48510 LEC 8 – DIODE AND RECTIFIER

Topic 8-1-1: Introduction to diode and its V-I characteristic

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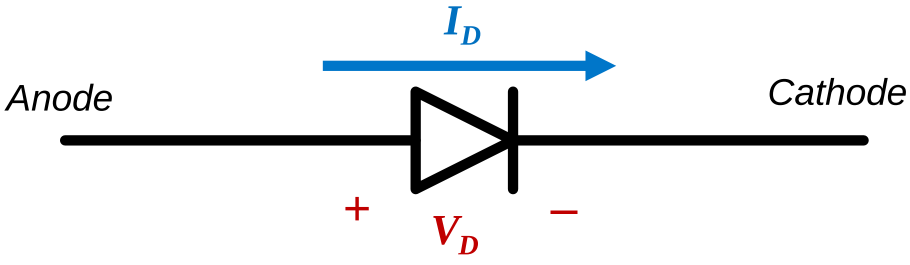
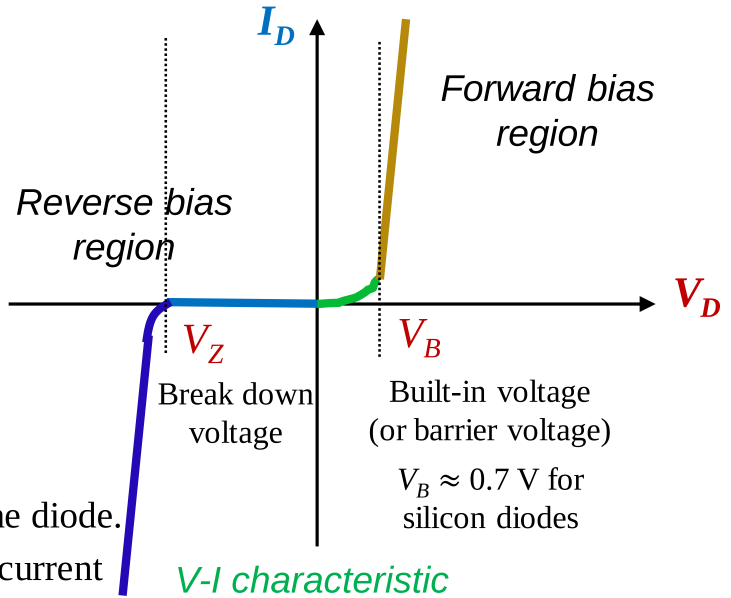
8-1-1 INTRODUCTION TO DIODE

Diode is the most used semiconductor device in electronic circuits. It is a two terminal device that, in most cases, **only allows current to flow in one direction.**

Diode is a **non-linear device** as the response is not linear with the excitation**.**



Schematic diode symbol



V-I characteristic

State 1: When $0 < V_D < V_B$, only very small current can leak through the diode.

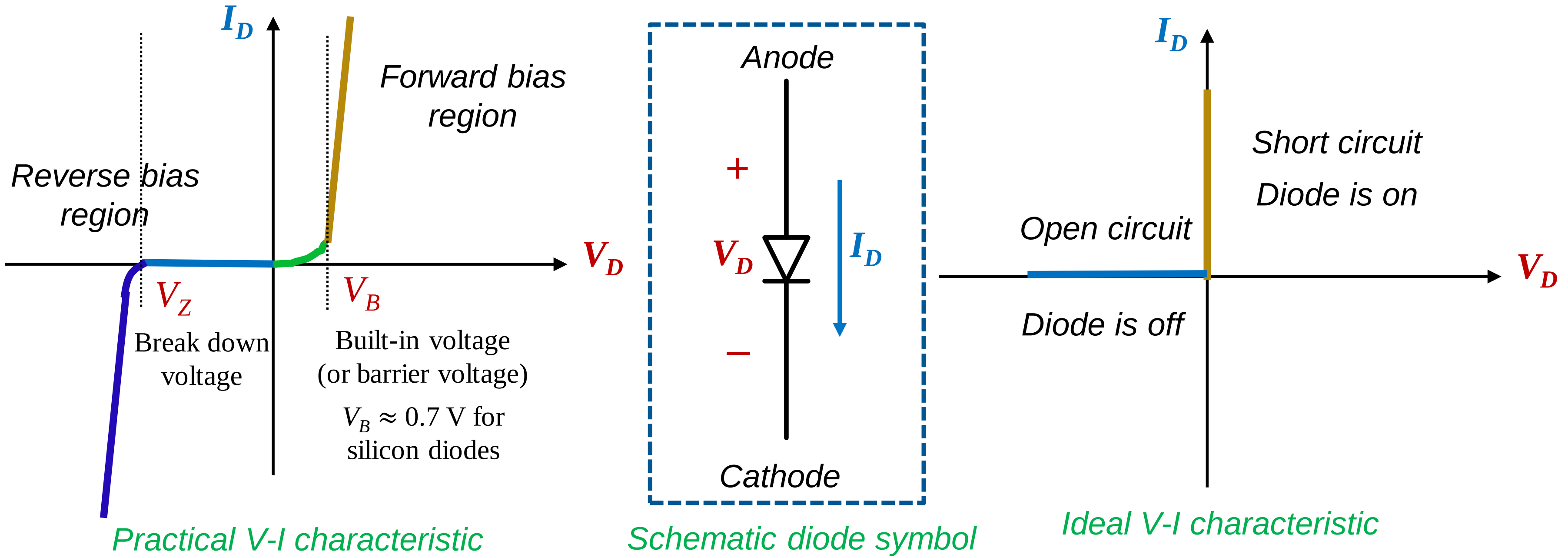
State 2: When $V_B \leq V_D$, diode can be seen as a very small resistor and current increases dramatically with voltage.

