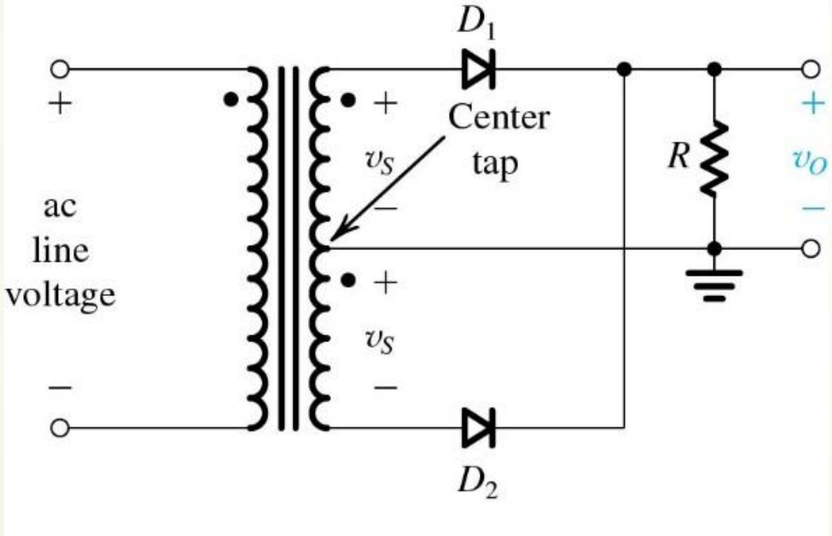
ENGR 305

Voltage Rectifier Circuits

September 18, 2025

The full-wave rectifier

- We consider the full-wave rectifier using a transformer with a center-tapped secondary winding.



(a)

The full-wave rectifier

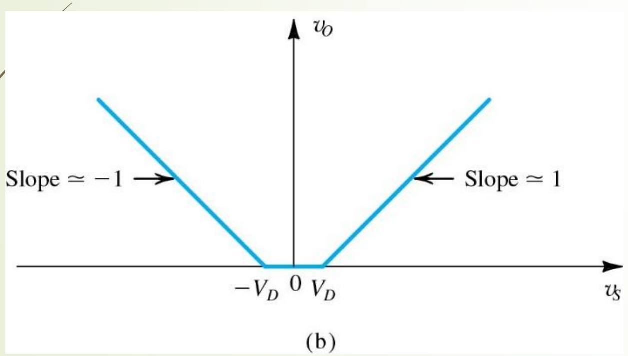
- The full-wave rectifier uses both halves of the input sinusoid.
  - It inverts the negative halves of the sine wave to produce a unipolar output.
- One possible implementation (as shown) has a **center-tapped** secondary winding.
- For the case when the input line voltage (feeding the primary) is positive:
  - Both signals labeled v_S will be positive.
  - Diode D_1 will conduct and D_2 will be reverse biased.
  - The current through D_1 will flow through R and back to the center tap of the secondary.
  - The circuit then behaves like a half-wave rectifier.

Full-wave rectifier

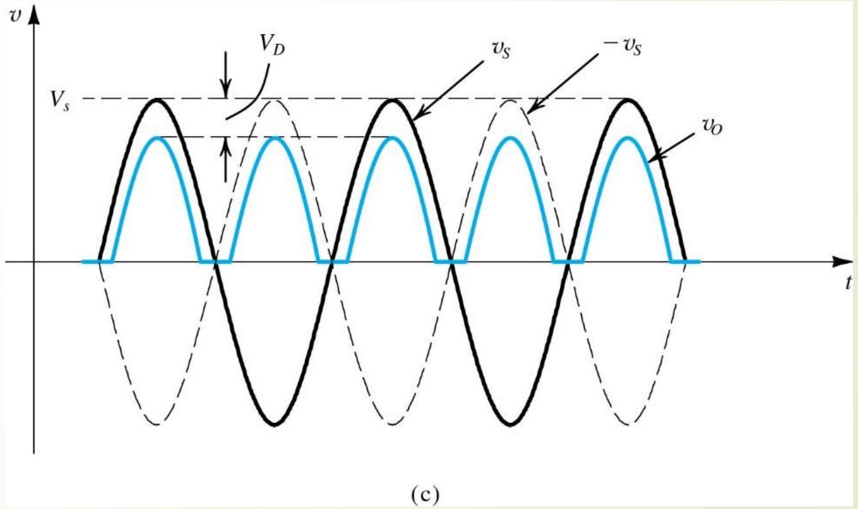
- During the negative half-cycle of the ac line voltage, both voltages labeled v_S will be negative.
  - Then D_1will be cut off while D_2 will conduct.
  - The current conducted by D_2 will flow through R and back to the center tap.
  - The circuit again behaves like a half-wave rectifier.
- Note that for both half cycles the current through *R* always flows in the same direction.
  - This causes the resulting v_O to be unipolar.
  - We again use the constant-voltage-drop model for the diode ($V_D = 0.7\ V$)

