XMUT204 Electronic Design
Note 2c: Diode Applications

1. Rectifier Circuits

We will now look at some applications of diode circuits, particularly in construction of power supplies where diodes are used for voltage rectification (e.g. AC to DC conversion) and voltage regulation (e.g. maintaining constant and stable energy supply).

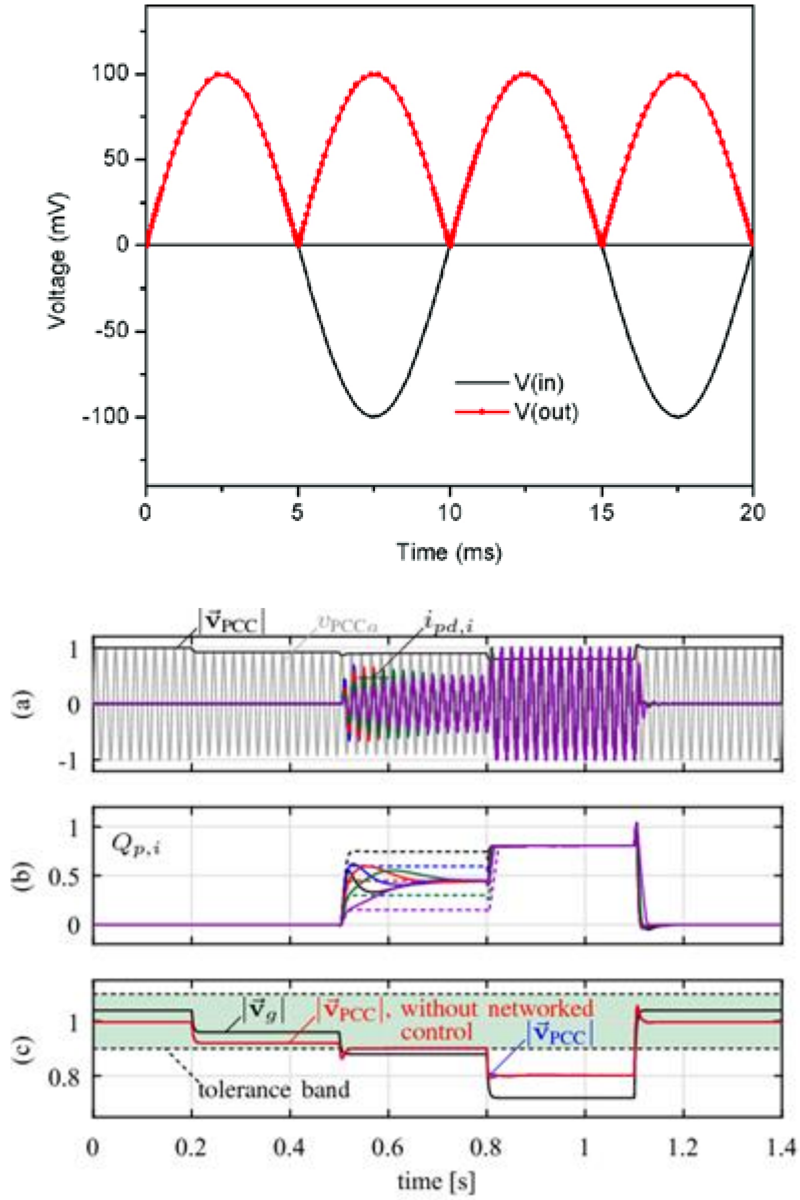


Figure 1: Voltage rectification (above) and voltage regulation (bottom)

In the diagram given above, a voltage rectification process is about converting an AC signal to DC signal whereas a voltage regulation is about providing the circuit with constant and stable voltage amid disturbances and change of condition of the supply.

The following diagram show parts that make up a power supply circuit. In this circuit diode rectifier plays the key role of rectification part of the power supply and the voltage regulator that typically consists of diode and transistor acting as regulating part.

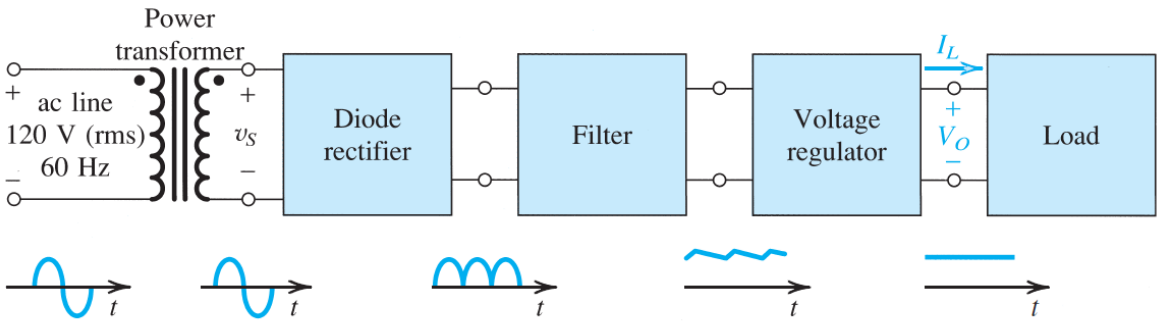


Figure 2: Block diagram of a typical power supply circuit

One important application of diodes is in rectification i.e. the process of converting an AC voltage (typically sinusoidal) into a DC voltage of one polarity. A rectifier can be classified as a non-linear device that modifies an input voltage such that the output is greater than or less than a threshold value. Depending on its circuit arrangement, this can be classified further as half-wave or full-wave rectifiers.

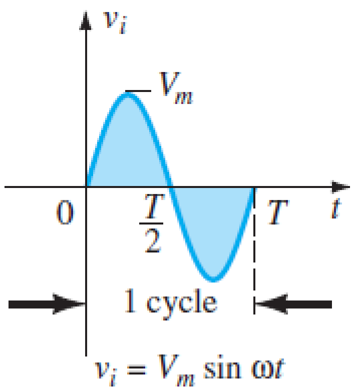


Figure 3: Input signal for diode rectification cases

2. Half-wave Rectifiers

We will look into the analysis of the half-wave rectifier circuit using ideal diode model and ideal diode + voltage source model in this section.

2.1. The Ideal Diode Model

For the analysis using the ideal diode model, a sinusoidal input signal (V_i) is used as input signal to diode (i.e. the diode is treated as an ideal diode) and on the other end the output signal (V_o) is taken across load resistor.

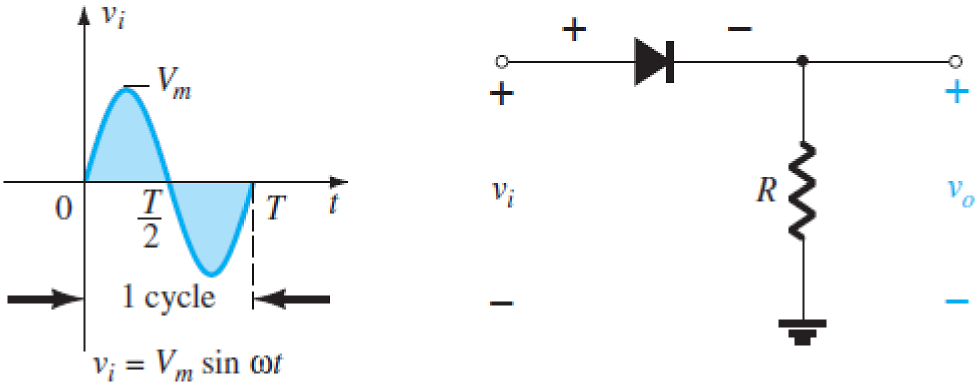


Figure 4: Ideal half-wave diode model rectification circuit

During time t = 0 to $t = T/2$ (positive half-cycle), the diode is forward biased, so we can model as: $V_o = V_i$.

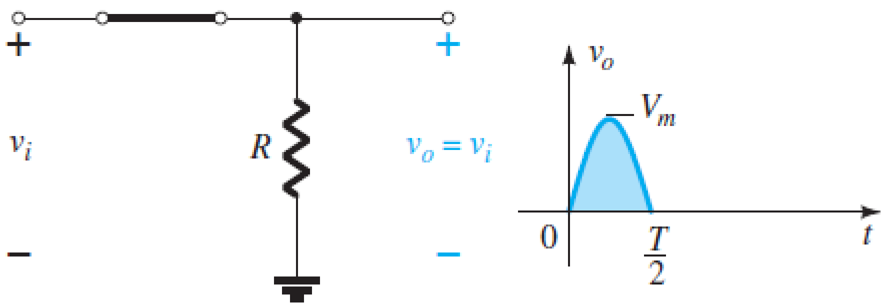


Figure 5: Positive cycle of forward biased half-wave diode rectification (ideal diode model)

We have no voltage drop across diode as input voltage V_i will appear over R as V_o. This results in a positive half cycle that appears unchanged at the output.

On the other hand, during the time $t = T/2$ to $t = T$ (negative half cycle) the diode is negatively biased and we can model diode as open circuit: V_o = 0 V.

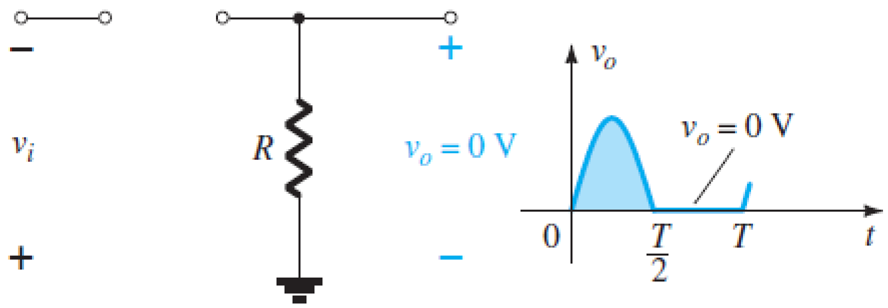


Figure 6: Negative cycle of forward biased half-wave diode rectification (ideal diode model)

The input voltage will then appear as $-V_d$ and no current will flow, so that the output voltage V_o = over the complete half cycle. When negative half cycles have been removed, as a result the signal now has an average DC value of $V_{dc} = (1/\pi)V_m$

$$V_{dc(ave)} = \frac{2}{2\pi}\int_0^{\pi} V_m \sin\theta \, d\theta$$

$$= \frac{V_m}{\pi}[-\cos\theta]_0^{\pi}$$

$$= \frac{2V_m}{\pi}$$

$$= 0.636\, V_m \text{ (for one full cycle)}$$

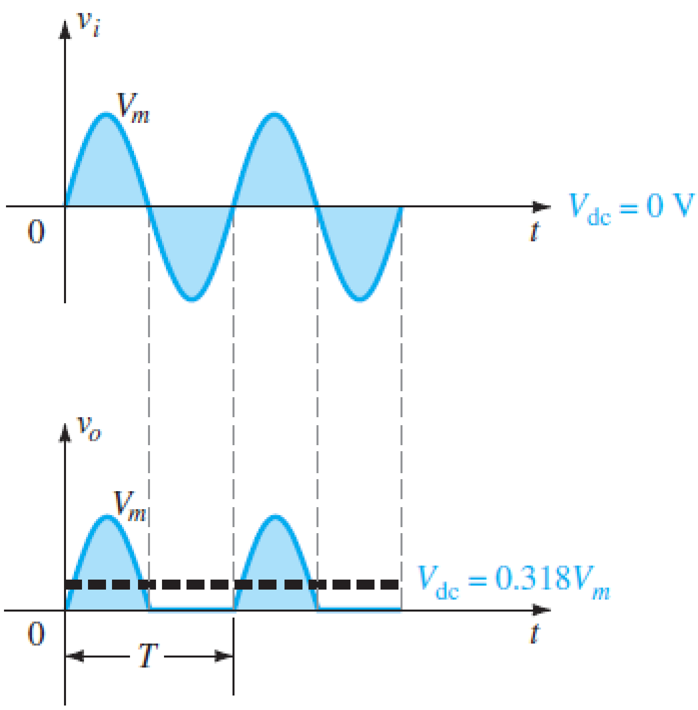


Figure 7: Average value of forward biased half-wave diode rectification

2.2. Half-wave Rectifier - The Ideal Diode Model + Voltage Source

We can improve the model of the system response by taking into account the approximate voltage drop over the diode. For a Silicon diode the input signal must be at least 0.7 V before the diode will turn ON – for the V_o < 0.7 V the diode will in open circuit state.

