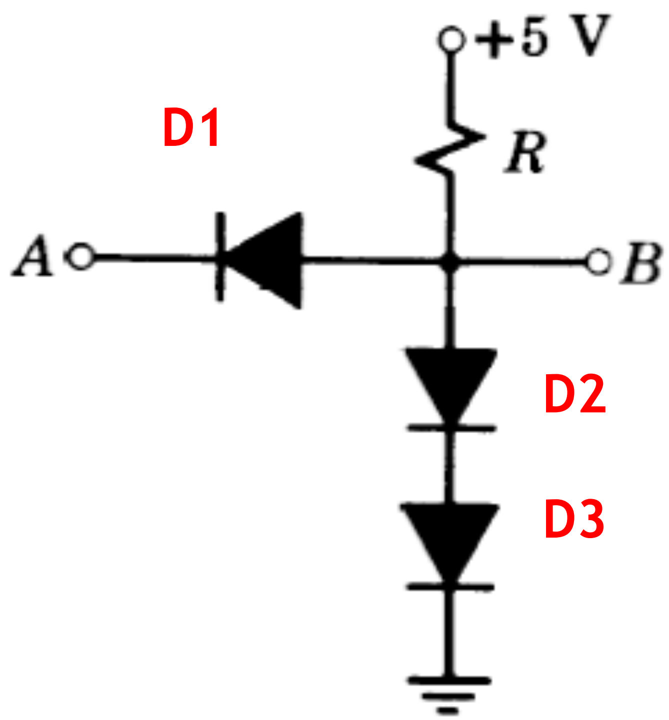

	D2,D3→FB	D2,D3→RB
D1→RB	Va>Vb>0 Vb = 0+2*0.7 = 1.4V	Vb<min(Va,0) Vb = ???
D1→FB	Vb>Va,Vb>0 Vb = min(Va+0.7,1.4)	

Va = 2 V, Vb = 1.4 V

Va = 1 V, Vb = min(1.7,1.4)=1.4 V

Va = 0 V, Vb = min(0.7,1.4)=0.7 V

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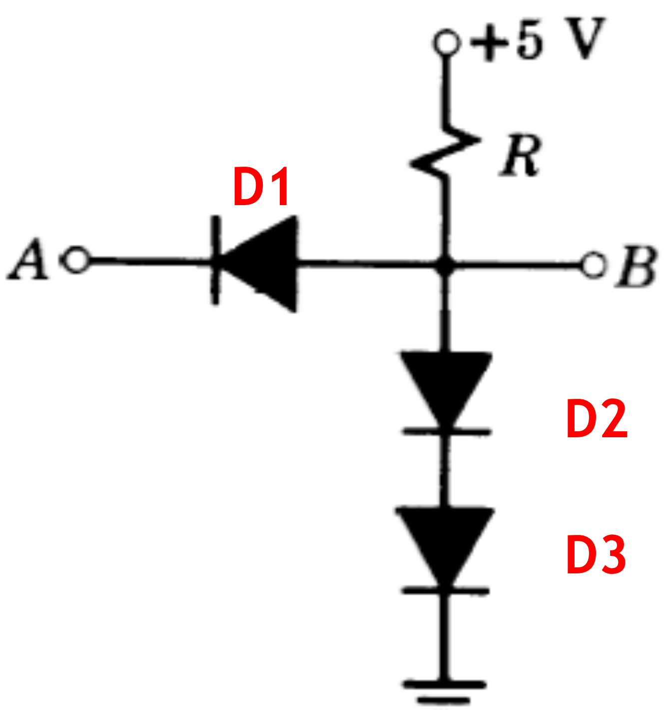
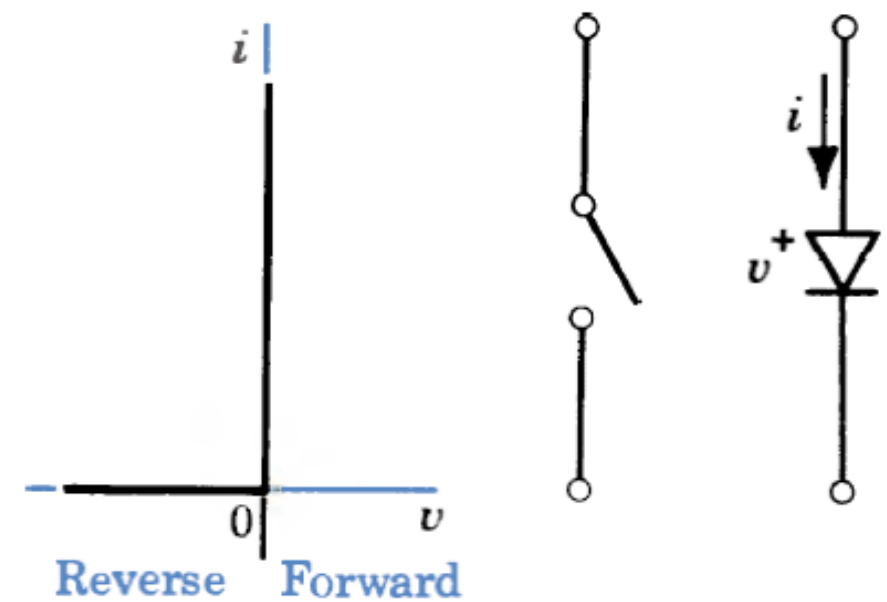