Full-wave rectifier

- The resulting v_O is unipolar as shown.
- The transfer characteristic is also shown.



Transfer characteristic for full-wave rectifier.

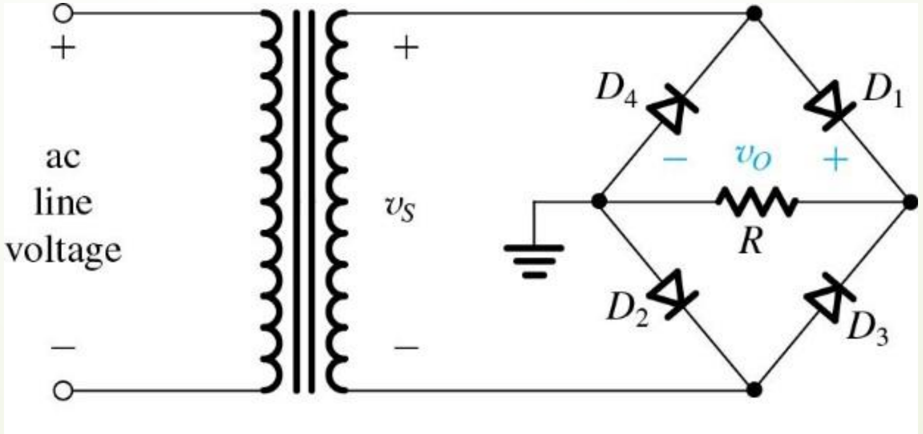


Full-wave rectifier

- Recalling that the Peak Inverse voltage (PIV) is an important parameter in rectifier design
  - During the positive half-cycles, D_1 is conducting while D_2 is cut off.
  - Voltage at the cathode of D_2 is v_O and at its anode is $-v_S$.
  - The reverse voltage across D_2 will be $(v_O + v_S)$
  - This reaches its maximum when v_O is at its peak value of $(V_S - V_D)$ and v_S is at its peak value of V_S
  - Then $PIV = 2V_S - V_D$

The Bridge rectifier

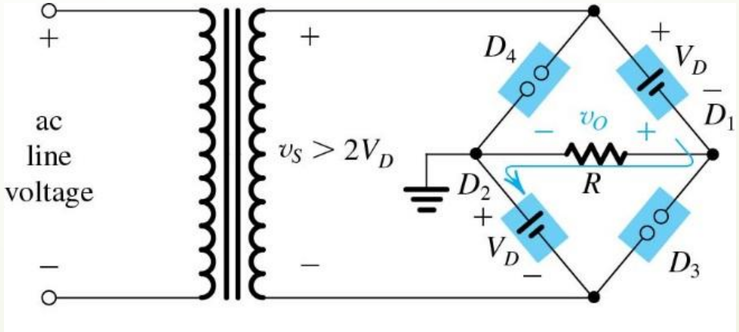
- The bridge rectifier is an alternative implementation to the full-wave rectifier.
  - It does not require a center-tapped transformer.
  - It does require four diodes instead of two diodes.