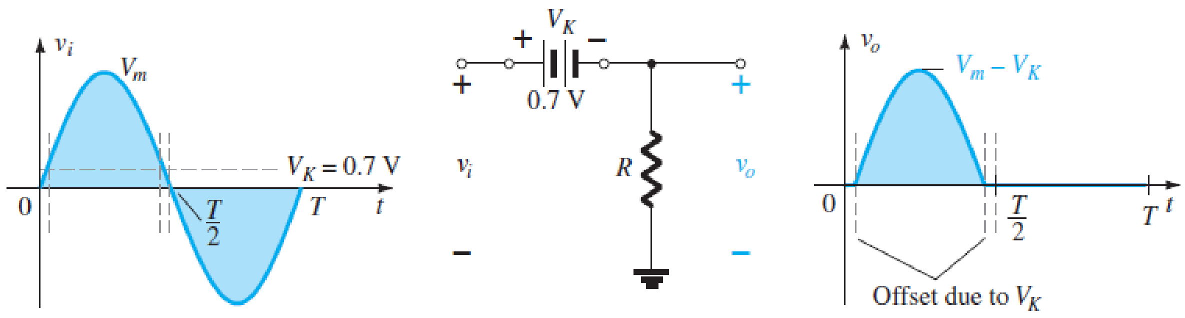


Figure 8: Half-wave rectifier circuit and waveforms

The DC voltage level will now reduce to:

$$V_{dc} = \left(\frac{1}{\pi}\right)(V_m - V_f)$$

A more realistic representation of half-wave rectified sine wave is by considering the diode as an ideal diode plus voltage source. This model will look like the signals observed in the output of a real-life half-wave rectifier circuit.

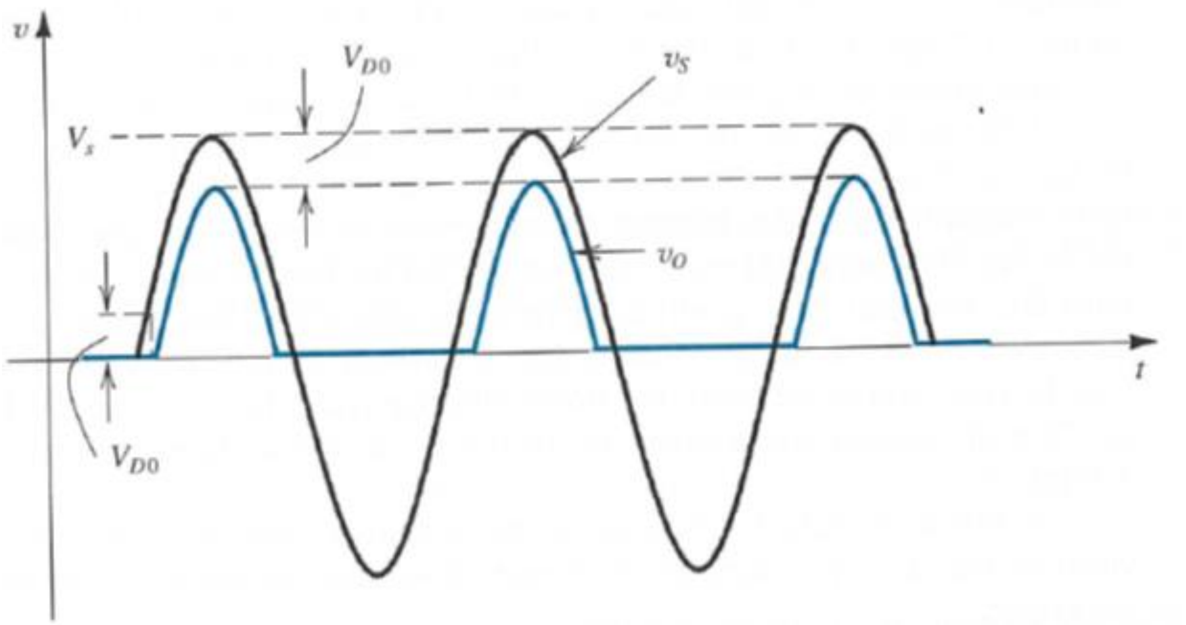
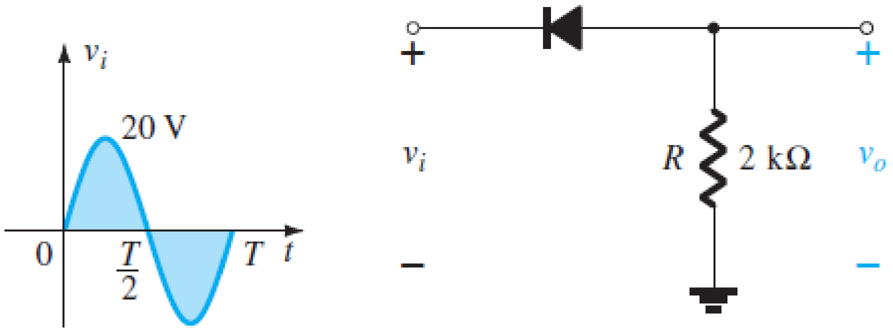


Figure 9: Output and input signals of half-wave diode rectifier with the ideal diode model + voltage source model

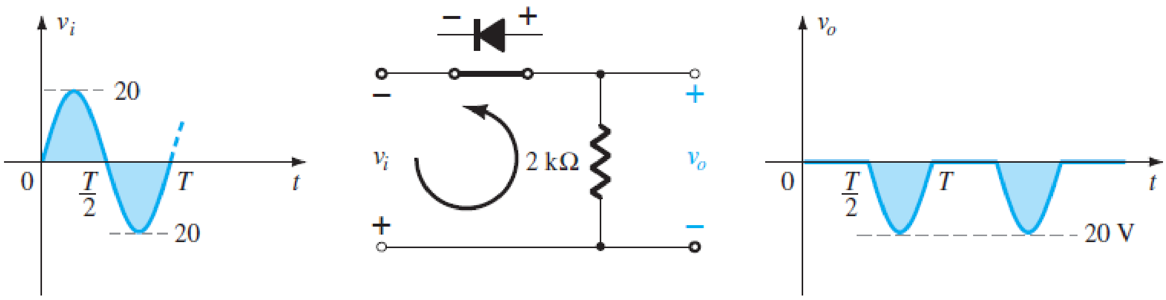
Example for Tutorial 1 – Half-Wave Rectifier

We can sketch the output voltage (V_o) and determine the DC level of the output for the circuit below using both an ideal diode as well as an ideal diode plus voltage source model. So, consider first an input voltage of 20 V and then 200 V. [10 marks]



Answer

During positive half cycle of input voltage (V_i), the diode will be reverse biased i.e. no current will flow and zero volts will appear over the load resistor. On the other hand, during negative half cycle, the diode is forward biased and current will flow i.e. only negative half cycle then permitted.



Thus, at input voltage at 20 V, for an ideal diode model, the output voltage is found from the following equation:

$$V_{dc} = -\left(\frac{1}{\pi}\right)V_{in} = -0.318(20) = -6.36\text{ V}$$

For ideal diode plus voltage source (V_d = 0.7 V for Si), the output voltage is:

$$V_{dc} = -\left(\frac{1}{\pi}\right)(V_{in} - V_d) = (0.318)(20 - 0.7) = -6.14\text{ V}$$

Note that the drop in dc level ~ 3.5%, this could be significant depending on the stated measurement error.

For V_i = 200 V, output voltage, V_o = -63.6 V with ideal diode model and it is V_o = -63.28 V for ideal diode plus voltage drop model.

In the end, for most application, this error is small enough to ignore!

2.3. Diode Device Parameters for Rectifiers

Two important device parameters must be taken into account when selecting diodes for rectifiers:

a. The diode current carrying capacity i.e. the maximum current that can flow through the diode in forward bias.

b. The peak inverse voltage (PIV) is the maximum voltage that can be put on the diode in reverse bias before it will go into breakdown.

For a half cycle rectifier, we need $PIV > V_m$ where V_m is the peak input voltage.

Relevant circuit parameters of the rectifier circuits that typically used in the circuit analysis are circuit currents: I_m, I_{dc}, and I_{rms}, input (P_{in}) and output (P_{out}) powers, output voltage (V_{out}), and efficiency of the rectifier circuit (η).

Example for Tutorial 2 – Parameters of Rectifier Device and Circuit

A diode having internal resistance R_d = 10 Ω is used for half-wave rectifier circuit. If the applied voltage is $v = 50\sin(\omega t)$ and load resistance R_L = 10 Ω. Find the following:

a.	PIV of the diode.	[2 marks]
b.	Currents I_m, I_{dc}, and I_{rms}.	[6 marks]
c.	AC power input and DC power output.	[4 marks]
d.	DC output voltage.	[2 marks]
e.	Efficiency of rectification.	[2 marks]

Answer

a. The PIV of the diode, $PIV > V_m$. As the maximum voltage, V_m = 50 V, then PIV > 50 V.

b. Since maximum voltage, V_m = 50 V, the maximum current of half-wave rectifier circuit is:

$$I_m = \frac{v_m}{R_d + R_L} = \frac{50}{10 + 1000} = 49.5 \text{ mA}$$

The DC current is:

$$I_{dc} = I_{avg} = \frac{I_m}{\pi} = \frac{49.5}{\pi} = 15.76 \text{ mA}$$

The RMS current is:

$$I_{rms} = \frac{I_m}{2} = \frac{49.5}{2} = 24.75 \text{ mA}$$

c. The AC power of half-wave rectifier circuit is:

$$P_{ac} = (I_{rms})^2(R_d + R_L) = (24.75 \times 10^{-3})^2 \times (10 + 1000) = 0.618 \text{ W}$$

The DC power is:

$$P_{dc} = (I_{dc})^2(R_L) = (15.76 \times 10^{-3})^2 \times (1000) = 0.248\text{ W}$$

d. The DC output voltage of half-wave rectifier circuit is:

$$V_{DC} = I_{dc} \times R_L = (15.76 \times 10^{-3}) \times 1000 = 15.76\text{ V}$$

e. The efficiency (η) of half-wave rectifier circuit is:

$$\eta = \frac{P_{dc}}{P_{ac}} = \left(\frac{0.248}{0.618}\right) \times 100 = 40.12$$

3. Full-wave Rectification

DC level obtained from a sinusoidal input voltage and a half-wave rectifier can be doubled by using a full-wave rectifier. This can be performed using two methods:

a. Centre-tapped transformer + two diodes

b. Bridge rectifier using four diodes - typically done using a diode bridge circuit consisting of four diodes i.e. made so that two diodes contact on positive half cycle and the other two conduct on negative half cycle.

3.1. A Centre-Tapped Transformer Rectifier

A Centre Tapped (CT) transformer works in more or less the same way as a conventional transformer. The difference lies in just the fact that its secondary winding is divided into two parts, so two individual voltages can be acquired across the two-line ends.

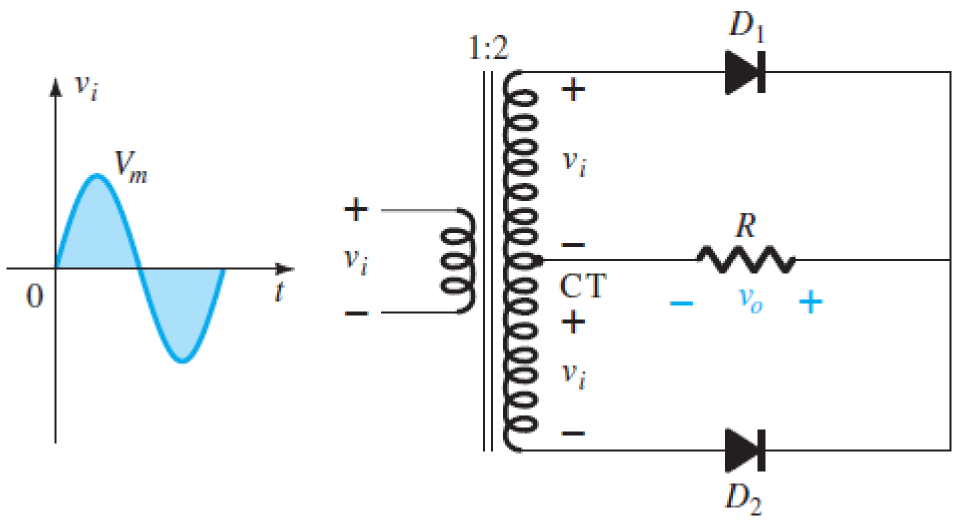


Figure 10: Centre-tap (CT) full-wave diode rectifier circuit

The internal structure of the CT transformer is the same as the conventional transformer. When an alternating current is supplied to the primary winding of the transformer, it creates a magnetic flux in the core.