State 3: When $V_Z < V_D < 0$, diode is reverse biased and current is 0.

State 4: When $V_D \leq V_Z$, diode is break down and can be seen as a very small resistor allowing current to flow in the opposite direction *(Zener diode usually working in this state).*

8-1-1 INTRODUCTION TO DIODE

In some cases, we consider diode to be ideal one and its ideal V-I characteristic is shown in the figure below.



In ideal case, the diode can be seen as short circuit when forward biased and as open circuit when reverse biased.

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Topic 8-1-2: How to analyse circuits consisting of diodes – Simpler case

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8-1-2 CIRCUIT ANALYSIS INVOLVING DIODES

The key to analysing circuits consisting of diodes is to determine the working state of the diodes. In other words, to **determine whether the diodes are “ON” or “OFF”.**

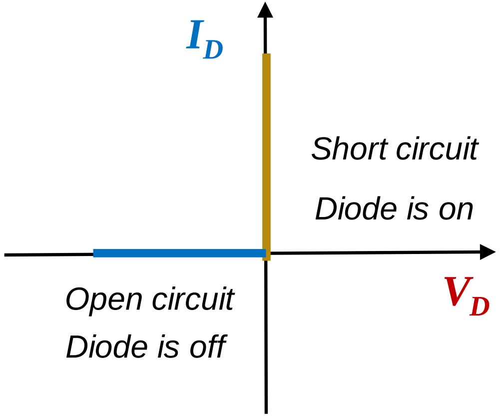
Case 1: when the working states of diodes can be easily determined.

It can be easily determined that D1 is forward biased and D2 is reverse biased by observing the voltage difference between the terminals of diodes assuming the current is 0 at the instant.

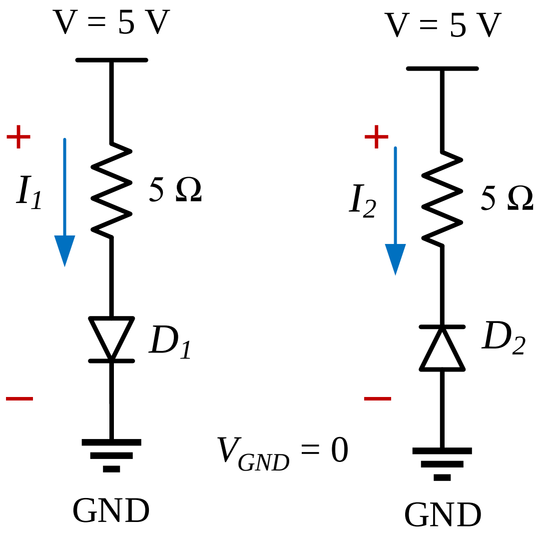
1) Considering the diodes *are ideal diodes*

D1 is ON (short circuit) $I_1 = 1$ A

D2 is OFF (Open circuit) $I_2 = 0$ A



Ideal V-I characteristic



8-1-2 CIRCUIT ANALYSIS INVOLVING DIODES

The key to analysing circuits consisting of diodes is to determine the working state of the diodes. In other words, to **determine whether the diodes are “ON” or “OFF”.**

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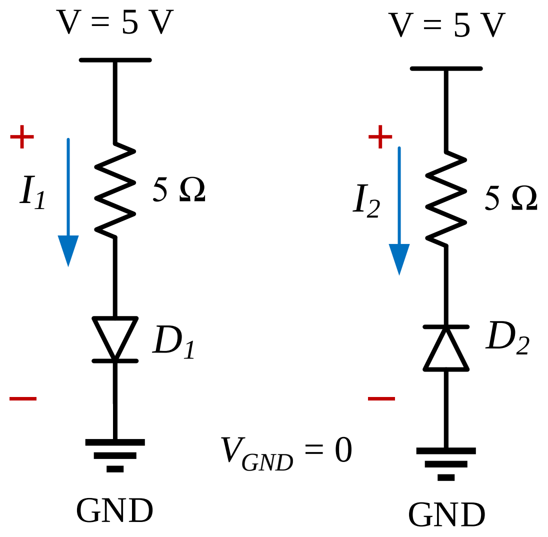
It can be easily determined that D1 is forward biased and D2 is reverse biased by observing the voltage difference between the terminals of diodes assuming the current is 0 at the instant.



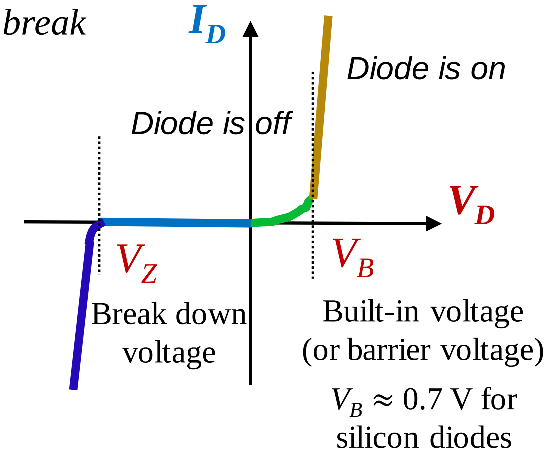
2) Considering the diodes *are silicon-based diodes that have a barrier voltage of 0.7 V and break down voltage is -20 V.*

It has enough voltage to fully open the diode (D1 is ON)

$$I_1 = \frac{V - V_D}{R} = \frac{5 - 0.7}{5} = 0.86\ A$$

D2 is reverse biased and not break down (D2 is OFF)

$$I_2 = 0\text{ A}$$



Practical V-I characteristic

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Topic 8-1-3: How to analyse circuits consisting of diodes – More complicated case

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8-1-3 CIRCUIT ANALYSIS INVOLVING DIODES

Case 2: when one cannot determine the current direction directly (this usually happens when more than 1 diode is involved or the circuit is more complicated).

