Topics Covered in Chapter 11
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11-2: Standard Wire Gage Sizes
11-3: Types of Wire Conductors
   11-4: Connectors
11-5: Printed Wiring
Topics Covered in Chapter 11

- 11-6: Switches
- 11-7: Fuses
- 11-8: Wire Resistance
- 11-9: Temperature Coefficient of Resistance
- 11-10: Ion Current in Liquids and Gases
- 11-11: Insulators
- 11-12: Troubleshooting Hints for Wires and Connectors
11-1: Function of the Conductor

- The main function of a conductor is to provide a pathway between a voltage source and a load with minimum $IR$ voltage drop.
- Large diameter wire is needed in high current circuits. The larger the diameter, the lower the resistance.
- However, the resistance of a wire increases as its length increases.
- The resistance of pure metals increases with temperature.
- Ideal conductors have no resistance.
11-1: Function of the Conductor

Conductors will use little power (0.06 W) which allows 99.94 W for the bulb.

Fig. 11-1: The conductors should have minimum resistance to light the bulb with full brilliance. (a) Wiring diagram. (b) Schematic diagram. \( R_1 \) and \( R_2 \) represent the very small resistance of the wire conductors.

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Sizes are specified by the American Wire Gage (AWG) system.
- Higher gage numbers mean thinner wire.
- Typical sizes are 22 AWG for electronic hookup wire and 12 AWG for home electrical wiring.

The cross-sectional area of round wire is measured in **circular mils**.
- One circular mil = cross sectional area of a wire with a diameter of 1 mil (1 mil = 0.001 in)
  - \[ \text{CMA} = (\text{diameter})^2 \]
- The higher the gage number and the thinner the wire, the greater its resistance for any length.
#22 wire

0.02535 inches

A mil is 0.001 inches.

Diameter in mils = \( \frac{0.02535}{0.001} = 25.35 \)

Circular mil area = \([\text{Diameter in mils}]^2 = 25.35^2 = 643\)
Wire Size

- The circular area of the wire doubles for every three gage sizes.

- # 19 is three gages larger than # 22 and has approximately twice the circular mil area. This is always the case when the gage number is decreased by 3.

<table>
<thead>
<tr>
<th>Gage</th>
<th>CMA</th>
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<tbody>
<tr>
<td>17</td>
<td>2048</td>
</tr>
<tr>
<td>18</td>
<td>1624</td>
</tr>
<tr>
<td>19</td>
<td>1288</td>
</tr>
<tr>
<td>20</td>
<td>1022</td>
</tr>
<tr>
<td>21</td>
<td>810</td>
</tr>
<tr>
<td>22</td>
<td>643</td>
</tr>
</tbody>
</table>
Most wire conductors are copper. The wire may be solid or stranded.

- **Solid wire** is made of one conductor.
  - If bent or flexed repeatedly, it may break.
  - It is typically used in applications not subject to repeated stresses, such as house wiring.

- **Stranded wire** is made up of multiple strands of wire braided together.
  - It is more resilient than solid wire.
  - It is typically used in applications like telephone and extension cords, and in speaker wire.
11-3: Types of Wire Conductors

- Two or more conductors in a common covering form a cable.
  - Each wire is insulated from the others.
  - Cables typically consist of multiple conductors, color-coded for identification.
- Constant spacing between two conductors through the entire length of the cable provides a transmission line.
  - Coaxial cable, typically used for cable television connections, is one example.
Fig. 11-6: Common types of connectors for wire conductors. (a) Spade lug. (b) Alligator clip. (c) Double banana-pin plug. (d) Terminal strip.
Fig. 11-6 (continued): Common types of connectors for wire conductors. (e) RCA-type plug for audio cables. (f) Phone plug. (g) F-type plug for cable TV. (h) Multiple-pin connector plug. (i) Spring-loaded metal hook as grabber for temporary connection in testing circuits.
Most electronic circuits are mounted on a plastic or fiberglass insulating board with printed wiring.

The components, such as resistors, coils, capacitors, etc., are on one side.

The other side has the conducting paths printed on the board with silver and copper, rather than using wire.

Use small iron (25-W rating) for desoldering to prevent wiring lift off.

Use desoldering braid to remove solder from PCB.

Fig. 11-7: Printed wiring board. (a) Component side with resistors, capacitors, and transistors. (b) Side with printed wiring for the circuit.
11-6: Switches

- A **switch** allows you to turn current in a circuit on and off.
- All switches have a current rating and a voltage rating.
- The current rating indicates the maximum allowable current the switch can carry when it is closed.
- The voltage rating indicates the maximum voltage that can be applied safely across the open contacts without internal arcing.
Fig. 11-8: Series switch used to open or close a circuit. (a) With the switch closed, current flows to light the bulb. The voltage drop across the closed switch is 0 V. (b) With the switch open, the light is off. The voltage drop across the open switch is 12 V.
### 11-6: Switches

- **Pole** refers to the number of completely isolated circuits that can be controlled by a switch.

