

VIDEO#37: Electronic Basics #37: What is Impedance? (AC Resistance?)

DC Circuits, Impedance, and Reactance

Basic Passive Components in DC Circuits

In DC circuits, the three most fundamental passive components are resistors, inductors, and capacitors.

- **Resistor:** As the name suggests, it resists the current flow and converts excess power into heat. It is commonly used in LED circuits to limit the current flow, ensuring the LED operates at its nominal value.
- **Capacitor:** It acts as an energy storage component and resists sudden changes in voltage.
- **Inductor:** Also an energy storage device, it resists sudden changes in current.

While resistors always resist the current flow, capacitors and inductors do not influence steady DC current flow except during switching (turning on or off the circuit).

Introduction to Impedance

Impedance is the concept of extending resistance to AC circuits. Unlike in DC circuits, where only resistors affect the current flow, in AC circuits, capacitors and inductors play a significant role.

In AC circuits:

- Inductors oppose changes in current.
- Capacitors oppose changes in voltage.

These effects lead to new forms of resistance called **reactance**, which changes based on frequency.

Experiment Setup

The experiment involves connecting a function generator output to an amplifier input. By varying the frequency and amplitude of a sine wave, the output voltage is amplified, allowing components to be tested at higher power levels.

Inductive Reactance

An inductor (214 μH) was connected to an AC voltage source (6V RMS, 10 kHz frequency).

Observations:

- The voltage wave leads the current wave by approximately 90° .
- The measured RMS current was 203mA.
- The inductor resists the current flow, behaving similarly to a resistor in this scenario.
- This resistance is called **inductive reactance (XL)**, measured in ohms (Ω).
- The equation for inductive reactance is:

$$X_L = 2\pi fL$$

where f is the frequency and L is the inductance.

- As the frequency increases, the inductive reactance increases, leading to lower current flow.

Capacitive Reactance

A capacitor (1 μF) was connected to the same AC voltage source (6V RMS, 3 kHz frequency).

Observations:

- The current wave leads the voltage wave by approximately 90° .
- The RMS current was measured as 110mA.
- This resistance is known as **capacitive reactance (XC)**, also measured in ohms (Ω).
- The equation for capacitive reactance is:

$$X_C = 1 / (2\pi fC)$$

where C is the capacitance and f is the frequency.

- Unlike inductors, capacitive reactance decreases with increasing frequency, leading to higher current flow.

Resistor Behavior in AC Circuits

- When a resistor is connected to an AC source, it does not introduce any phase shift between voltage and current.
- The resistance remains independent of frequency.
- Only the **ohmic resistance (R)** determines current flow.

Understanding Impedance

Impedance combines resistance and reactance into a single concept, represented as a complex number. To illustrate impedance:

- A **50 Ω resistor** and a **1 μ F capacitor** were connected in series with a 6.1V, 3kHz sine voltage.
- The total impedance cannot be calculated by simply adding resistance and reactance values directly; phase angles must be considered.
- **Impedance (Z)** is expressed in two forms:
 - **Polar Form:** Magnitude and phase angle representation.
 - **Cartesian Form:** Real and imaginary components.

$$Z = R + jX$$

where R is resistance, X is reactance, and j is the imaginary unit ($j = \sqrt{-1}$).

Complex Plane Representation of Impedance

In a complex plane:

- The **x-axis represents real values (resistance)**.
- The **y-axis represents imaginary values (reactance)**.

- **Capacitive reactance (XC)** is plotted downward.
- **Inductive reactance (XL)** is plotted upward.

By using trigonometry:

- **Magnitude of impedance:**

$$|Z| = \sqrt{R^2 + X^2}$$

- **Phase angle (θ):**

$$\theta = \arctan(X / R)$$

For the given example:

- **Impedance magnitude** = 72.9Ω
- **Current flow** = 83.7mA
- **Phase angle** = 46.7°

These calculated values closely match the practical measurements, showing the accuracy of impedance calculations.

Parasitic Effects in Real Components

In real-world components:

- Capacitors have **Equivalent Series Resistance (ESR)** and **Equivalent Series Inductance (ESL)**.
- Inductors have additional **parasitic resistance**, affecting their impedance.
- These parasitic effects cause deviations from ideal calculations.

Using an **LCR meter**, one can measure the complex impedance of a component at different frequencies.

Significance of Impedance in AC Circuits

The concept of impedance allows engineers to:

- Calculate current, voltage, and phase shifts in AC circuits.
- Design filters, power supplies, and signal processing circuits effectively.

- Understand challenges posed by frequency-dependent resistance and phase shifts.

With impedance, AC circuit analysis becomes manageable and predictable.

- DC circuits primarily deal with **resistance**, while AC circuits involve **impedance**, which includes **resistance and reactance**.
- **Inductors** resist changes in current, while **capacitors** resist changes in voltage.
- Impedance calculations involve both magnitude and phase angles.
- Real-world components have parasitic resistances and inductances, affecting ideal performance.
- Understanding impedance is crucial for designing and analyzing AC circuits.

By mastering these concepts, engineers can effectively design and troubleshoot both DC and AC circuits.