In this case, we need to make assumptions and validate which assumption is correct.

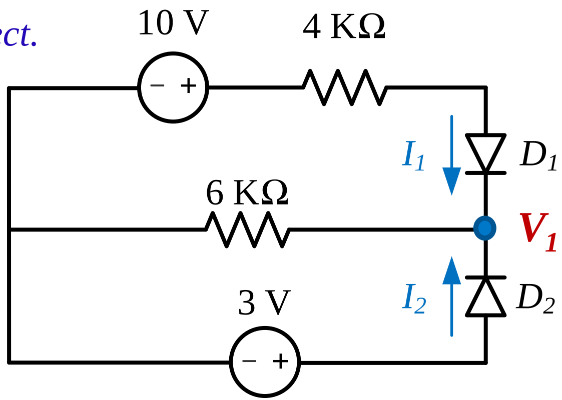
Step 1: Assume a state for each diode, either ON (short circuit) or OFF (open circuit). For a circuit having *n* diodes, there are 2^n possible combinations of diode states.

Assumption 1: *D1 is ON, D2 is ON.*

Assumption 2: *D1 is ON, D2 is OFF.*

Assumption 3: *D1 is OFF, D2 is ON.*

Assumption 4: *D1 is OFF, D2 is OFF.*



In this example, we are not able to find out whether the two diodes are ON or OFF, **because we don't know the value of V1.**

Step 2: For each assumption, analyse the circuit to determine the current through the ON-state diodes and voltage across OFF-state diodes.

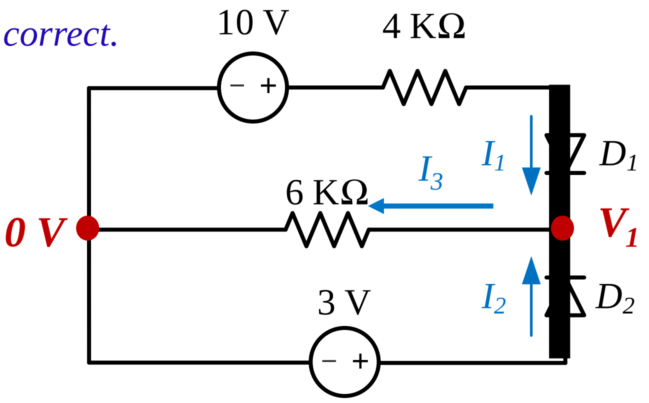
Step 3: Check to see if the result is consistent with the assumed state for each diode. Current must flow in the forward direction for diodes assumed to be ON. Furthermore, the voltage across the diodes assumed to be OFF must be reverse biased.

Step 4: If the results are consistent with the assumed states, the analysis is finished. Otherwise, return to step 1 and choose a different combination of diode states.

8-1-3 CIRCUIT ANALYSIS INVOLVING DIODES

Case 2: when one cannot determine the current direction directly (this usually happens when more than 1 diode is involved or the circuit is more complicated).

In this case, we need to make assumptions and validate which assumption is correct.



Equivalent circuit

Step 1: Assume a state for each diode.

Assumption 1: *D1 is ON, D2 is ON.*

Step 2: Analyse the circuit to determine the current through the ON-state diodes and voltage across OFF-state diodes.

Directly, we know V_1 = 3 V because the node is connected to the anode of a 3V source.

$$I_1 = \frac{10-3}{4K} = \frac{7}{4}\ mA \qquad KCL: \quad I_1 + I_2 = I_3$$

$$I_3 = \frac{3-0}{6K} = \frac{1}{2}\ mA \qquad I_2 = I_3 - I_1 = -\frac{5}{4}\ mA$$

Step 3: Check to see if the result is consistent with the assumed state for each diode. Current must flow in the forward direction for diodes assumed to be ON.

*I_2 is negative, meaning the current flow through D2 is in reverse direction, which is against the assumption -- **Wrong assumption.***

8-1-3 CIRCUIT ANALYSIS INVOLVING DIODES

Case 2: when one cannot determine the current direction directly (this usually happens when more than 1 diode is involved or the circuit is more complicated).

In this case, we need to make assumptions and validate which assumption is correct.

Step 1: Assume a state for each diode.

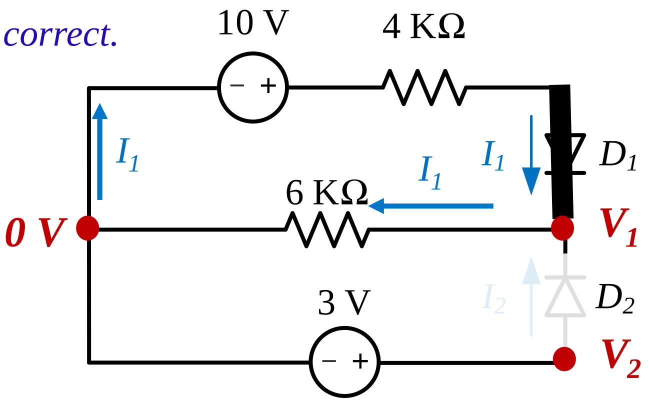
Assumption 2: *D1 is ON, D2 is OFF.*

Step 2: Analyse the circuit to determine the current through the ON-state diodes and voltage across OFF-state diodes.