- **Throw** refers to the number of closed contact positions that exist per pole.
  - SPST: single-pole, single-throw
  - DPDT: double-pole, double-throw
  - SPDT: single-pole, double-throw
  - DPST: double-pole, single-throw
11-6: Switches

Fig. 11-9: Switches. (a) Single-pole, single-throw (SPST). (b) Single-pole, double-throw (SPDT). (c) Double-pole, single-throw (DPST). (d) Double-pole, double-throw (DPDT).
Switch Applications

Fig. 11-10: Switch applications. (a) SPDT switch used to switch a 12-V source between two different loads. (b) DPST switch controlling two completely isolated circuits simultaneously. (c) DPDT switch used to reverse the polarity of voltage across a dc motor.
11-7: Fuses

- A **fuse** protects the circuit components against excessive current.
- Excessive current melts the fuse element, blows the fuse, and opens the series circuit before damage can occur to the components or wiring.
- **Slow-blow fuses** are designed to open only on a continued overload, such as a short circuit, rather than a temporary current surge.
11-7: Fuses

- When measured with an ohmmeter, a good fuse has practically zero resistance. An open fuse reads infinite ohms.

- When measured with a voltmeter, a good fuse has zero volts across its two terminals. If there is significant voltage across the fuse, it is open.
Fig. 11-18: When a fuse opens, the applied voltage is across the fuse terminals. (a) Circuit closed with good fuse. Note schematic symbol for any type of fuse. (b) Fuse open.
11-7: Fuses

- Sample Fuses

1 Amp fuse

15 Amp fuse

Blown fuse

Blown fuse (severe overload)
11-7: Fuses

- Circuit Board Fuses
Wire Resistance

- Resistance is proportional to the length of the wire.
- The resistance of a conductor can be found by the formula:

\[ R = \rho \left( \frac{l}{A} \right) \]

- \( \rho \) is the specific resistance of the conductor.
- \( l \) is the length of the wire.
- \( A \) is the cross-section of the wire.
11-8: Wire Resistance

- Specific Resistance
  - Specific resistance = $\rho = \text{CMA} [\text{circular mil area}] \cdot \Omega/\text{ft}$
  - Resistance of a conductor = $R = \rho \left(\frac{\text{length}}{\text{CMA}}\right)$

Find $R$ for 1000 ft. of #18 cu

$R = \rho \left(\frac{\text{length}}{\text{CMA}}\right)$

$R = 10.4 \left(\frac{1000}{1624}\right)$

$R = 6.4 \ \Omega$

<table>
<thead>
<tr>
<th>Material</th>
<th>Gage</th>
<th>CMA</th>
<th>$\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>17</td>
<td>2048</td>
<td>17</td>
</tr>
<tr>
<td>Copper</td>
<td>18</td>
<td>1624</td>
<td>10.4</td>
</tr>
<tr>
<td>Iron</td>
<td>19</td>
<td>1288</td>
<td>58</td>
</tr>
<tr>
<td>Nichrome</td>
<td>20</td>
<td>1022</td>
<td>676</td>
</tr>
<tr>
<td>Silver</td>
<td>21</td>
<td>810</td>
<td>9.8</td>
</tr>
<tr>
<td>Tungsten</td>
<td>22</td>
<td>643</td>
<td>33.8</td>
</tr>
</tbody>
</table>
Types of Resistance Wire

- Certain applications employing heating elements (e.g., toasters) require a wire with greater resistance than common conductors.
- More resistance will generate power dissipated as heat, without using excessive current.
- **Resistance wire** is the name used to describe wires with greater $R$ values than copper. Some examples of resistance wire include tungsten, nickel, or alloys like Nichrome.
11-9: Temperature Coefficient of Resistance

- **Temperature coefficient of resistance** indicates how much the resistance changes for a change in temperature. It is indicated by the alpha symbol (α).
  - A positive α value means $R$ increases with temperature.
  - A negative α value means $R$ decreases with temperature.
  - A value of 0 means $R$ stays constant.
α is generally positive for pure metals.

α is generally negative for semiconductors (silicon, germanium) and electrolyte solutions (sulfuric acid, water).

The increase in resistance may be calculated using the formula:

\[ R_t = R_0 + R_0(\alpha \Delta t) \]

- \( R_0 \) = the resistance at 20 °C.
- \( R_t \) = the resistance at the higher temperature
- \( \Delta t \) = the temperature rise over 20°C.
11-9: Temperature Coefficient of Resistance

- Positive Temperature Coefficient ($\alpha$)
  - Some devices show a large increase in resistance when energized.

Tungsten filament
($\alpha = 0.005$)

What’s the lamp’s resistance at 2020 °C?

- $R_t = R_0 + R_0(\alpha \Delta t)$
- $R_t = 2 \, \Omega + 2 \, \Omega \times 0.005 \times 2000 = 22 \, \Omega$
11-9: Temperature Coefficient of Resistance

- Hot Resistance and Superconductivity
  - There is often a great difference in the amount of resistance a wire has when hot in normal operations and when cold without its normal load current.
  - For example, a typical 100-W incandescent light bulb has a hot resistance of 144 Ω, but when the bulb is not lit, an ohmmeter reading of the cold bulb’s filament will read only about 10 Ω.
The opposite effect is created when some metals are cooled to absolute zero (0°K or −273°C). At this temperature some metals lose practically all their resistance.

