Chapter 15

Alternating Voltage and Current

Topics Covered in Chapter 15

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- 15-7: Period
- 15-8: Wavelength
- 15-9: Phase Angle
- 15-10: The Time Factor in Frequency and Phase
- 15-11: Alternating Current Circuits with Resistance
- 15-12: Nonsinusoidal AC Waveforms
- 15-13: Harmonic Frequencies
- 15-14: The 60-Hz AC Power Line
- 15-15: Motors and Generators
- 15-16: Three-Phase AC Power

15-1: Alternating Current Applications

- A **transformer** can only operate with alternating current to step up or step down an ac voltage.
- A transformer is an example of **inductance** in ac circuits where the changing magnetic flux of a varying current produces an induced voltage.
- **Capacitance** is important with the changing electric field of a varying voltage.
- The effects of inductance and capacitance depend on having an ac source.
- An important application is a **resonant circuit** with L and C that is tuned to a particular frequency.

15-2: Alternating-Voltage Generator

- Characteristics of Alternating Current
  - **Alternating voltage** and **alternating current** vary continuously in magnitude and reverse in polarity.
  - One **cycle** includes the variations between two successive points having the same value and varying in the same direction.
  - Frequency is measured in **hertz** (Hz).

15-2: Alternating-Voltage Generator

- The conductor loop rotates through the magnetic field to generate induced ac voltage across open terminals.
- At the horizontal position, the loop does not induce a voltage because the conductors do not cut across the flux.
- At the vertical position, conductors cut across the flux and produce maximum *v*.
- Each of the longer conductors has opposite polarity of induced voltage.

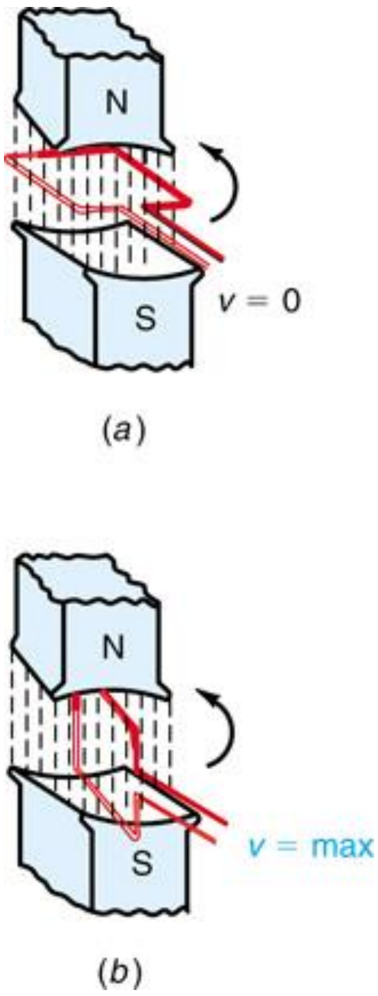


Fig. 15-2: Loop rotating in magnetic field to produce induced voltage *v* with alternating polarities. (*a*) Loop conductors moving parallel to magnetic field results in zero voltage. (*b*) Loop conductors cutting across magnetic field produce maximum induced voltage.

15-2: Alternating-Voltage Generator

- The Cycle
  - One complete revolution of the loop around the circle is a **cycle**.
  - The half-cycle of revolution is called an **alternation**.

15-2: Alternating-Voltage Generator

The voltage waveform shown in Fig. 15-3 is called a **sine** wave, **sinusoidal** wave , or **sinusoid** because the amount of induced voltage is <u>proportional to the sine</u> of the angle of rotation in the circular motion producing the voltage.

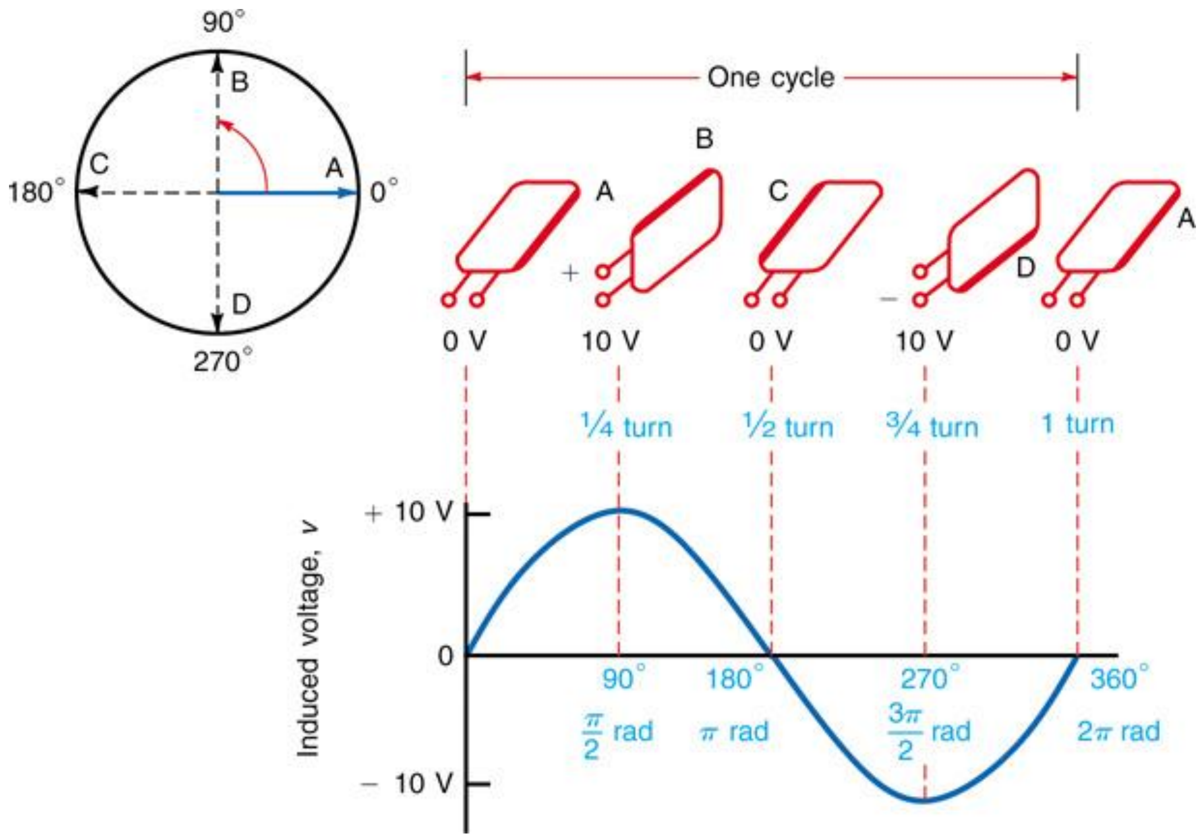


Fig. 15-3: One cycle of alternating voltage generated by rotating loop. Magnetic field, not shown here, is directed from top to bottom, as in Fig. 15-2.

