The Transformer

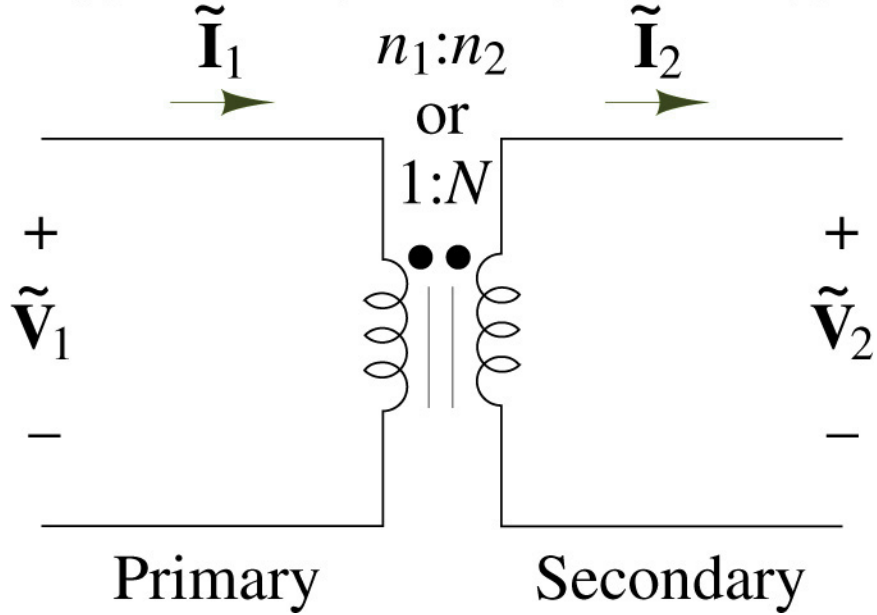The principle parts of a transformer and their functions are:

- The core, which makes a path for the magnetic flux.

- The primary coil, which receives energy from the ac source.

- The secondary coil, which receives energy from the primary winding and delivers it to the load.

- The enclosure, which protects the transformer from dirt, moisture, and mechanical damage.

Transformer Core

- The composition of a transformer core depends on voltage, current, and frequency. Commonly used core materials are air, soft iron, and steel. Each of these materials is suitable for certain applications. Generally, air-core transformers are used when the voltage source has a high frequency (above 20 kHz). Iron-core transformers are usually used when the source frequency is low (below 20 kHz).

- A soft-iron-core transformer is very useful where the transformer must be physically small, yet efficient. The iron-core transformer provides better power transfer than does the air-core transformer. A transformer whose core is constructed of laminated sheets of steel dissipates heat readily; thus it provides for the efficient transfer of power.

- The majority of transformers contain laminated-steel cores. These steel laminations are insulated with a nonconducting material, such as varnish, and then formed into a core. It takes about 40 laminations to make a core of 2 cm thick. The purpose of the laminations is to reduce losses which will be discussed later in this chapter.

- The most efficient transformer core is one that offers the best path for the most lines of flux with the least loss in magnetic and electrical energy.
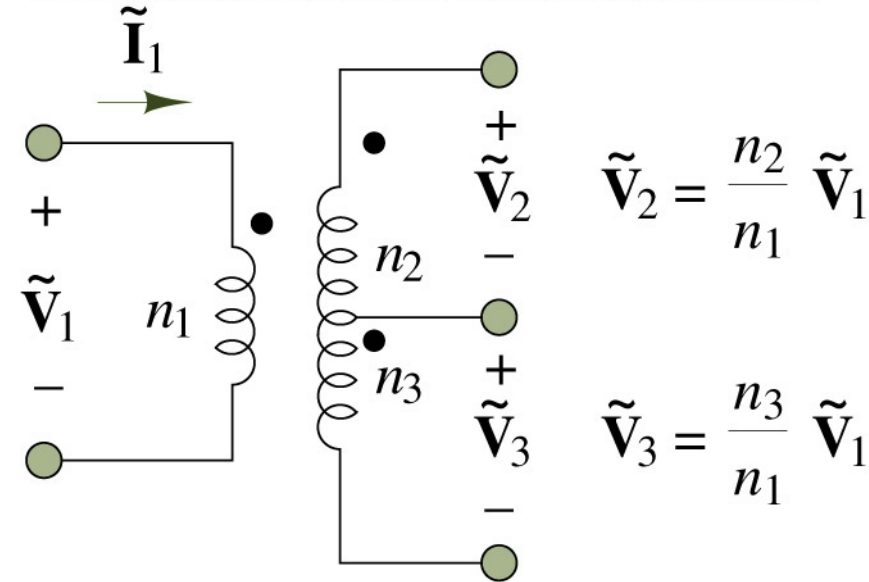
Ideal Transformer