In the secondary winding, an alternating magnetic flux is also induced in the winding as the flux flows through the ferromagnetic iron core and changes its direction with every cycle of the alternating current. In this way, an alternating current also flows through the two halves of the secondary winding of the transformer and flows to the external circuit.

The primary difference between conventional and CT transformers is that a former provides you with only one voltage, for example, say 240 V. But, the later will provide you with two voltages each of 240/2 i.e. 120 V, so that we can drive two independent circuits.

3.1.1. During Positive Half Cycle of Input Voltage

During this period, the top diode is in the forward bias arrangement and the bottom diode is in reverse bias. As a result, the current flows through resistor as indicated i.e. $V_o = V_i$ and $I_o = I_i$.

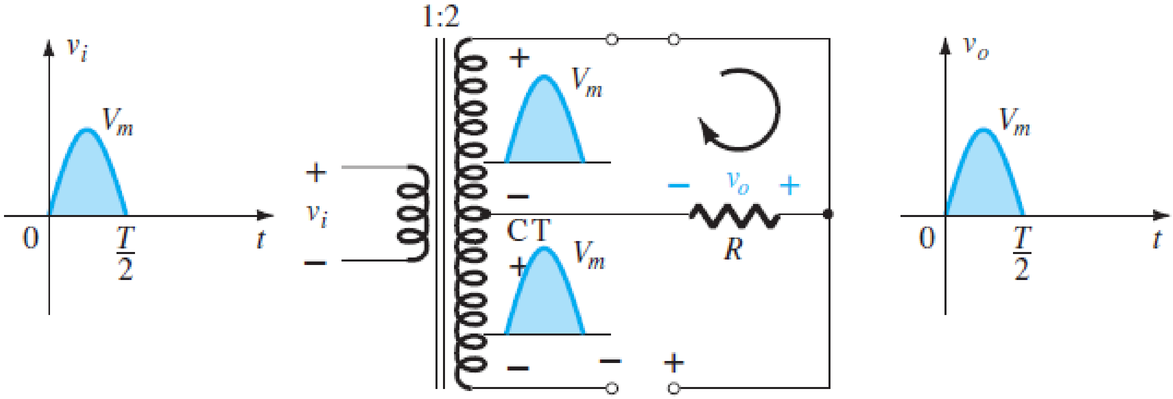


Figure 11: Positive cycle of CT full-wave diode rectification

3.1.2. During Negative Half Cycle of Input Voltage

In this period-of-time, the top diode is in reverse bias and the bottom diode is in forward bias. The current flows through resistor as indicated i.e. the same direction as in previous case. In the end, the negative input half-cycle appears as a positive output half-cycle.

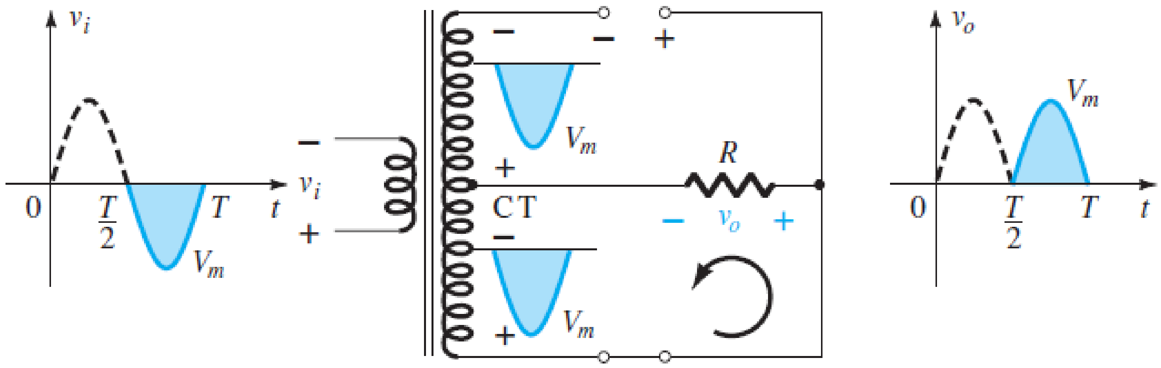


Figure 12: Negative cycle of CT full-wave diode rectification

3.2. A Diode Bridge Network

In this type of rectifier, the circuit consists of four diodes i.e. two of the four diodes will conduct on any half cycle of the input voltage.

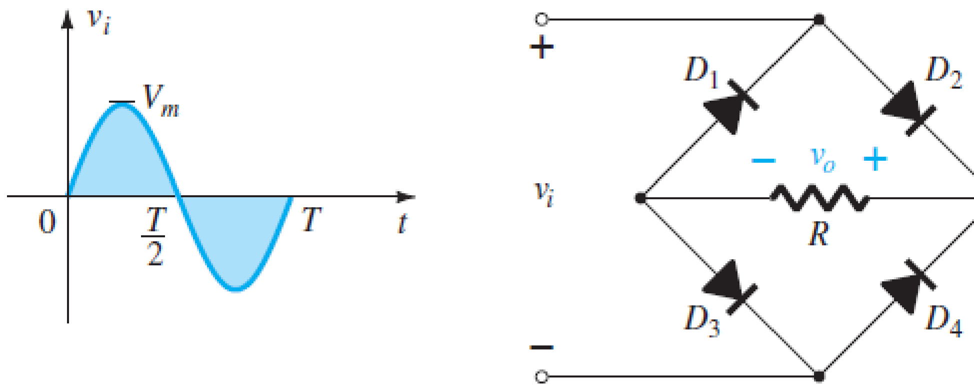


Figure 13: Full-wave bridge diode rectifier circuit

3.2.1. Diode Bridge on "+" Half Cycle

During period $t = 0$ to $t = T/2$, the diodes D_2 and D_3 are on and the output voltage can be taken over the resistor with polarity as shown below.

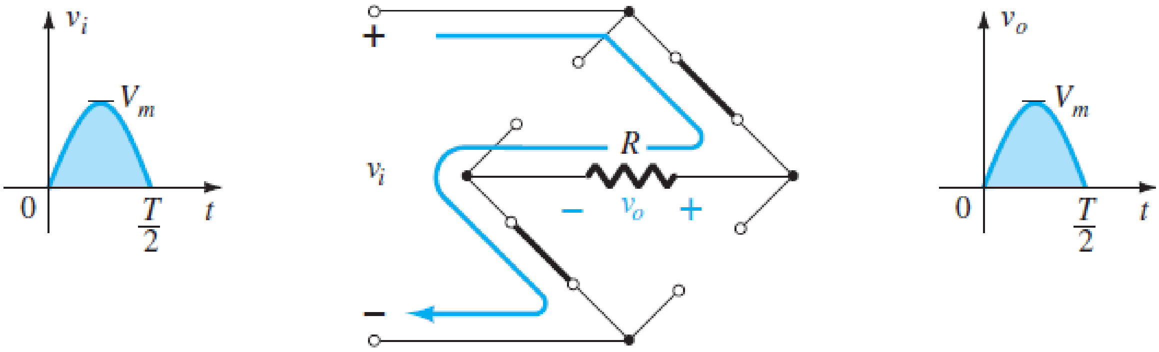


Figure 14: Positive cycle of full-wave bridge diode rectification

3.2.2. Diode Bridge on "-" Half Cycle – t from $T/2$ to T

In this particular period, both of the diodes D_1 and D_4 are now forward biased i.e. current will flow and the voltage across R will have the same polarity as in first half cycle.

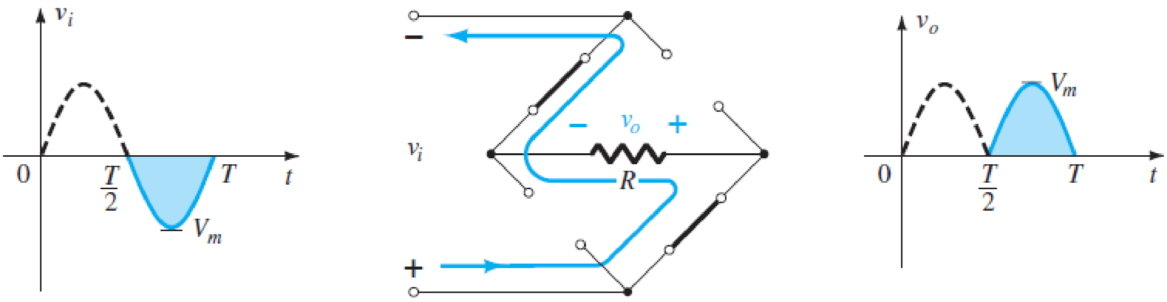


Figure 15: Negative cycle of full-wave bridge diode rectification

In each case (e.g. whether + and – half cycles), the polarity across the resistor is then the same i.e. converted to the same polarity output voltage.

For the full-wave bridge diode rectifier, the DC level of the signal has now been doubled from that of the half-wave diode rectifier.

For an ideal diode:

$$V_{dc} = \left(\frac{2}{\pi}\right) V_m$$

Or, when using the ideal diode + voltage source model:

$$V_{dc} = \left(\frac{2}{\pi}\right) (V_m - 2V_d)$$

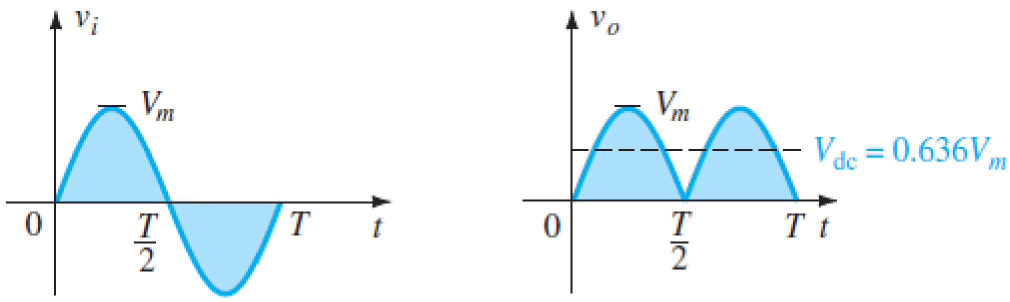


Figure 16: Average values of full-wave bridge diode rectification

For Silicon diodes rather than an ideal diode, then we might see further 0.7 V voltage drop across the diode.

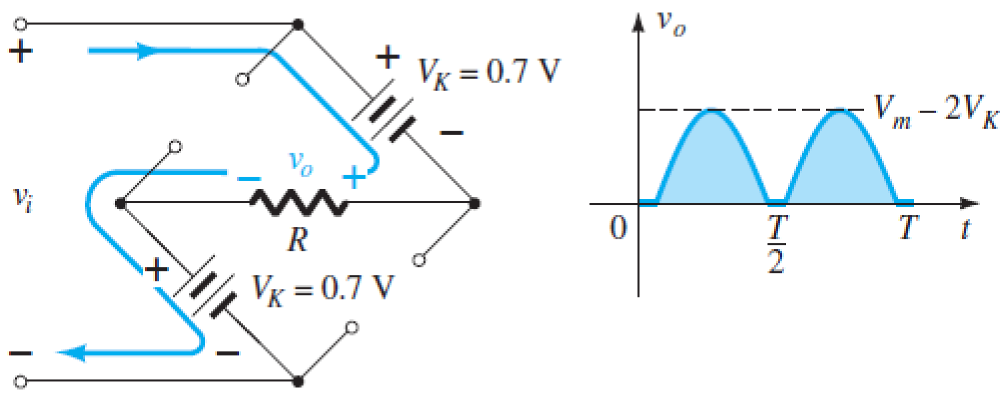
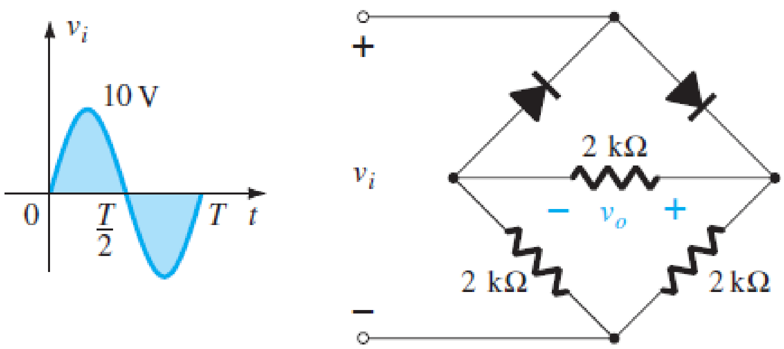