Directly, we know V_2 = 3 V because the node is connected to the anode of a 3V source.

There is only one closed mesh for current to flow:

$$I_1 = \frac{10}{4K + 6K} = 1\ mA \qquad V_1 = 6\ V$$



Equivalent circuit

Step 3: Check to see if the result is consistent with the assumed state for each diode. Current must flow in the forward direction for diodes assumed to be ON. Voltage across the diodes assumed to be OFF must be reverse biased.

I_1 is positive,

$V_1 > V_2$, reverse biased -- ***Correct assumption.***

8-1-3 CIRCUIT ANALYSIS INVOLVING DIODES

Case 2: when one cannot determine the current direction directly (this usually happens when more than 1 diode is involved or the circuit is more complicated).

In this case, we need to make assumptions and validate which assumption is correct.

Step 1: Assume a state for each diode.

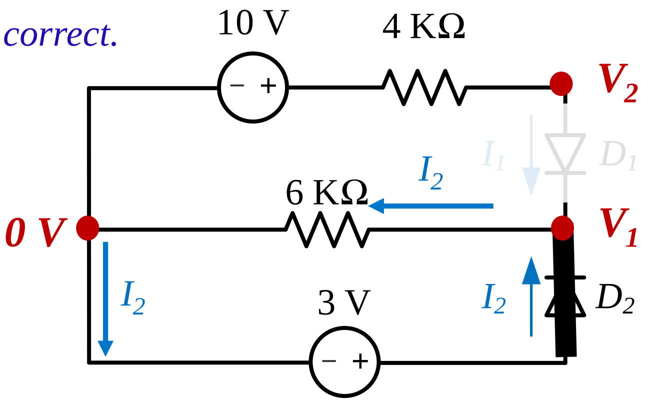
Assumption 3: *D1 is OFF, D2 is ON.*

Step 2: Analyse the circuit to determine the current through the ON-state diodes and voltage across OFF-state diodes.

Directly, we know $V_2 = 10\ V$ $\quad V_1 = 3\ V$

There is only one closed mesh for current to flow:

$$I_2 = \frac{3}{6K} = 0.5\ mA$$



Equivalent circuit

Step 3: Check to see if the result is consistent with the assumed state for each diode. Current must flow in the forward direction for diodes assumed to be ON. Voltage across the diodes assumed to be OFF must be reverse biased.

$V_1 < V_2$, *forward biased --* ***Wrong assumption.***

8-1-3 CIRCUIT ANALYSIS INVOLVING DIODES

Case 2: when one cannot determine the current direction directly (this usually happens when more than 1 diode is involved or the circuit is more complicated).

In this case, we need to make assumptions and validate which assumption is correct.

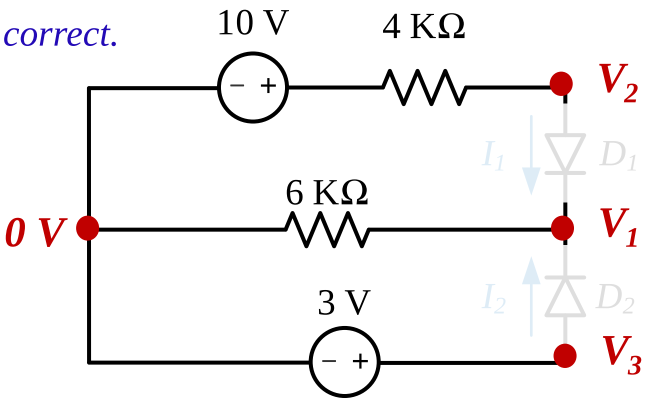
Step 1: Assume a state for each diode.

***Assumption 4**: D1 is OFF, D2 is OFF.*

Step 2: Analyse the circuit to determine the current through the ON-state diodes and voltage across OFF-state diodes.

There is no current in this circuit

$V_1 = 0\ V$ $V_3 = 3\ V$ $V_2 = 10\ V$



Equivalent circuit

Step 3: Check to see if the result is consistent with the assumed state for each diode. Current must flow in the forward direction for diodes assumed to be ON. Voltage across the diodes assumed to be OFF must be reverse biased.

$V_1 < V_2$, *forward biased*

$V_1 < V_3$, *forward biased* -- ***Wrong assumption.***

8-1-3 CIRCUIT ANALYSIS INVOLVING DIODES

Case 2: when one cannot determine the current direction directly (this usually happens when more than 1 diode is involved or the circuit is more complicated).

In this case, we need to make assumptions and validate which assumption is correct.

Step 1: Assume a state for each diode, either ON (short circuit) or OFF (open circuit). For a circuit having *n* diodes, there are 2^n possible combinations of diode states.

Assumption 1: *D1 is ON, D2 is ON.*

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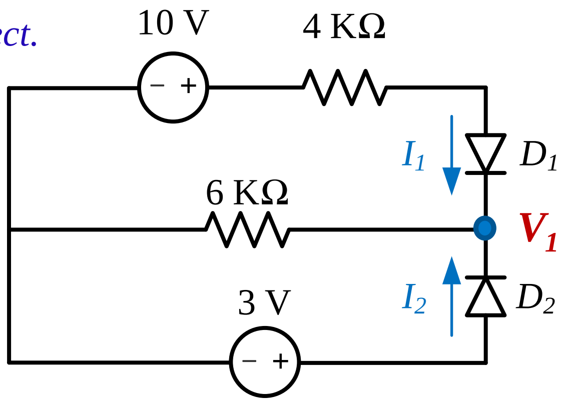