$\tilde{\mathbf{I}}_1$ $n_1 : n_2$ $\tilde{\mathbf{I}}_2$

or

$1 : N$

$+$

$\tilde{\mathbf{V}}_1$ $+$

$-$ $\tilde{\mathbf{V}}_2$

$-$

Primary   Secondary

Center-tapped Transformer

$\tilde{\mathbf{I}}_1$

$+$ $+$

$\tilde{\mathbf{V}}_2$

$\tilde{\mathbf{V}}_1$ n_1 n_2 $-$

$-$ n_3 $+$

$\tilde{\mathbf{V}}_3$

$-$

$$\tilde{\mathbf{V}}_2 = \frac{n_2}{n_1} \, \tilde{\mathbf{V}}_1$$

$$\tilde{\mathbf{V}}_3 = \frac{n_3}{n_1} \, \tilde{\mathbf{V}}_1$$

Operation of an Ideal Transformer

$$\tilde{I}_2 = \frac{\tilde{I}_1}{N} \qquad \tilde{V}_2 = N\tilde{V}_1$$
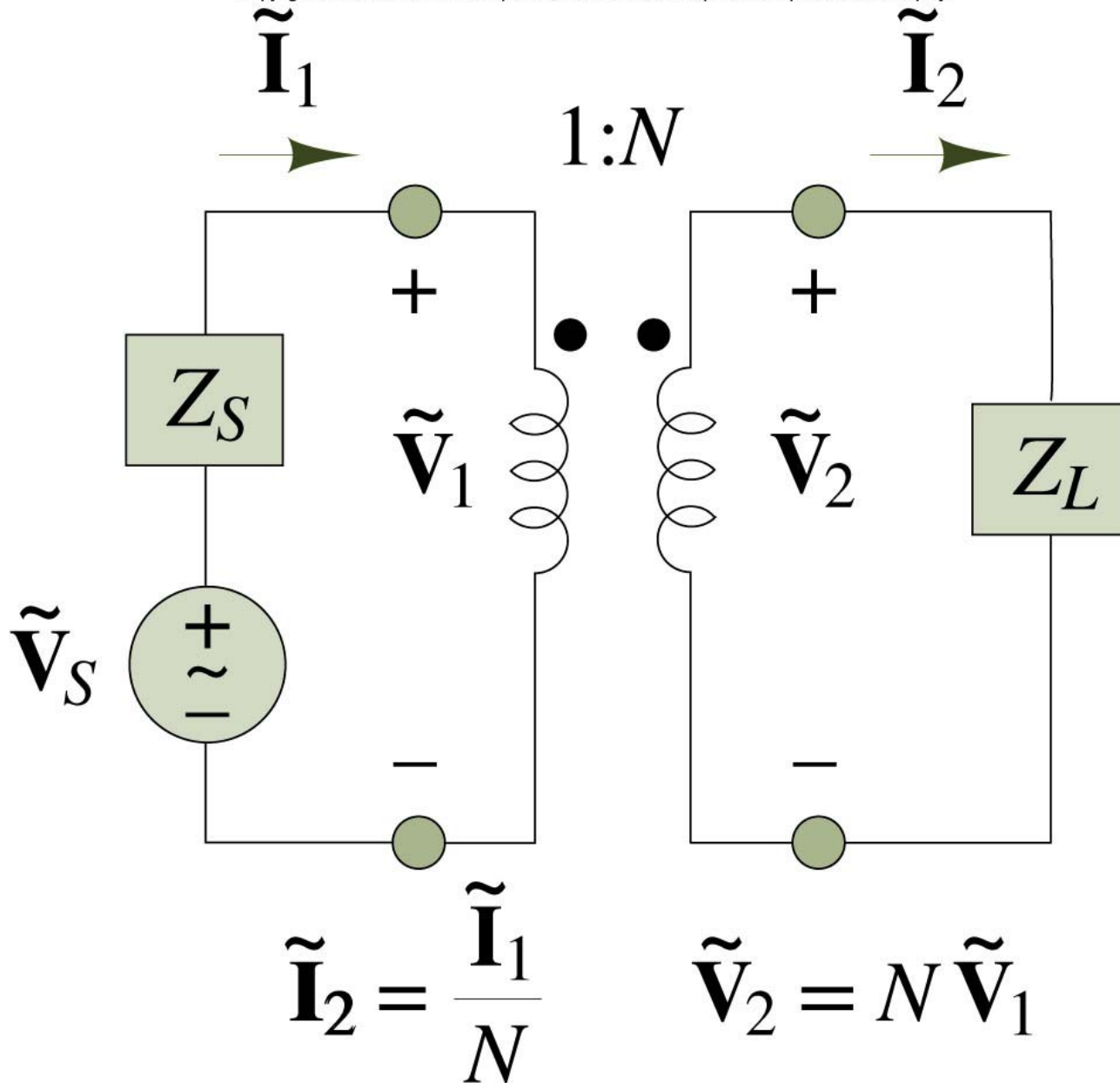
Impedance Reflection Across a Transformer
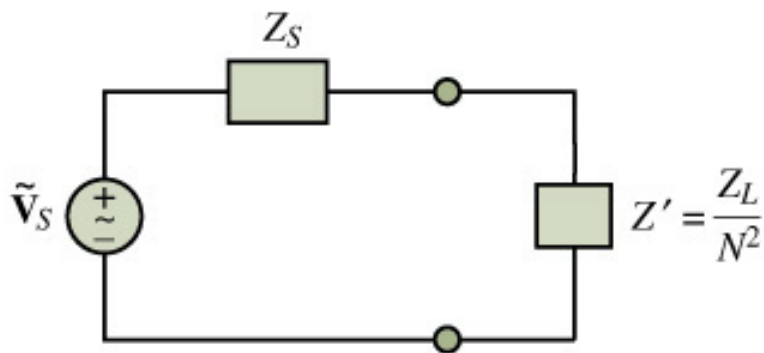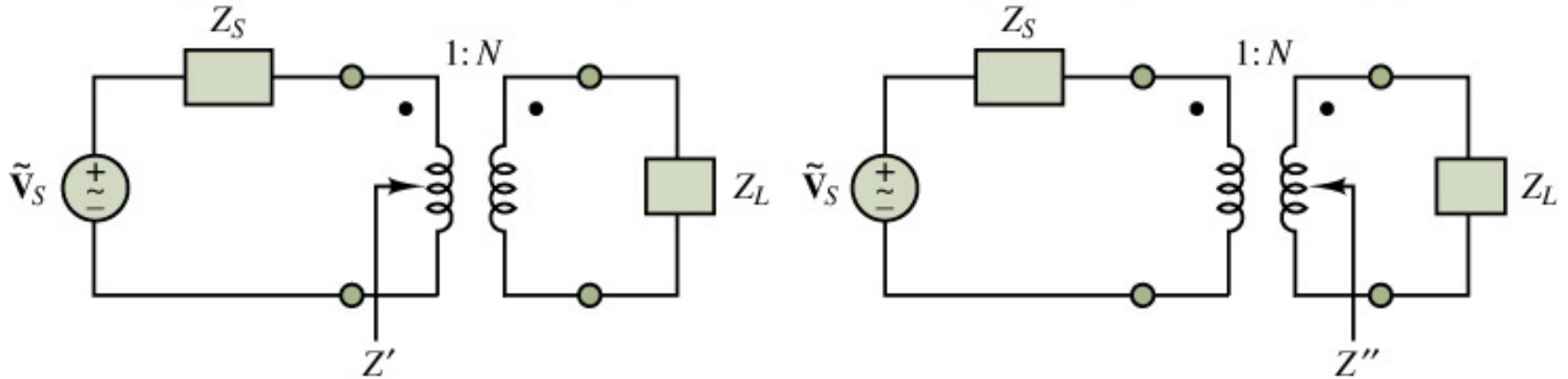
Reflected load
impedance circuit