Figure 17: Positive cycle of full-wave bridge diode rectification + diode voltage drop model

Example for Tutorial 3 – Full-Wave Rectifier

Determine the output waveform and calculate the output DC voltage for the rectifier circuit as shown below i.e. a full bridge diode rectifier with lower end pairs of the bridge are substituted with resistors. [12 marks]



Answer

For given bridge diode rectifier circuit, output voltage is:

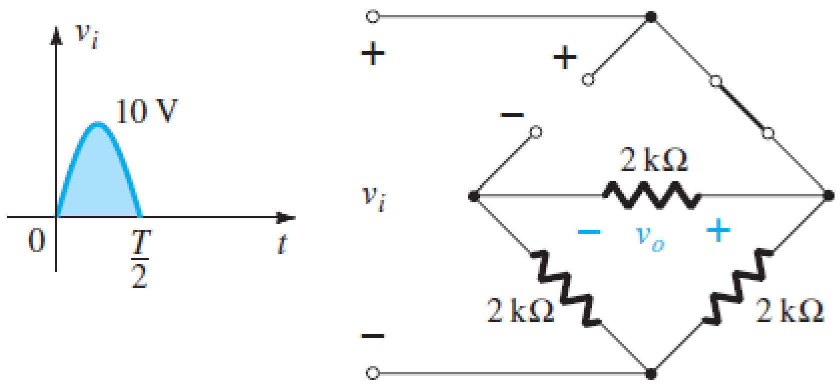
$$v_o = \frac{1}{2} v_i$$

Or

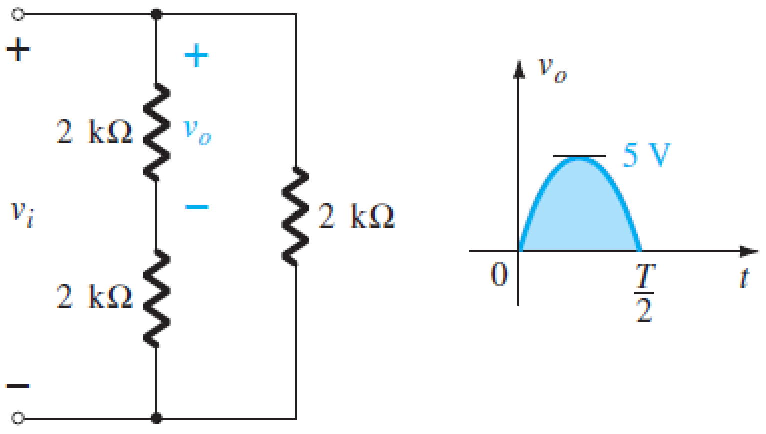
$$V_o(\max) = \frac{1}{2} V_i(\max) = \frac{1}{2}(10) = 5 \text{ V}$$

DC level of the circuit is calculated to the following:

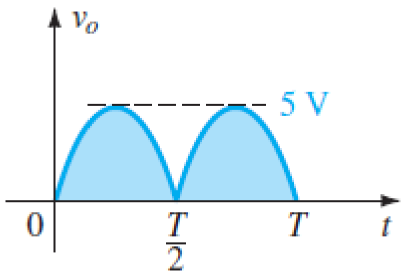
$$V_{dc} = \left(\frac{2}{\pi}\right) V_o = 0.636(5) = 3.18 \text{ V}$$



The redrawn circuit is as given in the figure below.



PIV is determined from the figure below that is equal to the maximum voltage across R, which is 5 V.



4. Ripples in Rectifier Circuits

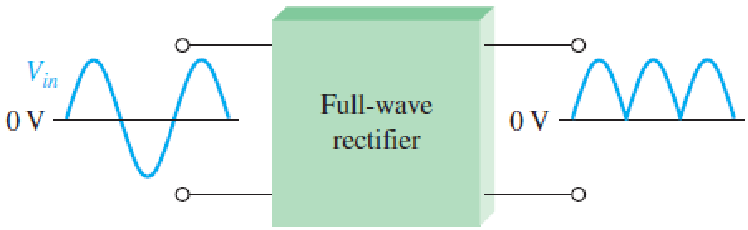
A power supply filter ideally eliminates the fluctuations in the output voltage of a half-wave or full-wave rectifier and produces a constant-level dc voltage. Filtering is necessary because electronic circuits require a constant source of dc voltage and current to provide power and biasing for proper operation.

Filters are implemented with capacitors, as you will see in this section. Voltage regulation in power supplies is usually done with integrated circuit voltage regulators. A voltage regulator prevents changes in the filtered dc voltage due to variations in input voltage or load.

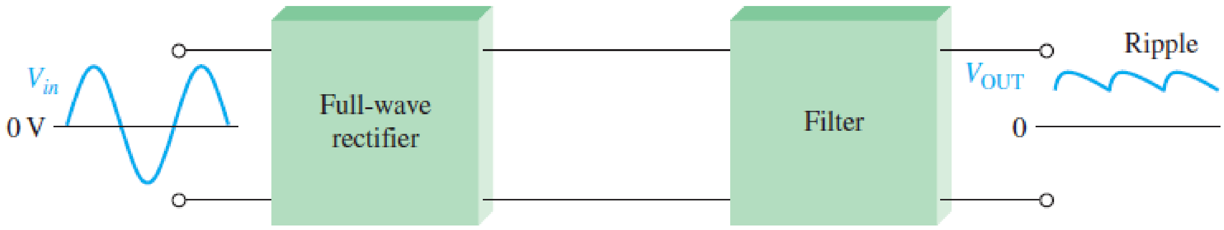
4.1. Filter in Power Supply

In most power supply applications, the standard 50 Hz ac power line voltage must be converted to an approximately constant dc voltage. The 50 Hz pulsating dc output of a half-wave rectifier or the 100 Hz pulsating output of a full-wave rectifier must be filtered to reduce the large voltage variations.

The figure given below illustrates the filtering concept showing a nearly smooth dc output voltage from the filter. The small amount of fluctuation in the filter output voltage is called ripple.



(a) Rectifier without a filter



(b) Rectifier with a filter (output ripple is exaggerated)

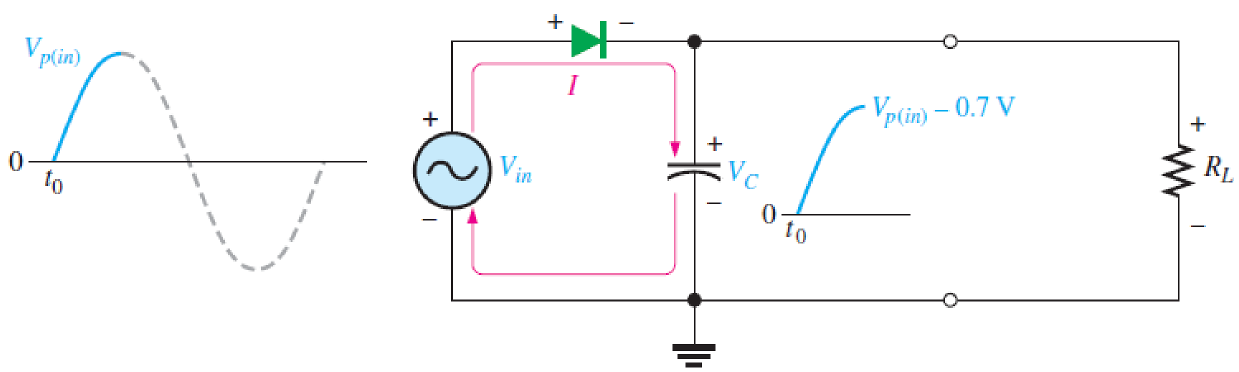
Figure 18: Full-wave rectifier circuits (i.e. without and with filter circuit)

4.2. Capacitor-Input Filter

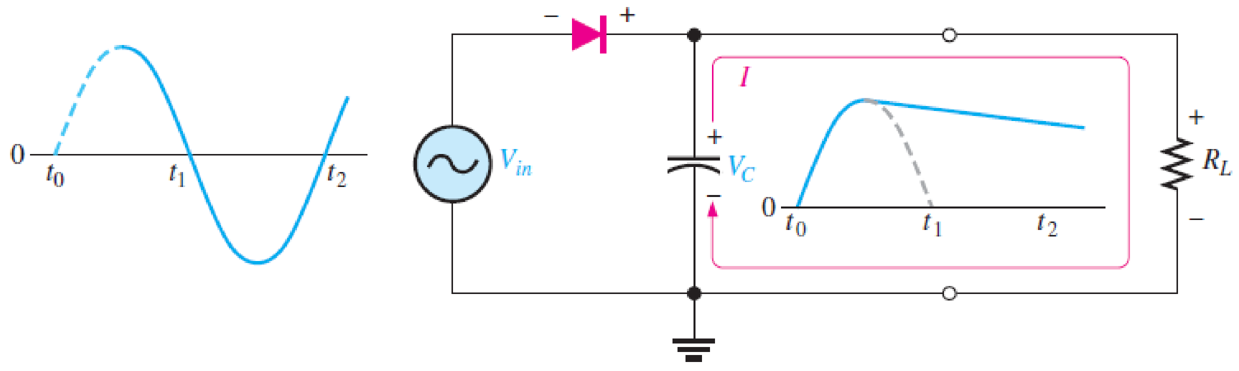
A half-wave rectifier with a capacitor-input filter is shown in the figure given below. The filter is simply a capacitor connected from the rectifier output to ground. R_L represents the equivalent resistance of a load. We will use the half-wave rectifier to illustrate the basic principle and then expand the concept to full-wave rectification.

During the positive first quarter-cycle of the input, the diode is forward-biased, allowing the capacitor to charge to within 0.7 V of the input peak, as illustrated in part (a) of the figure given below. When the input begins to decrease below its peak, as shown in part (b), the capacitor retains its charge and the diode becomes reverse-biased because the cathode is more positive than the anode.

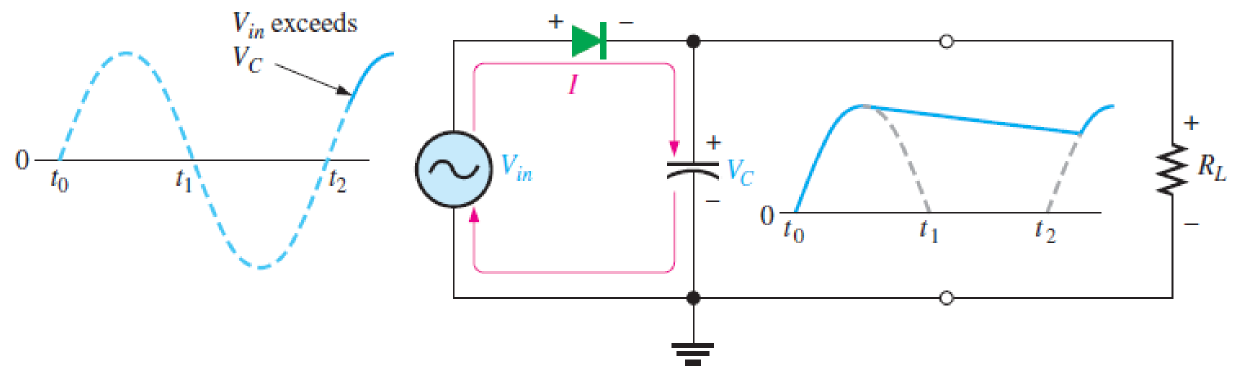
During the remaining part of the cycle, the capacitor can discharge only through the load resistance at a rate determined by the RLC time constant, which is normally long compared to the period of the input. The larger the time constant, the less the capacitor will discharge. During the first quarter of the next cycle, as illustrated in part (c), the diode will again become forward.



(a) Initial charging of the capacitor (diode is forward-biased) happens only once when power is turned on.



(b) The capacitor discharges through R_L after peak of positive alternation when the diode is reverse-biased. This discharging occurs during the portion of the input voltage indicated by the solid dark blue curve.



(c) The capacitor charges back to peak of input when the diode becomes forward-biased. This charging occurs during the portion of the input voltage indicated by the solid dark blue curve.