	D2,D3→FB	D2,D3→RB
D1→RB	Va>Vb>0 Vb = 0+2*0.7 = 1.4V	Vb<min(Va,0) Vb = ???
D1→FB	Vb>Va, Vb>0 Vb = min(Va+0.7,1.4)	Va<Vb<0 Vb = Va + 0.7

Va = 2 V, Vb = 1.4 V
Va = 1 V, Vb = min(1.7,1.4)=1.4 V
Va = 0 V, Vb = min(0.7,1.4)=0.7 V
Va = -1 V , Vb = -0.3 V

Diode as a Switch

- A diode (ideally) acts as a switch.
- This property can be used in a variety of circuits.
  - AC-DC Conversion : Rectifier
  - Peak Detection, DC Restoration : Clamper
  - Wave Shaping : Clipper

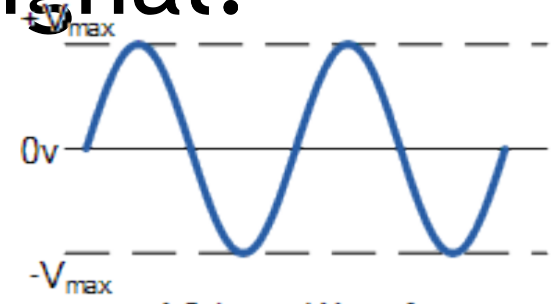


Rectifier

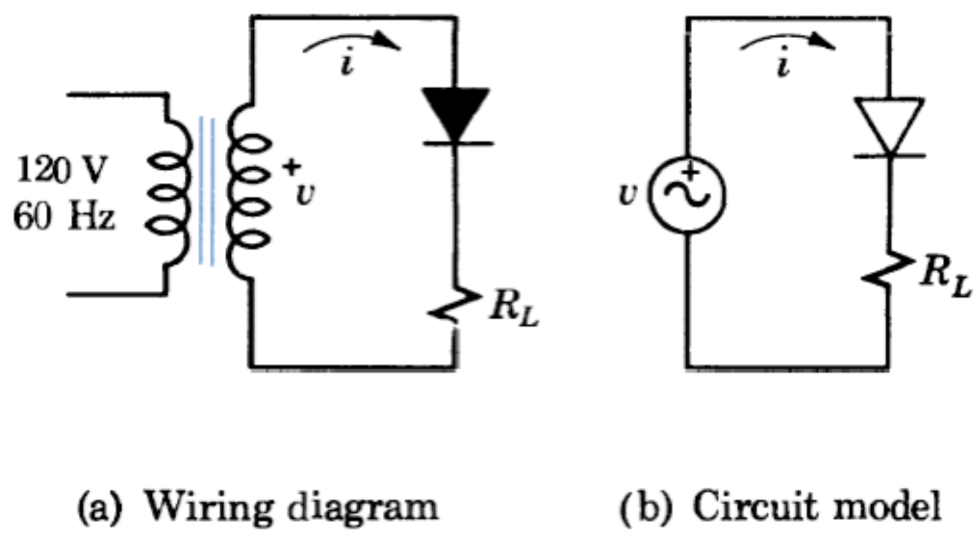
- Rectification : Conversion of an alternating current to unidirectional, but pulsating current by using a nonlinear element (like diode).
- Type :
  - Half-Wave Rectifier : Utilizes only one half of an AC signal for conversion.
  - Full-Wave Rectifier : Uses both halves of an AC signal for conversion

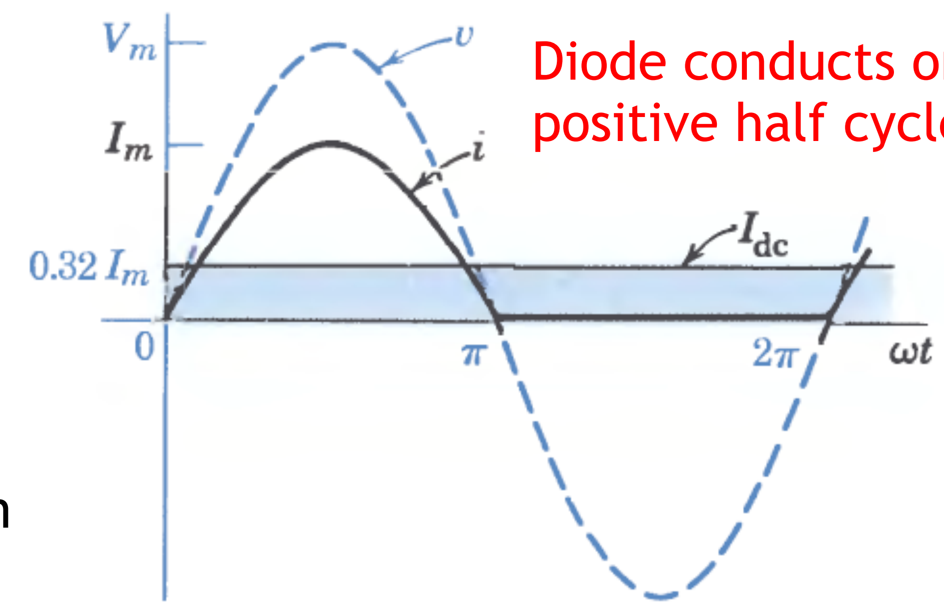
Half-Wave Rectifier (HWR)

