Capacitance

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VO1NO

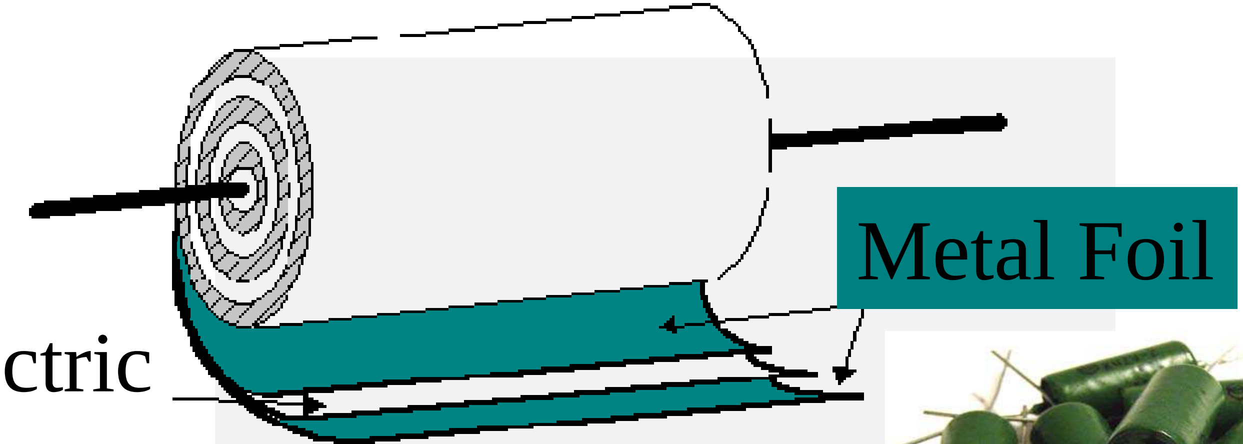
Capacitance

- **Capacitance** is the property of an electrical circuit that **opposes a change in voltage**.
- When a **voltage** applied across a circuit is **increased or decreased, capacitance resists that change.**

Construction of a Capacitor

- A basic capacitor consists of **2 conducting metallic plates** separated by a **layer of air or other insulating material** such as glass, mica or even oil.
- The **insulating material** is called the **Dielectric.**