Figure 19: Operation of a half-wave rectifier with a capacitor-input filter. The current indicates charging or discharging of the capacitor.

For a given input frequency, the output frequency of a full-wave rectifier is twice that of a half-wave rectifier, as illustrated in the figure given below.

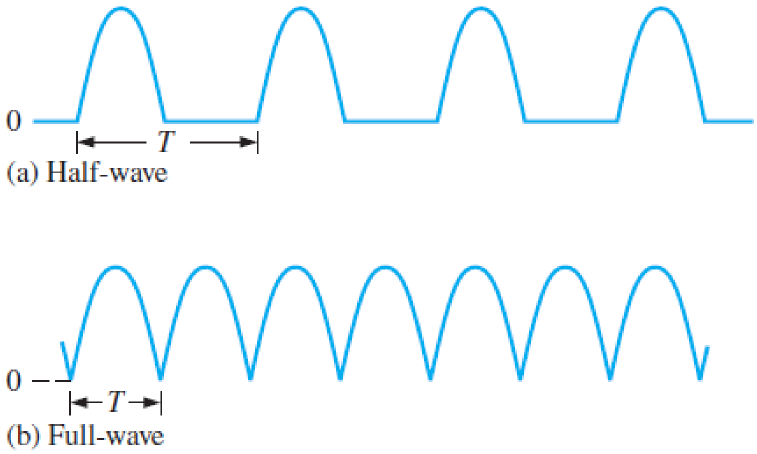


Figure 20: Waveforms of half-wave and full-wave rectifiers

This makes a full-wave rectifier easier to filter because of the shorter time between peaks. When filtered, the full-wave rectified voltage has a smaller ripple than does a half-wave voltage for the same load resistance and capacitor values. The capacitor discharges less during the shorter interval between full-wave pulses, as shown in the figure given below.

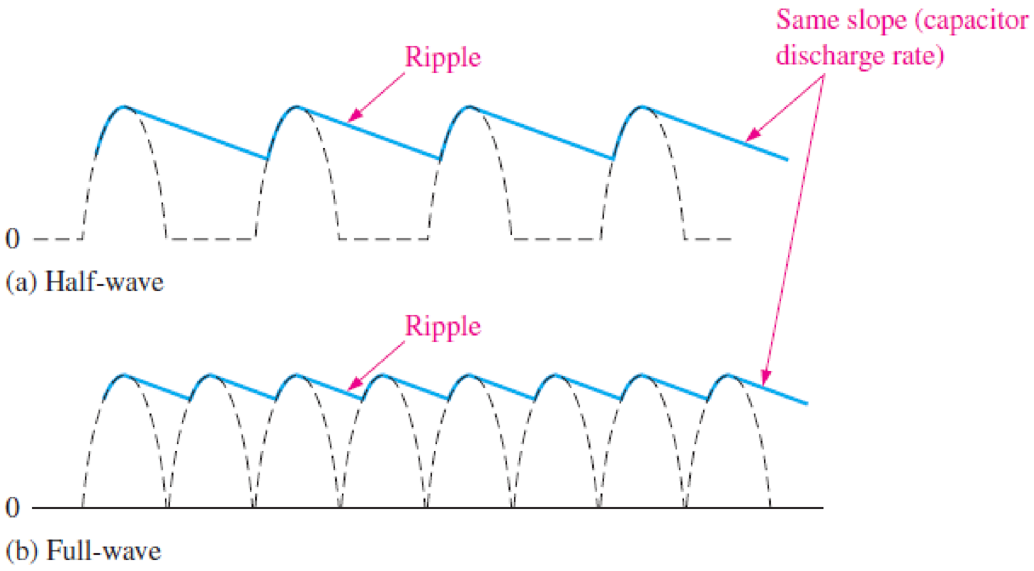


Figure 21: Ripple waveforms of half-wave and full-wave rectifiers

The period of a full-wave rectified voltage is half that of a half-wave rectified voltage. The output frequency of a full-wave rectifier is twice that of a half-wave rectifier.

For a full-wave rectifier, the peak primary voltage is calculated from:

$$V_{p(pri)} = \sqrt{2}\, V_{rms}$$

Where n is the transformer turns ratio, the peak secondary voltage is determined from:

$$V_{p(sec)} = nV_{p(pri)}$$

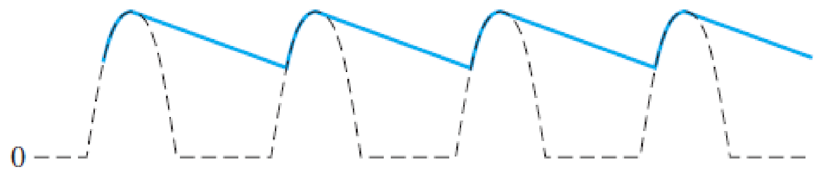
The unfiltered peak full-wave rectified voltage is calculated from:

$$V_{p(rect)} = V_{p(sec)} - (2)(V_{BE})$$

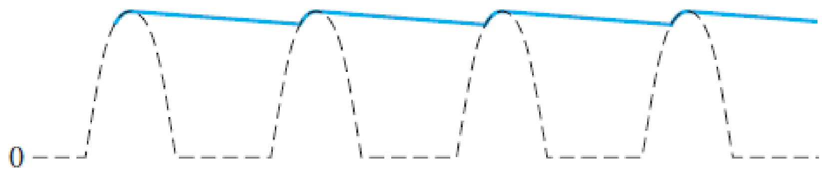
The variable $V_{p(rect)}$ is the unfiltered peak rectified voltage.

4.3. Ripple Factor (r)

Comparison of ripple voltages for half-wave and full-wave rectified voltages with the same filter capacitor and load and derived from the same sinusoidal input voltage.



(a) Larger ripple (blue) means less effective filtering.



(b) Smaller ripple means more effective filtering. Generally, the larger the capacitor value, the smaller the ripple for the same input and load.

Figure 22: Ripple Factors

The ripple factor (r) is an indication of the effectiveness of the filter and can be used further to determine the values of the components in the rectifier circuit.

For a full-wave rectifier with a capacitor-input filter, approximations for the peak-to-peak ripple voltage, $V_{r(pp)}$, and the dc value of the filter output voltage, V_{DC}, are derived below.

If the frequency of a full-wave rectified voltage is f, the approximate peak-to-peak ripple voltage at the output is:

$$V_{r(pp)} \cong \left(\frac{1}{fR_L C}\right) V_{p(rect)}$$

Then, the approximate dc value of the output voltage is determined as follows:

$$V_{DC} = \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)}$$

Thus, the ripple factor, r is:

$$r = \frac{V_{r(pp)}}{V_{DC}}$$

The equation given above where $V_{r(pp)}$ is the peak-to-peak ripple voltage and V_{DC} is the dc (average) value of the filter's output voltage, as illustrated in the figure below.

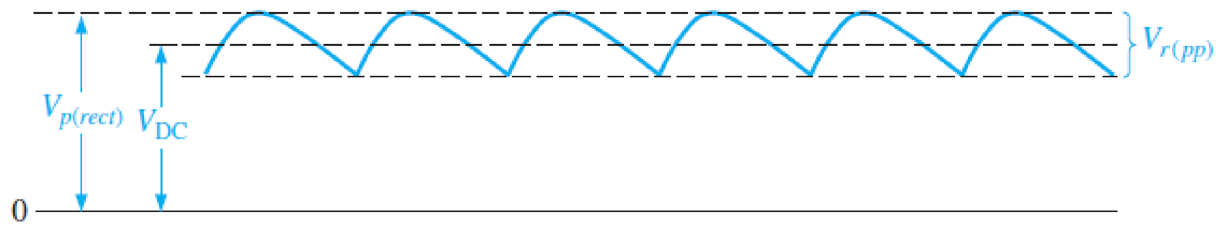


Figure 23: $V_{r(pp)}$ and V_{DC} determine the ripple factor, r.

The lower the ripple factor, the better the filter. Notice that if R_L or C increases, the ripple voltage decreases and the dc voltage increases.

As shown in the equations above, the ripple factor can be lowered by increasing the value of the filter capacitor or increasing the load resistance.

Example for Tutorial 4 – Ripples in Rectifier Circuit

For given diode rectifier circuits, perform the following tasks:

a. Define ripple factor and derive its expression from RMS and DC currents or voltages.
[14 marks]

b. Calculate ripple factor of half-wave rectifier circuit and comment on the results.
[8 marks]

c. Calculate ripple factor of full-wave rectifier circuit and comment on the results.
[8 marks]

Answer

a. As per definition, ripple factor is the ratio of RMS of AC component to RMS of DC components in rectified output.

Ripple factor is given in terms of RMS value of AC component to RMS value of DC component.

$$\text{Ripple factor}, \gamma = \frac{\sqrt{(I_{rms})^2 - (I_{dc})^2}}{I_{dc}}$$

Or

$$\text{Ripple factor}, \gamma = \frac{\sqrt{(V_{rms})^2 - (V_{dc})^2}}{V_{dc}}$$

Knowing I_{rms} and I_{dc}, we can find the ripple factor of the rectifier.

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

Or

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

Dividing throughout by I_{dc}, we get:

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2}$$

As I_{ac}/I_{dc} is the ripple factor, as a result the ripple factor is:

$$\text{Ripple factor}, \gamma = \frac{1}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

Then, as a result, we can derive the ripple factors for half-wave and full-wave rectifiers.

b. For a half-wave rectifier circuit, the RMS and DC currents of the circuit are:

$$I_{rms} = \frac{I_m}{2}$$

And

$$I_{dc} = \frac{I_m}{\pi}$$

As a result, the ripple factor for half-wave rectifier is:

$$\text{Halwave ripple factor}, \gamma_{HW} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

Ripple factor of half wave rectifier is about 1.21 by the derivation. As you can see, output voltage has much more AC component in DC output voltage so the half-wave rectifier is ineffective in the conversion of AC to DC.

c. For a full-wave rectifier circuit, the RMS and DC currents of the circuit are:

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

And

$$I_{dc} = \frac{2I_m}{\pi}$$

As a result, the ripple factor of full-wave rectifier is:

$$\text{Fullwave ripple factor}, \gamma_{FW} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.48$$

Thus

$$\gamma_{FW} = \frac{\text{Effective AC component}}{\text{DC component}} = 0.48$$

This shows that in the output of a full-wave rectifier, the DC component is more than the AC component. Consequently, the pulsations in the output will be less than in half-wave rectifier. For this reason, full-wave rectification is invariably used for conversion of AC into DC.

5. Clipper Networks

Clipper circuits (also called voltage limiter circuits) are diode networks that can "clip" an incoming signal without distorting the remaining waveform.

They will eliminate portions of the signal above or below a certain specified level.

The half-wave rectifier can then be called a clipper circuit as well, as all voltages below V_i = 0 has cut off (for positive cycle half wave rectifier).

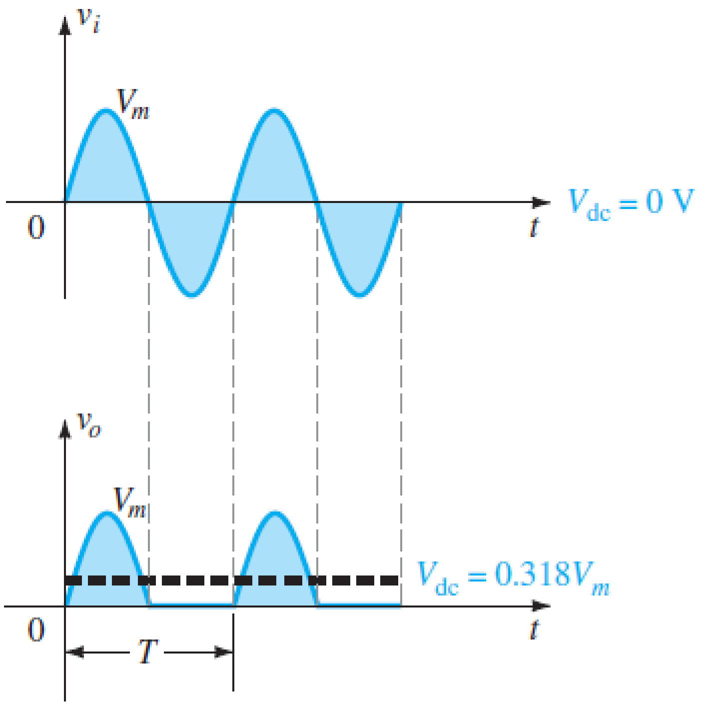


Figure 24: Input and output waveforms of the half-wave rectifier.

