Chapter 14

Transformers
Mutual Inductance

- When two coils are placed close to each other, a changing electromagnetic field produced by the current in one coil will cause an induced voltage in the second coil because of the mutual inductance.

- Mutual inductance is established by the inductance of each coil and by the amount of coupling between the two coils. To maximize coupling, the two coils are wound on a common core.
A voltage is induced in the second coil as a result of the changing current in the first coil, producing a changing magnetic field that links the second coil.
The Basic Transformer

- Source voltage is applied to the primary winding
- The load is connected to the secondary winding
- The core provides a physical structure for placement of windings and a magnetic path so that the magnetic flux lines are concentrated close to the coils
- Typical core materials are: air, ferrite, and iron
  - Air and ferrite cores are used at high frequencies
  - Iron cores are used for Audio Frequencies and power applications
The Basic Transformer

(a) Schematic symbol  
(b) Source/load connections
Schematic symbols specify the type of core

(a) Air core
(b) Ferrite core
(c) Iron core
Transformers with cylindrical-shaped cores

(a) Loosely coupled windings

(b) Tightly coupled windings. Cutaway view shows both windings.
Iron-core transformer construction with multilayer windings

(a) Core type has each winding on a separate leg.
(b) Shell type has both windings on the same leg.
Some common types of transformers

Small

Large
Turns Ratio

• Turns ratio \((n)\) is defined as the ratio of the number of turns in the secondary winding \((N_{\text{sec}})\) to the number of turns in the primary winding \((N_{\text{pri}})\)

\[ n = \frac{N_{\text{sec}}}{N_{\text{pri}}} \]

• With the turns ratio, the secondary voltage can be determined with the following formula:

\[ V_{\text{sec}} = n(V_{\text{pri}}) \]
Direction of Windings

- The direction of the windings determines the polarity of the voltage across the secondary winding with respect to the voltage across the primary.
- Phase dots are used to indicate polarities.
The direction of the windings determines the relative polarities of the voltages

(a) The primary and secondary voltages are in phase when the windings are in the same effective direction around the magnetic path.

(b) The primary and secondary voltages are 180° out of phase when the windings are in the opposite direction.
Phase dots indicate corresponding polarities of primary and secondary voltages

(a) Voltages are in phase.

(b) Voltages are out of phase.
Step-up Transformers

- A transformer in which the secondary voltage is greater than the primary voltage is called a **step-up transformer**

- The ratio of secondary voltage \( V_{sec} \) to primary voltage \( V_{pri} \) is equal to the ratio of the number of turns in the secondary winding \( N_{sec} \) to the number of turns in the primary winding \( N_{pri} \)

\[
\frac{V_{sec}}{V_{pri}} = \frac{N_{sec}}{N_{pri}}
\]
Step Up Transformer

$V_{pri}$

120 V rms

1:3

$V_{sec}$
Step-Down Transformer

- A transformer in which the secondary voltage is less than the primary voltage is called a step-down transformer.
- The amount by which the voltage is stepped down depends on the turns ratio.
- The turns ratio of a step-down transformer is always less than 1.
Step Down Transformer

$V_{pri}$

120 V rms

5:1
The Transformer as an Isolation Device

- Transformers are useful in providing electrical isolation between the primary circuit and the secondary circuit because there is no electrical connection between the two windings.
- In a transformer, energy is transferred entirely by magnetic coupling.
DC Isolation

- A transformer does not pass dc, therefore a transformer can be used to keep the dc voltage on the output of an amplifier stage from affecting the bias of the next amplifier.

- The ac signal is coupled through the transformer between amplifier stages.
DC isolation and ac coupling

No DC Voltage is Induced

Only AC Voltage is Induced
Power Line Isolation

- Transformers are often used to electrically isolate electronic equipment from the ac power line.
Current and Power

• When a load resistor is connected to the secondary winding, there is a current through the resulting secondary circuit because of the voltage induced in the secondary coil.

• This results in current in both the primary and secondary coils which is also effected by the turns ratio.
Primary Power Equals Load Power

- For an ideal transformer, the power delivered in the secondary ($V_{sec}I_{sec}$) equals the power in the primary ($V_{pri}I_{pri}$).
- Therefore:
  - If the voltage is stepped \textit{up} in the secondary, the current is stepped \textit{down} by the same amount.
  - If the voltage is stepped \textit{down} in the secondary, the current is stepped \textit{up} by the same amount.
Illustration of voltages and currents in a transformer with a loaded secondary winding

(a) Step-up transformer: \( V_{sec} > V_{pri} \) and \( I_{sec} < I_{pri} \)

(b) Step-down transformer: \( V_{sec} < V_{pri} \) and \( I_{sec} > I_{pri} \)
VA (Power) Rating

Current Capability
Of Secondary Depends Upon
Selected Voltage Output and VA Rating

\[ I_{sec} = \frac{VA}{V_{sec}} \]

- \[25A = 3KV/120V\]
- \[12.5A = 3KV/240V\]
Tapped Transformers

• The center tap (CT) transformer is equivalent to two secondary windings with half the voltage across each

• Center tap windings are used for rectifier supplies and impedance-matching transformers
FIGURE 14-28 Application of a center-tapped transformer in ac-to-dc conversion.

