Chapter 3

Review of Basic Electrical and Magnetic Circuit Concepts

Symbols and Conventions

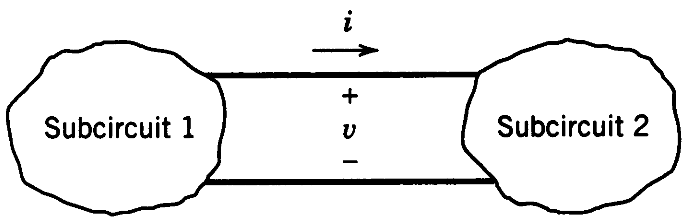


Figure 3-1 Instantaneous power flow.

- Symbols
- Polarity of Voltages; Direction of Currents
- MKS SI units

Sinusoidal Steady State

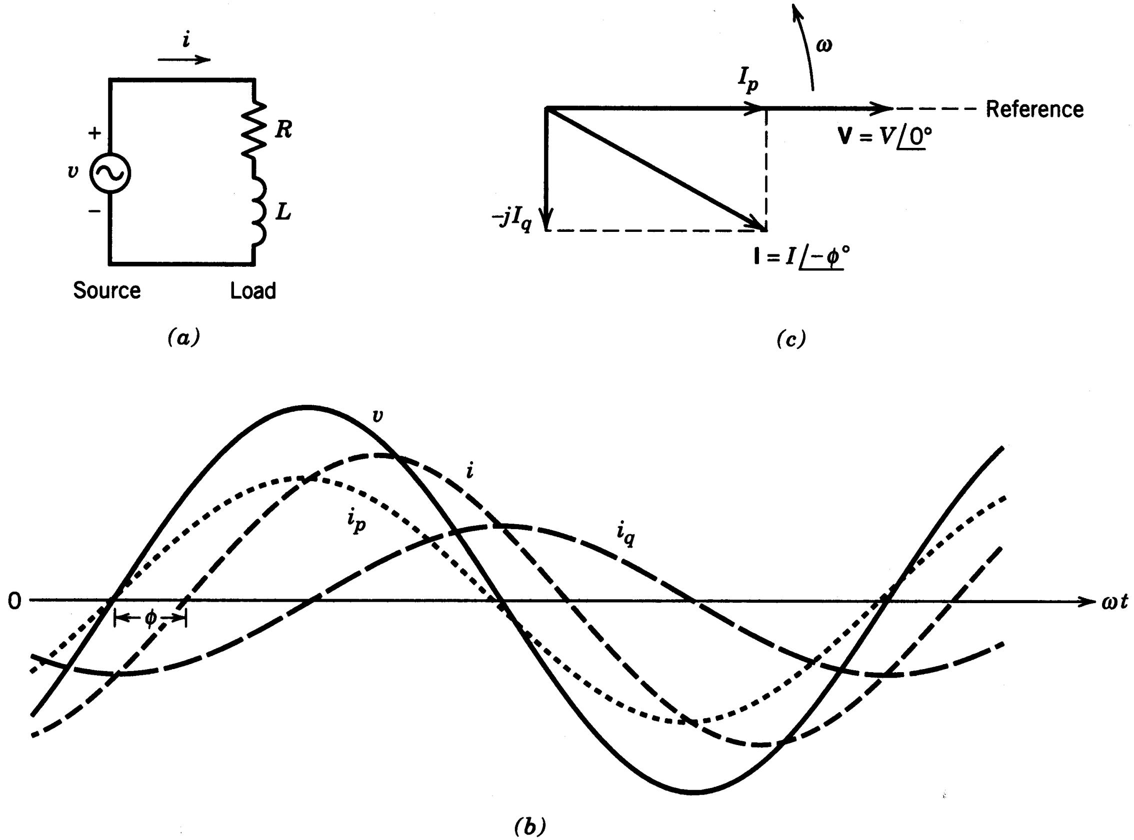


Figure 3-2 Sinusoidal steady state.

Three-Phase Circuit

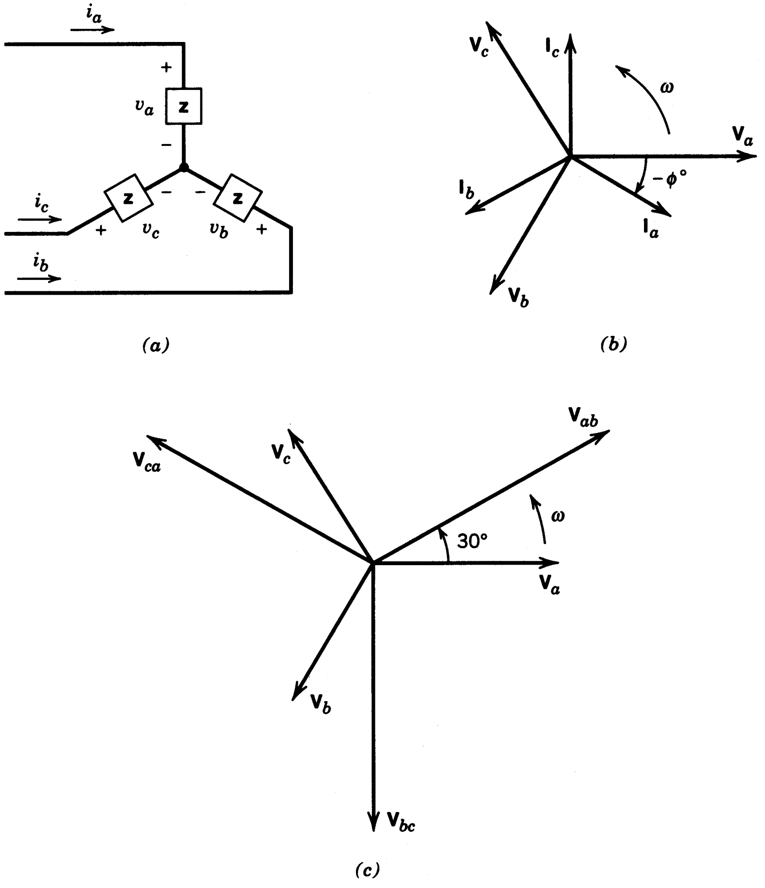
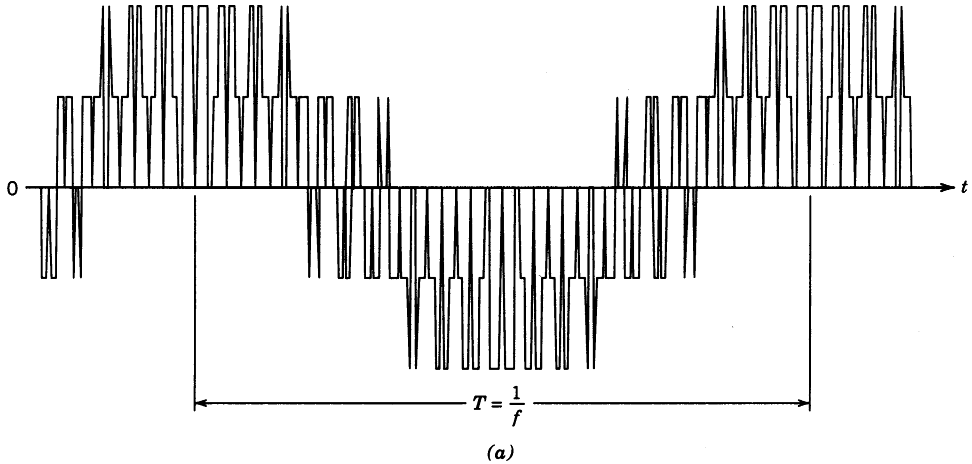


Figure 3-3 Three-phase circuit.