5.1. Diode Clipper Circuit

In this section, we will have a look at two types of diode clipper circuits e.g. positive diode clipper circuit and negative diode clipper circuit.

5.1.1. Positive Diode Clipper Circuit

Note where output is taken as shown in the diagram below.

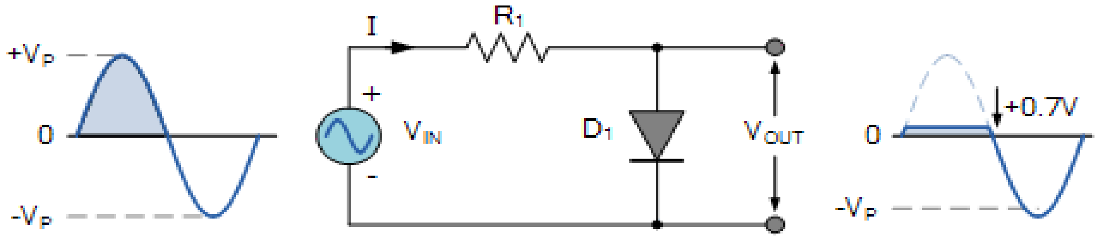


Figure 25: A single diode clipper circuit and its waveforms (forward biased).

By treating the diode as an ideal diode plus voltage source, in forward bias, we get a constant voltage drop of ~0.7 V across the diode when $V_i \geq 0.7$ V as the diode will then be switched ON. In reverse bias, or when $V_i < 0.7$ V, we will have V_i across the diode as the diode is OFF. Overall in this circuit, all voltages where $V_i \geq 0.7$ V is then cut off from the output.

5.1.2. Negative Diode Clipper Circuit

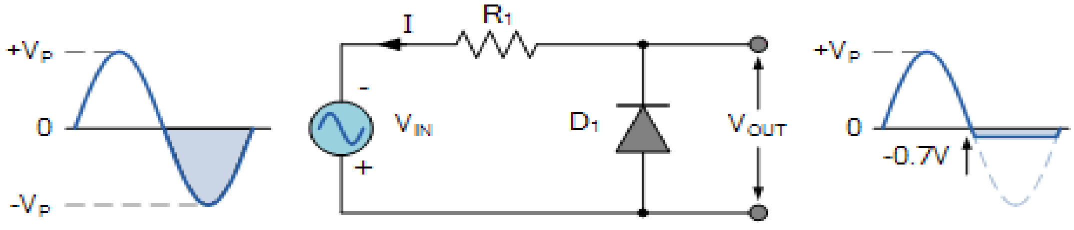


Figure 26: A single diode clipper circuit and its waveforms (reverse biased).

Here the reverse is true from positive diode clipper. The diode is forward biased during the negative half cycle of the sinusoidal waveform and limits or clips it to -0.7 volts while allowing the positive half cycle to pass unaltered when reverse biased. As the diode limits the negative half cycle of the input voltage, it is therefore called a negative clipper circuit.

5.1.3. Clipping Both Cycles

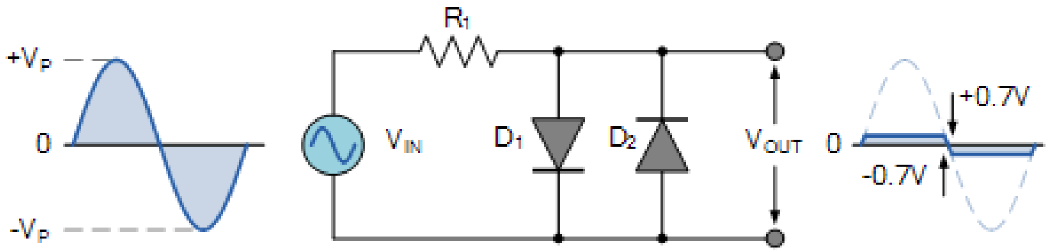


Figure 27: A single diode clipper circuit and its waveforms (forward and reverse biased).

If we connected two diodes in inverse parallel as shown, then both the positive and negative half cycles would be clipped as diode D_1 clips the positive half cycle of the sinusoidal input waveforms while diode D_2 clips the negative half cycle. Then, diode clipping circuits can be used to clip the positive half cycle, the negative half cycle or both.

For ideal diodes, the output waveform above would be zero. However, due to the forward bias voltage drop across the diodes the actual clipping point occurs at +0.7 volts and -0.7 volts respectively. But, we can increase this ± 0.7 V threshold to any value we want up to the maximum value, (V_{PEAK}) of the sinusoidal waveform either by connecting together more diodes in series creating multiples of 0.7 volts, or by adding a voltage bias to the diodes.

5.2. Biased Clipping Circuits

To produce diode clipping circuits for voltage waveforms at different levels, a bias voltage, V_{BIAS} is added in series with the diode as shown. The voltage across the series combination must be greater than V_{BIAS} + 0.7 V before the diode becomes sufficiently forward biased to conduct.

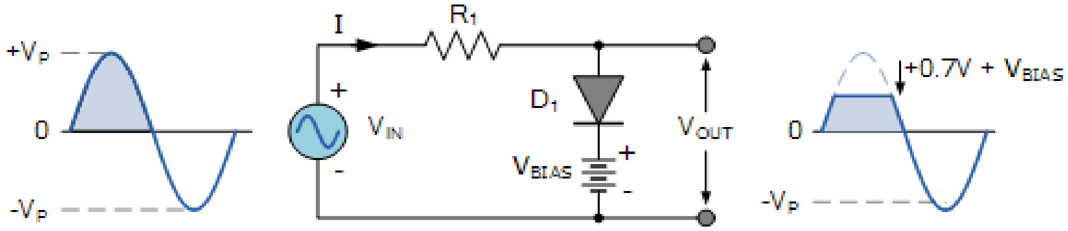


Figure 28: Equivalent circuit of a single diode clipper circuit and its waveforms (forward biased).

For example, if the V_{BIAS} level is set at 4.0 volts, then the sinusoidal voltage at the diode's anode terminal must be greater than 4.0 + 0.7 = 4.7 volts for it to become forward biased. Any anode voltage levels above this bias point are clipped off.

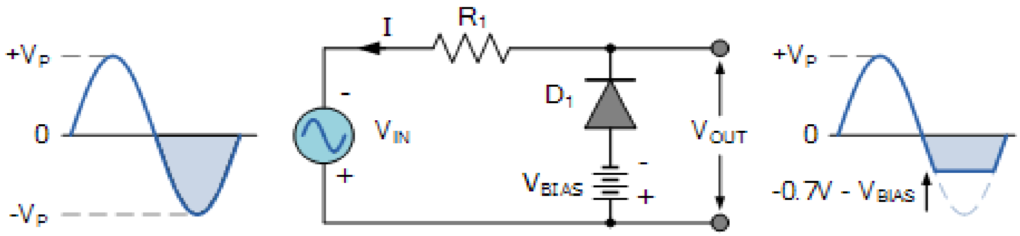


Figure 29: Equivalent circuit of a single diode clipper circuit and its waveforms (reverse biased).

A variable diode clipping or diode limiting level can be achieved by varying the bias voltage of the diodes. If both the positive and the negative half cycles are to be clipped, then two biased clipping diodes are used. But, for both positive and negative diode clipping, the bias voltage need not be the same. The positive bias voltage could be at one level, for example 4 V, and the negative bias voltage at another, for example 6 V as shown.

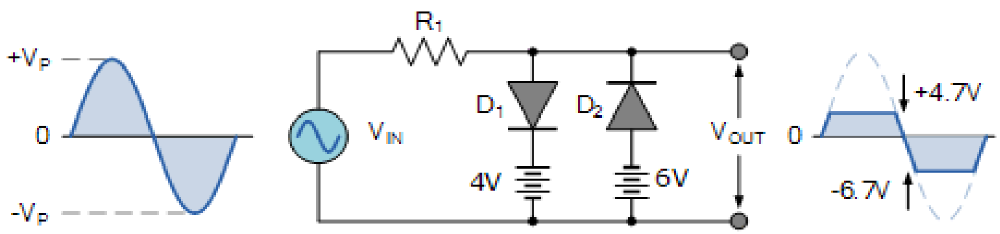
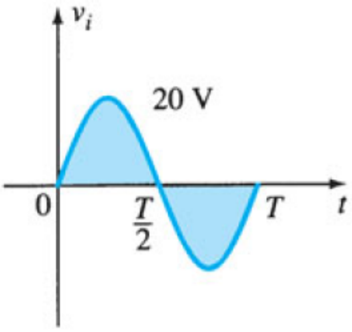


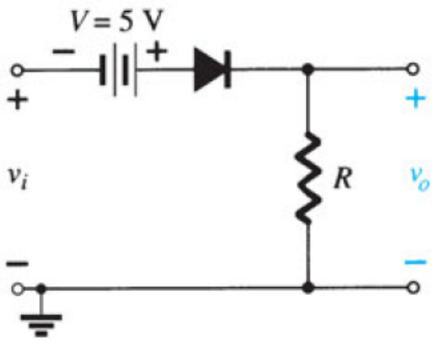
Figure 30: Equivalent circuit of a single diode clipper circuit and its waveforms (forward and reverse biased).

When the voltage of the positive half cycle reaches +4.7 V, diode D_1 conducts and limits the waveform at +4.7 V. Diode D_2 does not conduct until the voltage reaches –6.7 V. Therefore, all positive voltages above +4.7 V and negative voltages below –6.7 V are automatically clipped.

Example for Tutorial 5 – Clipper Circuits

1. Determine the output waveform for the sinusoidal input of the circuit shown below. The output is taken directly across the resistor R. [8 marks]



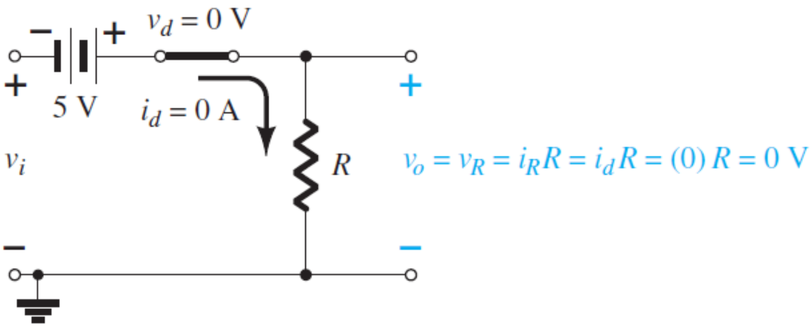


Answer

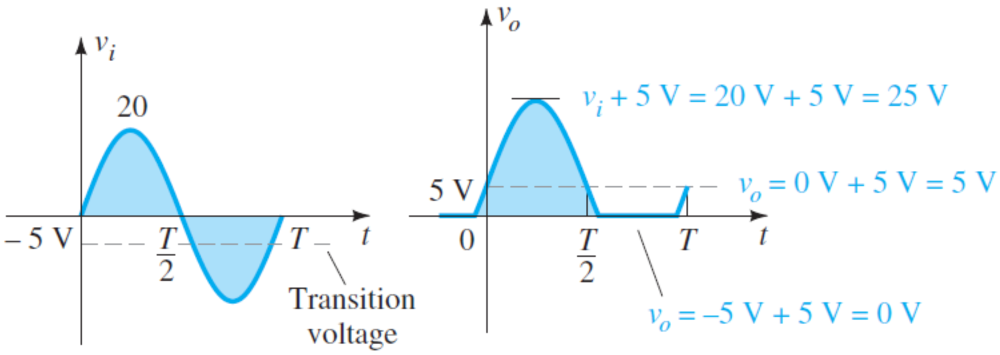
The positive region of v_i and the dc supply are both applying "pressure" to turn the diode on. The result is that we can safely assume the diode is in the "on" state for the entire range of positive voltages for v_i. Once the supply goes negative, it would have to exceed the dc supply voltage of 5 V before it could turn the diode off.