15-2: Alternating-Voltage Generator

- Angular Measure and Radian Measure
  - The cycle of voltage corresponds to rotation of the loop around a circle, so parts of the cycle are described in angles.
  - The **radian** (rad) is an angle equivalent to 57.3 .
  - A radian is the angular part of the circle that includes an arc equal to the radius *r* of the circle.
  - A circle’s circumference equals $2\pi r$, so one cycle equals 2π rad.

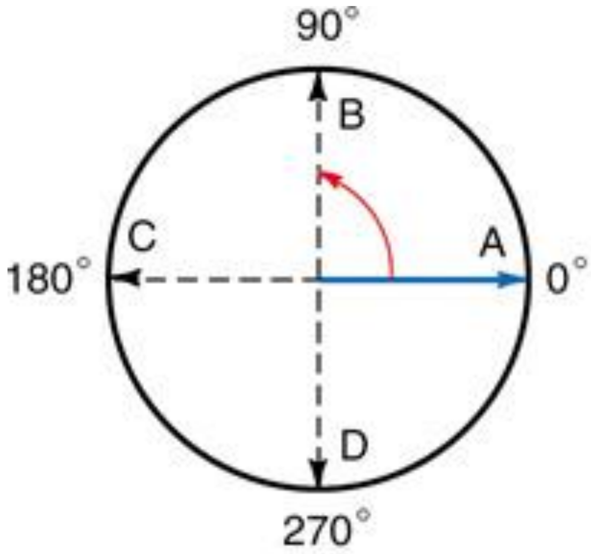


Fig. 15-3(a).

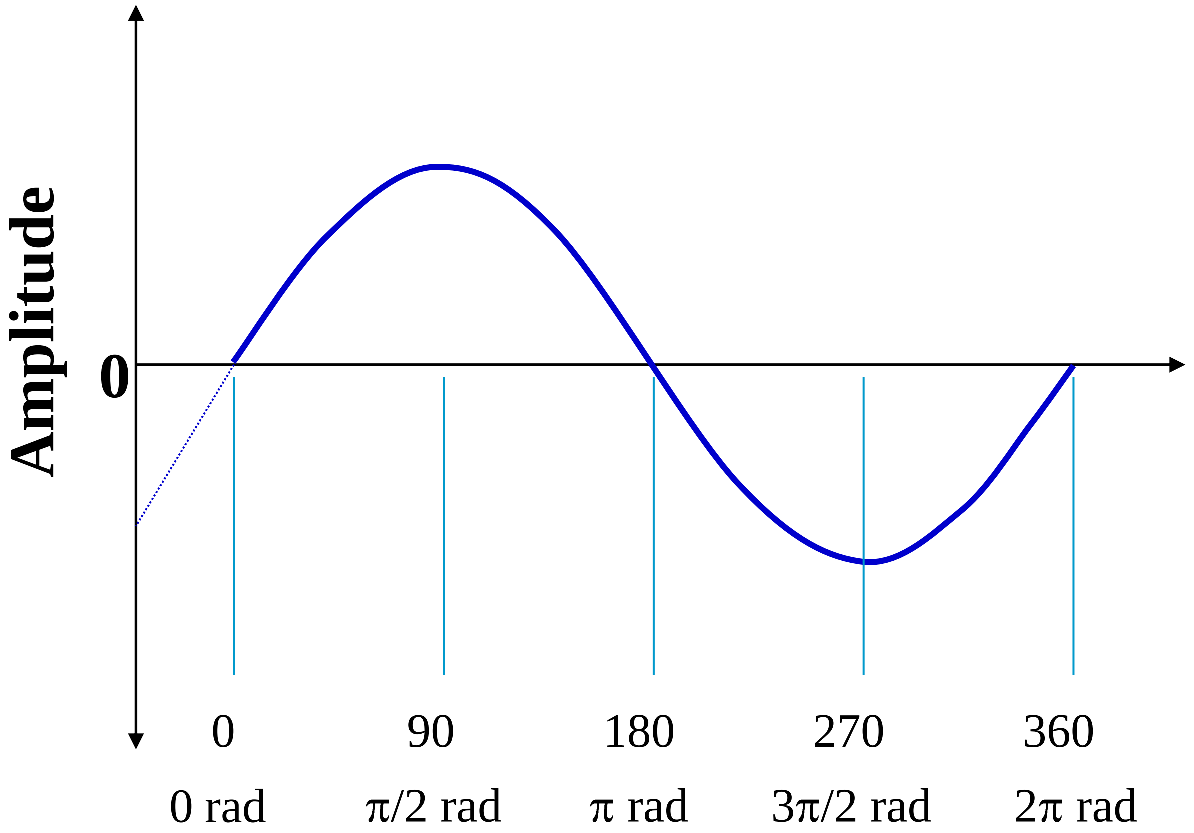
15-2: Alternating-Voltage Generator

- Angular Measure and Radian Measure

Angular Measurement	**Radian Equivalent**
Zero degrees	Zero radians
360	2π rad
180	½ 2π rad, or π rad
90°	½ × π rad, or $\pi/2$ rad
270° (180°+ 90°)	π rad + $\pi/2$ rad = $3\pi/2$ rad

15-2: Alternating-Voltage Generator

- Angular Measure and Radian Measure



15-3: The Sine Wave

- The voltage waveform pictured here is called a sine wave, sinusoidal wave, or sinusoid.
- The induced voltage is proportional to the sine of the angle of rotation in the circular motion producing the voltage.