$$Z' = \frac{Z_L}{N^2}$$
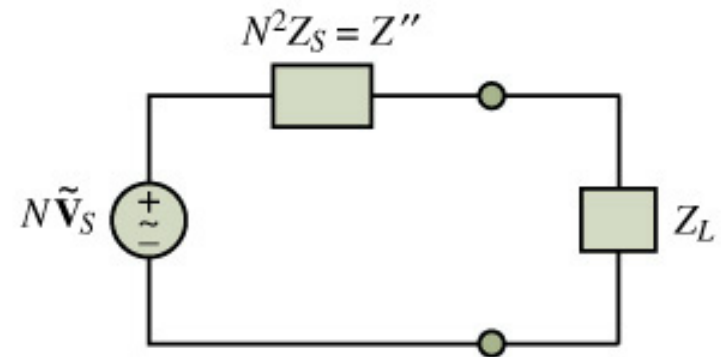
Reflected source
impedance circuit

$$N^2 Z_S = Z''$$

The Maximum Power Transfer Problem in AC Circuits

$$\tilde{V}_S = V_S \angle \theta$$
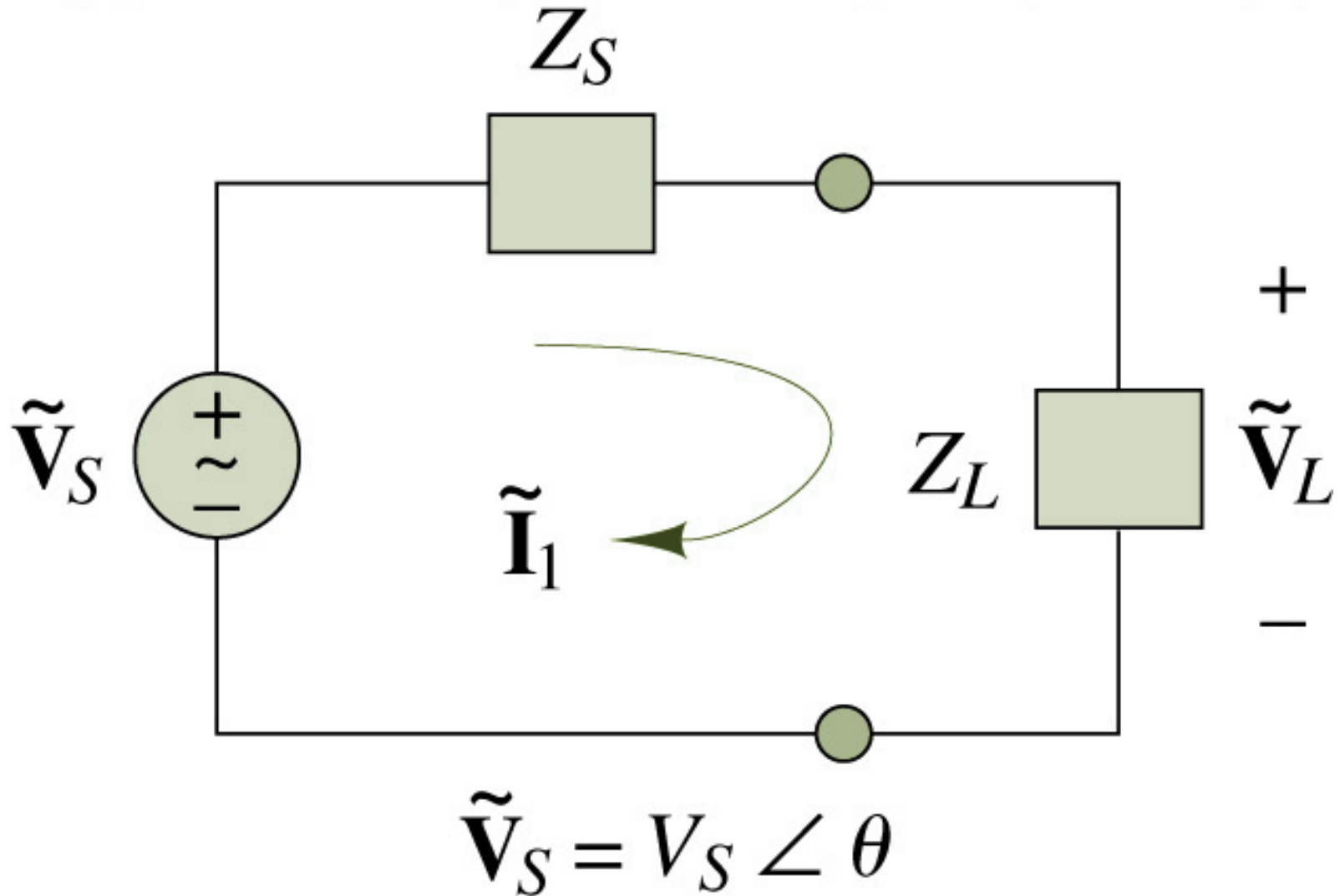
Maximum Power Transfer in an AC Circuit with a Transformer