Steady State in Power Electronics



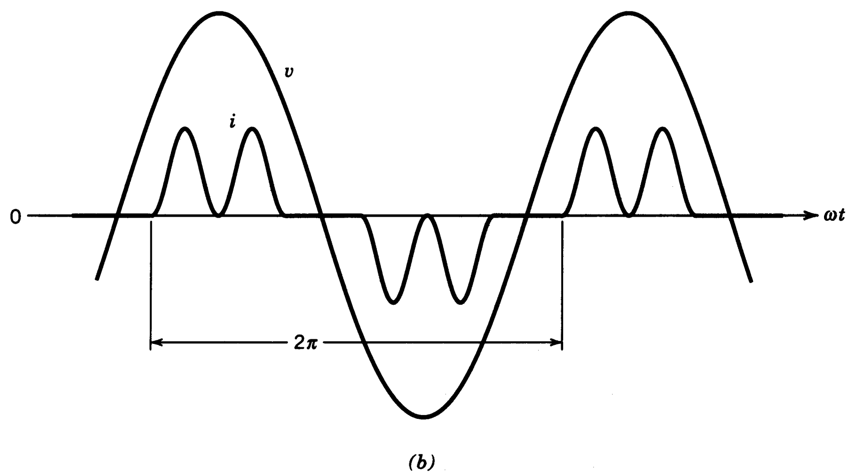


Figure 3-4 Nonsinusoidal waveforms in steady state.

Fourier Analysis

Table 3-1 Use of Symmetry in Fourier Analysis

Symmetry	*Condition Required*	a_h and b_h
Even	$f(-t) = f(t)$	$b_h = 0 \quad a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$
Odd	$f(-t) = -f(t)$	$a_h = 0 \quad b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$
Half-wave	$f(t) = -f(t + \frac{1}{2}T)$	$a_h = b_h = 0$ for even h $a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$ for odd h $b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$ for odd h
Even quarter-wave	Even and half-wave	$b_h = 0$ for all h $a_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\cos(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$
Odd quarter-wave	Odd and half-wave	$a_h = 0$ for all h $b_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\sin(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$

Distortion in the Input Current

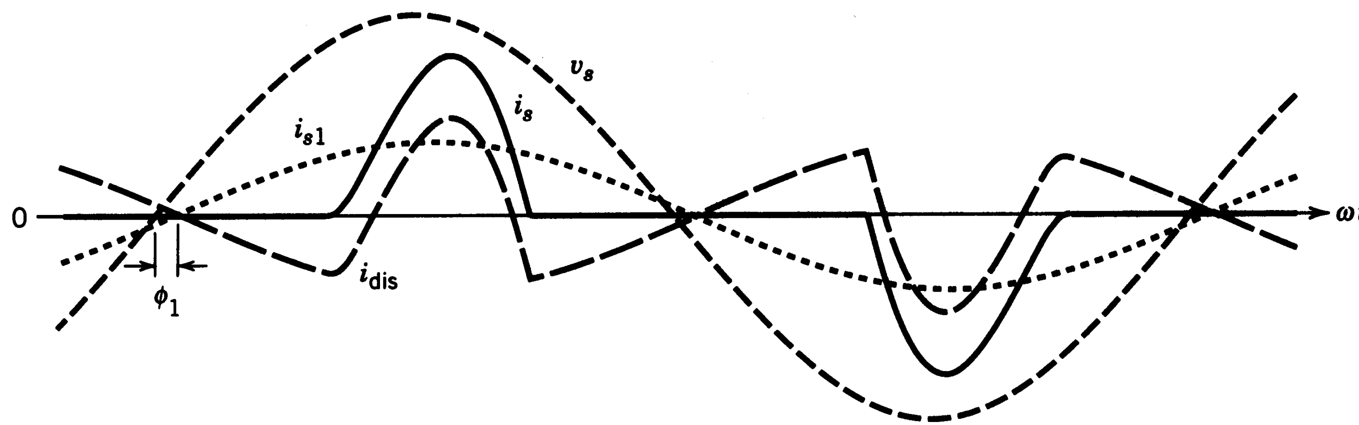


Figure 3-5 Line-current distortion.

- Voltage is assumed to be sinusoidal
- Subscript “1” refers to the fundamental
- The angle is between the voltage and the current fundamental

Phasor Representation

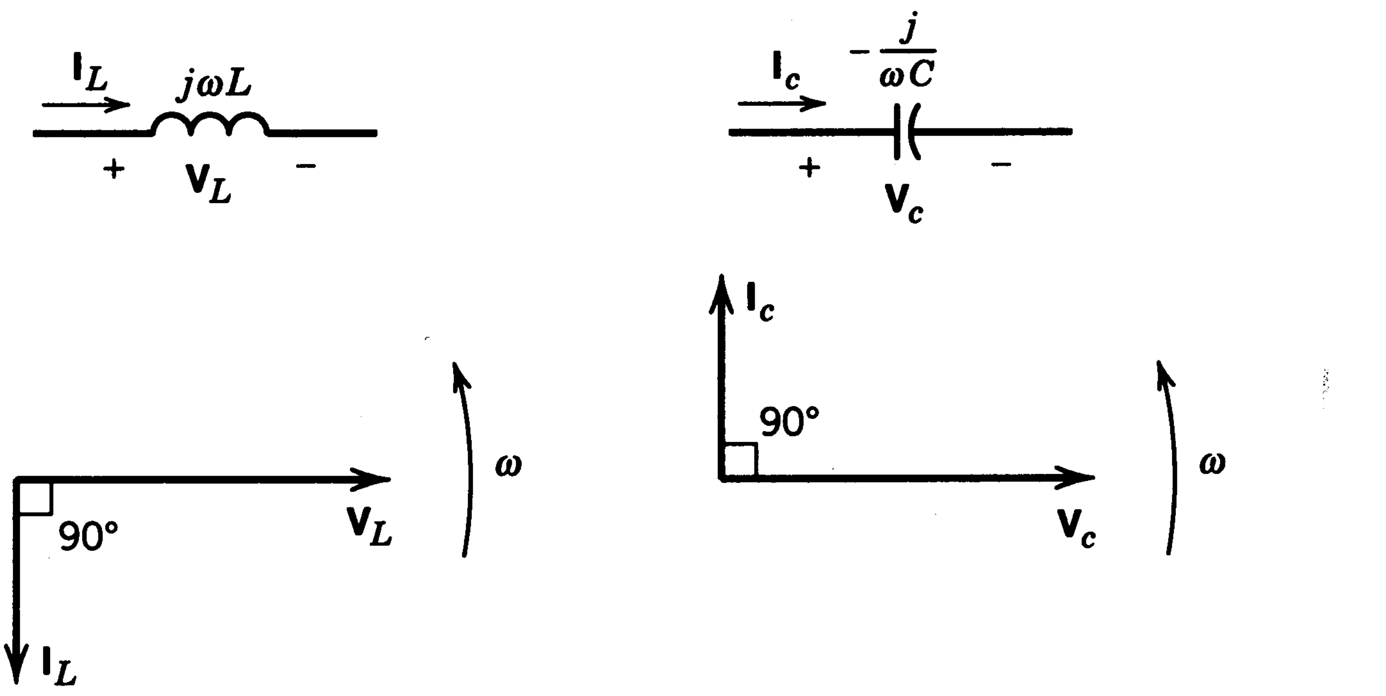


Figure 3-6 Phasor representation.