- A Half-wave rectifier circuit uses a single diode to recover one HALF of an AC signal.



Input Waveform





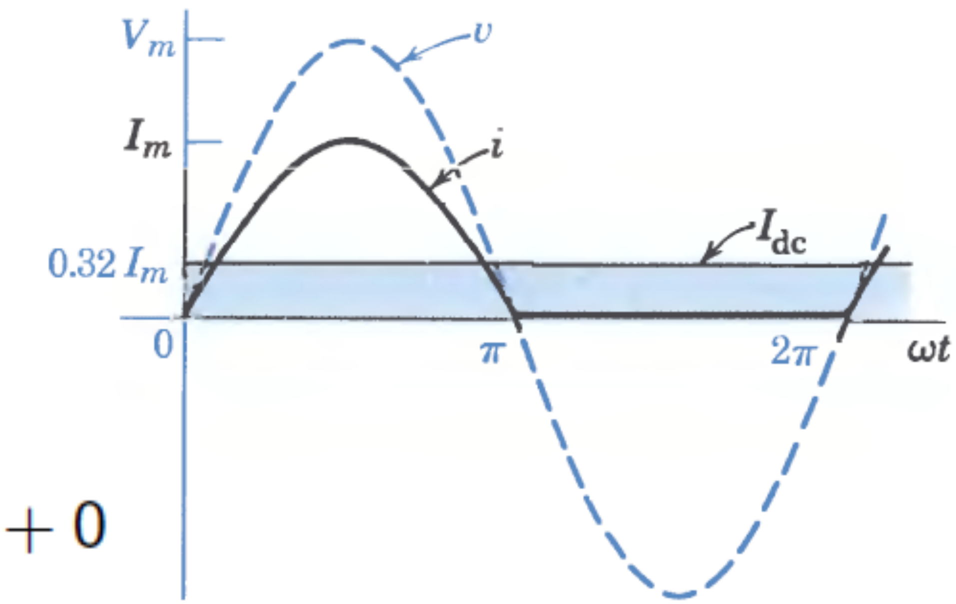
Diode conducts only in positive half cycle

Output Waveform

HWR : DC/Average Value

- Assuming ideal diode

$$
\begin{aligned}
i &= \frac{v}{R_L} = \frac{V_m \sin \omega t}{R_L} \quad \text{for} \quad 0 \le \omega t \le \pi \\
&= 0 \quad \text{for} \quad \pi \le \omega t \le 2\pi
\end{aligned}
$$

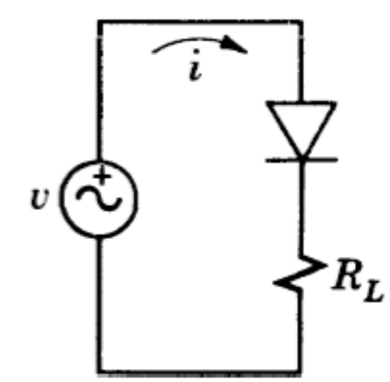


$$I_{dc} = \frac{1}{2\pi} \int_0^{2\pi} i \; d(\omega t) = \frac{1}{2\pi} \int_0^{\pi} \frac{V_m \sin \omega t}{R_L} \; d(\omega t) + 0$$