Source   Transformer   Load

Equivalent circuit referred
to transformer primary
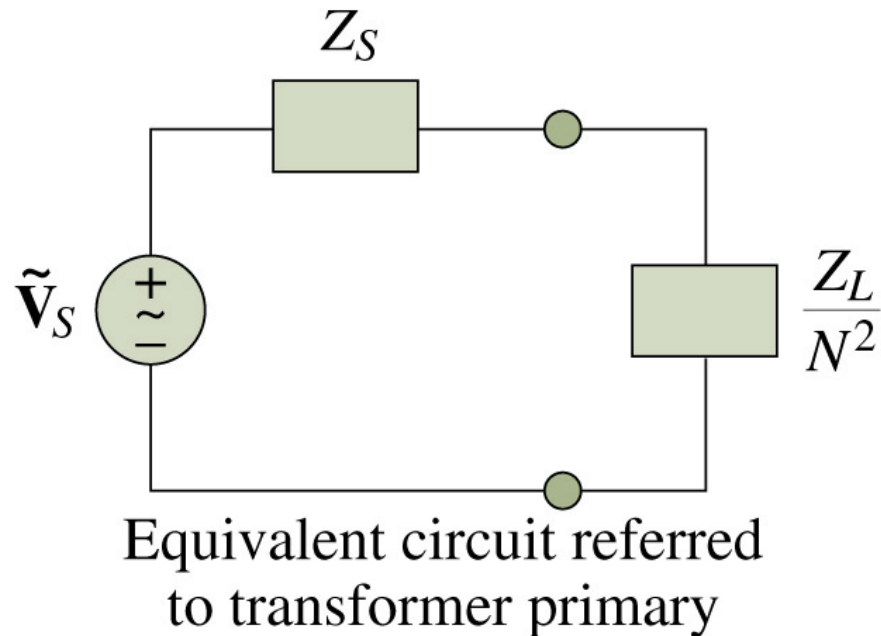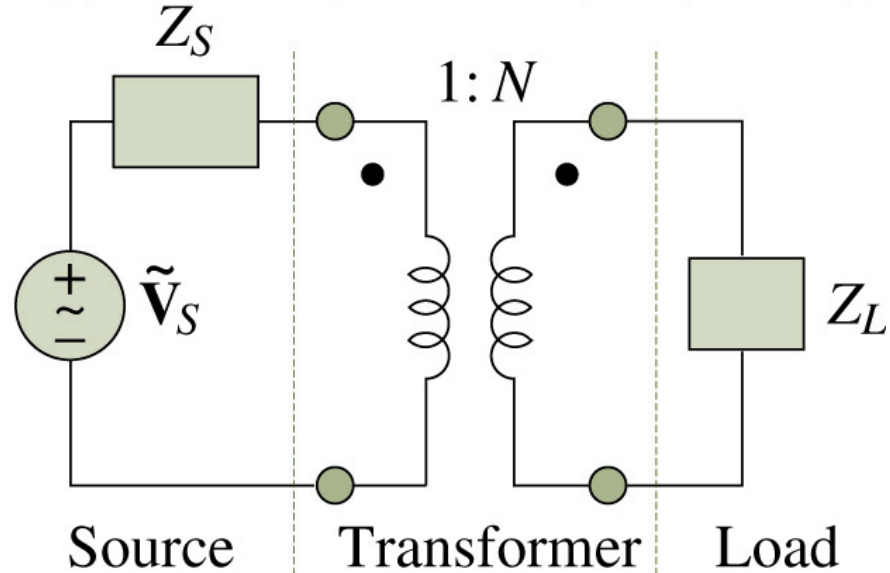
Electric Power Transmission: (a) Direct Power Transmission; (b) Power Transmission with Transformers
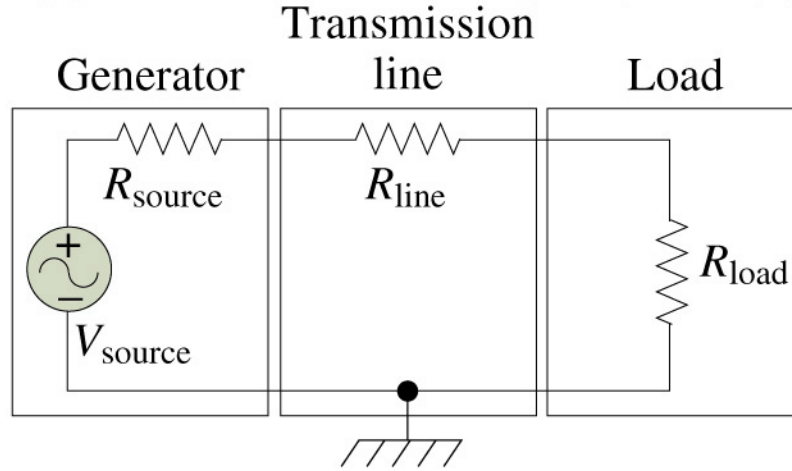
(a)
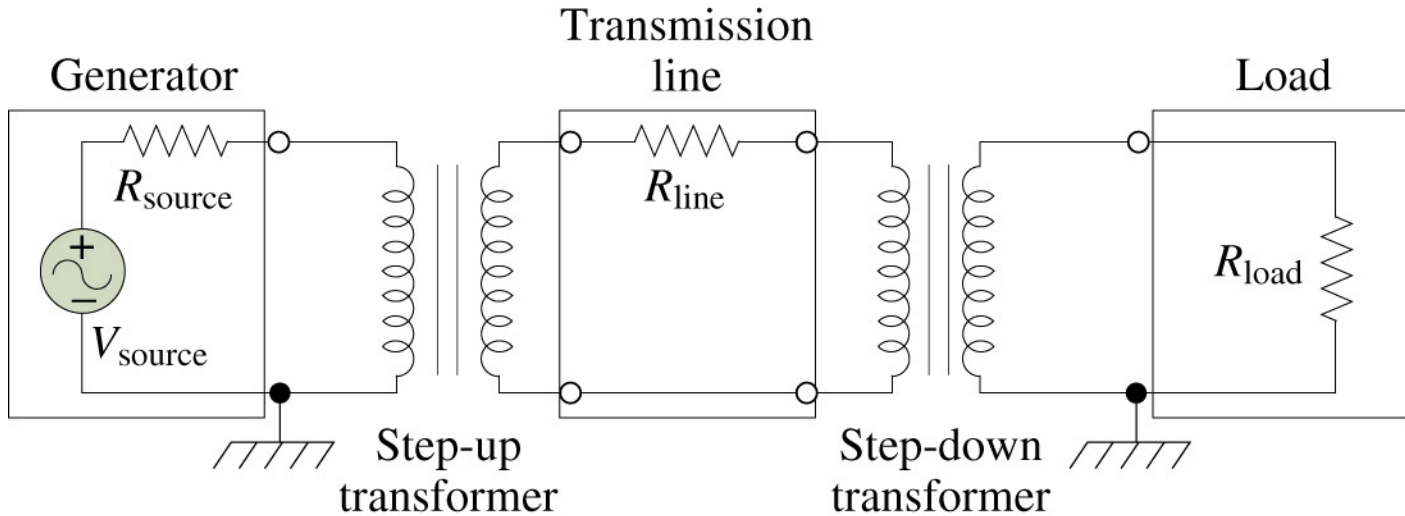
(b)