Response of L and C

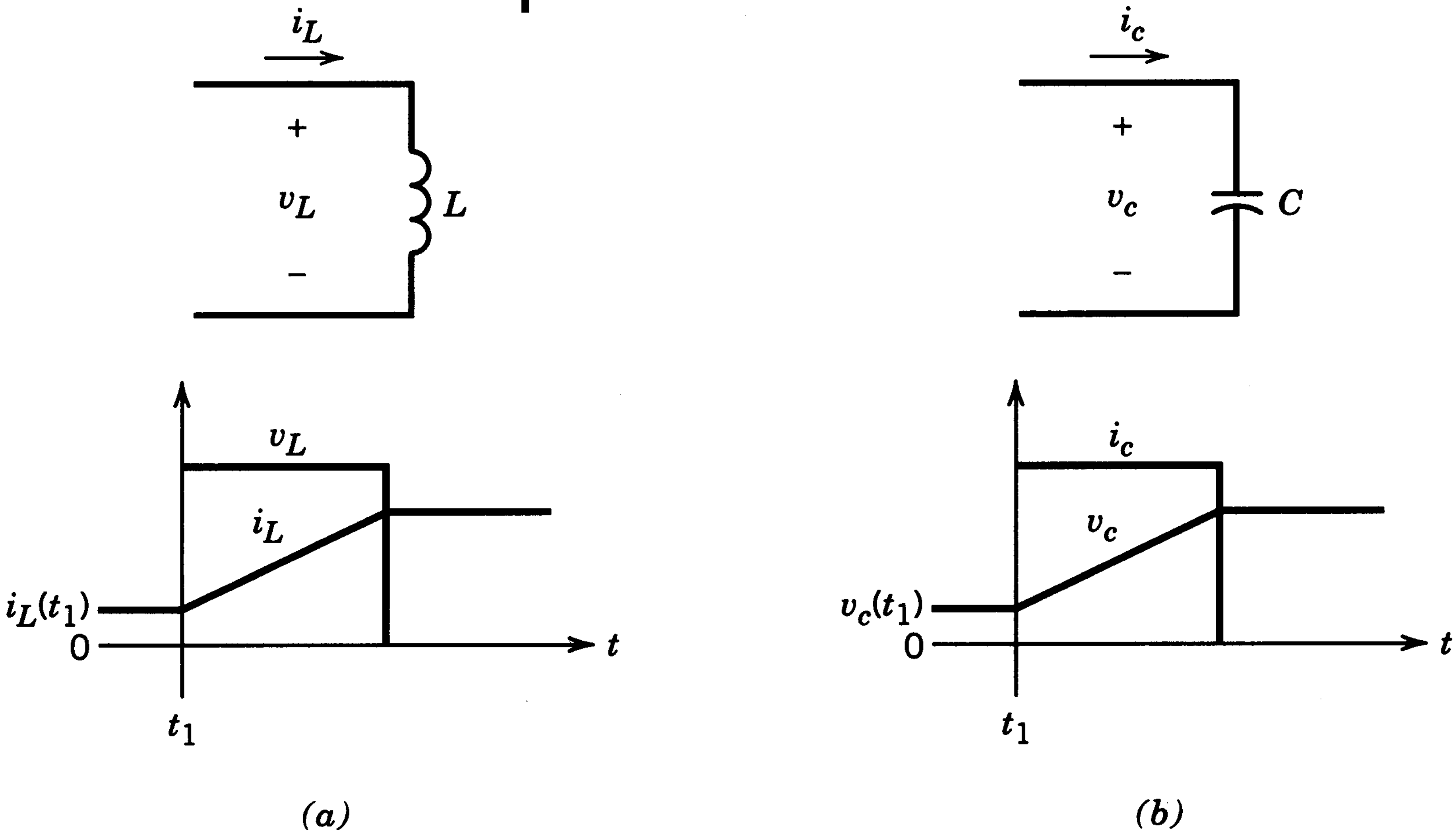


Figure 3-7 Inductor and capacitor response.

Inductor Voltage and Current in Steady State

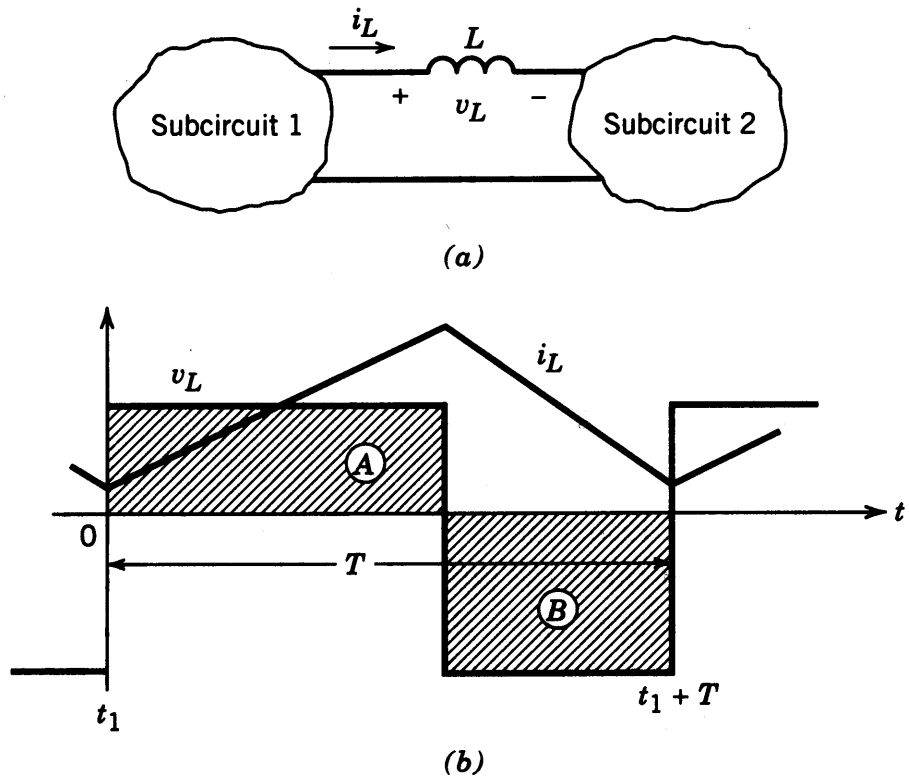


Figure 3-8 Inductor response in steady state.