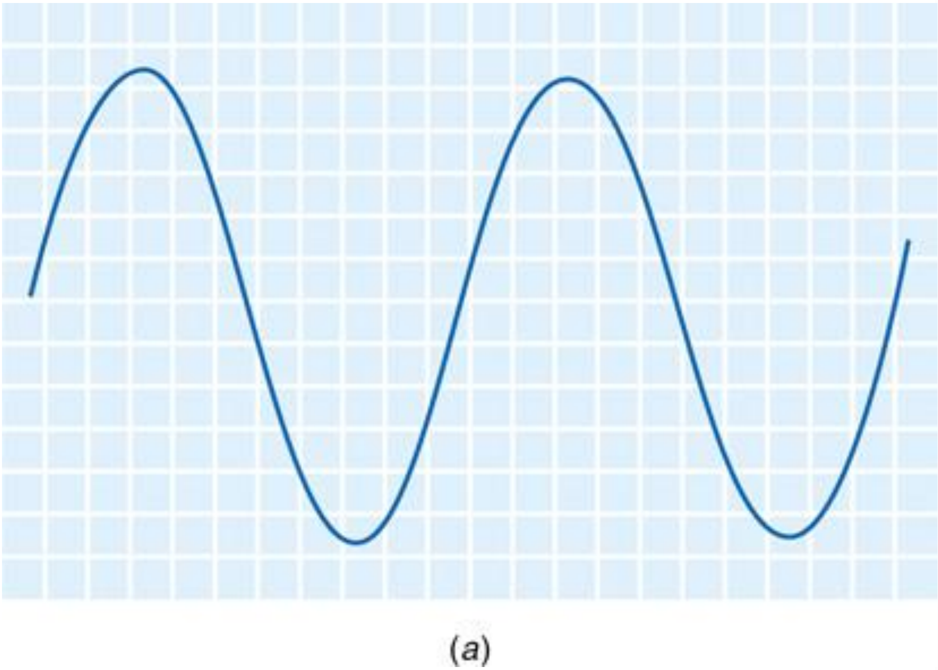


Fig. 15-1(a): Waveform of ac power-line voltage with frequency of 60 Hz. Two cycles are shown. Oscilloscope readout.

15-3: The Sine Wave

- With a sine wave, the induced voltage increases to a maximum at 90 , when the loop is vertical, just as the sine of the angle of rotation increases to a maximum at 90°.
- The instantaneous value of a sine-wave voltage for any angle of rotation is expressed in the formula:

$$v = V_M \sin \Theta$$

  - Θ (theta) is the angle
  - sin = the abbreviation for sine
  - V_M = the maximum voltage value
  - v = the instantaneous value of voltage at angle Θ.

15-3: The Sine Wave

- Characteristics of the Sine-Wave AC Waveform:
  - The cycle includes 360° or 2π rad.
  - The polarity reverses each half-cycle.
  - The maximum values are at 90° and 270°.
  - The zero values are at 0° and 180°.
  - The waveform changes its values the fastest when it crosses the zero axis.
  - The waveform changes its values the slowest when it is at its maximum value.

15-4: Alternating Current

- When a sine wave of alternating voltage is connected across a load resistance, the current that flows in the circuit is also a sine wave.
- The sine wave frequency of an alternating voltage is the same as the alternating current through a series connected load resistance.

15-4: Alternating Current

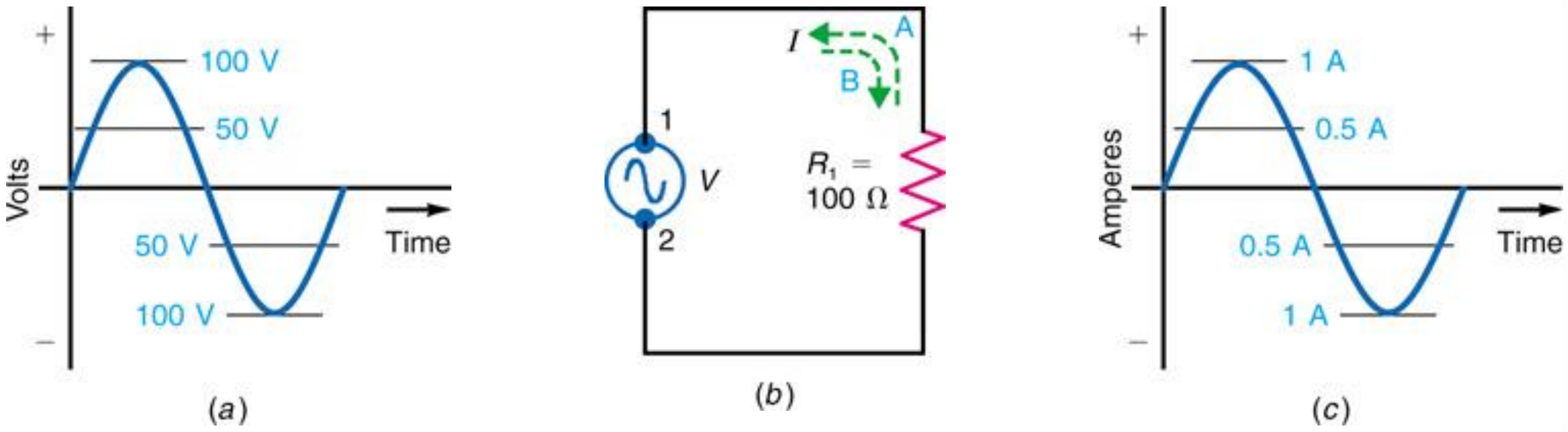


Fig. 15-5: A sine wave of alternating voltage applied across *R* produces a sine wave of alternating current in the circuit. (*a*) Waveform of applied voltage. (*b*) AC circuit. Note the symbol for sine-wave generator *V.* (*c*) Waveform of current in the circuit.

15-4: Alternating Current

- After the first half-cycle, polarity reverses and current flows in the opposite direction.
- The negative half-cycle of applied voltage is as useful as the positive half-cycle in producing current.
- The direction does not matter in the application. The motion of electrons against resistance produces power dissipation.
- Only *v* and *i* waveforms can be compared.

15-5: Voltage and Current Values for a Sine Wave

- The following specific magnitudes are used to compare one wave to another:
  - **Peak value**: maximum value V_M or I_M. This applies to the positive or negative peak.
    - **Peak-to-peak**: usually, but not always, double the peak value, as it measures distance between two amplitudes.
  - **Average value**: Arithmetic average of all values in one half-cycle (the full cycle average = 0).
  - **Root-Mean-Square (RMS)** or **Effective Value**: Relates the amount of a sine wave of voltage or current to the DC values that will produce the same heating effect.