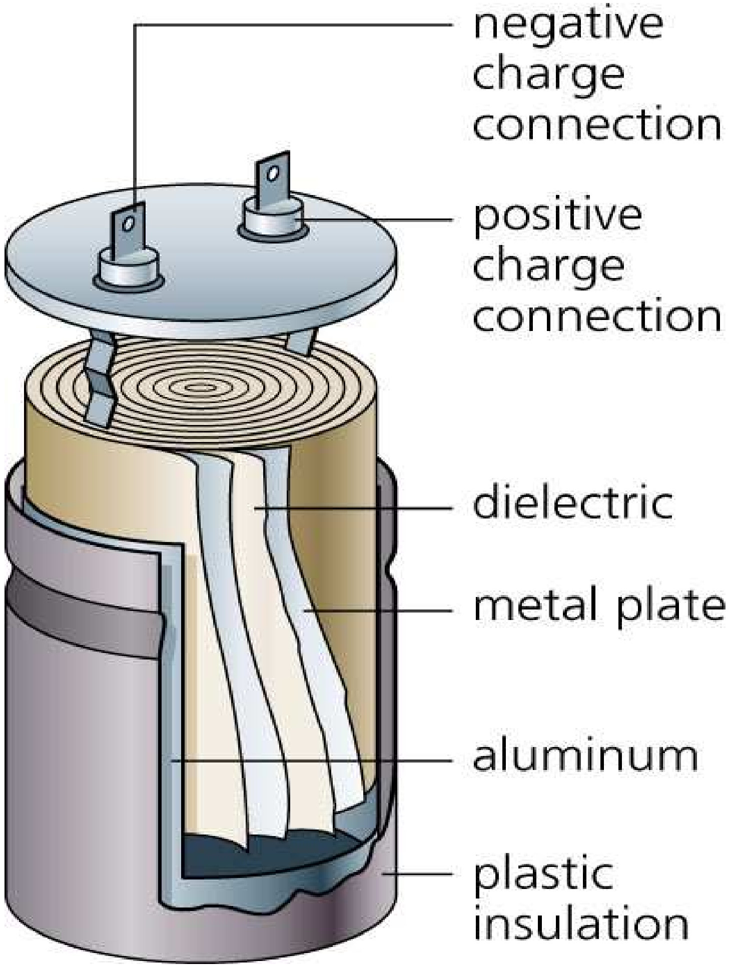
Axial Lead Capacitor



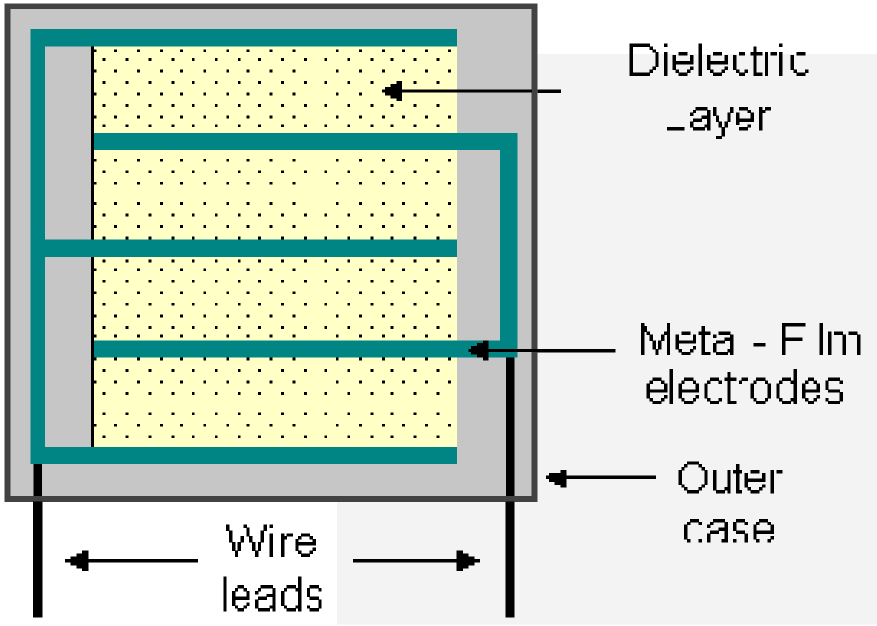
Metal Foil

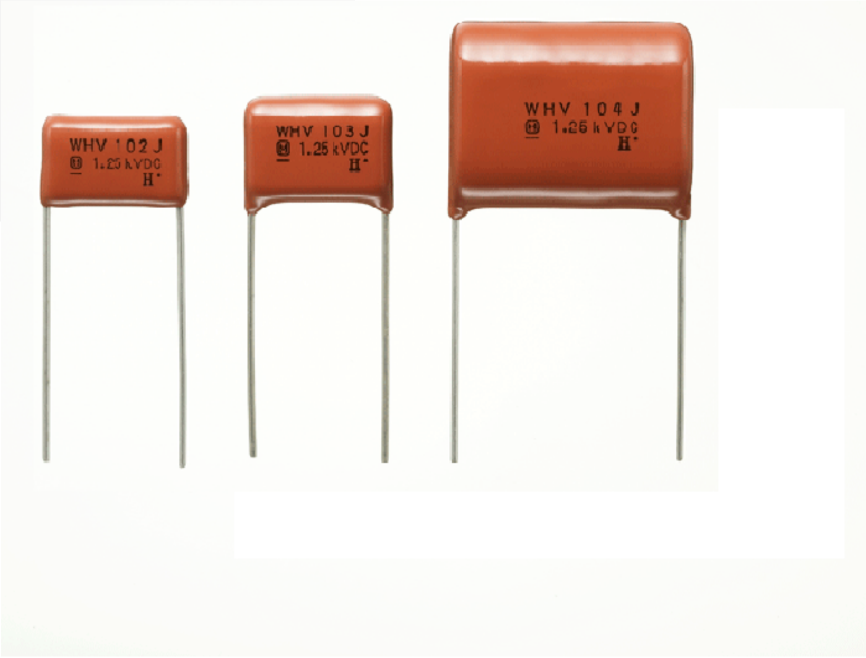
Dielectric Film

Electrolytic Capacitor



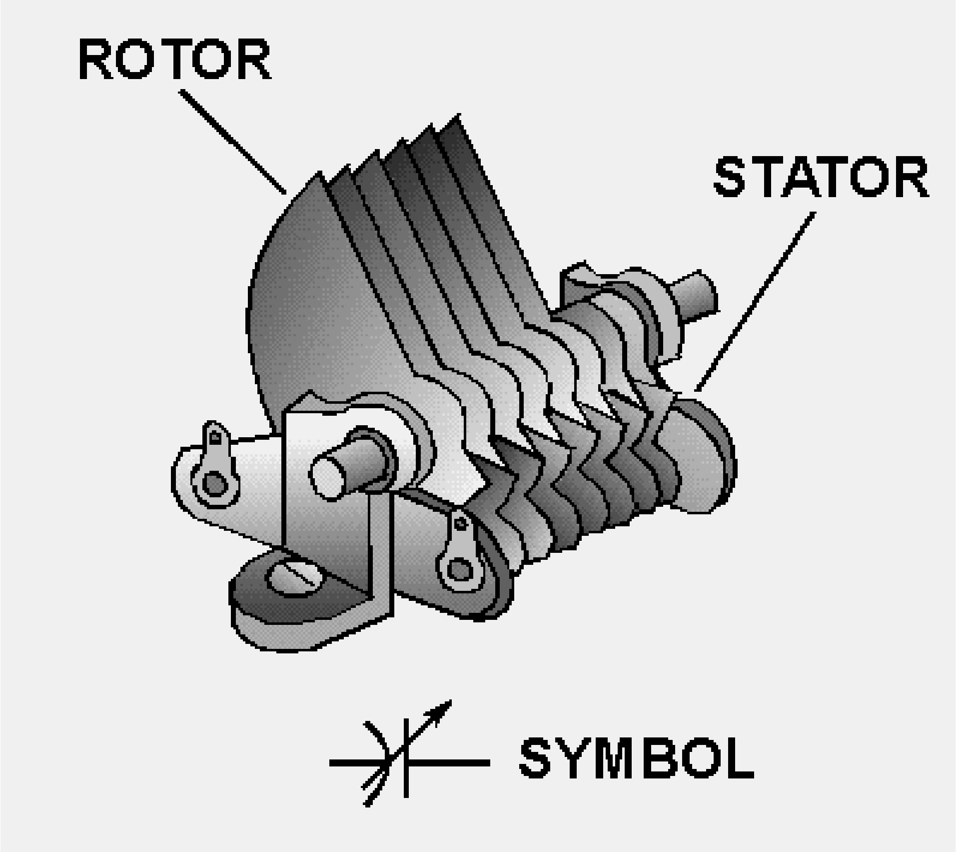