Electric Power Transmission: (c) Equivalent Circuit Seen by Generator; (d) Equivalent Circuit Seen by Load
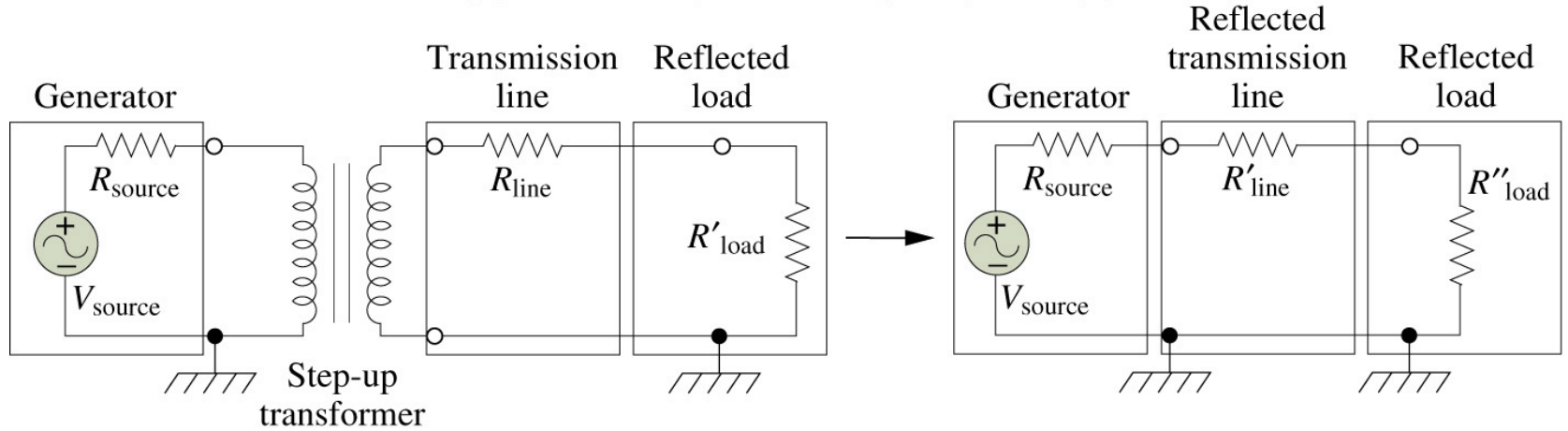
(c)
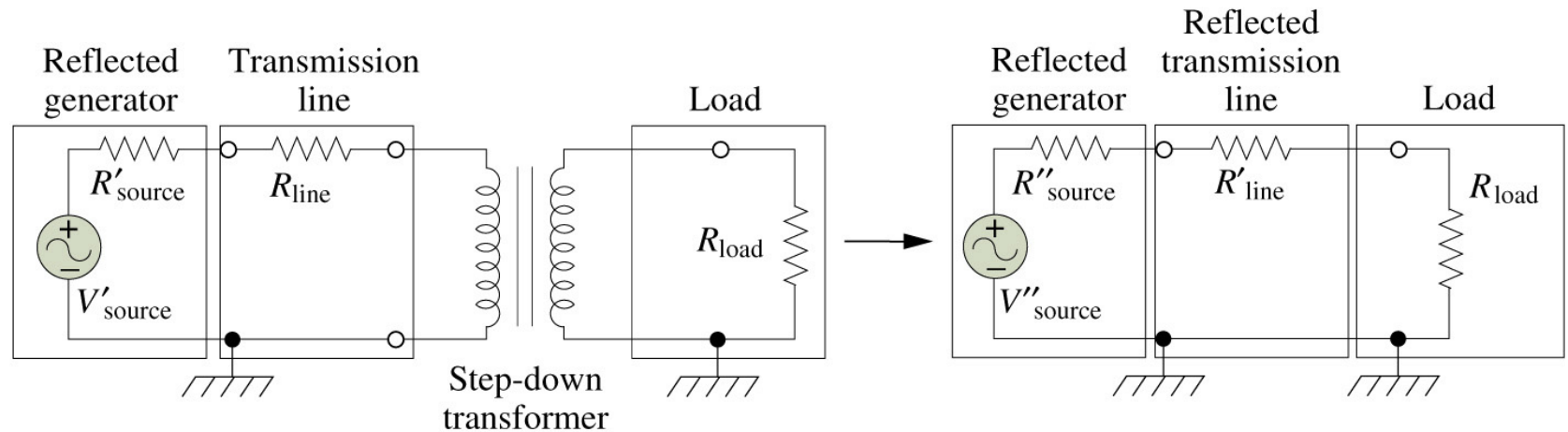
(d)