- Volt-seconds over *T* equal zero.

Capacitor Voltage and Current in Steady State

- Amp-seconds over *T* equal zero.

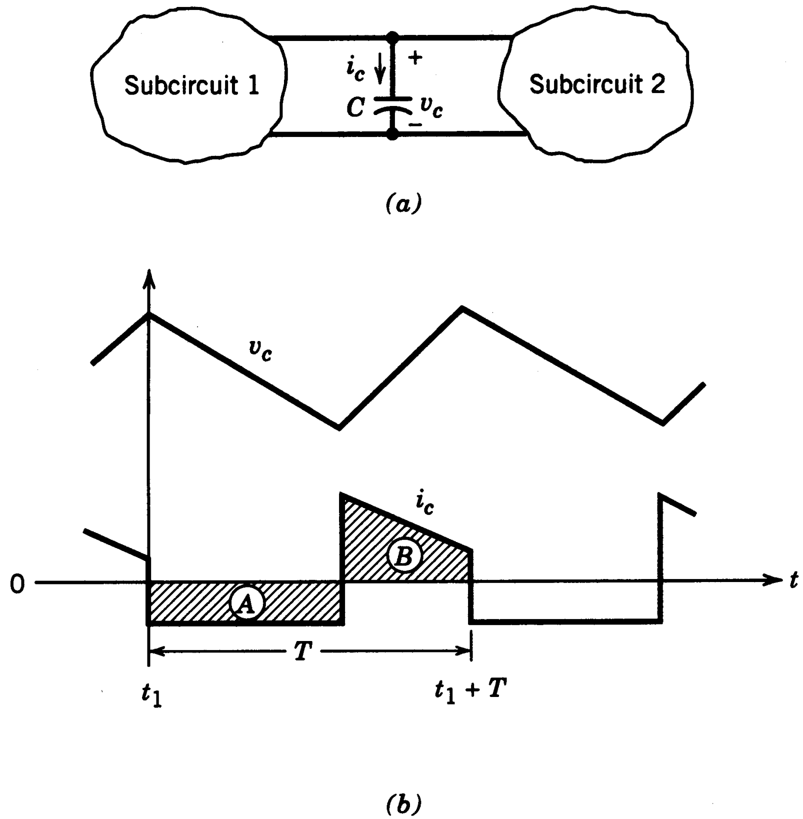


Figure 3-9 Capacitor response in steady state.

Ampere's Law

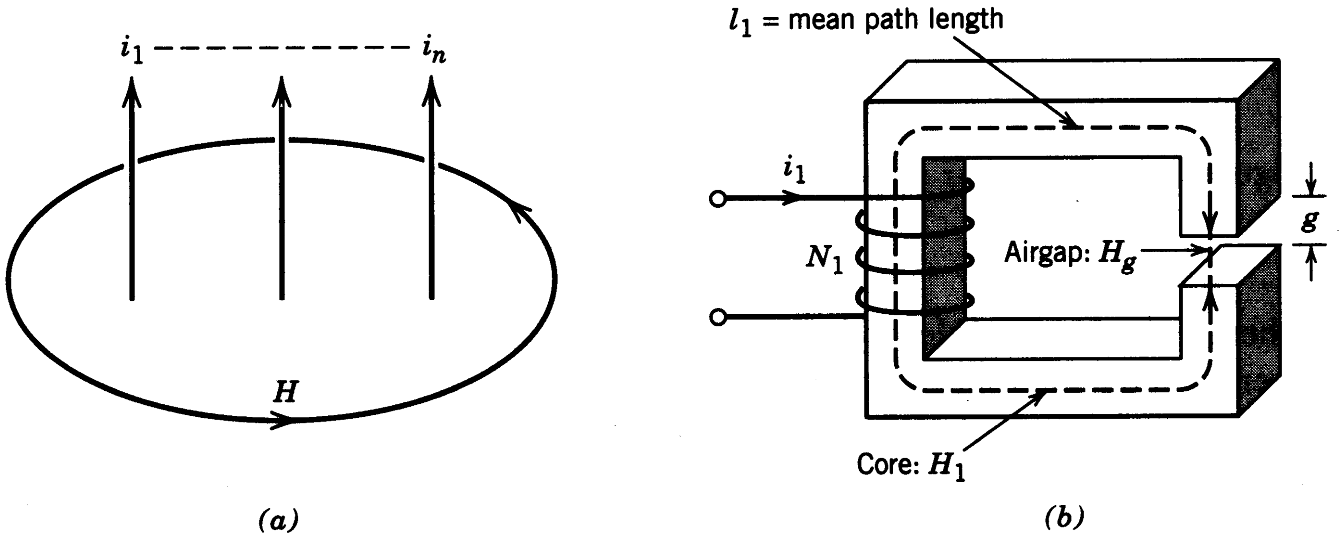


Figure 3-10 (*a*) General formulation of Ampere's law. (*b*) Specific example of Ampere's law in the case of a winding on a magnetic core with an airgap.

- Direction of magnetic field due to currents
- Ampere's Law: Magnetic field along a path

