Chapter 26
AC Circuits

Topics:
- AC sources
- Resistor circuits and AC power
- The transmission and use of electricity
- Capacitor circuits
- Inductors and inductor circuits
- Oscillation circuits

Sample question:
Transmission lines carry alternating current at voltages as high as 500,000 V. Why are such high voltages used? And why can birds perch safely on such high-voltage wires?

Answer
1. What is the name of the device that is used to change the voltage of AC electricity?
   - D. Transformer

Reading Quiz
2. What quantity with units of ohms, besides resistance, is introduced in this chapter?
   - A. Inductance
   - B. Reactance
   - C. GFI
   - D. Transformance
Answer

2. What quantity with units of ohms, besides resistance, is introduced in this chapter?

B. Reactance

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**An AC Voltage Source**

The emf oscillates as \( \mathcal{E} = \mathcal{E}_0 \cos 2\pi ft \).

\[ T = \frac{1}{f} \]

This is one oscillation period.

\[ \mathcal{E} = \mathcal{E}_0 \cos(2\pi ft) = \mathcal{E}_0 \cos \left( \frac{2\pi t}{T} \right) \]

Emf of an AC voltage source

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**Resistor Circuits**

The instantaneous current in the resistor is \( i_R = \frac{v_R}{R} \). The potential decreases in the direction of the current.

This is the current direction when \( \mathcal{E} > 0 \). A half cycle later it will be in the opposite direction.

\[ \Delta V_{\text{source}} = \mathcal{E} \]

\[ \Delta V_R = -v_R \]

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**Resistor Voltages and Currents**

\[ v_R = V_R \cos 2\pi ft \]

\[ i_R = I_R \cos 2\pi ft \]

Lowercase symbols represent *instantaneous* values of current or voltage. They change sinusoidally with time.

Uppercase symbols represent *peak* values of current or voltage. They are fixed quantities.

\[ i_R = \frac{v_R}{R} = \frac{V_R \cos 2\pi ft}{R} = I_R \cos 2\pi ft \]
AC Power in Resistors

Average power loss in a resistor with peak current $I_R$

$$P_R = \frac{1}{2} I_R^2 R$$

Root-Mean-Square Current and Voltage

If we define

$$I_{\text{rms}} = \frac{I_R}{\sqrt{2}} \quad \text{and} \quad V_{\text{rms}} = \frac{V_R}{\sqrt{2}}$$

then we can write

$$P_R = \left( \frac{I_R}{\sqrt{2}} \right)^2 R = \left( I_{\text{rms}} \right)^2 R$$

and

$$P_R = \left( I_{\text{rms}} \right)^2 R = \frac{\left( V_{\text{rms}} \right)^2}{R} = I_{\text{rms}} V_{\text{rms}}$$

The expressions for AC power are identical to those used for DC currents if rms currents and voltages are used.

Transformers

Primary coil

$N_1$ turns

$V_1 \cos 2\pi ft$

Iron core

Secondary coil

$N_2$ turns

$V_2 \cos 2\pi ft$

Load

The magnetic field lines follow the iron core.

$$V_2 = \frac{N_2}{N_1} V_1 \quad \text{or} \quad (V_2)_{\text{rms}} = \frac{N_2}{N_1} (V_1)_{\text{rms}}$$

Transformer voltages for primary and secondary coils with $N_1$ and $N_2$ turns

Checking Understanding

Suppose that an ideal transformer has 10 turns in its primary coil and 20 turns in its secondary coil. The current through the primary coil is shown in the graph on the upper left. Which of the other graphs best represents the current through the secondary coil?
Answer

Suppose that an ideal transformer has 10 turns in its primary coil and 20 turns in its secondary coil. The current through the primary coil is shown in the graph on the upper left. Which of the other graphs best represents the current through the secondary coil?
### Physiological Effects and Electrical Safety

**TABLE 26.1** Physiological effects of currents passing through the body.

<table>
<thead>
<tr>
<th>Physiological effect</th>
<th>AC current (mA)</th>
<th>DC current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of sensation</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Let-go current</td>
<td>15</td>
<td>75</td>
</tr>
<tr>
<td>Paralysis of respiratory muscles</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Heart fibrillation, likely fatal</td>
<td>&gt;50</td>
<td>&gt;300</td>
</tr>
</tbody>
</table>

### Electrical Dangers

- **Slide 26-17**

- **Slide 26-18**

- **Slide 26-19**

- **Slide 26-20**

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### Capacitor Circuits

- **(a)** The instantaneous current to and from the capacitor

\[ i_C = \text{The instantaneous capacitor voltage is } v_C = \frac{q}{C}. \text{ The potential decreases from } + \text{ to } - . \]

- **(b)**

\[ E = E_0 \cos 2\pi ft \]

\[ v_C = V_C \cos 2\pi ft \]

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### Voltage, Charge, and Current for a Capacitor in an AC Circuit

\[ I_C = (2\pi f C)V_C = \frac{V_C}{X_C} \]

where

\[ X_C = \frac{1}{2\pi f C} \]
Capacitive Reactance

\[ X_C = \frac{1}{2\pi fC} \]

The reactance is very large at low frequencies.

Inductance and Inductors

\[ v_L = L \frac{\Delta i_L}{\Delta t} \]

Units of inductance:

1 henry = 1 H = 1 V \cdot s/A = 1 \Omega \cdot s

The circuit symbol for an inductor

Inductor Circuits

(a) The instantaneous current through the inductor

\[ i_L \]

The instantaneous inductor voltage is \( v_L = L(\Delta i_L/\Delta t) \).

(b) The direction of the emf is opposite to the case where the current is increasing.

Inductor Currents and Voltages

\[ v_L \text{ and } i_L \]

\( i_L \) peaks \( \frac{1}{4}T \) after \( v_L \) peaks. We say that the current lags the voltage by 90°.

\[ V_L, I_L, T \]

\( v_L \) is changing rapidly.

\( v_L \) is large...

\( ... \) when \( i_L \) is changing rapidly.

Current \( i_L \)

Voltage \( v_L \)
Inductive Reactance

The reactance increases with increasing frequency.

\[ V_L = (2\pi f L)I_L \]

or

\[ I_L = \frac{V_L}{2\pi f L} = \frac{V_L}{X_L} \]

where

\[ X_L = 2\pi f L \]

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**Energy of an LC Circuit and a Block on a Spring**

Block on spring:

\[ f = \frac{1}{2\pi \sqrt{\frac{k}{m}}} \]

LC circuit:

\[ f = \frac{1}{2\pi \sqrt{\frac{1}{LC}}} \]

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**The RLC Circuit**

Circuit current \( i \)

\( L = 1 \mu \text{H}, C = 1 \text{nF} \)

\( R = 3 \Omega \)

The greater the resistance \( R \), the more rapidly the current decays.

\( R = 6 \Omega \)
The Driven $RLC$ Circuit

\[ f_0 = \frac{1}{2\pi} \sqrt{\frac{1}{LC}} \]

\[ I_{\text{max}} = \frac{E_0}{R} \]

The current reaches its maximum value $I_{\text{max}}$ at an intermediate frequency $f_0$.

At low frequencies the current approaches zero because the capacitive reactance becomes very large.

At high frequencies the current approaches zero because the inductive reactance becomes very large.

The Driven $RLC$ Circuit for Different Values of $R$

\[ I = \frac{E_0}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{E_0}{\sqrt{R^2 + (2\pi f L - 1/2\pi f C)^2}} \]