A Typical Residential Wiring Arrangement

10
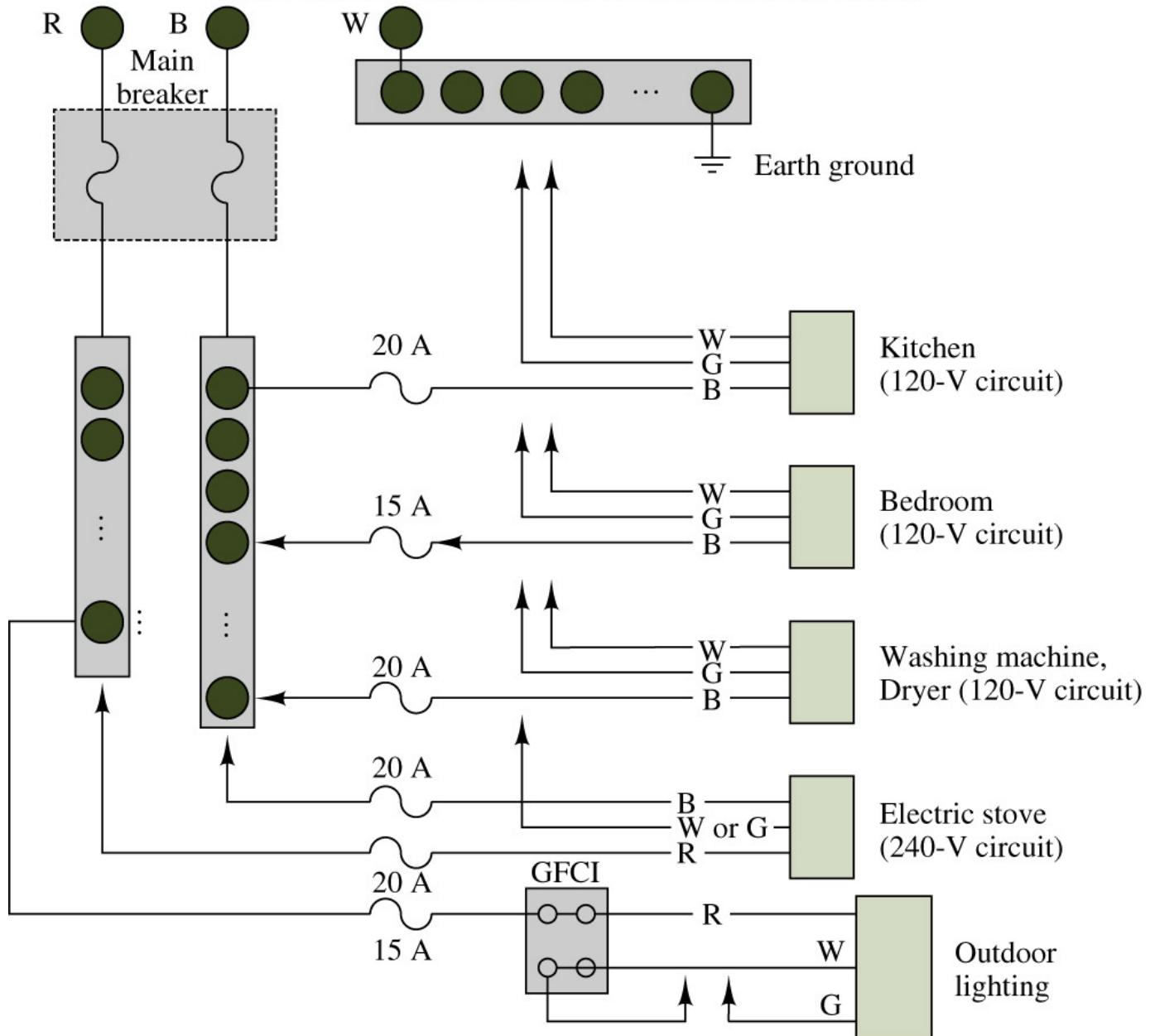
Structure of an AC Power Distribution Network