(a)

The bridge rectifier

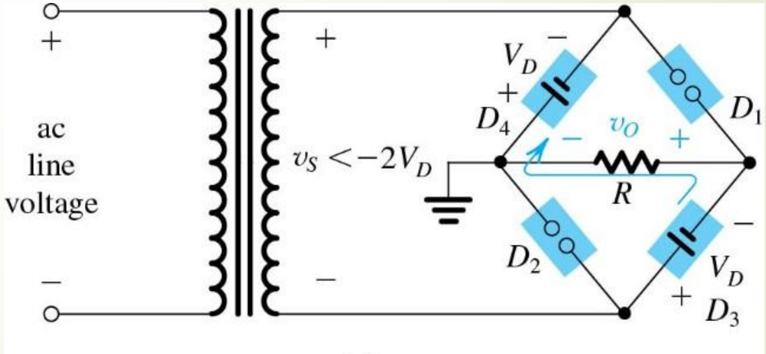
- During the *positive* half-cycles of the input voltage, v_S is positive
  - Current is conducted through diode D_1, resistor R, and diode D_2.
  - Diodes D_3 and D_4 will be reverse biased.
  - Since there are two diodes in the conduction path, v_O will be lower than v_S by two diode drops.



(b)

The bridge rectifier

- During the *negative* half-cycles of the input voltage, v_S is negative.
  - Thus, $-v_S$ will be positive, forcing current through D_3, *R* and D_4.
  - Diodes D_1 and D_2 will be reverse biased.
  - During both half-cycles, current flows through R in the same direction (from right to left)
  - Then v_O will always be positive.



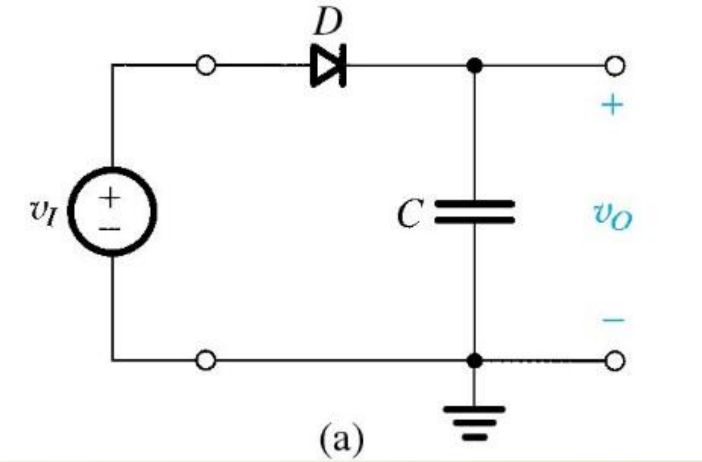
(c)

The bridge rectifier

- We want to determine the peak inverse voltage (PIV) of each diode.
- The reverse voltage across D_3can be found from the loop formed by D_3, R and D_2
  - $v_{D3}(reverse) = v_O + v_{D2}(forward)$
- The maximum value of v_{D3} occurs at the peak of $v_O$and is given by
  - $PIV = V_S - 2V_D + V_D = V_S - V_D$
- Here the PIV is about half the value for the full-wave rectifier with a center-tapped transformer.

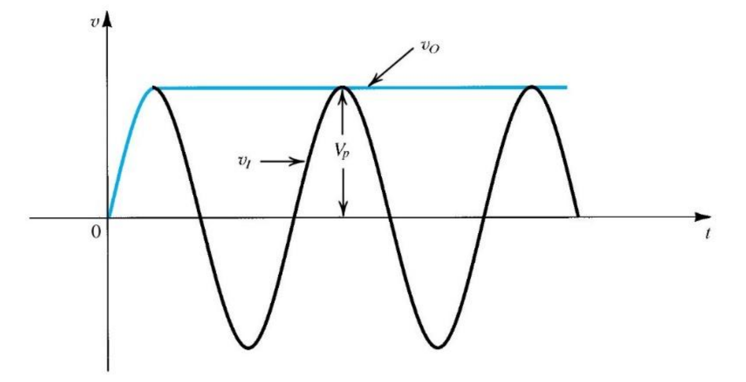
Rectifier with a filter capacitor

- The output voltage waveform of the rectifier circuits is not suitable for a dc power supply.
- A simple way to reduce the variation in the output voltage is to place a capacitor across the load resistor, called a **filter capacitor.**
- We first consider the simple circuit shown.