The transition model is substituted in the figure below, and we find that the transition from one state to the other will occur when:

$$v_i + 5 = 0 \qquad \text{or} \qquad v_i = -5\text{ V}$$



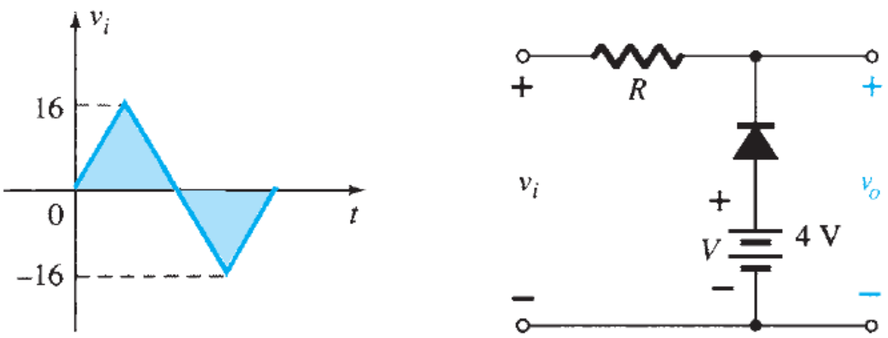
In the figure below, a horizontal line is drawn through the applied voltage at the transition level. For voltages less than -5 V the diode is in the open-circuit state and the output is 0 V, as shown in the sketch of v_o.



Using the figure above, we find that for conditions when the diode is on and the diode current is established the output voltage will be the following, as determined using Kirchhoff's voltage law:

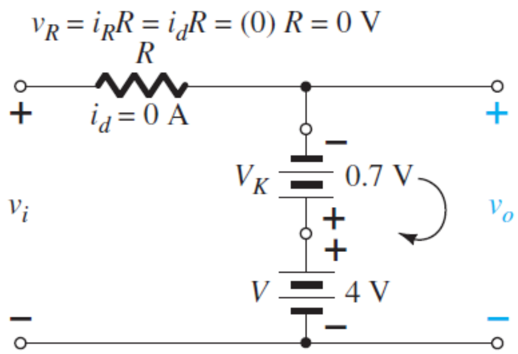
$$v_o = v_i + 5$$

2. Determine v_o for the network of the circuit given below. In this example the output is defined across the series combination of the 4-V supply and the diode using a silicon diode with V_K = 0.7 V. [12 marks]



Answer

The transition voltage can first be determined by applying the condition i_d = 0 A at v_d = V_D = 0.7 V and obtaining the network of the figure below.



Applying Kirchhoff's voltage law around the output loop in the clockwise direction, we find that:

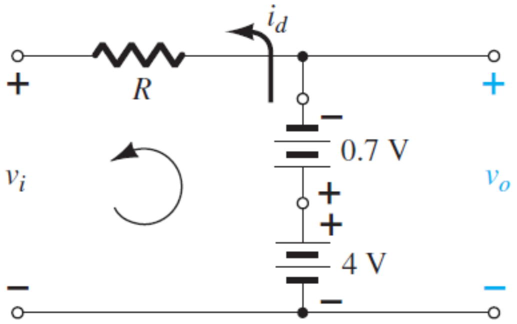
$$v_i + V_K - V = 0$$

And

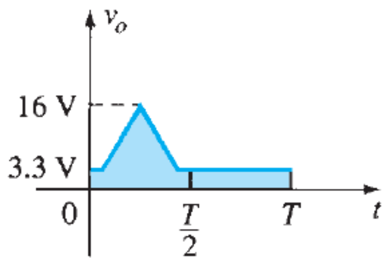
$$v_i = V - V_K = 4 - 0.7 = 3.3$$

For input voltages greater than 3.3 V, the diode will be an open circuit and $v_o = v_i$. For input voltages less than 3.3 V, the diode will be in the "on" state and the network of the circuit results given below, where:

$$v_o = 4 - 0.7 = 3.3$$



The resulting output waveform appears in the figure below. Note that the only effect of V_K was to drop the transition level to 3.3 from 4 V.



6. Clamping Networks

These circuits will clamp an AC signal to a different voltage level i.e. also called AC shifter circuits. These circuits should contain the following elements:

- Diode
- Resistor
- Capacitor
- Independent DC supply to introduce a shift.

The time constant of RC must be chosen so that it is long enough so that the capacitor does not discharge significantly during the time that the diode is OFF.

6.1. Diode Clamper

The following diagram shows an example of a clamper circuit i.e. clamping the signal to the zero level (ideal diode).

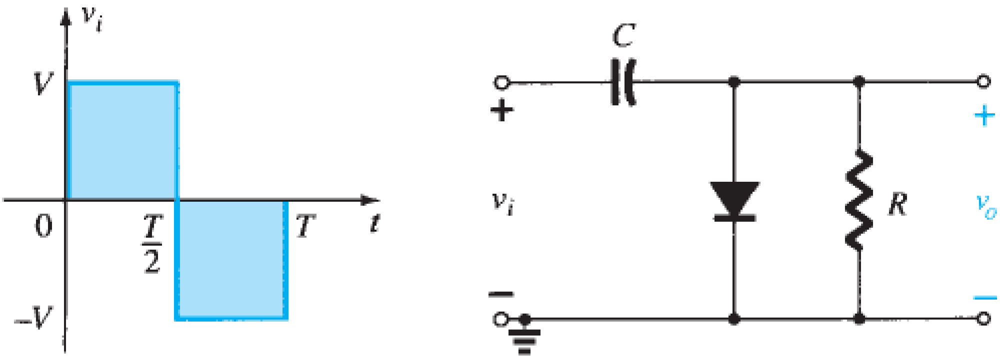


Figure 31: A voltage clamper circuit with a diode application.

For the period $0 < t < T/2$, diode is in forward bias and ON. This will short out diode so that capacitor charges quickly through diode. Then, this charges to voltage V.

Output voltage during this time is output over shorted diode as a result $V_o = 0$ V.

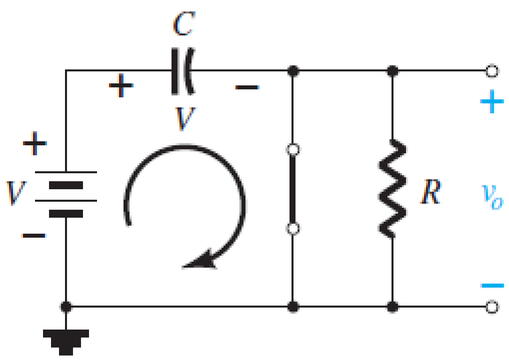


Figure 32: A voltage clamper circuit with a diode application (forward powered).

For the period $T/2 < t < T$, the diode is in reverse bias and OFF. The diode now appears as an open circuit, but diode will discharge through the capacitor. With a long time-constant RC, the charge (and thus voltage) will remain on capacitor until the end of the cycle.

Write a KVL around the loop:

$$-V_S - V_C - V_o = 0$$

So that $V_S = V_C$

$$V_o = \text{-2 V}$$

During negative input cycle, the output will then be -2 V. This then results on:

- Total voltage swing of input cycle appears over the negative output cycle.
- Zero level has shifted down by -1 V.

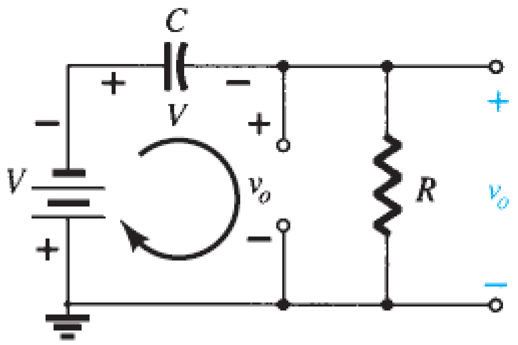


Figure 33: A voltage clamper circuit with a diode application (reverse powered).

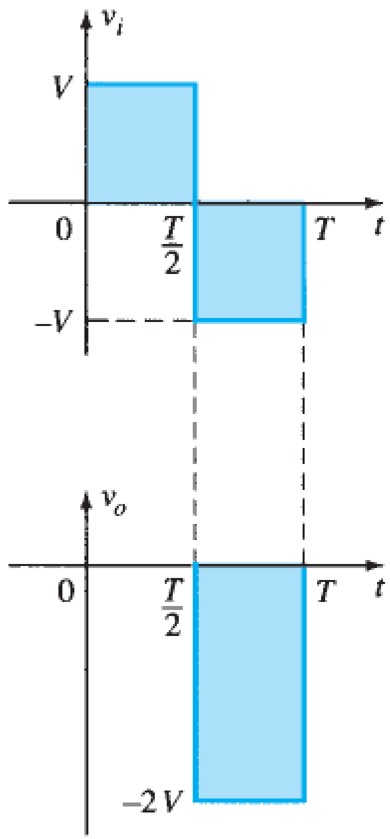


Figure 34: Output voltage waveforms of a voltage clamper circuit with a diode application.

For clamping network as a general rule, the total swing of the output signal is equal to the total swing of the input signal.

Steps for analysing clamping networks:

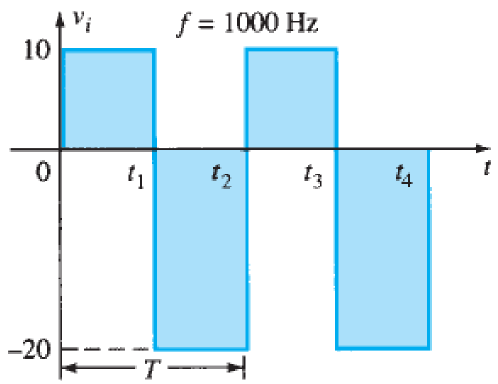
1. Start by considering that part of the input signal that will forward bias the diode.
2. During the diode ON time, assume the capacitor will charge up instantaneously to the voltage level as determined by the network.
3. Assume that during the diode OFF cycle the capacitor will maintain its charge i.e. hold its voltage level.
4. Keep polarity of V_o in mind at all times to ensure proper voltage level.
5. Total swing of the output should equal total swing of the input.

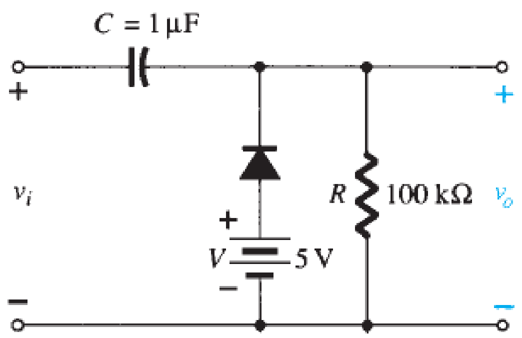
6.2. Biased Diode Clampers

In this section, we will look into diode clamper circuits with biased voltage. As before, having voltage source connected with the diode, this time in a clamper circuit, enables the circuit that can clamp (e.g. limit) the input signal to a specific operational level the with additional voltage offset inserted.

Example for Tutorial 6 – Clamper Circuits

The following example shows a diode clamper circuit realised with biased voltage by adding a voltage source in series with the diode in the circuit (with additional 5 V voltage offset inserted). Determine V_o and time constant of the circuit for the following diode circuit and input signal. [14 marks]



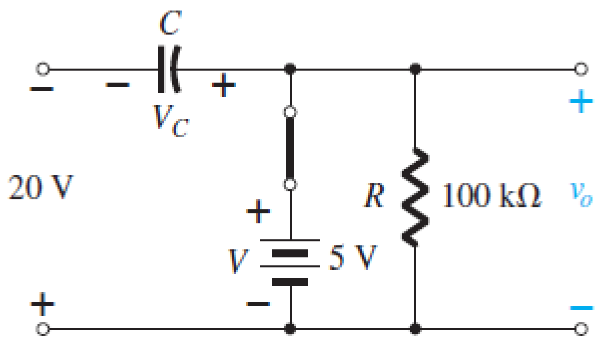


Answer

Start analysis in period t_1 to t_2 in order to start with ON diode. Applying the KVL in the circuit:

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

Knowing that V_C = 25 V, the capacitor charges to 25 V.