18 kV

Generator

Generating plant

345 kV

3φ step-down transformer

140 kV

46 kV

3φ step-down transformer

3φ step-down transformer (substation)

4,800 V

3φ step-down transformer to industrial or commercial customer

4,800 V

Center-tap transformer

120/240 V Three-wire service

Example 1: A transformer reduces voltage from 120 volts in the primary to 6 volts in the secondary. If the primary winding has 300 turns and the secondary has 15 turns, find the voltage and turns ratio.

Example 2: Example 2: An iron core transformer with a primary voltage of 240 volts has 250 turns in the primary and 50 turns in the secondary. Find the secondary voltage.

Example 3: When operated at 120 V in the primary of an iron core transformer, the current in the primary is 4 A. Find the current in the secondary if the voltage is stepped up to 500 V.

Example 4: A transformer with 480 turns on the primary and 60 turns on the secondary draws 0.6 amps from a 120 V line. Find Is.

More About the Transformer!
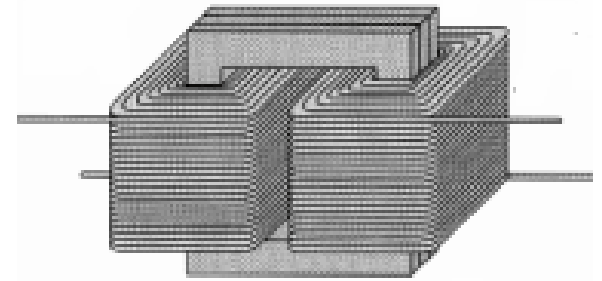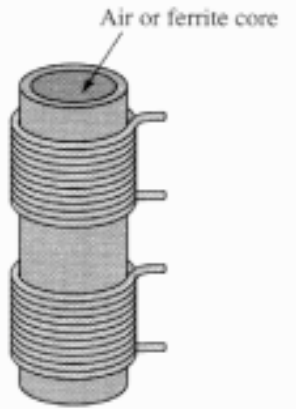
Air or ferrite core

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Applications of Transformers

- Transformers have many applications in power transmission and electronics:

- They may be used to minimise energy losses due to voltage drop in transmitting electricity over long distances.

- They match loads with internal resistance so that there is maximum power transfer.

- They couple signals between electronic stages.

Transformer Core

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Losses in Transformers

All transformers have copper and core losses, and flux leakage. Copper loss is ohmic power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss, in watts, may be found using the following equation

Copper Losses $= I_p R_p + I_s R_s$

Where, I_p is the primay current, I_s is the secondary current, R_p is the primary resistance, and R_s is the secondary resistance.

Core losses are caused by two factors: hysteresis and eddy current losses. Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the iron core. It can be used by laminations!

Efficiency of Transformer

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{Power Outpt}}{\text{Power Output} + \text{Copper Losses} + \text{Core Losses}} \times 100\%$$

- Example 4:   A 5:1 step-down transformer has a full-load secondary current of 20 amps. A short circuit test for copper loss at full load gives a wattmeter reading of 100 W. If $R_P = 0.3$, find R_S and power loss in the secondary.

  Ans: = R_S = 0.24; Power Loss in the secondary = $I_s^2 R_s$ = 96 W.