15-5: Voltage and Current Values for a Sine Wave

- The average value is 0.637 peak value.
- The rms value is 0.707 peak value.
- The peak value is 1.414 rms value.
- The peak-to-peak value is 2.828 rms value.

15-5: Voltage and Current Values for a Sine Wave

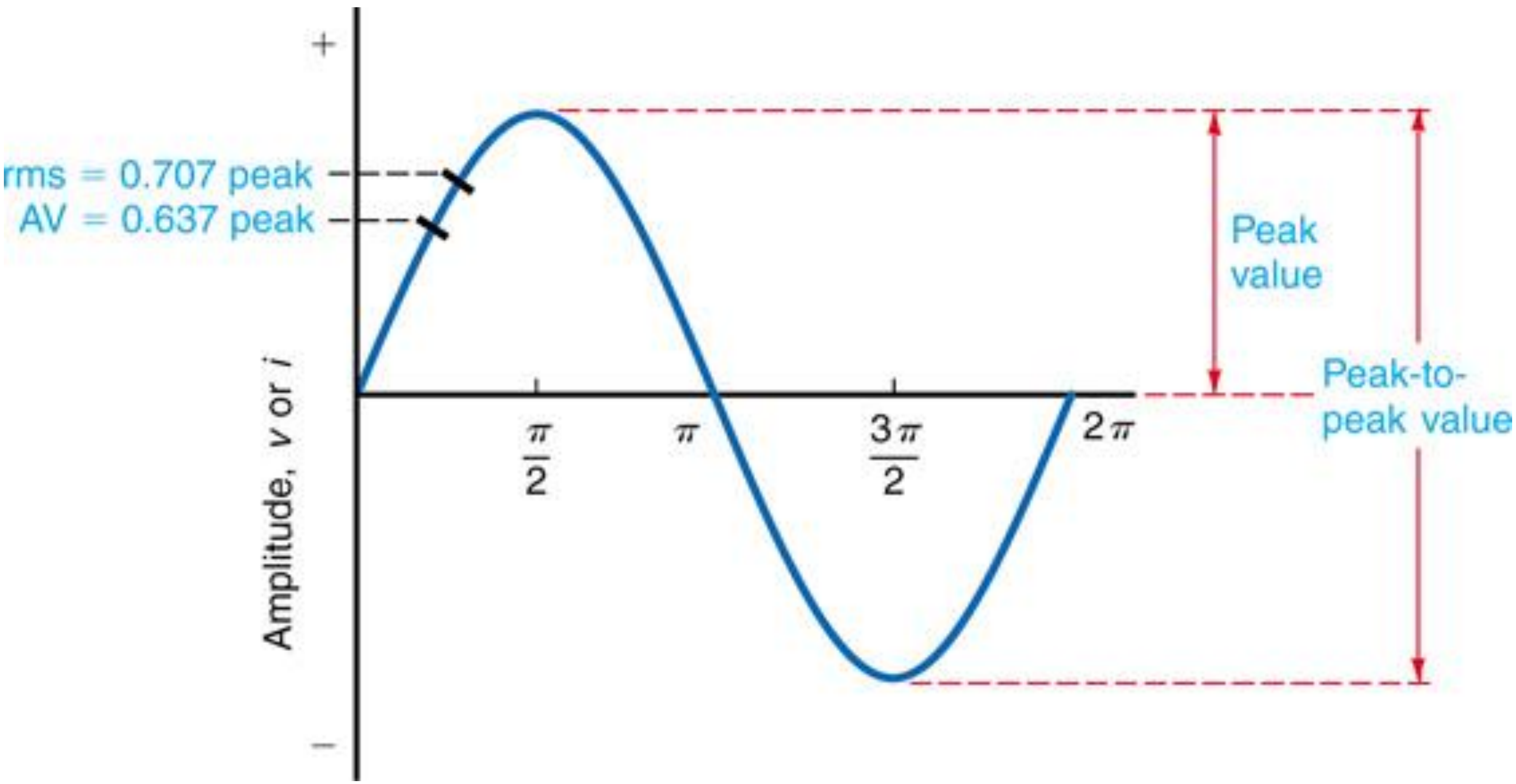
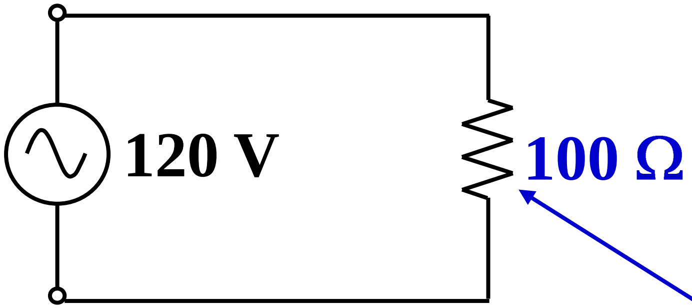


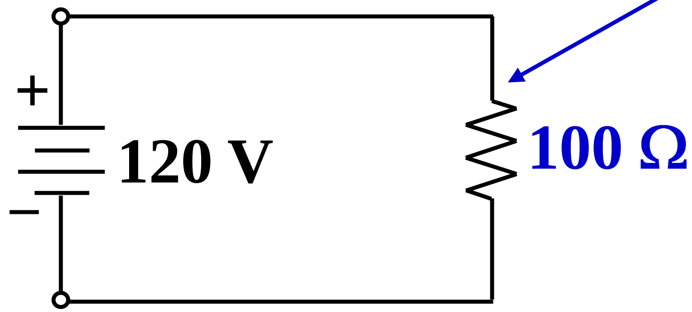
Fig. 15-6: Definitions of important amplitude values for a sine wave of voltage or current.

15-5: Voltage and Current Values for a Sine Wave

The *default* sine wave ac measurement is V_{rms} .



V_{rms} is the *effective* value. The heating effect of these two sources is identical.