In this example, we are not able to find out whether the two diodes are ON or OFF, **because we don't know the value of V1.**

48510 LEC 8 – DIODE AND RECTIFIER

Topic 8-2-1: Half-Wave Rectifier

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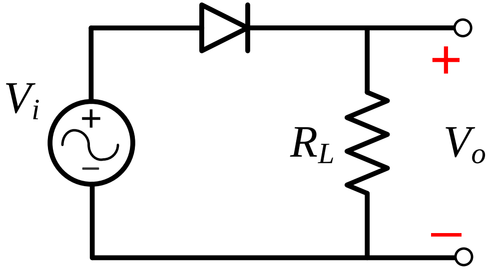
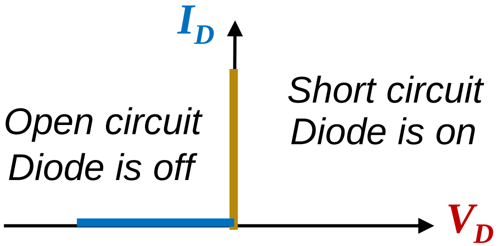
8-2-1 HALF-WAVE RECTIFIER

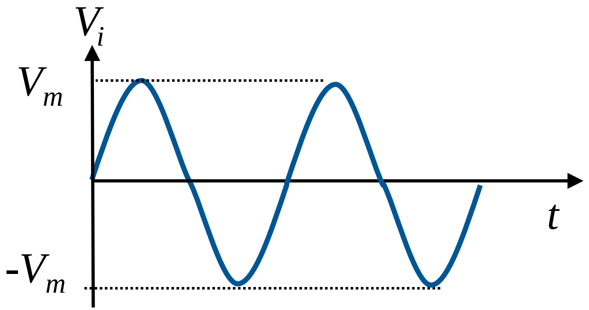
Rectifier converts **a bipolar signal (the current direction changes with time)** into a **unidirectional one (the current always flow in one direction).** This figure below shows a diode rectifier fed by a sinusoidal voltage source $V_i = V_m sin(\omega t)$.



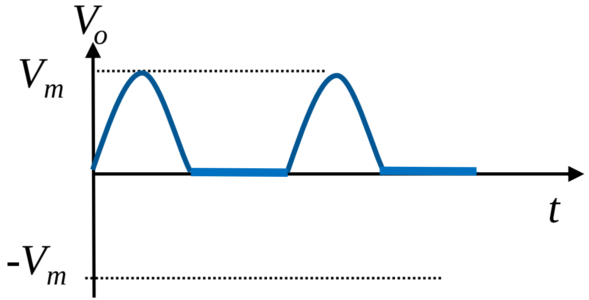
Half-wave rectifier



Ideal V-I characteristic



Voltage input



Voltage output

Assume the **diode is ideal,**

1) When $V_i > 0$, the diode is forward biased and turned ON. It can be seen as short circuit and all the voltage is applied on the load resistor, thus $V_o = V_i = V_m sin(\omega t)$.

2) When $V_i \leq 0$, the diode is reverse biased and turned OFF. It can be seen as open circuit and there is no current so the voltage on the load resistor is $V_o = 0$.

8-2-1 HALF-WAVE RECTIFIER

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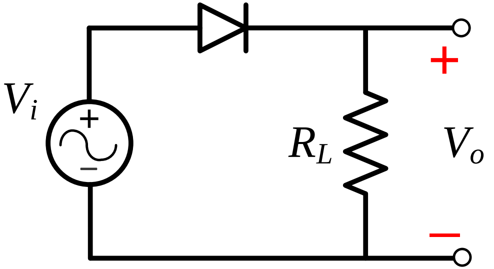
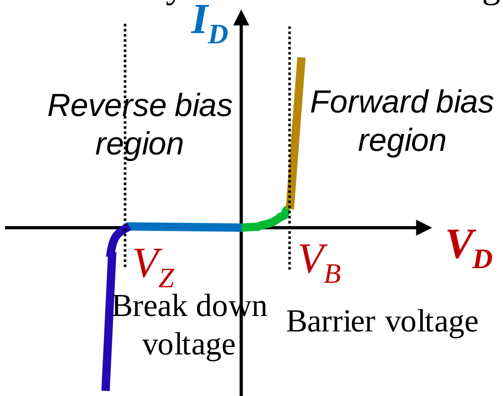
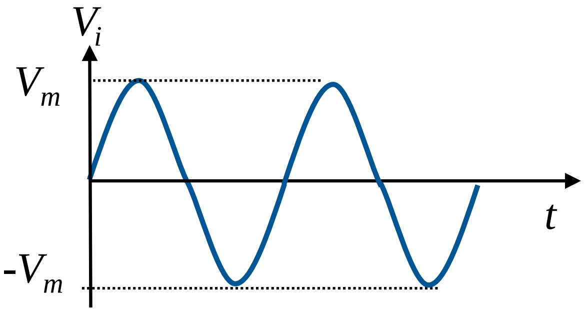


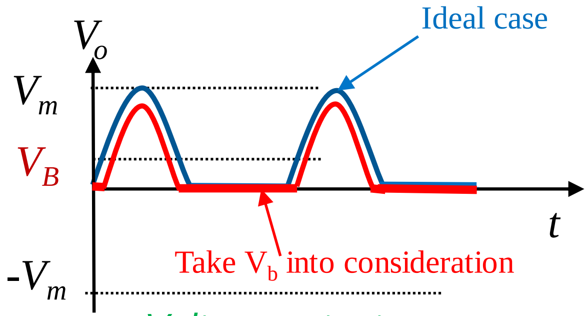
Half-wave rectifier



Practical V-I characteristic



Voltage input



Voltage output

Considering a more realistic case: **the diode has a barrier voltage of V_B.**

1) When $V_i \le V_B$, the diode is OFF. It can be seen as open circuit and there is no current so the voltage on the load resistor is $V_o = 0$.