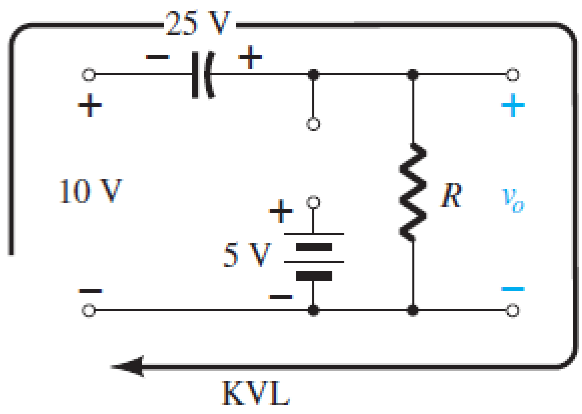


Then, perform analysis in period t_2 to t_3 in order to start with OFF diode. Applying the KVL:

$$10 + 25 - V_o = 0$$

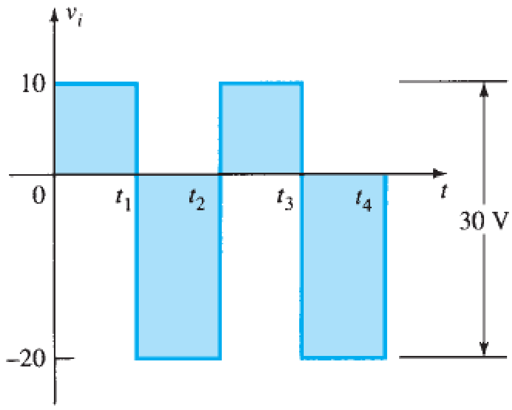
Thus

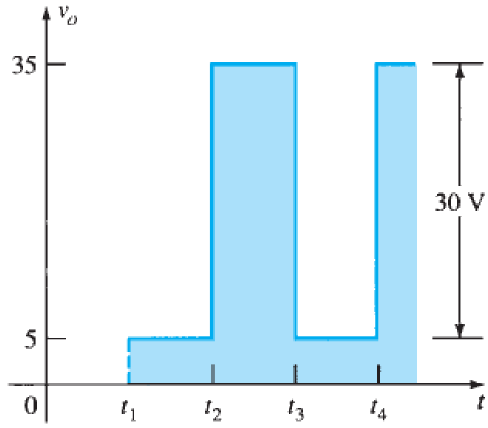
$$V_o = 35 \text{ V}$$



Time constant of circuit

$$\tau = RC = (100 \times 10^3)(0.1 \times 10^{-6}) = 0.01 \text{ s}$$



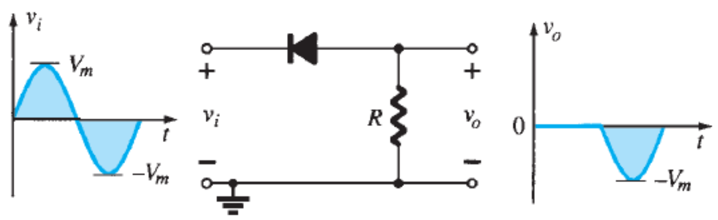


Appendix - Summary of Clippers and Clamper Circuits

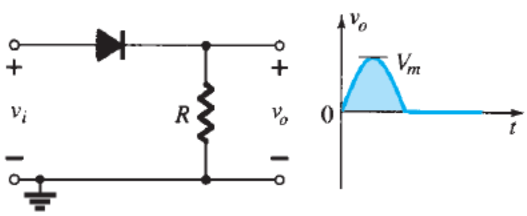
A. Clipper Circuits

Simple Series Clippers (Ideal Diodes)

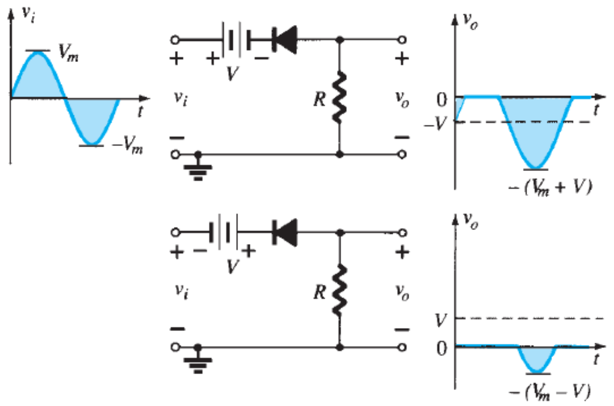
POSITIVE

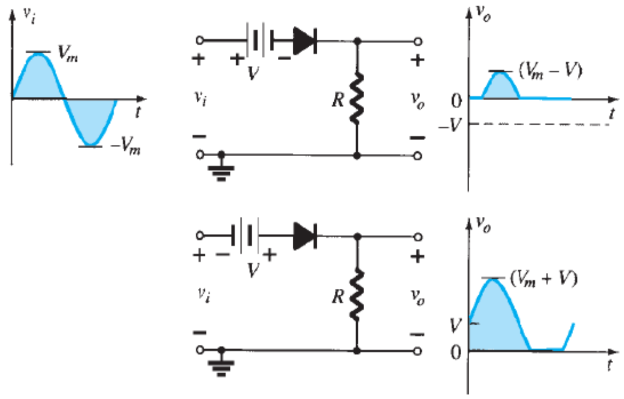


NEGATIVE

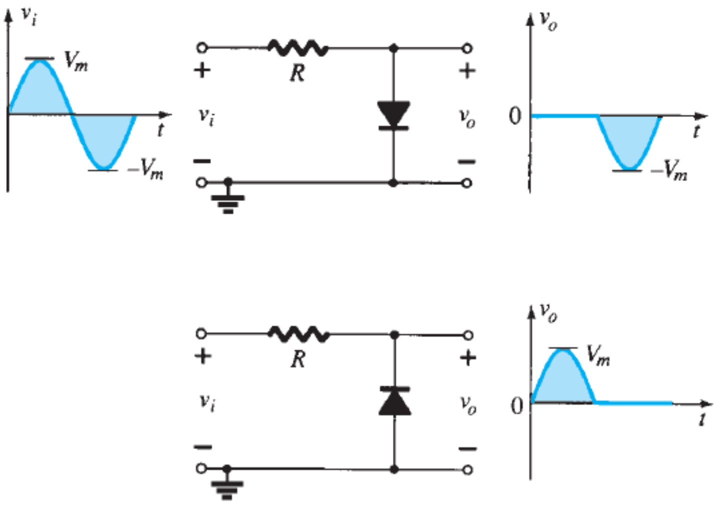


Biased Series Clippers (Ideal Diodes)

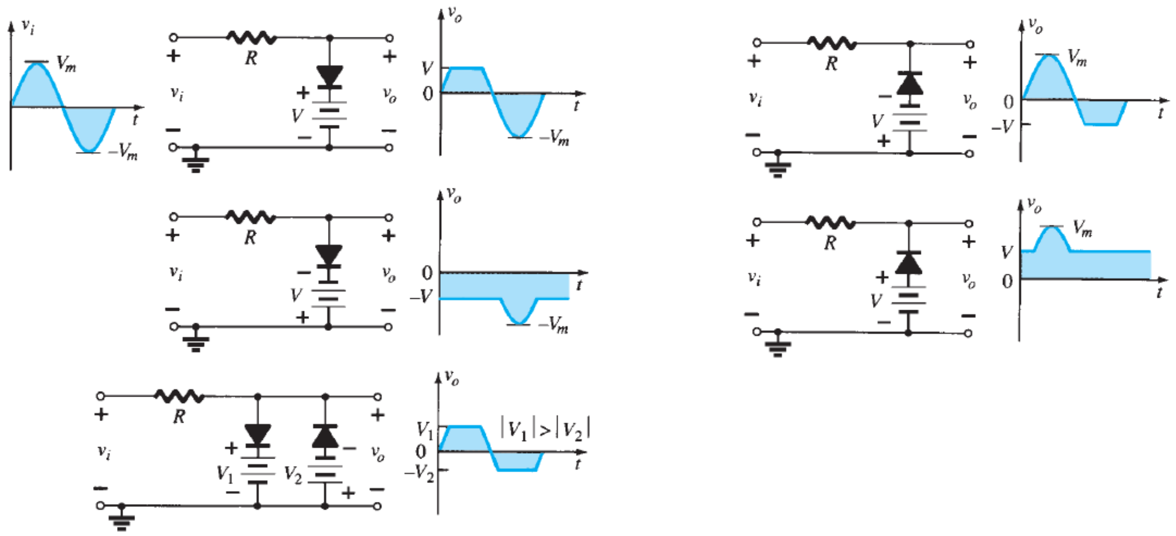




Simple Parallel Clippers (Ideal Diodes)

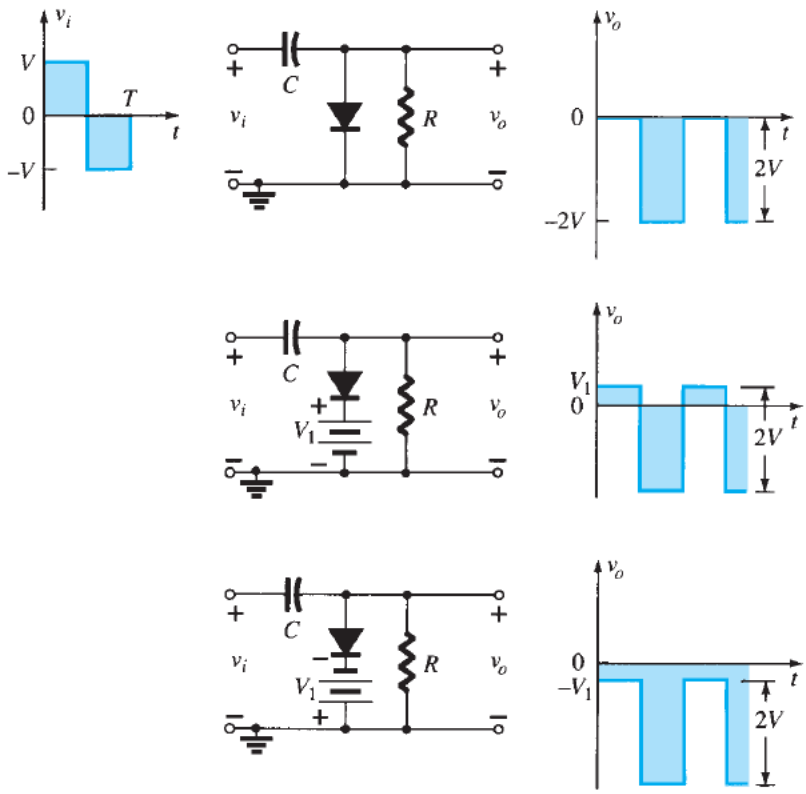


Biased Parallel Clippers (Ideal Diodes)

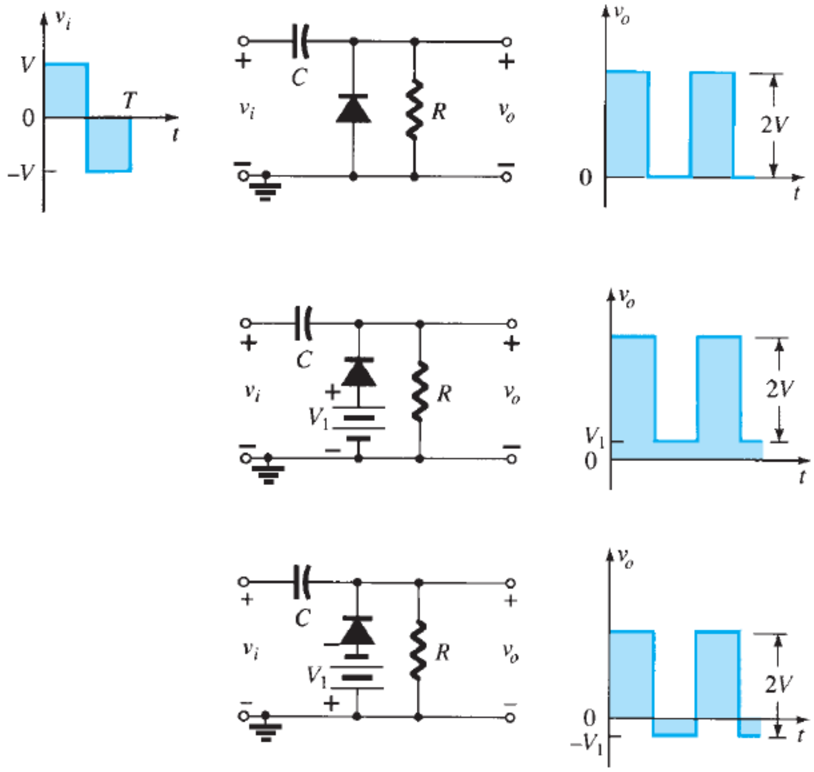


B. Clamper Circuits

Forward Biasing Circuits



Reversed Biasing Circuits



v_i
V
0
T
t
–V
C
R
v_i
v_o
2V
V_1
$-V_1$