Radial Lead Capacitor



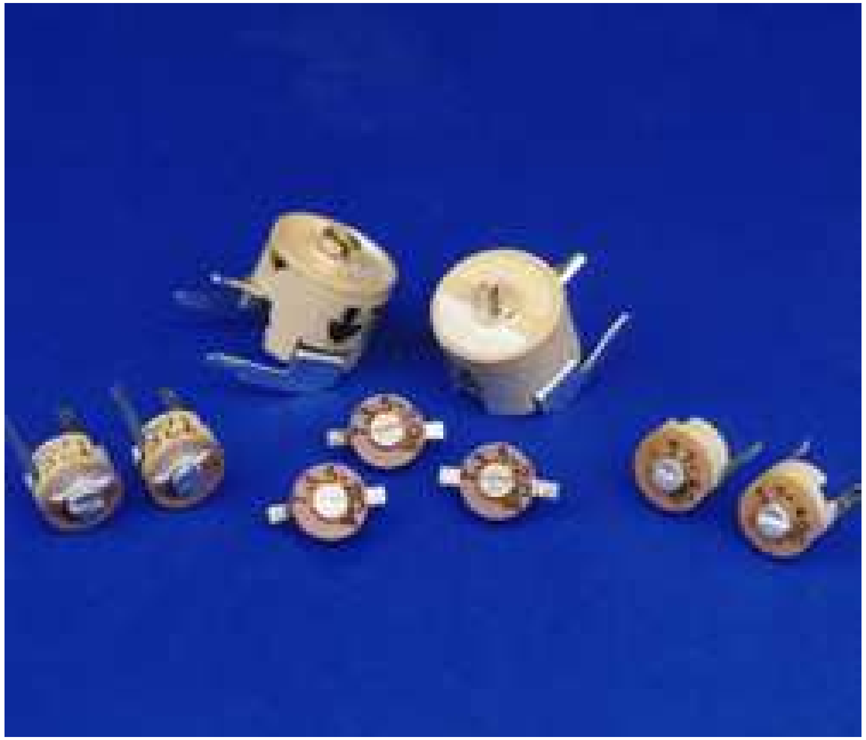


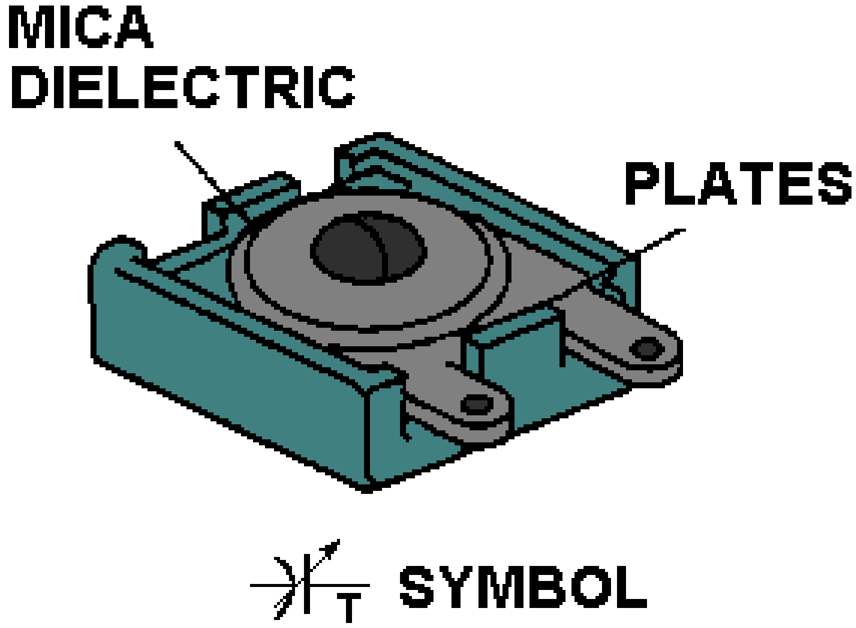
Ceramic Disc Capacitor

Variable Capacitor

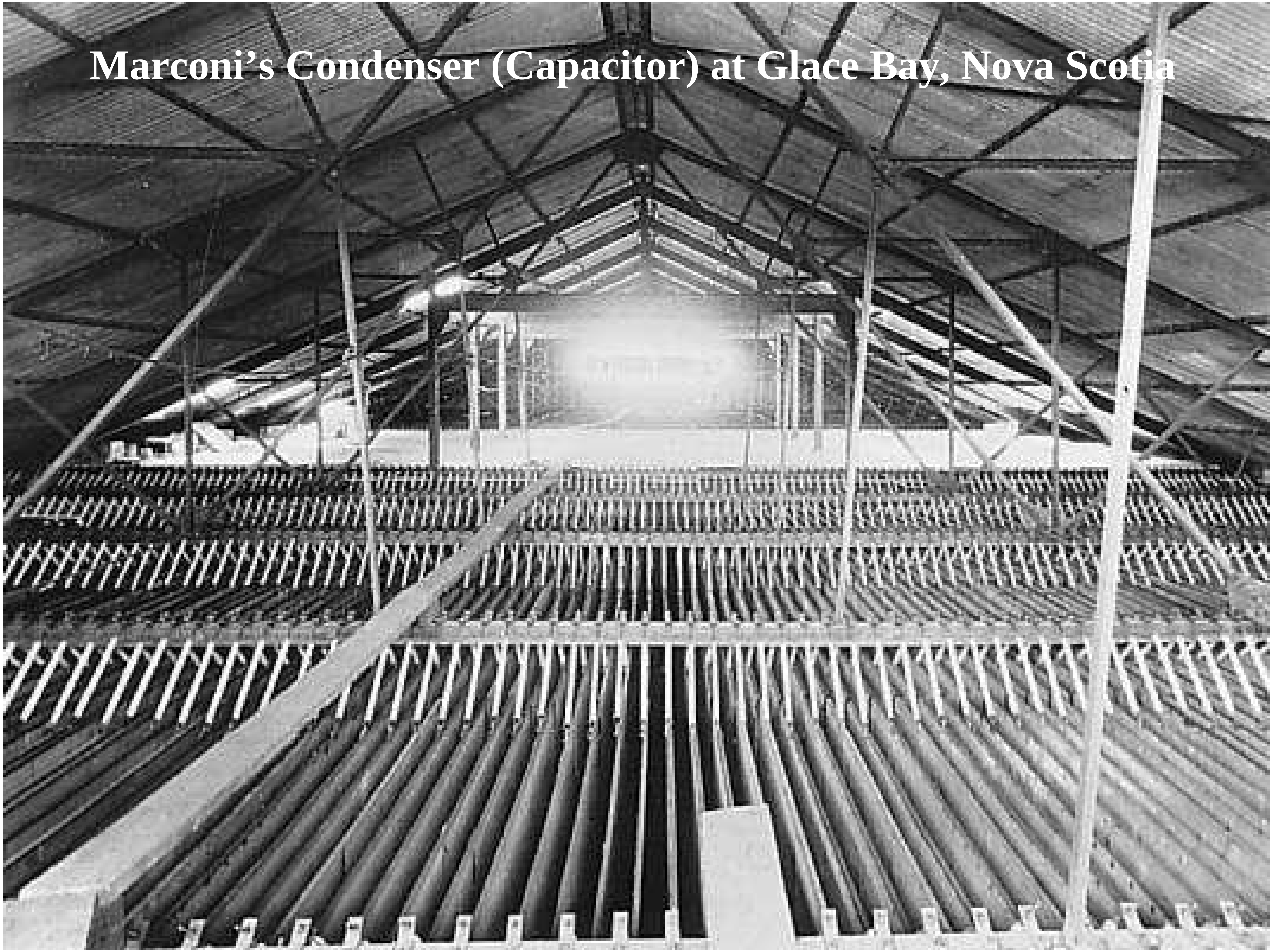


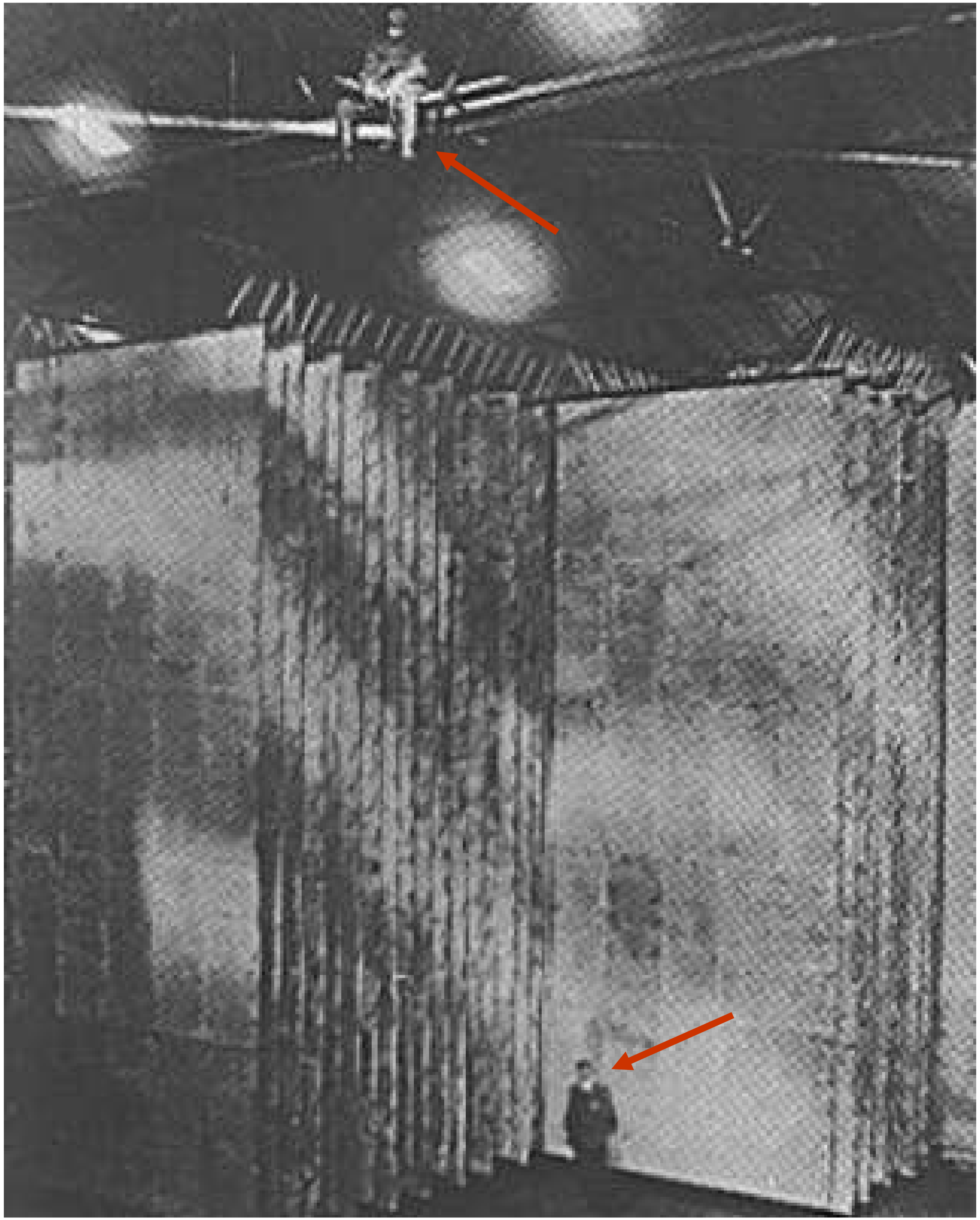
Trimmer Capacitors





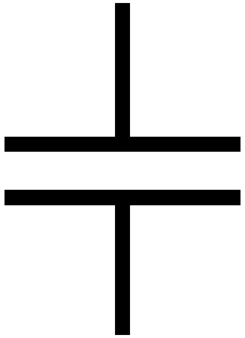
Marconi’s Condenser (Capacitor) at Glace Bay, Nova Scotia



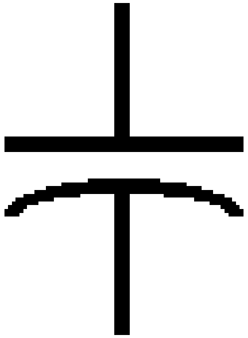


A similar capacitor at Marconi’s station in Clifden, Ireland. Note the size of the two men!