$$= \frac{V_m}{\pi R_L} = \frac{I_m}{\pi}$$

$$V_{dc} = \frac{V_m}{\pi}$$

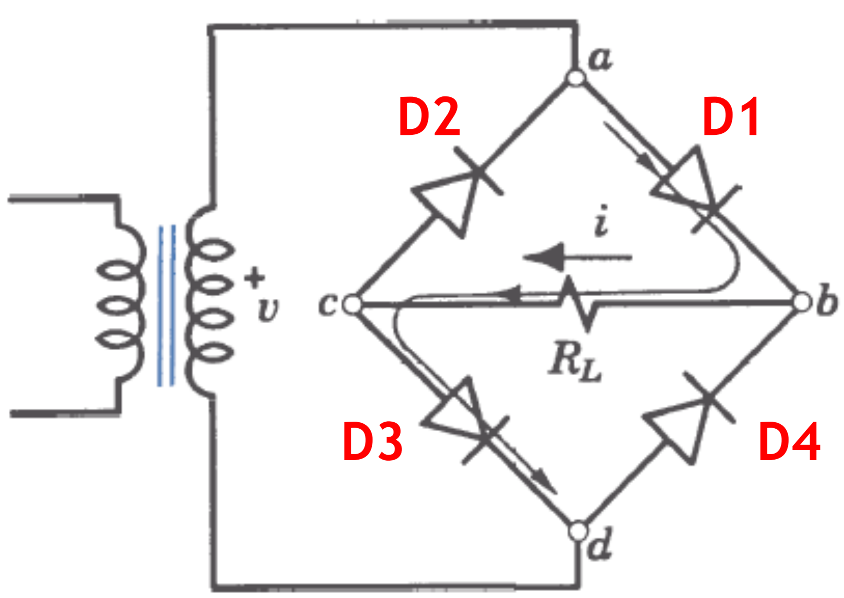
Approx. 32%

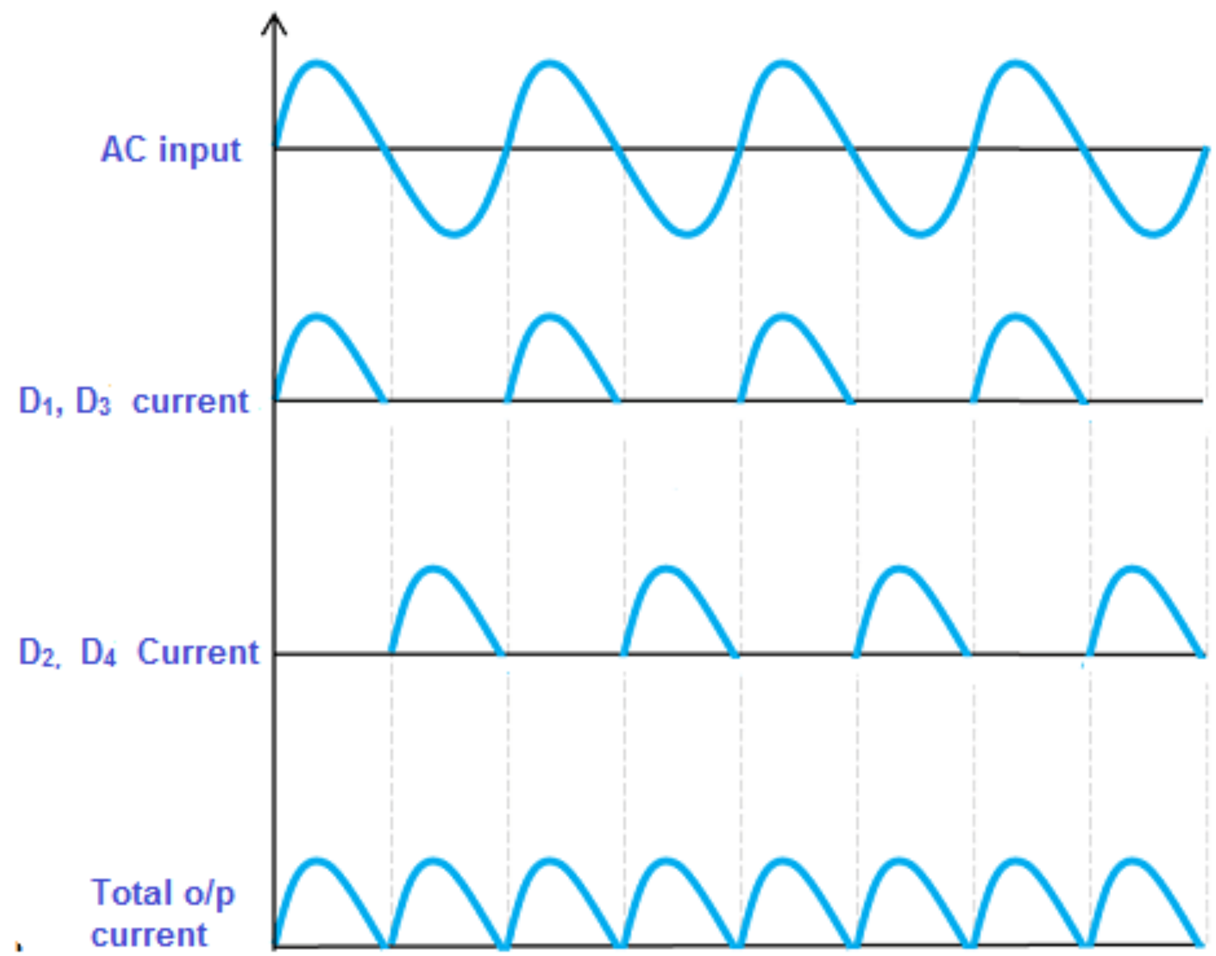


Full-Wave Rectifier (FWR)

- Is there a way to utilize BOTH halves of the AC signal to produce a unidirectional output voltage/current?
- Bridge Rectifier :

$$V_{DC} = \frac{2}{\pi} V_m \approx 64\% \text{ of } V_m$$





+ve ½ cycle of V : Diodes D1 and D3 conduct: D2 and D4 are off (a-b-c-d)