Rectifier with a filter capacitor

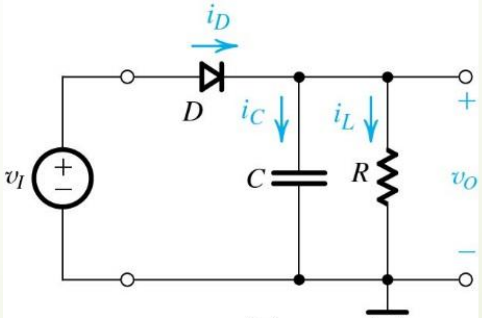
- Let the input v_I be a sinusoid with a peak value V_p
- Assume the diode to be *ideal*.
- As v_I goes positive, the diode conducts and the capacitor is charged so that $v_O = v_I$
- This continues until v_I reaches its peak value V_p. As v_I decreases, the diode becomes reverse biased and the output remains (theoretically) constant at the value V_p.



(b)

Rectifier with a filter capacitor

- Consider the more practical circuit with a load resistance R connected across the capacitor.
  - For a sinusoidal input, the capacitor charges to the peak value of input of V_p.
  - Then the diode cuts off, and the capacitor discharges through the load resistance R.
  - The capacitor discharge continues until the time at which v_I exceeds the capacitor voltage.
  - We choose a value for C so that the time constant CR is much greater than the discharge interval.

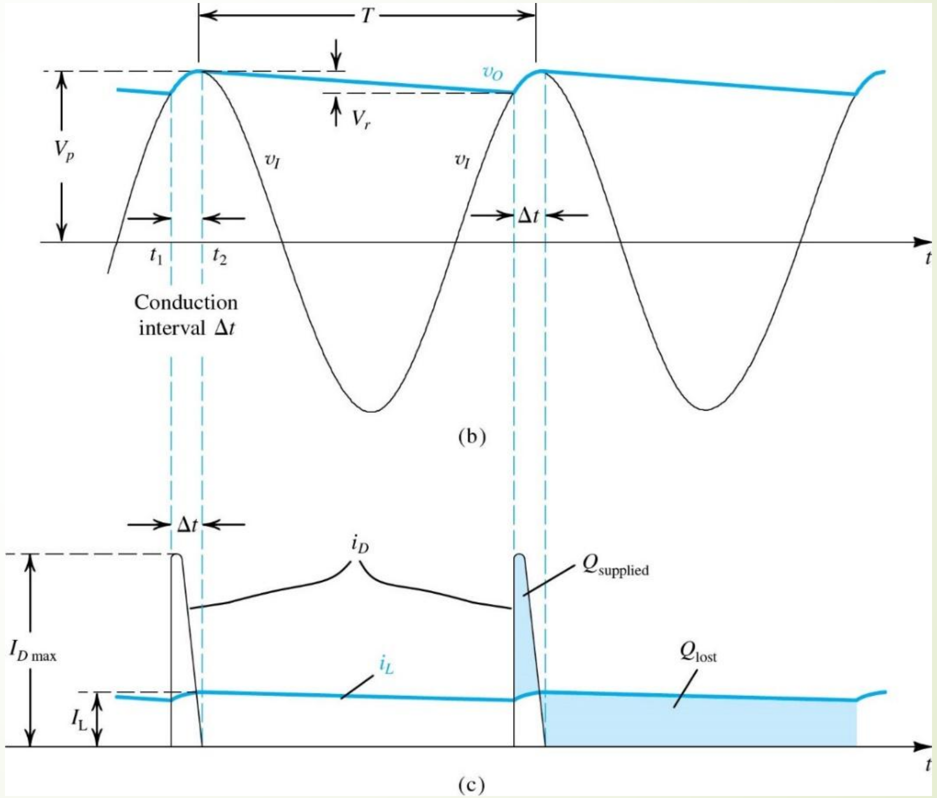


(a)

Peak rectifier circuit – voltage and current

Here we see the input and output voltage waveforms under the assumption that $CR \gg T$, where T is the period of the input sinusoid.