2) When $V_i > V_B$, the diode is turned ON. The diode can be seen as a short circuit but the source needs to overcome the barrier voltage, so the voltage on the load resistor is $V_o = V_i - V_B = V_m sin(\omega t) - V_B$.

48510 LEC 8 – DIODE AND RECTIFIER

Topic 8-2-2: Half-Wave Rectifier with Smoothing Capacitor

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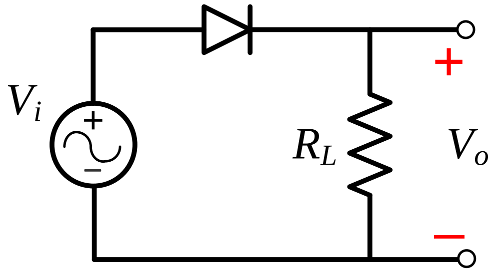
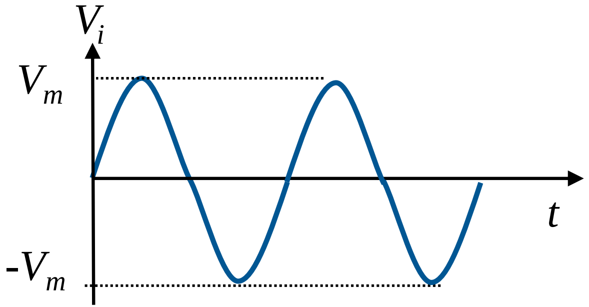
8-2-2 HALF-WAVE RECTIFIER WITH CAPACITOR

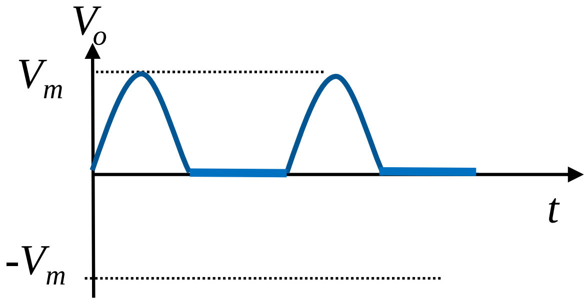
With only a diode and a resistor, the output voltage of the half-wave rectifier changes rapidly with time. For most applications, a steady voltage is requested.



Half-wave rectifier



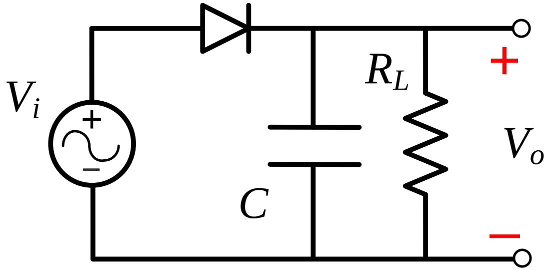
Voltage input



Voltage output

To smooth the rectifier output, we can place a large capacitor across the output terminals of the rectifier.

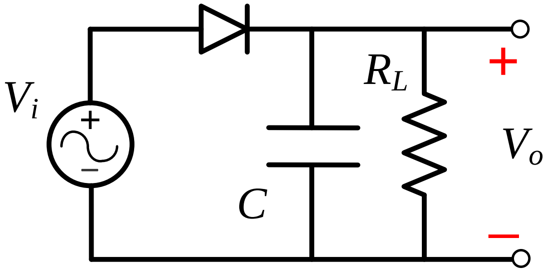
The capacitor serves as a temporality source and it will keep charging and discharging which makes the output voltage more stable.



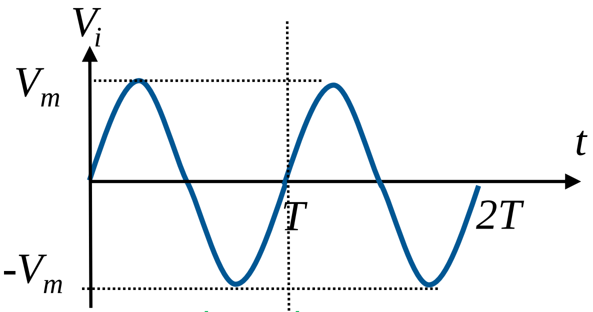
Half-wave rectifier with smoothing capacitor

8-2-2 HALF-WAVE RECTIFIER WITH CAPACITOR

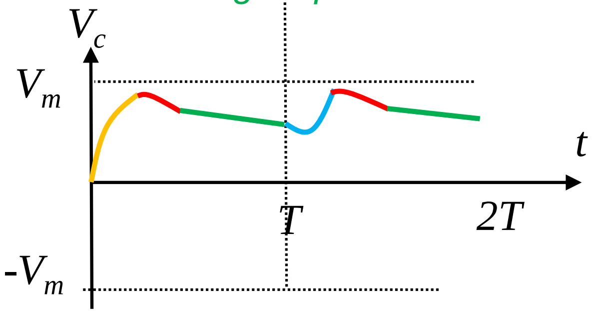
The capacitor serves as a temporality source and it will keep charging and discharging which makes the output voltage more stable.