Direction of Magnetic Field

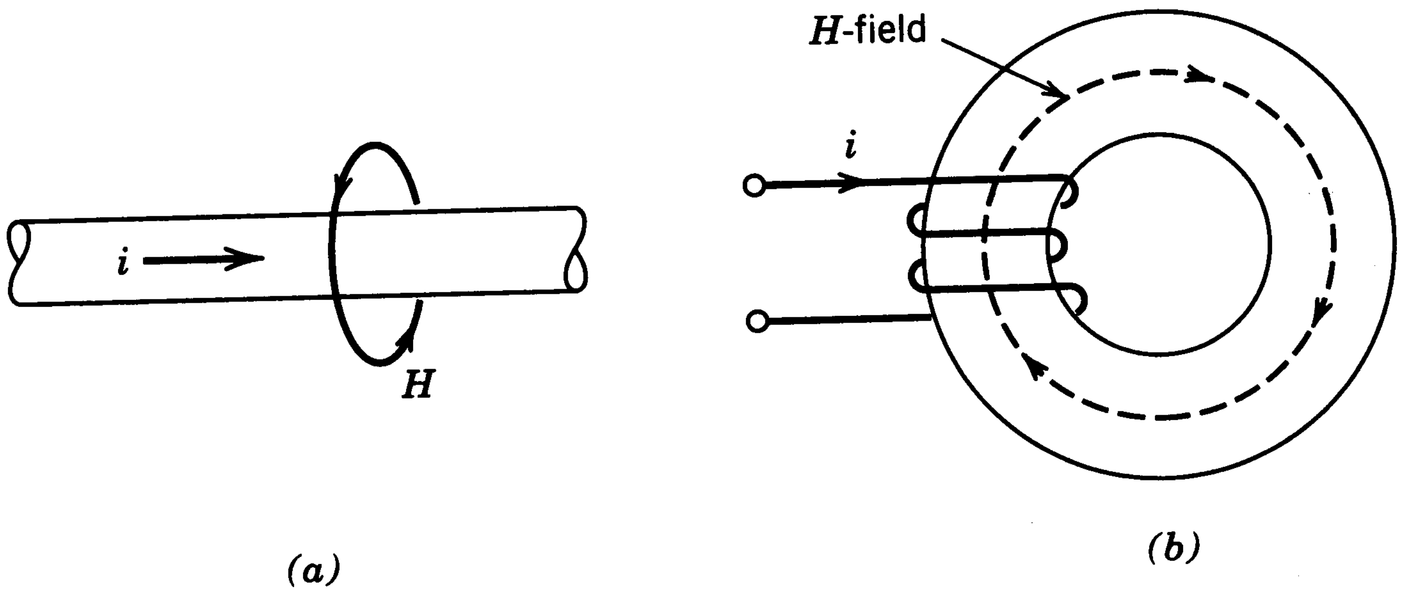


Figure 3-11 Determination of the magnetic field direction via the right-hand rule in (*a*) the general case and (*b*) a specific example of a current-carrying coil wound on a toroidal core.

B-H Relationship; Saturation

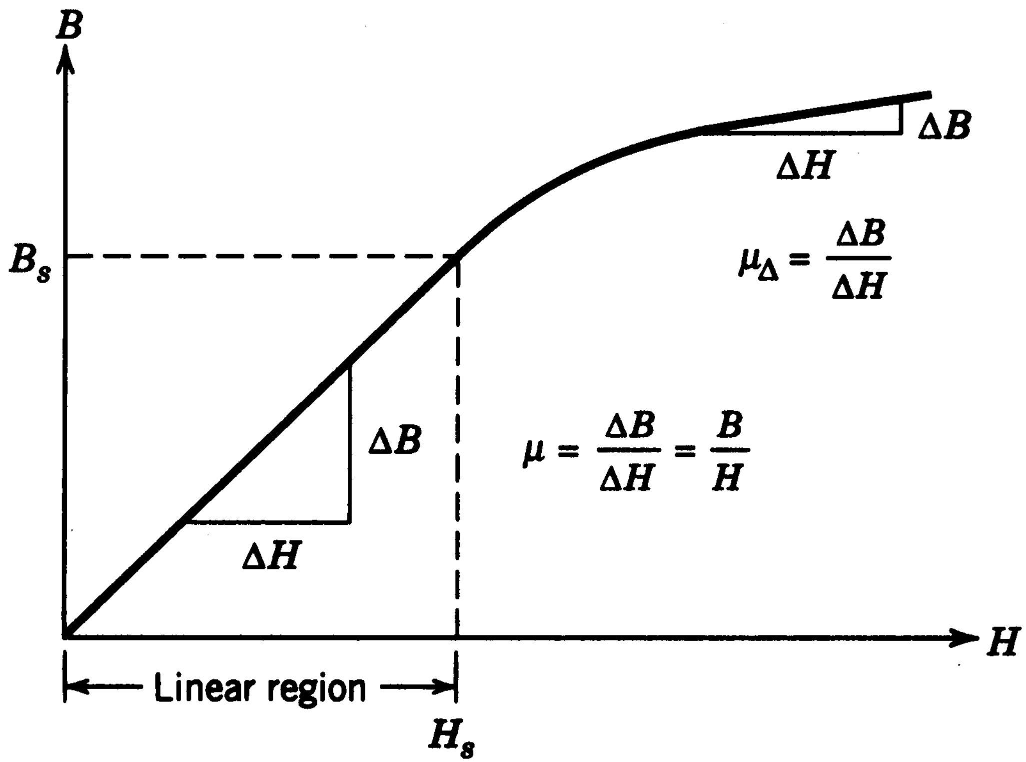


Figure 3-12 Relation between B- and H-fields.