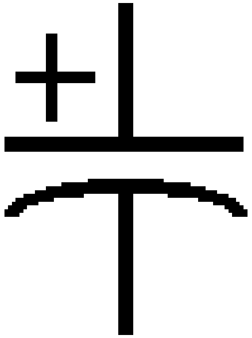
Capacitor Symbols



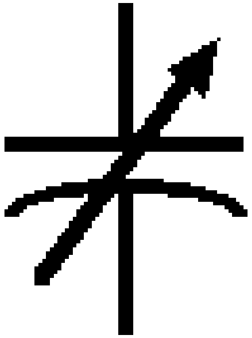
Normal



Normal

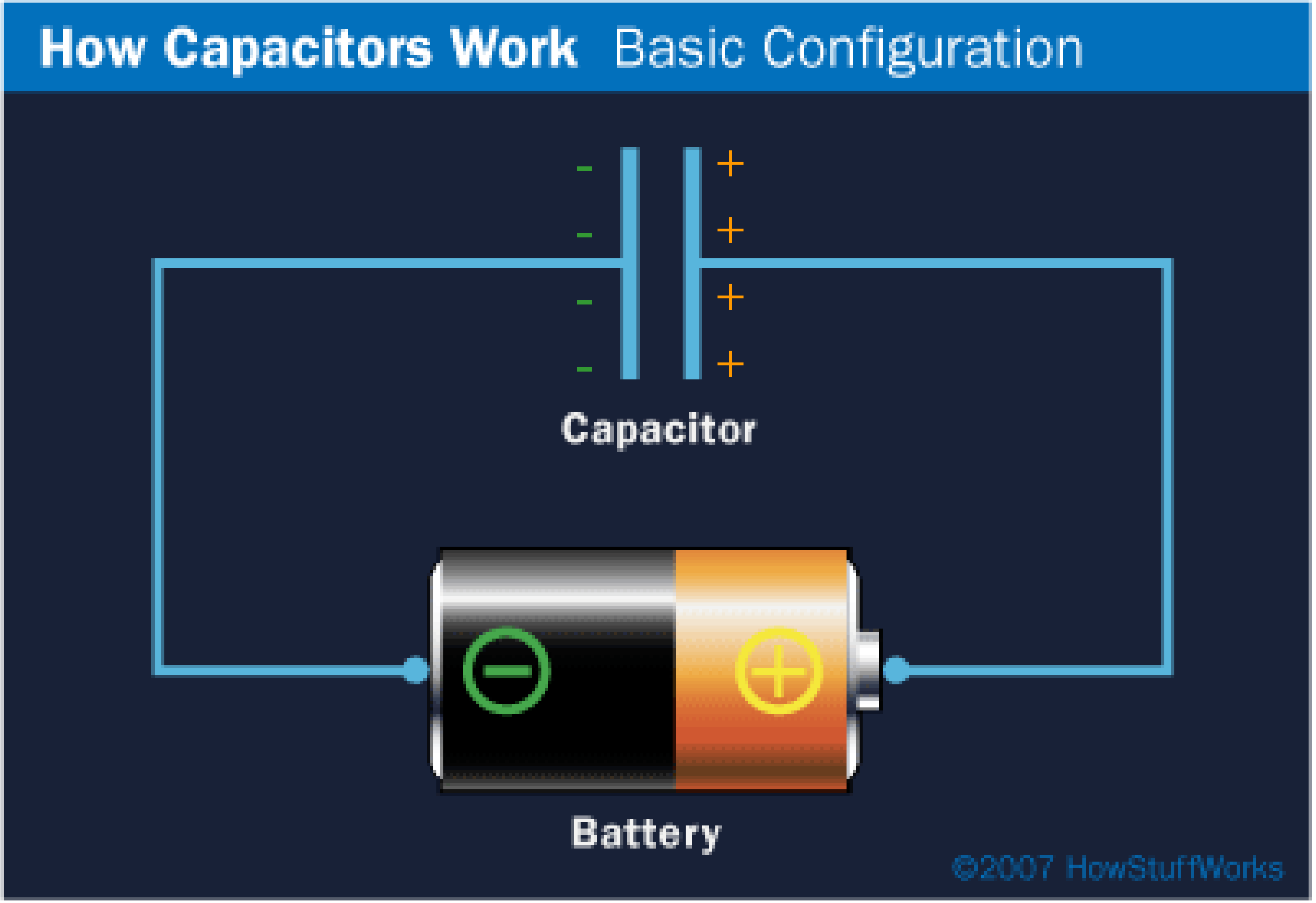


Electrolytic



Variable

Capacitors in a DC Circuit



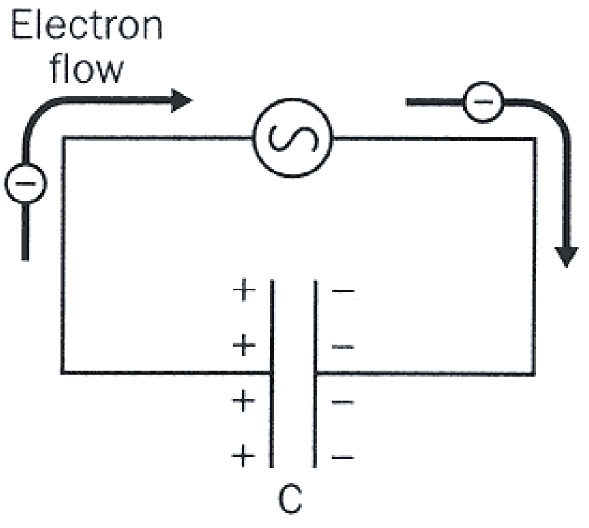
Capacitors in a DC Circuit

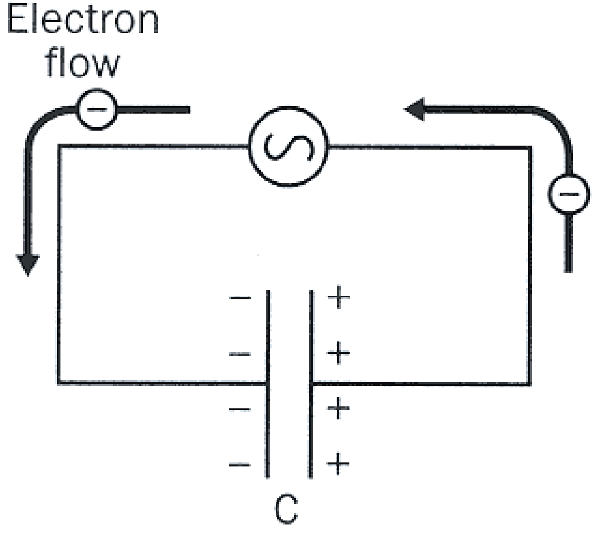
- When **first connected** to a battery, **electrons flow** from the **negative battery terminal** to the **capacitor plate** and remain there because the dielectric prevents them from travelling to the opposite plate.
- **Electrons** on the **opposite plate** are **attracted** to the **positive battery terminal.**
- Eventually, the capacitor reaches the **same voltage** as the battery, and **no more electrons flow.**
- The capacitor is then said to be **Charged.**
- **Capacitors block the flow of DC.**

Capacitors in an AC Circuit

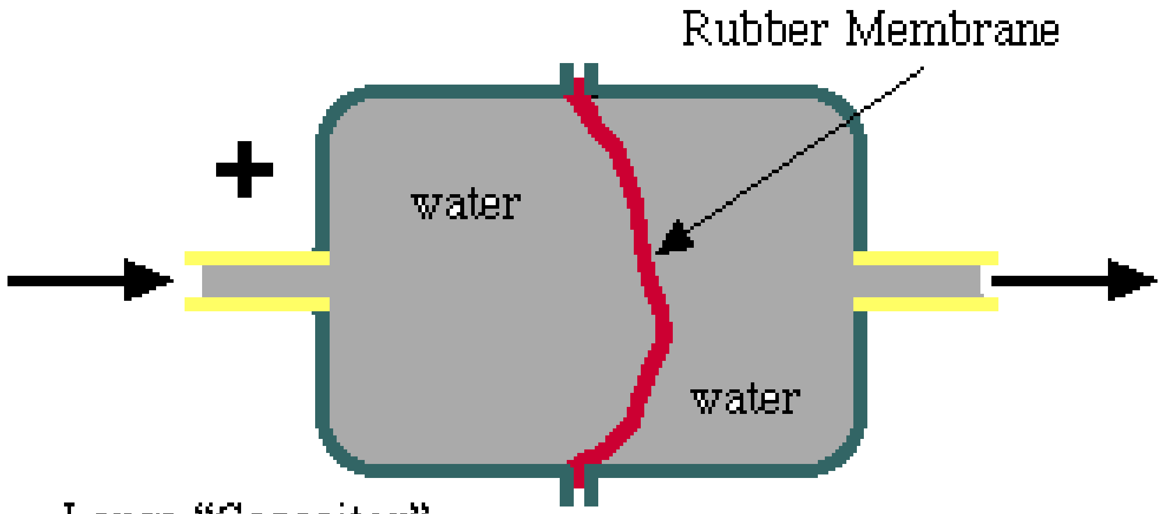
- **Current cannot** pass through a capacitor but **Alternating Current appears to.**