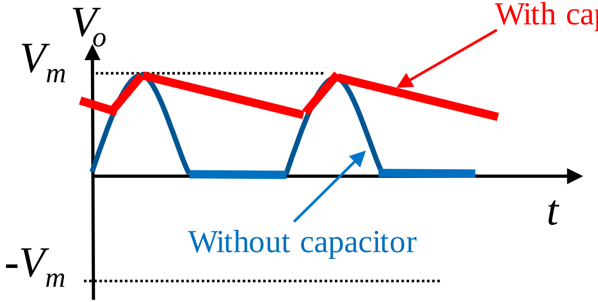
Half-wave rectifier with smoothing capacitor



Voltage input



Voltage on capacitor



Voltage output

8-2-2 HALF-WAVE RECTIFIER WITH CAPACITOR

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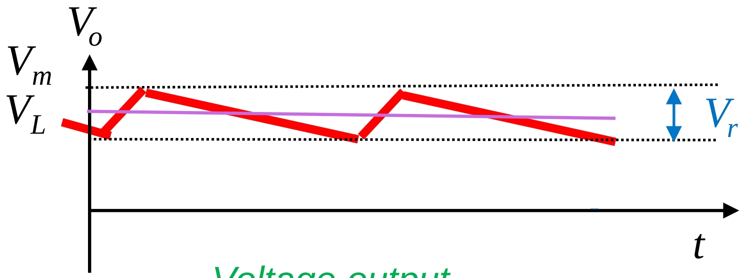
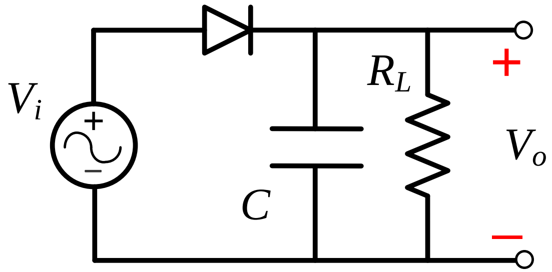


Voltage output



Half-wave rectifier with smoothing capacitor

V_m is the peak voltage;
V_r is the peak-to-peak ripple voltage;
V_L is the average load voltage: $V_L = V_m - \frac{1}{2}V_r$
I_L is the average load current: $I_L = \frac{V_L}{R_L}$
T is the time period of the input voltage.

For half-wave rectifier circuit

$$V_r = \frac{I_L T}{C} \qquad C = \frac{I_L T}{V_r}$$

The larger the capacitance,
the smaller the ripple

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Topic 8-2-1: Full-Wave Rectifier

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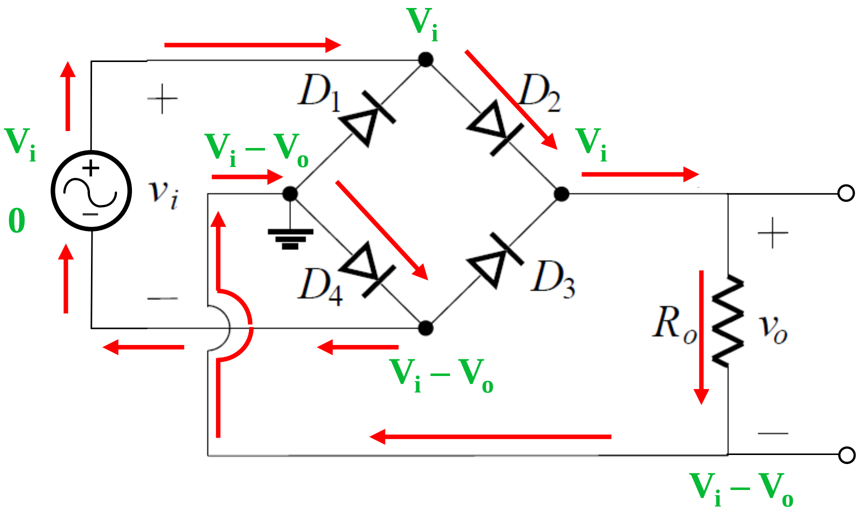
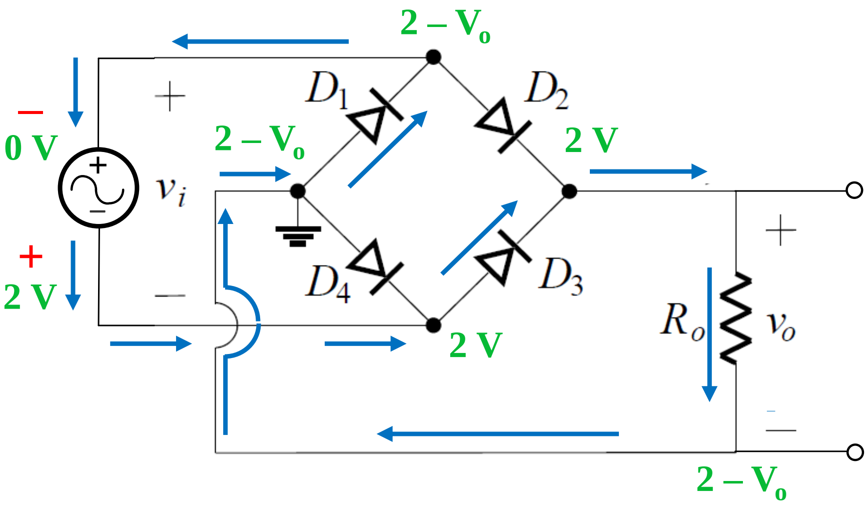
8-2-1 FULL-WAVE RECTIFIER

Full-wave rectifier utilizes both halves of the input signal – it inverts the negative halves of the waveform.