- Definition of permeability

Continuity of Flux Lines

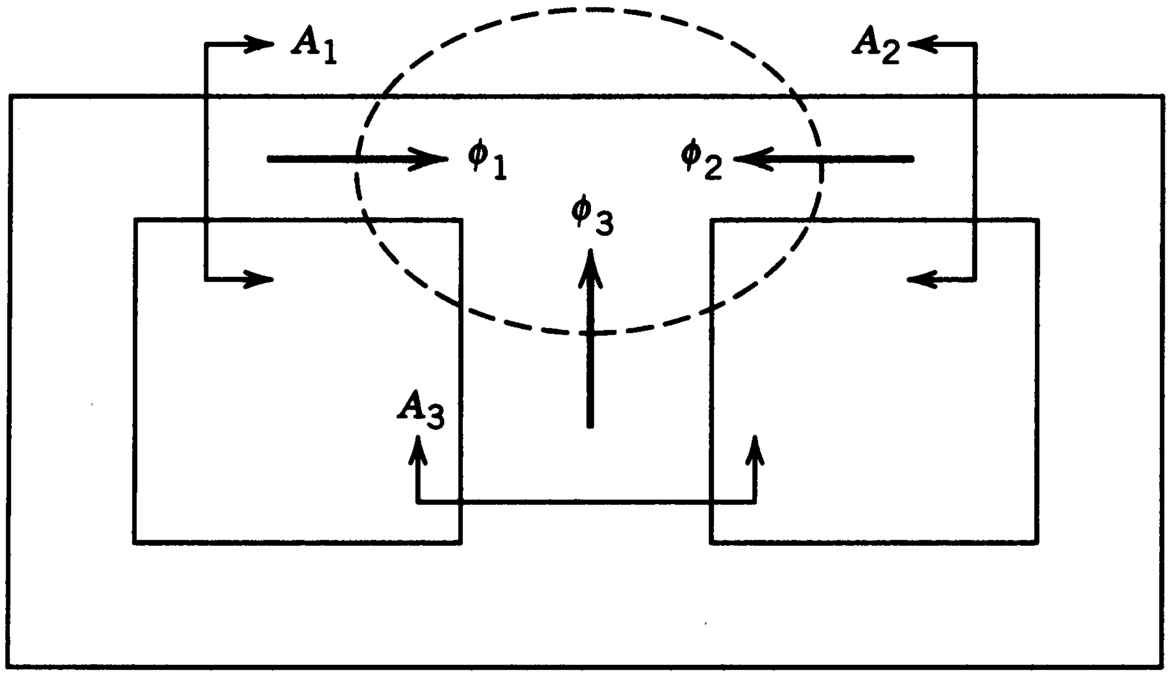


Figure 3-13 **Continuity of flux.**

$$f_1 + f_2 + f_3 = 0$$

Concept of Magnetic Reluctance

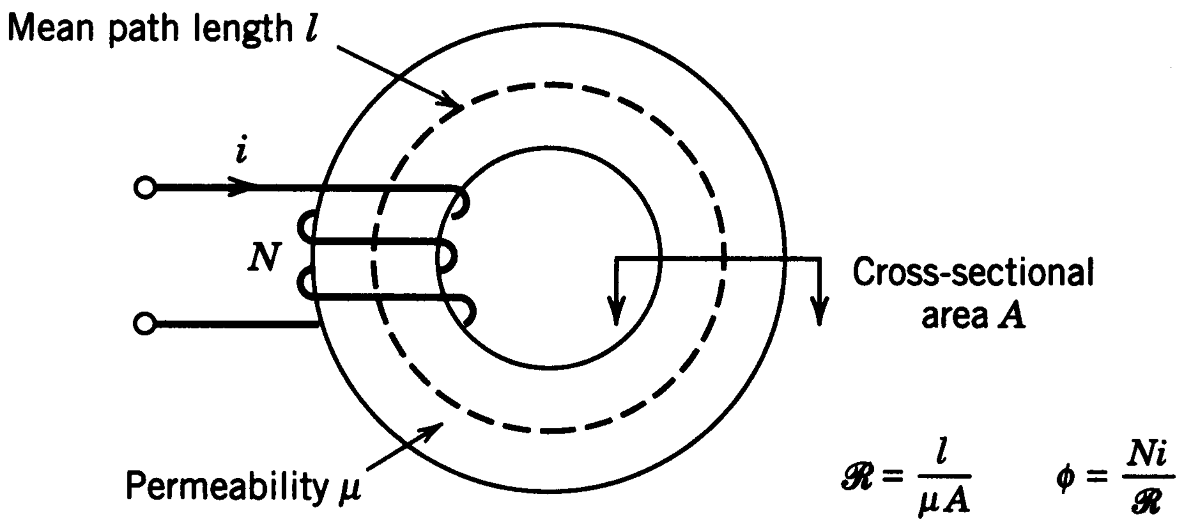


Figure 3-14 Magnetic reluctance.

- Flux is related to ampere-turns by reluctance

Analogy between Electrical and Magnetic Variables

Table 3-2 Electrical–Magnetic Analogy

Magnetic Circuit	*Electric Circuit*
mmf Ni	v
Flux ϕ	i
reluctance $\mathcal{R}$	R
permeability μ	$1/\rho$, where ρ = resistivity

Analogy between Equations in Electrical and Magnetic Circuits

Table 3-3 Magnetic–Electrical Circuit Equation Analogy

Magnetic	*Electrical (dc)*
$\dfrac{Ni}{\phi} = \mathcal{R} = \dfrac{l}{\mu A}$	Ohm's law: $\dfrac{v}{i} = R = \dfrac{l}{A/\rho}$
$\phi \sum_k \mathcal{R}_k = \sum_m N_m i_m$	Kirchhoff's voltage law: $i \sum_k R_k = \sum_m v_m$
$\sum \phi_k = 0$	Kirchhoff's current law: $\sum_k i_k = 0$

Magnetic Circuit and its Electrical Analog

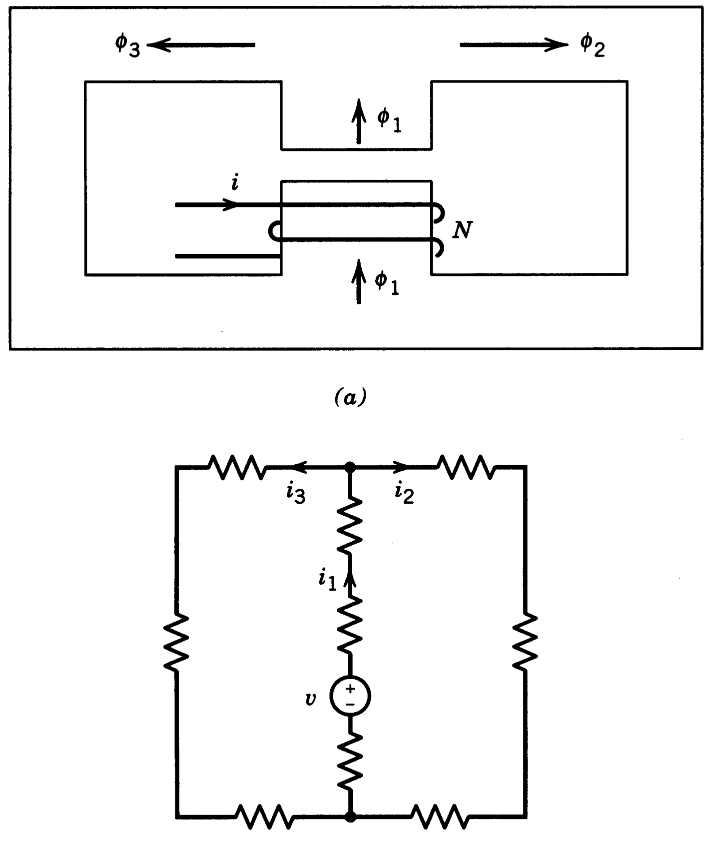


Figure 3-15 (*a*) Magnetic circuit. (*b*) An electrical analog.

Faraday's Law and Lenz's Law

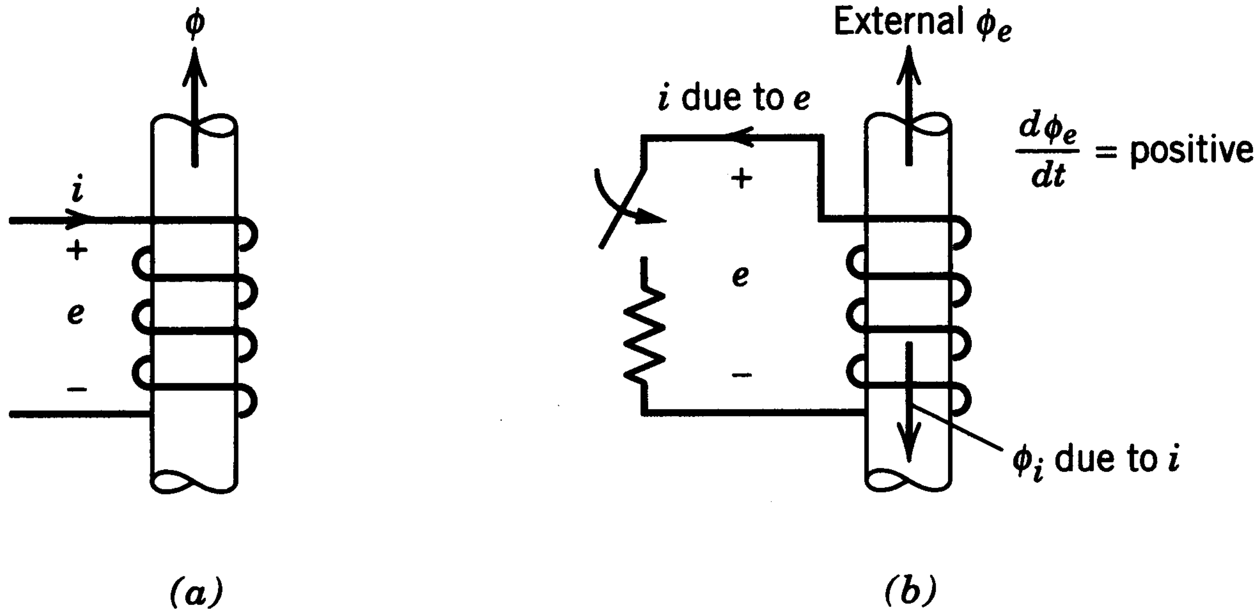


Figure 3-16 (*a*) Flux direction and voltage polarity. (*b*) Lenz's law.