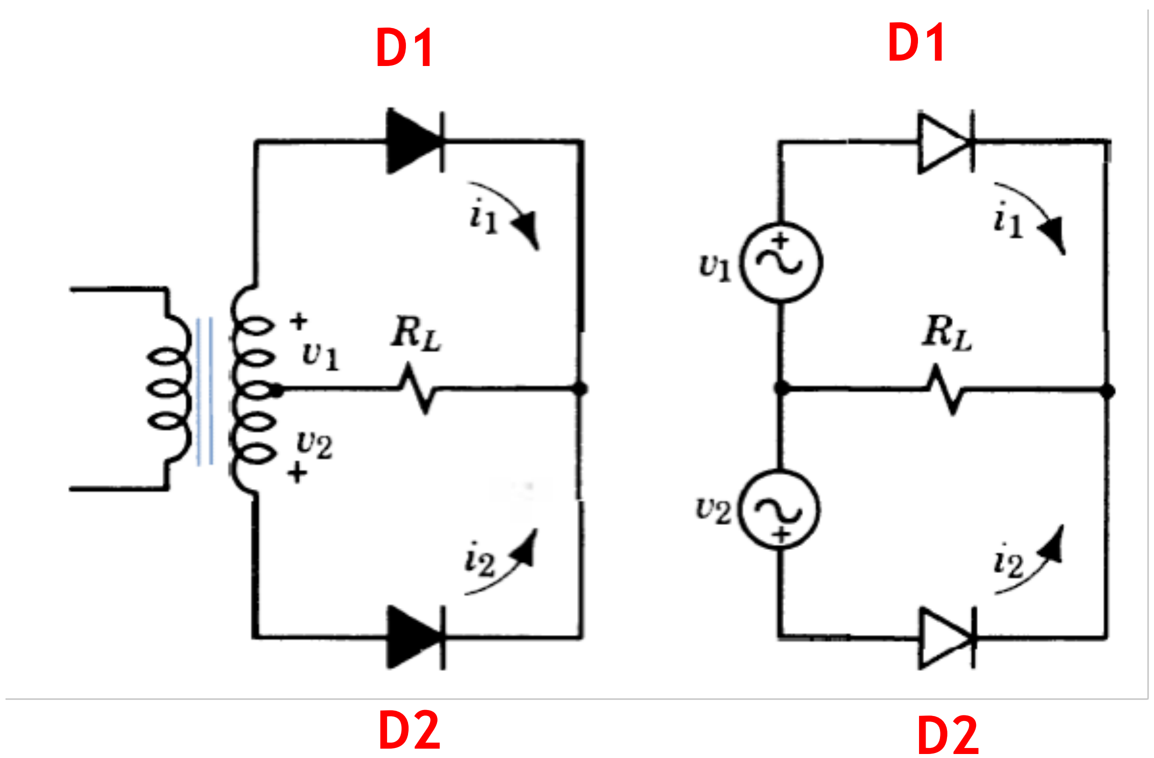
-ve ½ cycle of V : Diodes D2 and D4 conduct: D1 and D3 are off (d-b-c-a)

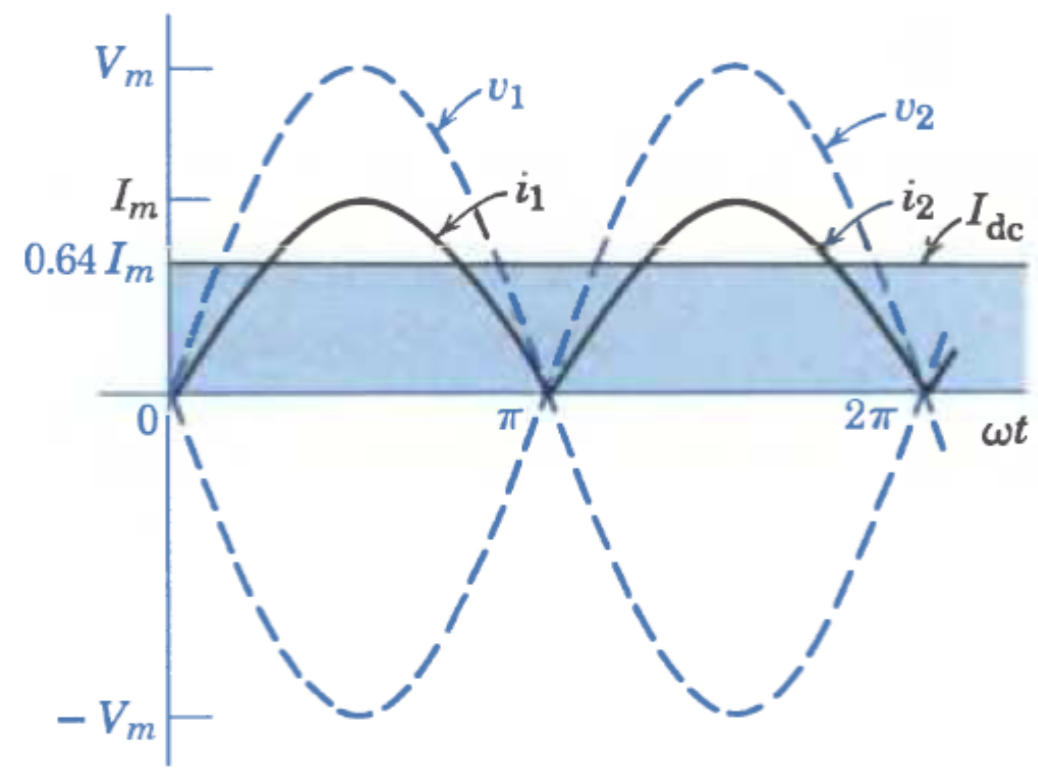
Full-Wave Rectifier (FWR)