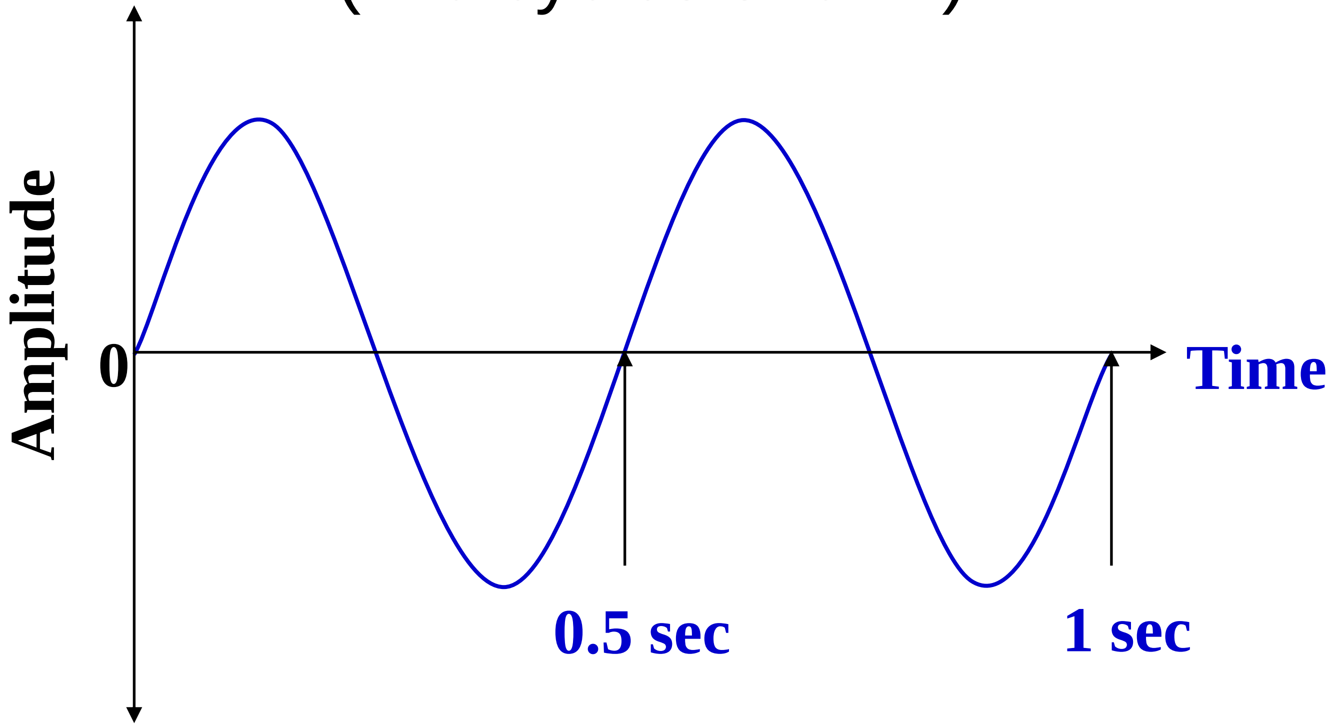
Same power dissipation

15-6: Frequency

- **Frequency** (f) is the number of cycles per second.
- **Cycle** is measured between two successive points having the same value and direction.
- One cycle per second is 1 Hz.

15-6: Frequency

Sine Wave Frequency
(two cycles shown)



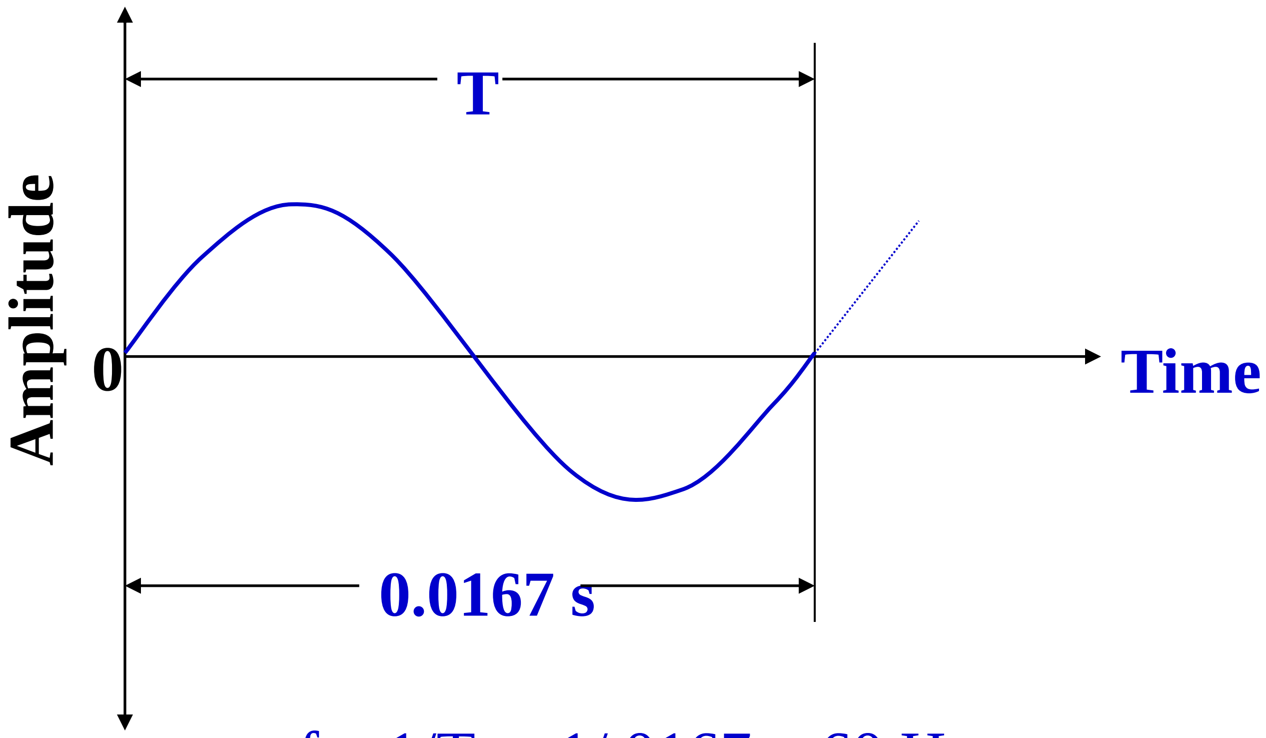
f = 2 Hz

15-7: Period

- **Period** (T) is the time per cycle.
- $T = 1/f$
- $f = 1/T$
- The higher the frequency, the shorter the period.