Inductance L

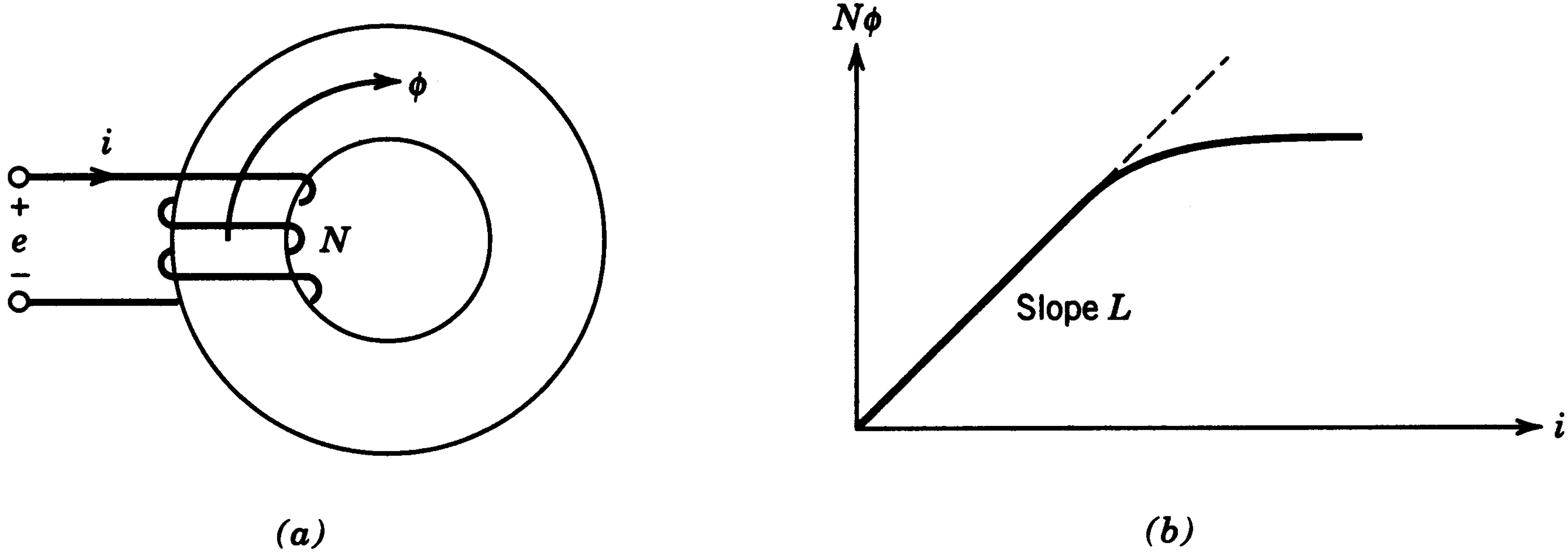
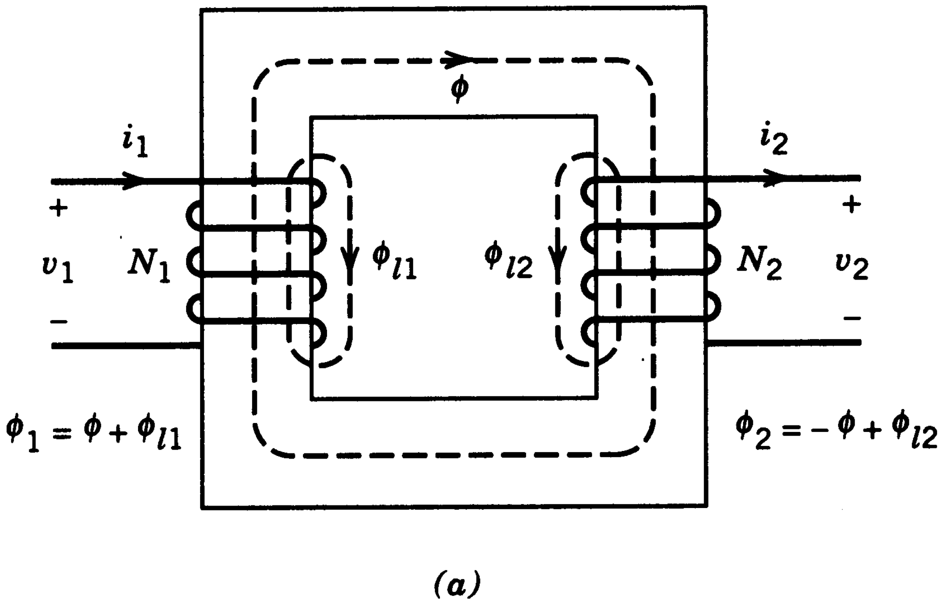


Figure 3-17 Self-inductance L.

- Inductance relates flux-linkage to current

Analysis of a Transformer



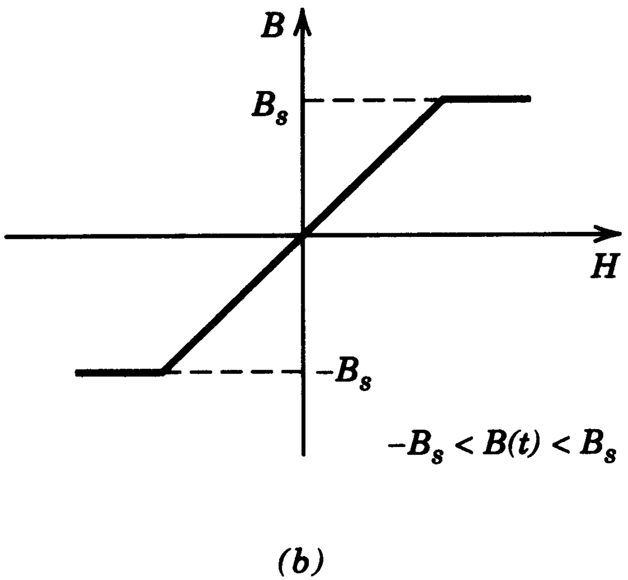


Figure 3-18 (*a*) Cross section of a transformer. (*b*) The *B–H* characteristics of the core.