- Bridge Rectifier has some disadvantages.
  - Needs 4 diodes
  - Power is always dissipated in 2 of the diodes (in series with the load).

Full-Wave Rectifier (FWR)

- FWR with centre-tapped transformer :





+ve 1/2 cycle of v : D_1 conducts and D_2 is off
-ve 1/2 cycle of v : D_2 conducts and D_1 is off

$$V_{dc} = \frac{2}{\pi} V_m$$
$$v_{1,2} = V_m \sin(\omega t \pm \pi/2 + \phi)$$

Vm is the maximum OUTPUT Voltage

FWR – Comparison

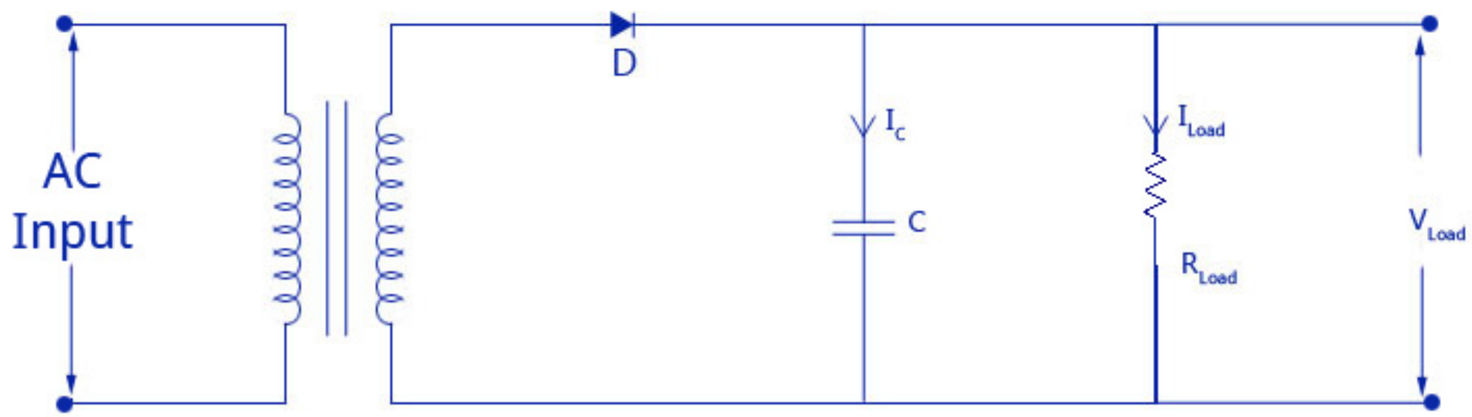
Full wave bridge rectifier	Full wave rectifier with center tap transformer
4 diodes required	2 diodes required
More power dissipation	Less power dissipation
Less expensive transformer	More expensive transformer required
Lower operating efficiency	Higher operating efficiency

Signal Filtering

- In both HWR and FWR, the output voltage varies from 0 to Vmax.
- This variation between max and min voltage is called ‘ripple voltage’. Undesirable.
- Filter : Removes these pulsations and improves the DC component.
- Capacitor Filter : Connect a Capacitor across the rectifier to reduce ripple.

Capacitor Filter with Rectifier (HWR)