When $V_i > 0$



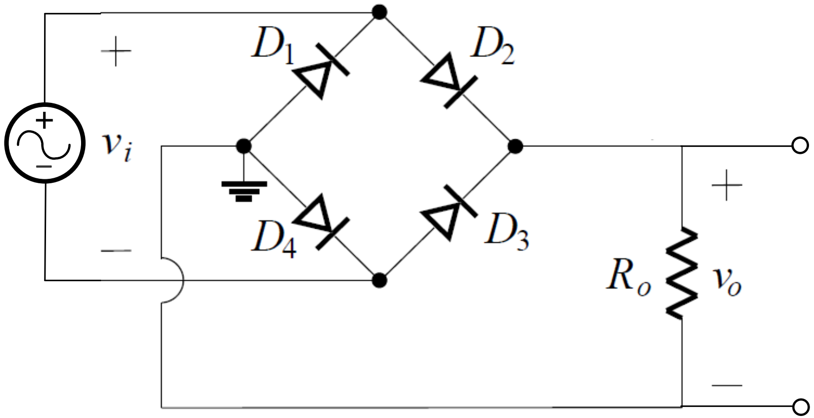
When $V_i < 0$



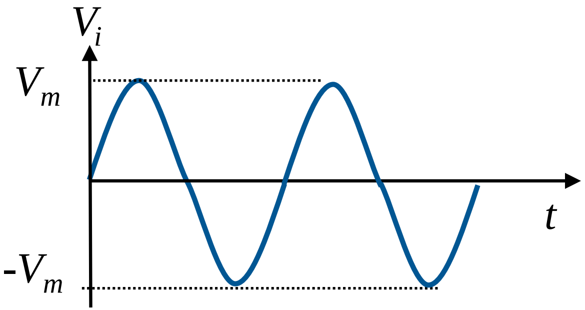
No matter the input voltage is positive or negative, the current flows through the load resistor is always in one direction and output voltage is always positive.

8-2-1 FULL-WAVE RECTIFIER

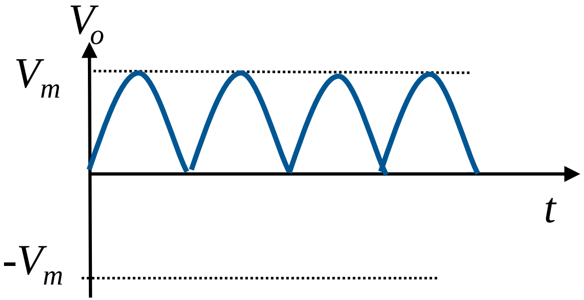
Full-wave rectifier utilizes both halves of the input signal – it inverts the negative halves of the waveform.



Full-wave rectifier



Voltage input

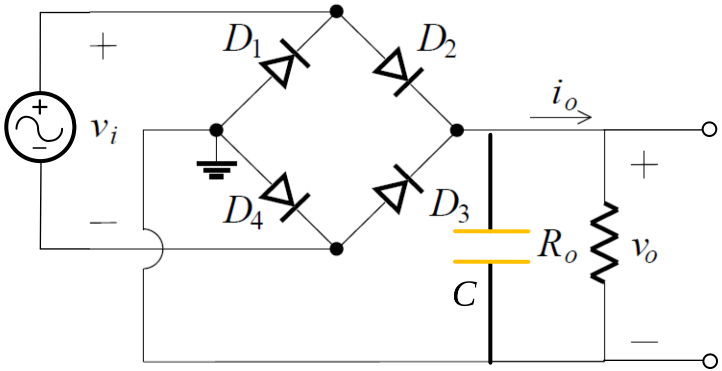


Voltage output

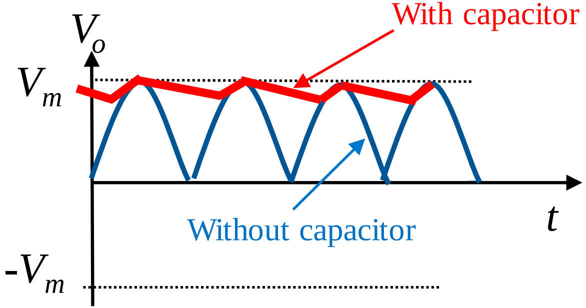
No matter the input voltage is positive or negative, the current flows through the load resistor is always in one direction and output voltage is always positive.

8-2-1 FULL-WAVE RECTIFIER WITH CAPACITOR

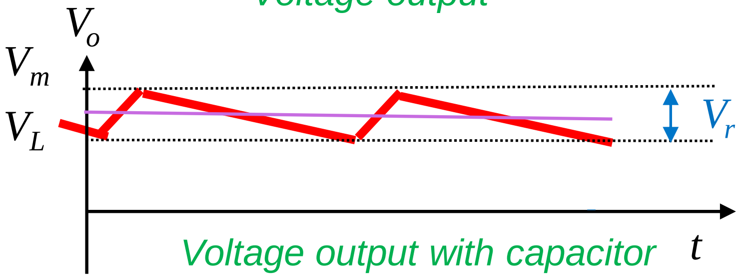
Similar to the half-wave rectifier, **one could add a capacitor to smooth the output.**



Full-wave rectifier with smoothing capacitor



Voltage output



Voltage output with capacitor

V_m is the peak voltage;

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V_L is the average load voltage: $V_L = V_m - \frac{1}{2}V_r$

I_L is the average load current: $I_L = \frac{V_L}{R_L}$

T is the time period of the input voltage.

For full-wave rectifier circuit

$$V_r = \frac{I_L T}{2C} \qquad C = \frac{I_L T}{2V_r}$$

The ripple is smaller compared to the half-wave rectifier