The waveforms of the load current, $i_L = {}^{v_O}/_{R}$ and of the diode current (when it is conducting) $i_D = i_C + i_L = C\frac{dv_I}{dt} + i_L$ are shown.



Peak rectifier circuit - observations

1. The diode conducts for a brief interval, Δt, near the peak of the input sinusoid and supplies the capacitor with charge equal to that lost during the much longer discharge interval, which is approximately equal to T.
2. Assuming an ideal diode, the diode conduction begins at time t_1, at which the input v_I equals the exponentially decaying output v_O. Conduction stops at t_2, shortly after the peak of v_I.
3. During the diode-off interval, the capacitor C discharges through R, and so v_O decays exponentially with a time constant CR. The discharge interval begins just past the peak of v_I. At the end of the discharge interval, $v_O = V_p - V_r$, where V_r is the peak-to-peak ripple voltage.
4. When V_r is small, v_O is almost constant and equal to the peak value of v_I. Thus the dc output voltage is approximately equal to V_p.

Peak rectifier circuit

- Similarly, the current i_L is almost constant, with its dc component given by
  - $I_L = \frac{V_p}{R}$
- During the diode-off interval, v_O can be expressed as
  - $v_O = V_p e^{-t/CR}$
- At the end of the discharge interval we have
  - $V_p - V_r \cong V_p e^{-T/CR}$
- Now, since $CR \gg T$, we can use the approximation $e^{-T/CR} \cong 1 - T/CR$ to get
  - $V_r \cong V_p \frac{T}{CR}$
- To keep V_r small we must select a capacitance C so that $CR \gg T$.

Peak rectifier circuit

- The **ripple voltage** V_r in the previous equation can be expressed in terms of the frequency $f = 1/T$ as
  - $V_r = \frac{V_p}{fCR}$
- Using the previous expression for I_L we can express V_r as
  - $V_r = \frac{I_L}{fC}$
- Assuming that the diode conduction ceases almost at the peak of v_I, we can determine the **conduction interval** $\Delta \boldsymbol{t}$ from
- $V_p cos(\omega\Delta t) = V_p - V_r$ where $\omega = 2\pi f = 2\pi/T$ is the angular frequency of v_I.

Peak rectifier circuit

- Since $(\omega\Delta t)$ is a small angle, we can use the approximation $cos(\omega\Delta t) \cong 1 - \frac{1}{2}(\omega\Delta t)^2$
  - Which gives $\omega\Delta t = \sqrt{2\,{}^{V_r}/_{V_p}} \xrightarrow{\text{yields}} \Delta t = \frac{T}{2\pi}\sqrt{\frac{2V_r}{V_p}}$
  - We note that when $V_r \ll V_p$ the conduction angle $\omega\Delta t$ will be small.
- Another interpretation is that the charge supplied by the diode to the capacitor during the conduction interval must equal the charge that the capacitor loses during the discharge interval.
- The average capacitor, diode and load currents are related by $i_{Cav} = i_{Dav} - I_L$
- Then, the supplied charge is $Q_{supplied} = i_{Cav}\Delta t \cong (i_{Dav} - I_L)\frac{T}{2\pi}\sqrt{\frac{2V_r}{V_p}}$
- The lost charge is $Q_{lost} = CV_r = I_L T$

Peak rectifier circuit

- Equating the equations for supplied charge and lost charge, the average diode current during conduction is
  - $i_{Dav} = I_L\left(1 + \pi\sqrt{2\,{}^{V_p}/_{V_r}}\right)$
- To select an appropriate diode, we must find the peak value of diode current.
  - We evaluate the current equation at the onset of conduction ($t = -\Delta t$ where t = 0 at the peak)
  - $I_{Dmax} = I_L\left(1 + 2\pi\sqrt{2\,{}^{V_p}/_{V_r}}\right)$
- From these two equations, we see that for $V_r \ll V_p$, $i_{Dmax} \cong 2i_{Dav}$
  - This correlates with the fact that the waveform of i_D is almost a right-angle triangle.