15-7: Period

Period (T)



f = 1/T = 1/.0167 = 60 Hz

15-9: Phase Angle

- **Phase angle** (Θ) is the angular difference between the same points on two different waveforms of the same frequency.
  - Two waveforms that have peaks and zeros at the same time are in phase and have a phase angle of 0°.
  - When one sine wave is at its peak while another is at zero, the two are 90° out of phase.
  - When one sine wave has just the opposite phase of another, they are 180° out of phase.

15-9: Phase Angle

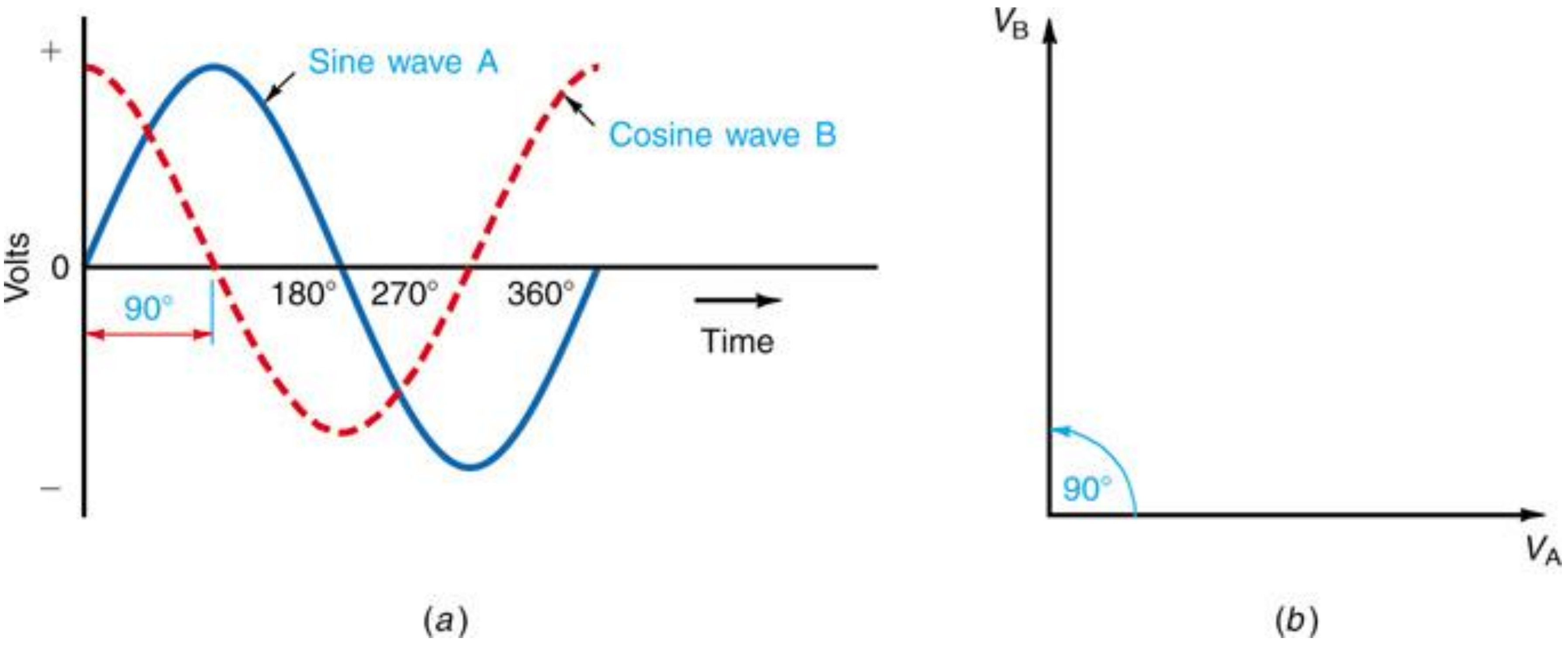


Fig. 15-10: Two sine-wave voltages 90° out of phase. (*a*) Wave B leads wave A by 90°. (*b*) Corresponding phasors V_B and V_A for the two sine-wave voltages with phase angle Θ = 90°. The right angle shows quadrature phase.

15-9: Phase Angle

- Phase-Angle Diagrams
  - Similar to vectors, **phasors** indicate the amplitude and phase angle of ac voltage or current.
    - A vector quantity has direction in space, but a phasor angle represents a difference in time.
  - The length of the phasor represents the amplitude of the waveform.
  - The angle represents the phase angle of the waveform.

15-9: Phase Angle

- Phase-Angle Diagrams
  - The phasor corresponds to the entire cycle of voltage.
  - The phase angle of one wave can be specified only with respect to another as a reference. Usually the reference phasor is horizontal.

