CHAPTER 1

CIRCUIT VARIABLES

CONTENTS

1.1 Circuit Theory
1.2 System of Units
1.3 Voltage and Current
1.4 Passive Sign Convention
1.5 Power and Energy
1.1 Circuit Theory

- Electrical engineering covers rather diverse fields which involve the generation, transmission, and processing of electrical energy and/or signals.
  
  Example: Power systems, Signal-processing systems, Computer systems, Control systems, Communication systems.

- An electrical circuit is a mathematical model that approximates the behavior of an actual electrical system.

- Circuit theory is a special case of electromagnetic field theory: the study of static and moving electrical charges.
1.1 Circuit Theory

- **Basic assumptions**
  1. The electrical signals are transmitted throughout the circuit without time delay. This system is called a lumped-parameter system.
  2. No electromagnetic radiation happens.
  3. Only linear circuits are considered in this course.

1.2 System of Units

- The International System of Units (SI) enables engineers to communicate their results efficiently if they use the same units of measure.
- The SI units are based on the following defined quantities.
# 1.2 System of Units

## Table 1: The SI Units

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Basic Unit</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>meter</td>
<td>m</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>Time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>Electric current</td>
<td>ampere</td>
<td>A</td>
</tr>
</tbody>
</table>

## Table 2: Derived Units in SI

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit Name (Symbol)</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>hertz (Hz)</td>
<td>$s^{-1}$</td>
</tr>
<tr>
<td>Force</td>
<td>newton (N)</td>
<td>$kg \cdot m/s^2$</td>
</tr>
<tr>
<td>Energy</td>
<td>joule (J)</td>
<td>$N \cdot m$</td>
</tr>
<tr>
<td>Power</td>
<td>watt (W)</td>
<td>$J/s$</td>
</tr>
<tr>
<td>Charge</td>
<td>coulomb (C)</td>
<td>$A \cdot s$</td>
</tr>
<tr>
<td>Voltage</td>
<td>volt (V)</td>
<td>$J/C$</td>
</tr>
</tbody>
</table>
## 1.2 System of Units

### Table 2: Derived Units in SI (cont.)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit Name (Symbol)</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td>ohm (Ω)</td>
<td>$V/A$</td>
</tr>
<tr>
<td>Conductance</td>
<td>siemens (S)</td>
<td>$A/V$</td>
</tr>
<tr>
<td>Capacitance</td>
<td>farad (F)</td>
<td>$C/V$</td>
</tr>
<tr>
<td>Magnetic flux</td>
<td>weber (Wb)</td>
<td>$V\cdot s$</td>
</tr>
<tr>
<td>Inductance</td>
<td>henry (H)</td>
<td>$Wb/A$</td>
</tr>
</tbody>
</table>

### Table 3: Standardized Prefixes

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>atto</td>
<td>a</td>
<td>$10^{-18}$</td>
</tr>
<tr>
<td>femto</td>
<td>f</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>pico</td>
<td>p</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>micro</td>
<td>μ</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>centi</td>
<td>c</td>
<td>$10^{-2}$</td>
</tr>
</tbody>
</table>
### 1.2 System of Units

Table 3: Standardized Prefixes (cont.)

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>deci</td>
<td>d</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>deka</td>
<td>da</td>
<td>10</td>
</tr>
<tr>
<td>hecto</td>
<td>h</td>
<td>$10^{2}$</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>$10^{3}$</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>$10^{6}$</td>
</tr>
<tr>
<td>giga</td>
<td>G</td>
<td>$10^{9}$</td>
</tr>
<tr>
<td>tera</td>
<td>T</td>
<td>$10^{12}$</td>
</tr>
</tbody>
</table>

### 1.3 Voltage and Current

Voltage is the energy per unit charge created by the separation of charges.

SI unit: volt (V)

$$v = \frac{d\varepsilon}{dq}$$

- $v$ = the voltage in volts
- $\varepsilon$ = the energy in joules
- $q$ = the charge in coulombs
1.3 Voltage and Current

Electric current is the rate of charge flow.

SI unit: ampere (A)

\[ i = \frac{dq}{dt} \]

- \( i \) = the current in amperes
- \( q \) = the charge in coulombs
- \( t \) = the time in seconds
1.3 Voltage and Current

Physiological reactions to current levels in humans

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Current Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barely perceptible</td>
<td>3 ~ 5 mA</td>
</tr>
<tr>
<td>Extreme pain</td>
<td>30 ~ 50 mA</td>
</tr>
<tr>
<td>Muscle paralysis</td>
<td>50 ~ 70 mA</td>
</tr>
<tr>
<td>Heart stoppage</td>
<td>500 mA</td>
</tr>
</tbody>
</table>

Note: Data taken from W.F. Cooper, Electrical Safety Engineering 2nd ed. (London: Butterworth, 1986); and C.D. Winburn, Practical Electrical Safety (Monticello, N.Y.: Marcel Dekker, 1988)

1.3 Voltage and Current

Andre-Maria Ampere
1775-1836
Scotland

19XX-20XX
R.O.C. Taiwan
1.4 Passive Sign Convention

- The circuit elements (or components) considered in this course can be two-terminal, three-terminal, or four-terminal components.

- They are ideal mathematical models and may not be realized in the physical world.

- However, actual devices and systems can be modeled by using these ideal elements.

**Two-terminal element** (example: resistor)

![Resistor Diagram]

**Three-terminal element** (example: npn transistor)

![NPN Transistor Diagram]
1.4 Passive Sign Convention

- **four-terminal element** (example: coupling inductors)

For a two-terminal element, the reference voltage polarity and the reference current direction can be arbitrarily assigned.

If passive sign convention is chosen, then the current reference direction is automatically chosen to be in the direction of the reference voltage drop across the element.

Hence, only one reference is required.
1.4 Passive Sign Convention

Choose voltage polarity reference

Implies the current reference direction

Choose current direction reference

Implies the voltage polarity reference

1.5 Power and Energy

- The output capacity of an electrical system is often expressed in terms power or energy.
- Power is work done per unit time
- SI unit: watt (w)

\[ p = \frac{d\varepsilon}{dt} \]

- \( p \) = the power in watts
- \( \varepsilon \) = the energy in joules
- \( t \) = the time in seconds
1.5 Power and Energy

From definitions of $v$ and $i$

\[
p = \frac{d \varepsilon}{dt} = \frac{d \varepsilon}{dq} \times \frac{dq}{dt} = vi
\]

\[
\therefore \quad p = vi
\]

$p$ = the power in watts
$v$ = the voltage in volts
$i$ = the current in amperes

If passive sign convention is adopted, then

$p > 0$, this power is dissipated in (or being delivered to) the component or circuit.

$p < 0$, this power is being extracted (or generated) from the component or circuit.
1.5 Power and Energy

Energy can be calculated by integrating the corresponding power

\[ \varepsilon = \int p \, dt \]

\( \varepsilon \) = the energy in joules
\( p \) = the power in watts
\( t \) = the time in second

Summary

- Objective 1: Understand and be able to use SI units and the standard prefixes for powers of 10.
- Objective 2: Know and be able to use the definitions of \( v \) and \( i \).
- Objective 3: Know and be able to use the definitions of \( p \) and \( \varepsilon \).
- Objective 4: Be able to use the passive sign convention and interpret the meaning of the algebraic sign of \( p \).
Assignment : Chapter Problems

- Problem 1.17
  1.19(a)
  1.23
  1.30

- Due within one week.