- If the **voltage** across the plates of the capacitor is **continuously varied,** the **number of electrons varies.**
- As the voltage changes then, **it appears as though a current is flowing** even though **electrons do not actually traverse** the dielectric.

Capacitors in an AC Circuit

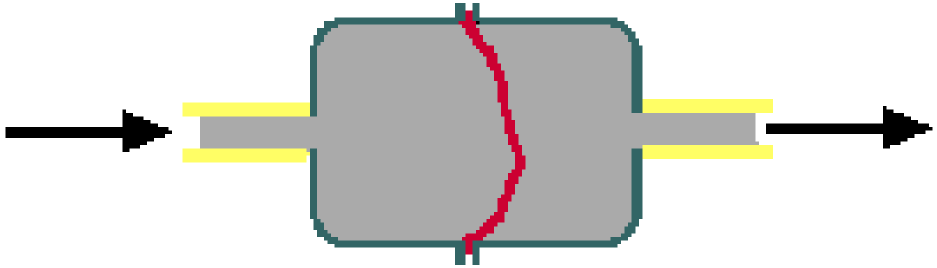




Water Reservoir Analogy



Large “Capacitor”



Small “Capacitor”

Electrons

- **Individual electrons** are **too small** to have an effect in everyday electronics, so we use a **larger number** of them to make **practical measurements.**
- The **Coulomb** is equal to **6.3 x 10^{18} electrons** (6,300,000,000,000,000,000 electrons).
- For example, one Ampere = 1 Coulomb per Second.

The Farad

- The **unit of measure** for capacitance is the **Farad.**
- One **Farad** is the **capacitance** in which a charge of **1 Coulomb** produces a **difference of 1 Volt** between the plates.
- One **Farad** is **much too large** a value for practical circuits however.