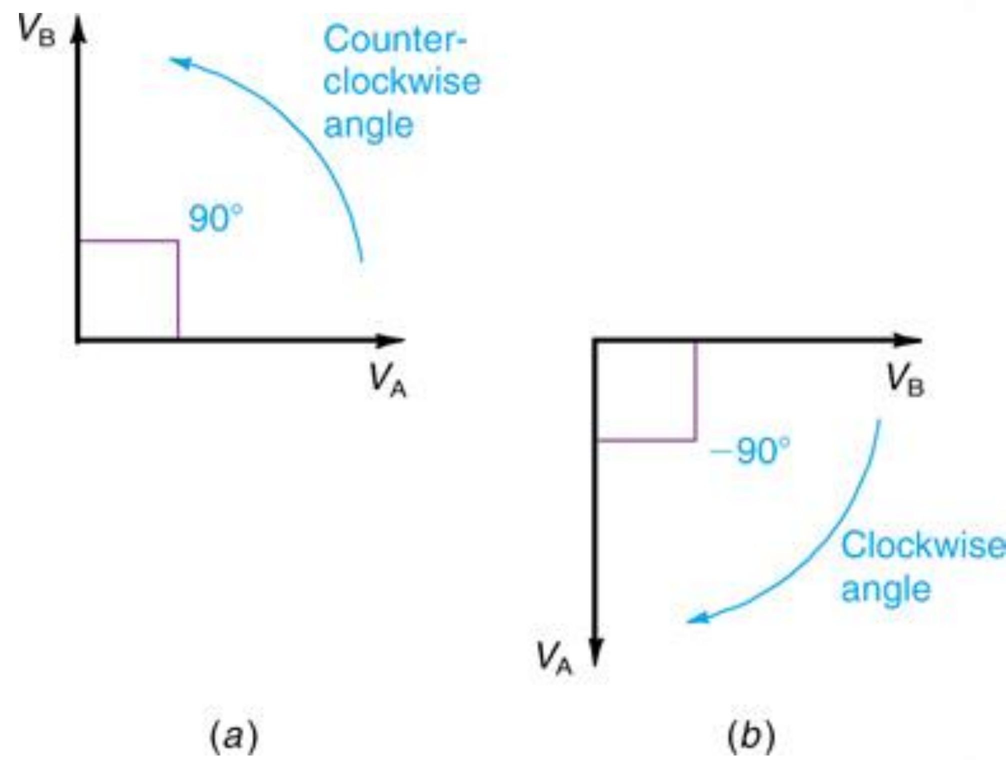


Fig. 15-11: Leading and lagging phase angles for 90°. (*a*) When phasor V_A is the horizontal reference, phasor V_B leads by 90°. (*b*) When phasor V_B is the horizontal reference, phasor V_A lags by −90°.

15-11: Alternating Current Circuits with Resistance

- Series AC Circuit with *R*.
  - The 4-A current is the same in all parts of the series circuit. (Note: This principle applies for either an ac or dc source.)
  - The series voltage drops are equal to V = I x R
  - The sum of the individual IR drops equals the applied voltage (120V).

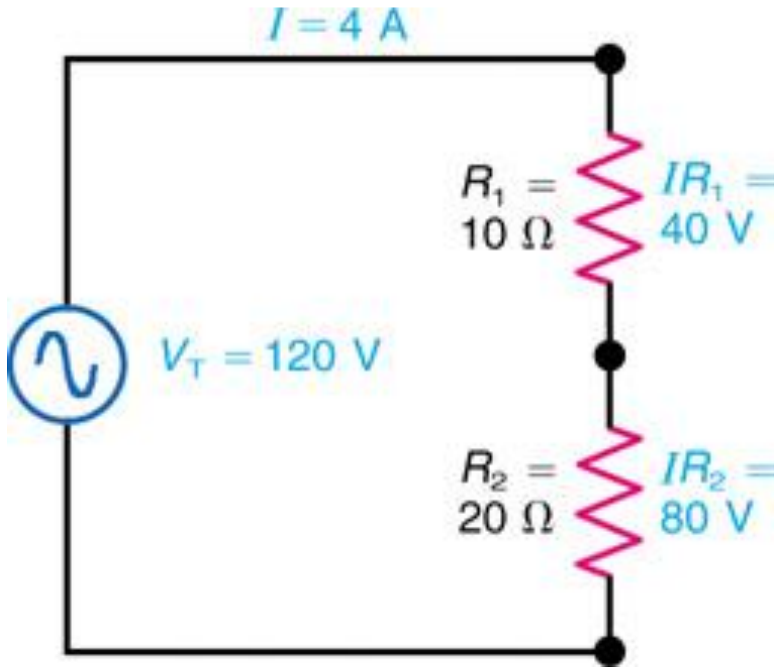


Fig. 15-16: Series ac circuit with resistance only.

15-11: Alternating Current Circuits with Resistance

- Parallel AC Circuit with *R*.
  - The voltage across the parallel branches is the same as the applied voltage.
  - Each branch current is equal to the applied voltage (120V) divided by the branch resistance.
  - Total line current is the sum of the branch currents (18A).

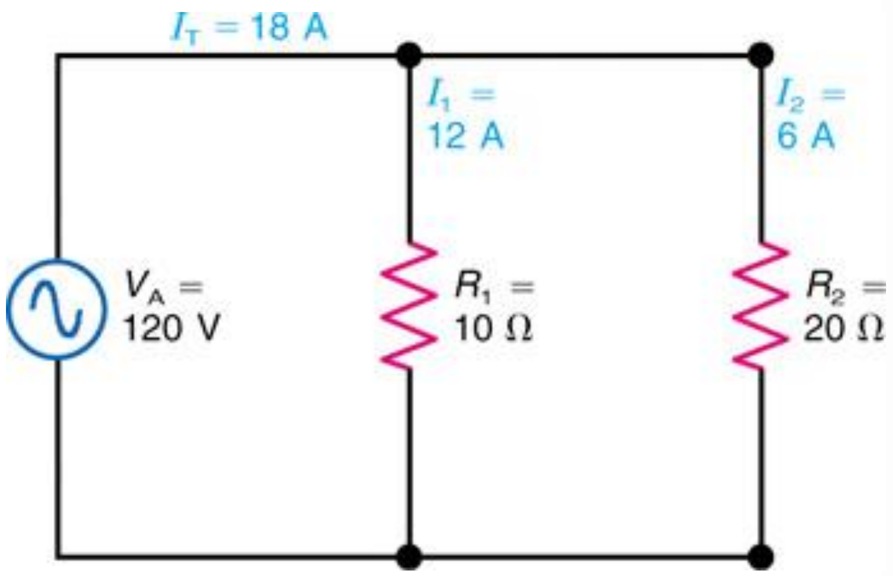


Fig. 15-17: Parallel ac circuit with resistance only.

15-11: Alternating Current Circuits with Resistance

- Series-Parallel AC Circuit with *R*.
  - The main line current I_T produced by the 120V source is equal to V/R_T.
  - Since the branch resistances are equal, the 4-A I_T divides equally.
  - Parallel branch currents add to equal the 4-A current in the main line.