- With the capacitor, the voltage across the load 'decays' slowly



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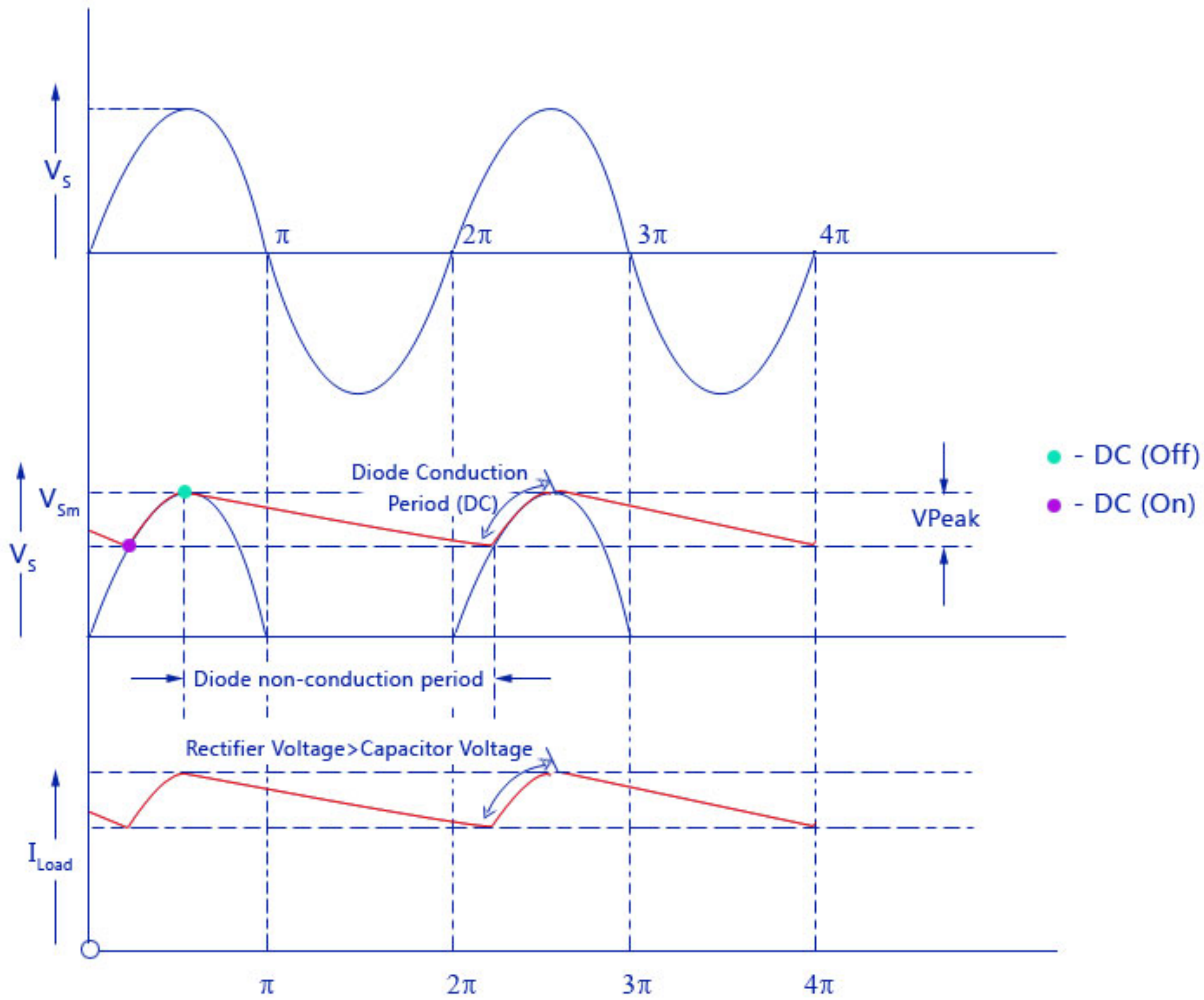
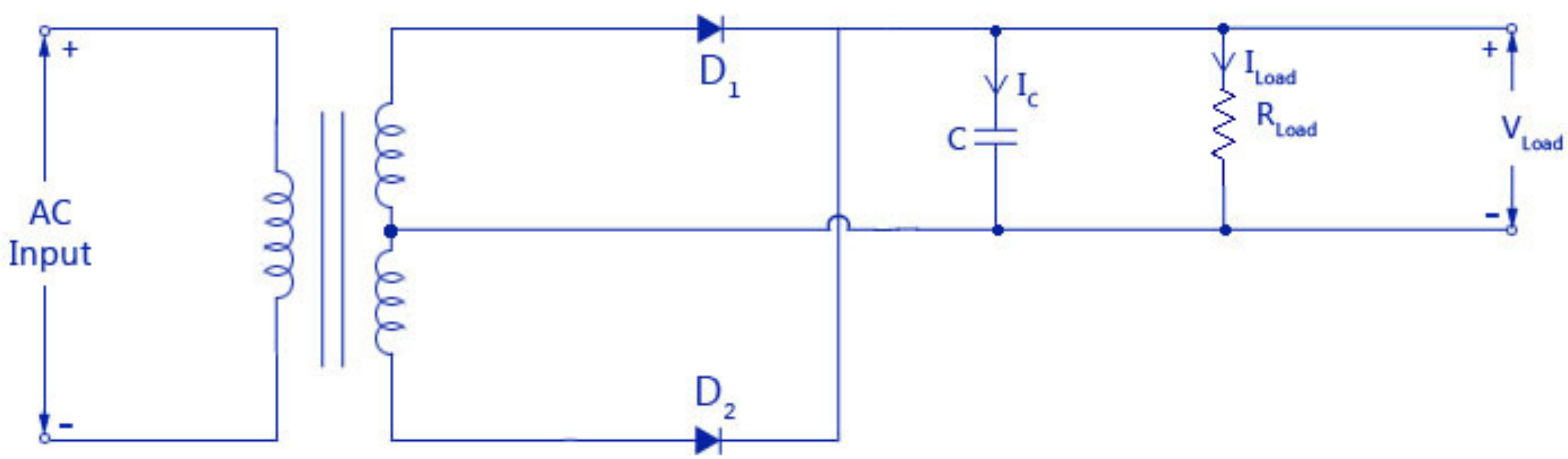