Transformer Equivalent Circuit

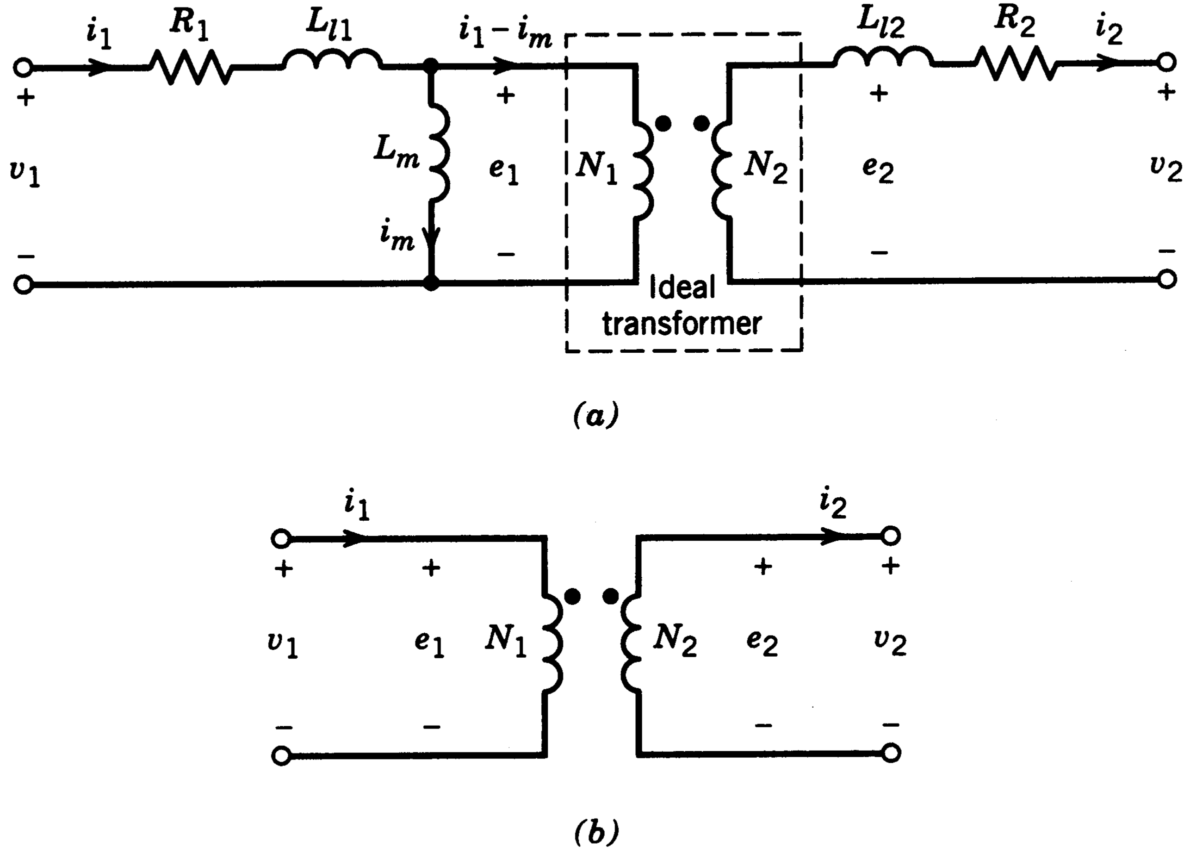
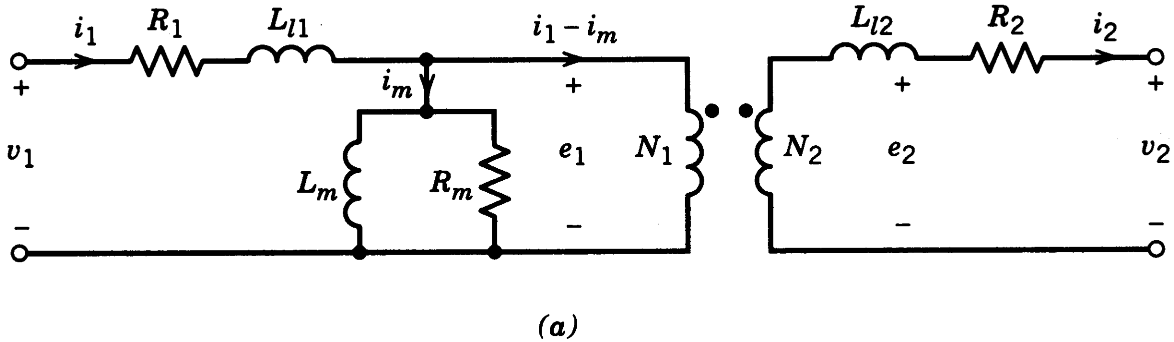


Figure 3-19 Equivalent circuit for (*a*) a physically realizable transformer wound on a lossless core and (*b*) an ideal transformer.

Including the Core Losses



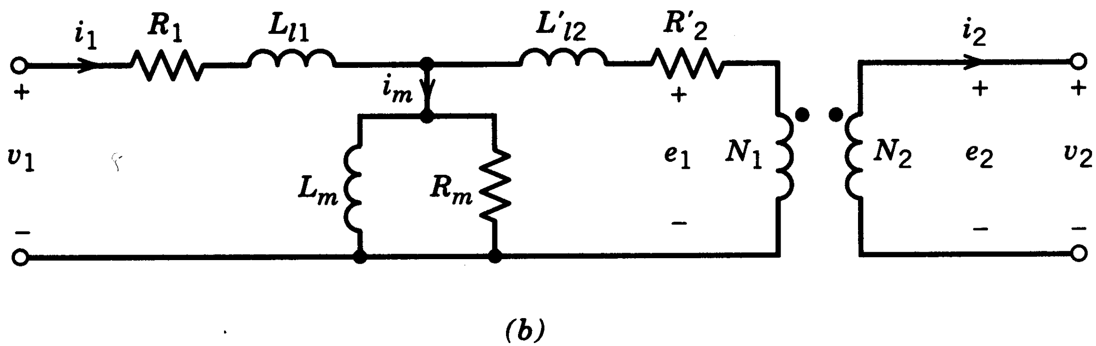


Figure 3-21 Equivalent circuit of a transformer including the effects of hysteresis loss. (*a*) Circuit components are on both sides (coil 1 and coil 2 sides) of the ideal transformer. (*b*) Components from the secondary (coil 2) side are reflected across the ideal transformer to the primary (coil 1) side.

Transformer Core Characteristic

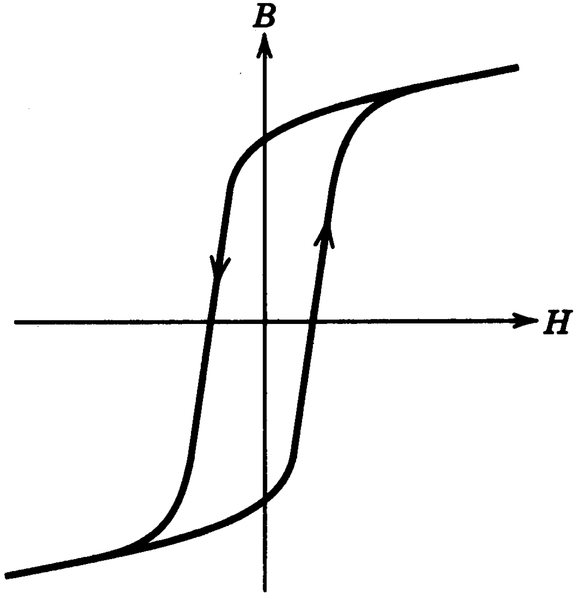


Figure 3-20 *B–H* characteristic of a transformer core having hysteresis and hence magnetic losses.