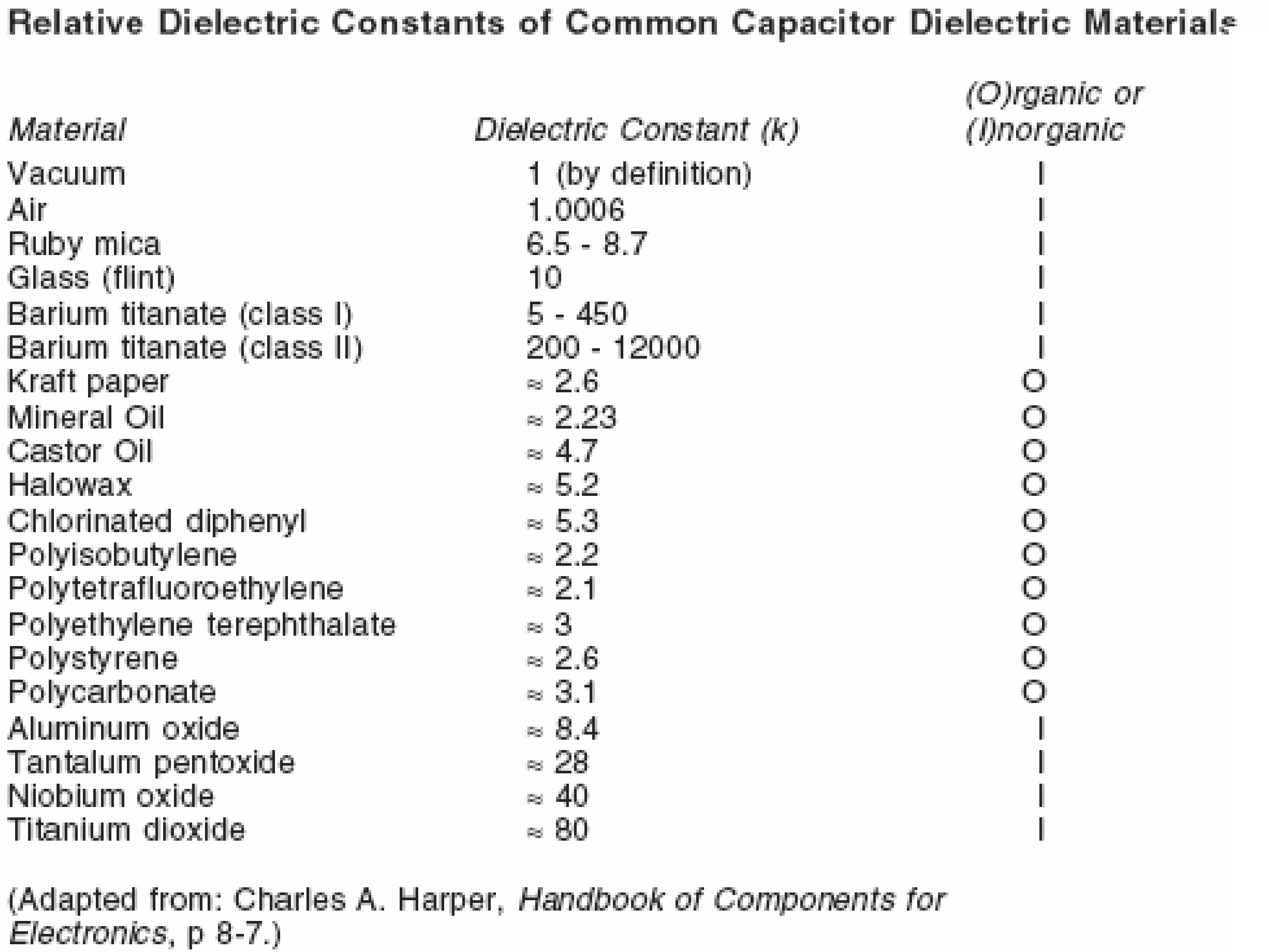
Practical Capacitor Units

- Practical capacitors are measured in:
  - **Microfarads**, or **millionths of a Farad.** They are abbreviated as **µf**, and equal to **1 x 10^{-6} Farads.** The old abbreviation was mfd.
  - **Picofarads**, or **millionth millionths of Farads**, are equal to **1 x 10^{-12} Farads.** They are abbreviated as pf. They were originally called Micromicrofarads, and you may still encounter the abbreviation mmf.

Factors Affecting Capacitance

- **Plate Area:** The **larger the plate area**, the **greater the capacitance.**
- **Distance Between the Plates:** The **closer together** the plates, the **greater the capacitance.** Of course, it is necessary to **prevent the charge** from **jumping the gap (arcing).**
- **Changing the Dielectric: Greater capacitance** can be obtained by using a **dielectric other than air.** Glass, mica, oil and mylar are some of the materials that have a greater **Dielectric Constant** than air. This is because they **permit the plates** to be **closer together,** and because they have **electrons** that can **move slightly.**

Dielectric Materials



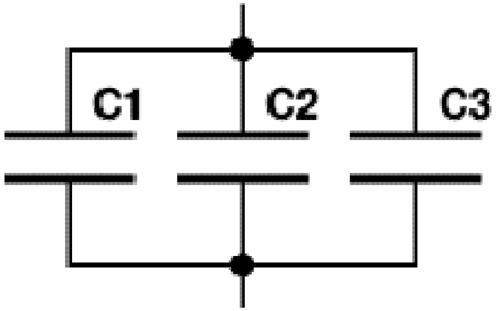
Relative Dielectric Constants of Common Capacitor Dielectric Materials

Material	*Dielectric Constant (k)*	*(O)rganic or (I)norganic*
Vacuum	1 (by definition)	I
Air	1.0006	I
Ruby mica	6.5 - 8.7	I
Glass (flint)	10	I
Barium titanate (class I)	5 - 450	I
Barium titanate (class II)	200 - 12000	I
Kraft paper	≈ 2.6	O
Mineral Oil	≈ 2.23	O
Castor Oil	≈ 4.7	O
Halowax	≈ 5.2	O
Chlorinated diphenyl	≈ 5.3	O
Polyisobutylene	≈ 2.2	O
Polytetrafluoroethylene	≈ 2.1	O
Polyethylene terephthalate	≈ 3	O
Polystyrene	≈ 2.6	O
Polycarbonate	≈ 3.1	O
Aluminum oxide	≈ 8.4	I
Tantalum pentoxide	≈ 28	I
Niobium oxide	≈ 40	I
Titanium dioxide	≈ 80	I

(Adapted from: Charles A. Harper, *Handbook of Components for Electronics*, p 8-7.)