Through this process, called cryogenics, massive currents and very strong electromagnetic fields can be produced.
Liquids and gases can conduct electric charges, just as metals can.

In solids like metals, the atoms cannot move among each other. Each atom remains neutral while the drift of free electrons conducts the charge.

In liquids and gases, the atoms can move among each other. The atoms therefore gain or lose electrons easily, resulting in atoms that are no longer neutral.

The charged atoms are called ions.
Ions are the electrical charge carriers in liquids and gases.

A **negative ion** is an atom that has an excess number of electrons.

A **positive ion** is an atom that is missing one or more electrons.
Formation of Ions

Fig. 11-19: Formation of ions. (a) Normal sodium (Na) atom. (b) Positively charged ion indicated as Na\(^+\), missing one free electron.
Ion Current

As with electron flow, opposite ion charges attract and like charges repel.

The resultant motion of ions provides electric current (ionization current).

Ion charges are heavier than electron charges because ions contain the atom’s nucleus. The amount of current is determined by the rate at which the charge moves.
Ionization in Liquids

- Ions are formed in liquids when salts or acids are dissolved in water, or when metals are immersed in acid or alkaline solutions.

- Liquids that are good conductors because of ionization are called **electrolytes**.
11-10: Ion Current in Liquids and Gases

- Ionization in Gases
  - Gases have a minimum **striking potential**, which is the lowest applied voltage that will ionize the gas. Before ionization, the gas is an insulator, but ionization current makes the ionized gas have a low resistance.
  - The amount of voltage needed to reach the striking potential varies by gas and with gas pressure.
11-10: Ion Current in Liquids and Gases

- Ionic Bonds
  - On the next slide is an illustration depicting the bond that forms table salt (NaCl).
  - The sodium ion has a charge of +1 because it is missing 1 electron.
  - The chlorine ion has a charge of −1 because it has an extra electron.
  - When two such ions are placed near each other, an electrical attraction will form an ionic bond.
Fig. 11-20: Ionic bond between atoms of sodium (Na) and chlorine (Cl) to form a molecule of sodium chloride.
Insulators have very high resistance (many megohms).

Insulators can have one of two functions:
- To isolate conductors to eliminate conduction between them.
- To store a charge when voltage is applied.

Common insulator materials include:
- air and vacuum
- rubber and paper
- porcelain, and plastics

Insulators are also called dielectrics, meaning that they can store a charge.
11-11: Insulators

- Every insulator has a point at which a high enough voltage will cause an arc, breaking down its internal structure and forcing it to conduct.

- **Dielectric strength** refers to the voltage breakdown rating of a material. The higher the dielectric strength, the better the insulator.
### 11-11: Insulators

#### Table 11-4: Voltage Breakdown of Insulators

<table>
<thead>
<tr>
<th>Material</th>
<th>Dielectric Strength, V/mil</th>
<th>Material</th>
<th>Dielectric Strength, V/mil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air or vacuum</td>
<td>20</td>
<td>Paraffin wax</td>
<td>200-300</td>
</tr>
<tr>
<td>Bakelite</td>
<td>300-550</td>
<td>Phenol, molded</td>
<td>300-700</td>
</tr>
<tr>
<td>Fiber</td>
<td>150-180</td>
<td>Polystyrene</td>
<td>500-760</td>
</tr>
<tr>
<td>Glass</td>
<td>335-2000</td>
<td>Porcelain</td>
<td>40-150</td>
</tr>
<tr>
<td>Mica</td>
<td>600-1500</td>
<td>Rubber, hard</td>
<td>450</td>
</tr>
<tr>
<td>Paper</td>
<td>1250</td>
<td>Shellac</td>
<td>900</td>
</tr>
<tr>
<td>Paraffin oil</td>
<td>380</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11-11: Insulators

- Voltage Breakdown of Insulation Materials
  - Power transmission lines can operate as high as 1 million volts.
  - What is the length of the arc path?

\[
\frac{1 \text{ M}}{20} = 50,000 \text{ mils} = 4.17 \text{ feet.}
\]

(dielectric strength of air)
11-11: Insulators

- Insulator Discharge Current
  - An insulator storing a charge may be discharged in one of the following ways:
    1. Conduction through a conducting path, such as a wire across the insulator.
    2. Brush discharge, such as the ionization of air particles surrounding a charged pointed wire. This ionization may produce a corona effect, a bluish or reddish glow.
    3. Spark discharge, caused by current flowing across an insulator at the moment the insulator breaks down.
For many types of electronic equipment, an open circuit may result in the wire conductors, connectors, or switch contacts.

Wires and printed wiring can be checked for continuity with an ohmmeter.
Connectors may be checked for continuity between the wire and the connector.

- The connector may be tarnished, oxidized, or rusted.
- The connector may be loose.
- The wires may be incorrectly connected to plug connections.

Switch contacts may be dirty or pitted. Such switches must be replaced rather than cleaned.