$$\tau = R_L C \gg T$$

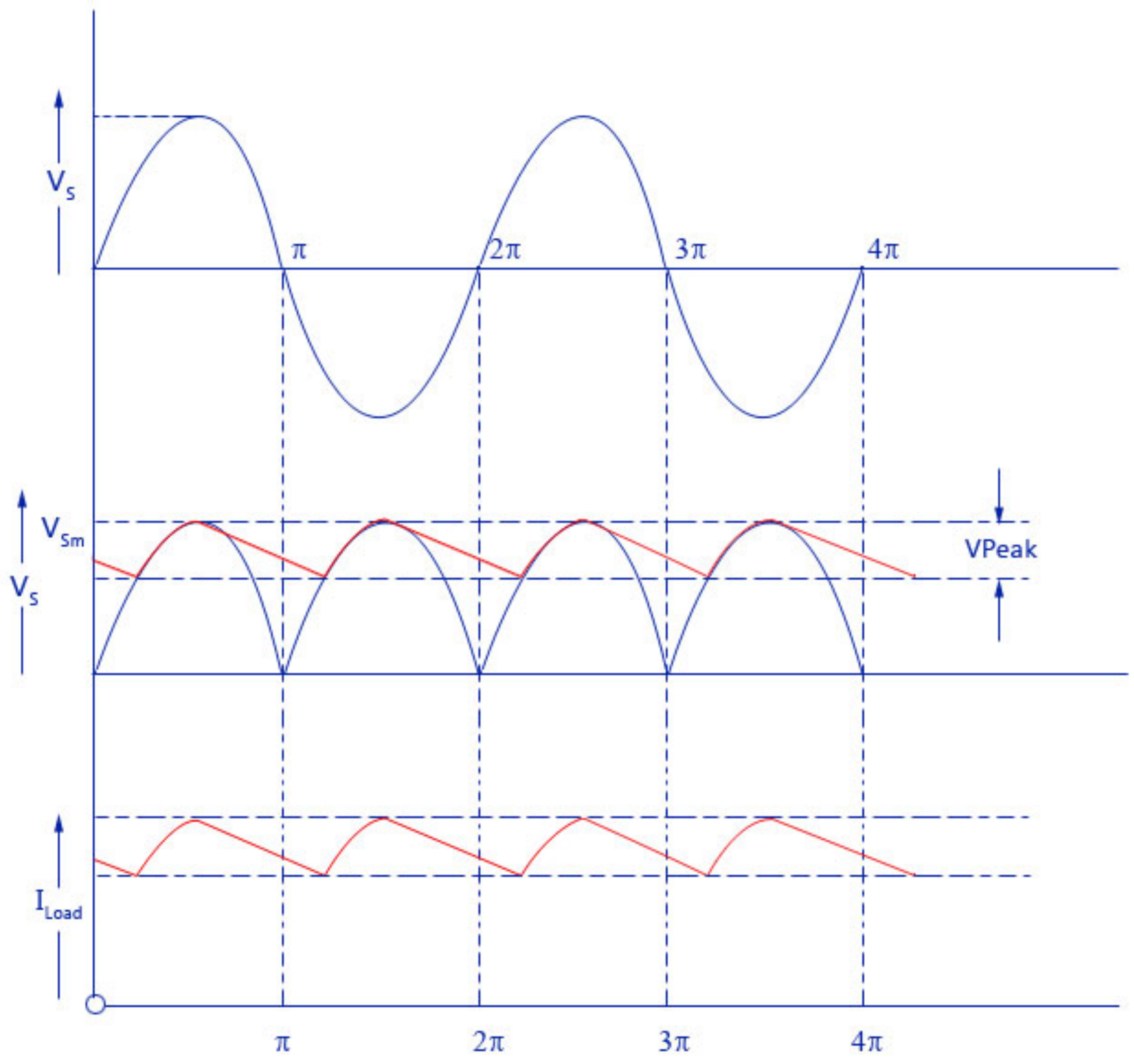
Output Voltage remains almost constant

$$V_r = \frac{\Delta q}{C} \approx \frac{I_{dc} T}{C} = \frac{I_{dc}}{fC} = \frac{V_{dc}}{f R_L C}$$

Capacitor Filter with Rectifier (FWR)



Capacitor Filter with Rectifier (FWR)



Here the discharge time is T/ 2.

$$\tau = R_L C \gg T$$

$$V_r = \frac{\Delta q}{C} \approx \frac{I_{dc}T}{2C}$$
$$= \frac{I_{dc}}{2fC} = \frac{V_{dc}}{2fR_LC}$$