The rectifier takes these two half-cycles and combines them to get this waveform.
Utility-pole transformer in a typical power distribution system

![Diagram of a utility-pole transformer in a power distribution system. The transformer is connected to the 2400 V line and provides 110 V to the building through the service entrance. The diagram also shows the Earth ground connection.]
Household Wiring Voltage Distribution
Household Wiring

120 volts rms 60 Hz is the U.S. Standard

Three wires to house: two high voltage or "hot" wires and a "neutral" return wire which is tied to ground at multiple locations.

One circuit can supply a "hot" wire to several circuits in parallel. Their neutrals are tied to the neutral tie block. The ground wire is a separate path to the neutral block which is grounded.

hot #1 goes negative with respect to ground while hot #2 goes positive. This "out of phase" arrangement makes possible either 120v or 240v circuits.

Separate "circuits" with individual fuses or circuit breakers.

240 volt receptacle uses both "hot" wires.

The standard U.S. household wiring design has two 120 volt "hot" wires and a neutral which is at ground potential. The two 120 volt wires are obtained by grounding the centertap of the transformer supplying the house so that when one hot wire is swinging positive with respect to ground, the other is swinging negative. This versatile design allows the use of either hot wire to supply the standard 120 volt household circuits. For higher power applications like clothes dryers, electric ranges, air conditioners, etc., both hot wires can be used to produce a 240 volt circuit.
Splitting 240V to 120V
Transformers can have multiple taps to select desired voltages
Multiple-Winding Transformers

- Multiple-winding transformers have more than one winding on a common core. They are used to operate on, or provide, different operating voltages.

220V is Always Applied to Primary in Examples B and C
Multiple-secondary transformer

Textbook Example

For Tube Circuit Power Supply

350V/700V for Tube Plates
6.3V for Tube Heaters
5V for Low Voltage Circuits
Auto Transformers

In an autotransformer, one winding serves as both the primary and the secondary. The winding is tapped at the proper points to achieve the desired turns ratio for stepping up or down the voltage.
Impedance Matching

- When a source is connected to a load, maximum power is delivered to the load when the load impedance is equal to the fixed internal source impedance.
- One application of transformers is in the matching of a load resistance to a source resistance in order to achieve maximum transfer of power.
- This is termed “impedance matching”.
- Transformers designed specifically for impedance matching usually show the input and output impedance they are designed to match.
An antenna directly coupled to a TV receiver

Old Antenna/TV Systems had matching 300 Ohms
Matching Transformer

- The coaxial cable has an Impedance of 75 Ohms
- The TV has an antenna input Impedance of 300 Ohms
- The reflected-resistance characteristics provided by a transformer are used to make the load resistance appear to have the same value as the source resistance

![Newer Coaxial Cable 75 Ohm System Requires Matching Transformer for Older TVs](image)

\[ n = \sqrt{\frac{R_{\text{sec}}}{R_{\text{pri}}}} \]

\[ n = \sqrt{\frac{300 \text{ Ohms}}{75 \text{ Ohms}}} \]

\[ n = 2 \Rightarrow 1:2 \]
Impedance matching for a Speaker System

\[ n = \sqrt[10:1]{8 \text{ ohms}} = \sqrt[10:1]{800 \text{ ohms}} \]

\[ n = 0.1 \Rightarrow 10:1 \]
Basic transformer-coupled dc power supply
Troubleshooting: Open primary winding.

(a) Conditions when the primary winding is open

- $I_{pri} = 0$
- $I_{sec} = 0$
- $V_L = 0$

(b) Checking the primary winding with an ohmmeter

Disconnect source from primary winding.
Troubleshooting: Open secondary winding

(a) Conditions when the secondary winding is open

(b) Checking the secondary winding with the ohmmeter
Troubleshooting: Shorted secondary winding

(a) Secondary winding completely shorted

(b) Secondary winding partially shorted

(c) Checking the secondary winding with the ohmmeter

![Image of troubleshooting diagram]