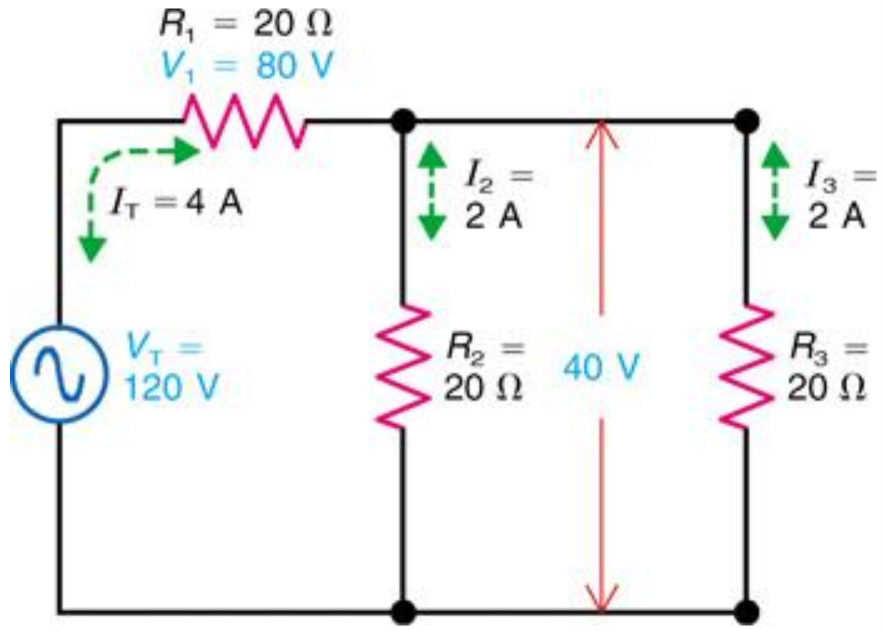
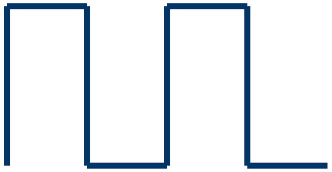


Fig. 15-18: Series-parallel ac circuit with resistance only.

15-12: Nonsinusoidal AC Waveforms

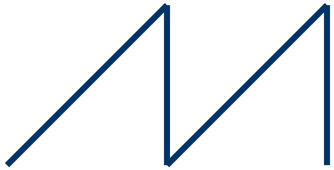
- In many electronic applications, other waveforms besides sine and cosine are important. Some of those forms are shown below.

Square wave



Common in digital electronic circuitry

Sawtooth wave



Used in timing and control circuitry

Pulse wave

Used in digital and control circuitry

15-12: Nonsinusoidal AC Waveforms

- Key **Similarities** and **Differences** between Sinusoidal and Nonsinusoidal Waveforms
  - For all waveforms, the cycle is measured between two points having the same amplitude and varying in the same direction.
  - Peak amplitude is measured from the zero axis to the maximum positive or negative value.
  - Peak-to-peak amplitude is better for measuring nonsinusoidal waveshapes because they can have unsymmetrical peaks.

15-12: Nonsinusoidal AC Waveforms

- Key Similarities and Differences between Sinusoidal and Nonsinusoidal Waveforms
  - The rms value 0.707 applies only to sine waves.
  - Phase angles apply only to sine waves.
  - All the waveforms represent ac voltages. Positive values are shown above the zero axis, and negative values are shown below the axis.

15-14: The 60-Hz AC Power Line

- Almost all homes in the US are supplied alternating voltage between 115 and 125 V rms, at a frequency of 60 Hz.
- The incoming voltage is wired to all the wall outlets and electrical equipment in parallel.
- The 120-V source of commercial electricity is the 60-Hz **power line** or the **mains**, indicating that it is the main line for all the parallel branches.

15-14: The 60-Hz AC Power Line

- Applications in Residential Wiring:
  - Residential wiring uses ac power instead of dc, because ac is more efficient in distribution from the generating station.
  - House wiring uses 3-wire, single-phase power.
  - The voltages for house wiring are 120 V to ground, and 240 V across the two high sides.
    - A value higher than 120 V would create more danger of fatal electric shock, but lower voltages would be less efficient in supplying power.

15-14: The 60-Hz AC Power Line

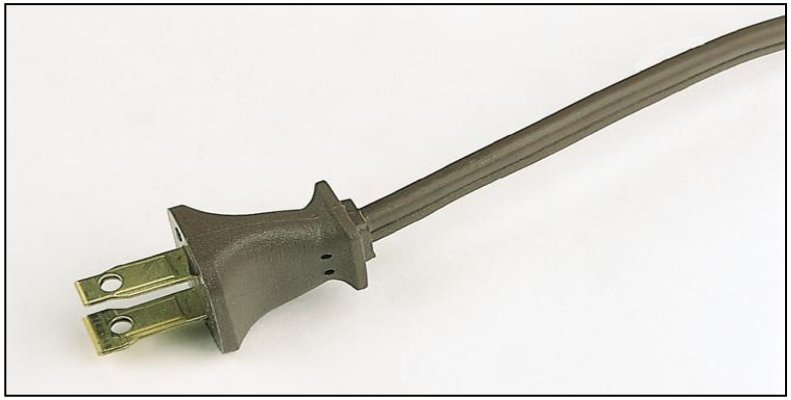
- Applications in Residential Wiring:
  - Higher voltage can supply electric power with less I^2R loss, since the same power is produced with less I.
  - Although the frequency of house wiring in North America is 60 Hz, many places outside N. America use a 50 Hz standard for house wiring.

15-14: The 60-Hz AC Power Line

- Grounding
  - **Grounding** is the practice of connecting one side of the power line to earth or ground.
  - The purpose is safety:
    - Grounding provides protection against dangerous electric shock.
    - The power distribution lines are protected against excessively high voltage, particularly from lightning.

15-14: The 60-Hz AC Power Line

- Grounding
  - Plug connectors for the ac power line are configured to provide protection because they are polarized with respect to the ground connections.



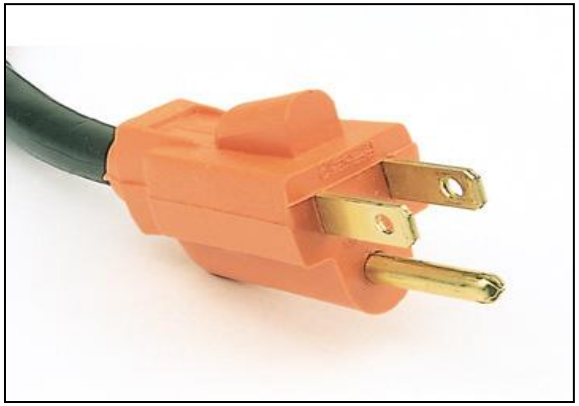


Fig. 15-22: Plug connectors polarized for ground connection to an ac power line. (*a*) Wider blade connects to neutral. (*b*) Rounded pin connects to ground.

15-14: The 60-Hz AC Power Line

- Grounding
  - The ground-fault circuit interrupted (GFCI) is a device that can sense excessive leakage current and open the circuit as a protection against shock.

Fig. 15-23: Ground-fault circuit interrupter (GFCI).