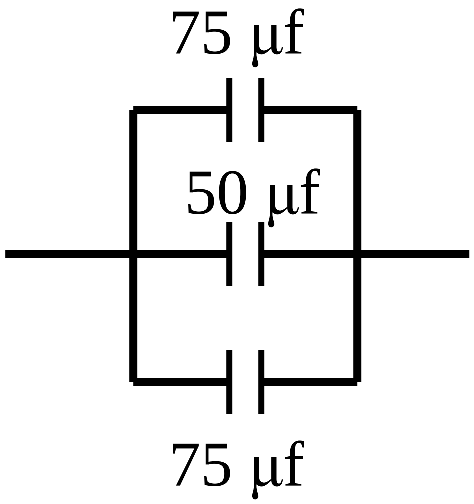
Capacitors in Parallel

- **Capacitors** in **Parallel add their values.**
- This is because it is **equivalent** to a **single capacitor** with a **greater surface area.**



$$C_T = C1 + C2 + C3$$

Example of Capacitors in Parallel



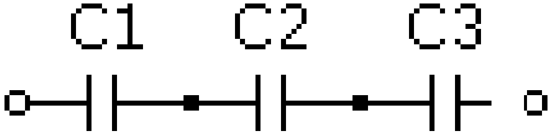
C_T = C1 + C2 + C3

C_T = 75μf + 50μf + 75μf

C_T = 200μf

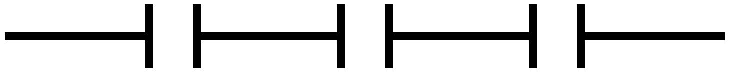
Capacitors in Series

- Capacitors in Series must be treated the same way that resistors and inductors in parallel are treated.



$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

Example of Capacitors in Series



$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

$$C_T = \frac{1}{\frac{1}{50} + \frac{1}{75} + \frac{1}{25}}$$

$$C_T = \frac{1}{\frac{3}{150} + \frac{2}{150} + \frac{6}{150}}$$

$$C_T = \frac{1}{\frac{11}{150}} = 150/11\mu f = 13.64\mu f$$

Working Voltage

- All capacitors have a **characteristic working voltage**, sometimes called the **voltage rating.**
- It is the **maximum DC voltage** that the capacitor can **sustain continuously** without **excessive leakage** or **breaking down** – ie: having the charge jump from one plate to the other **(arc).**
- **Arcing** will **destroy most capacitors.** Electrolytics can **self-heal** after small arcs. Even **air-gap variable capacitors** can be **damaged** by arcing.

Surge Voltage

- **Surge voltage** is the **maximum voltage** that can be **withstood** for a **few seconds** after the start-up of a circuit.
- It was an important parameter for **tube circuits,** but is **not very relevant** for modern solid-state circuits.

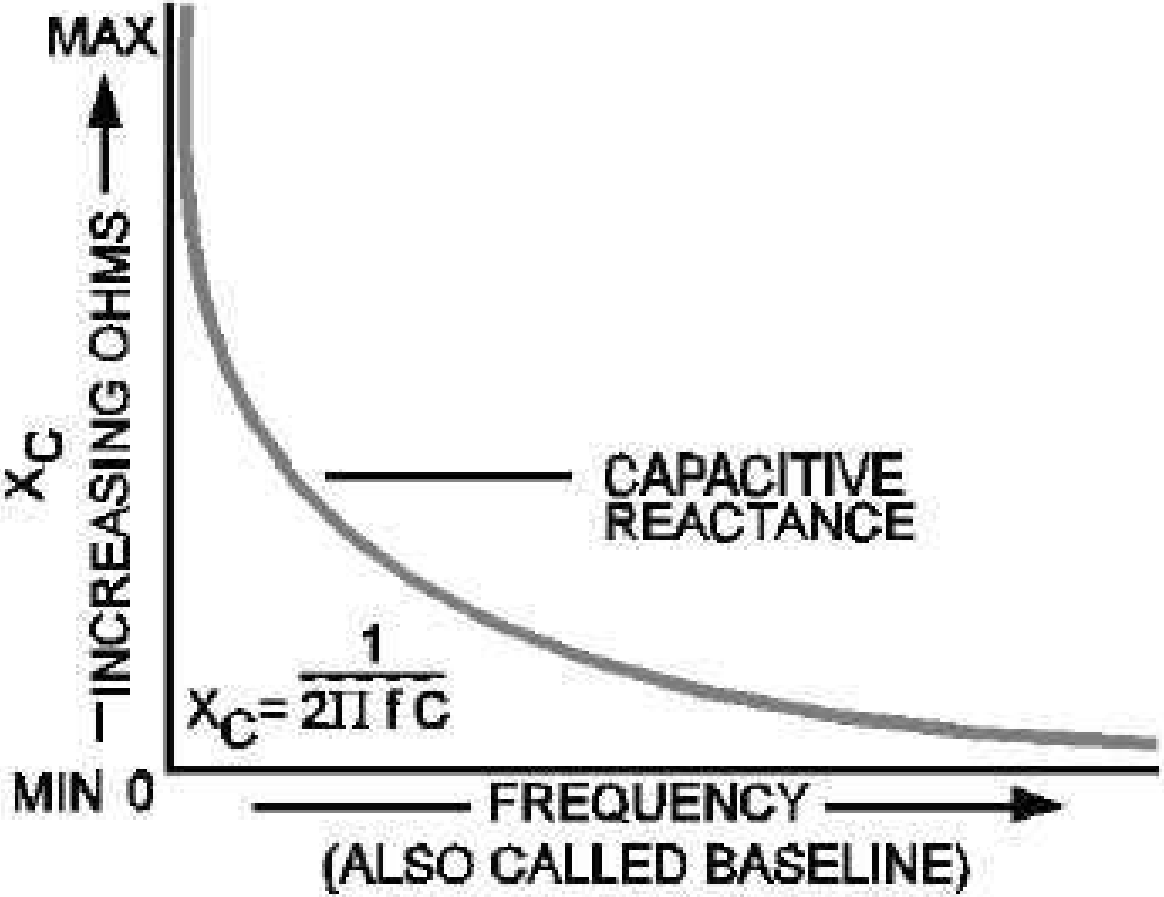
Reactance

- **Reactance** is the **opposition** to the **flow of Alternating Current (AC).**
- **Reactance** has **no effect** on the flow of **Direct Current (DC).**

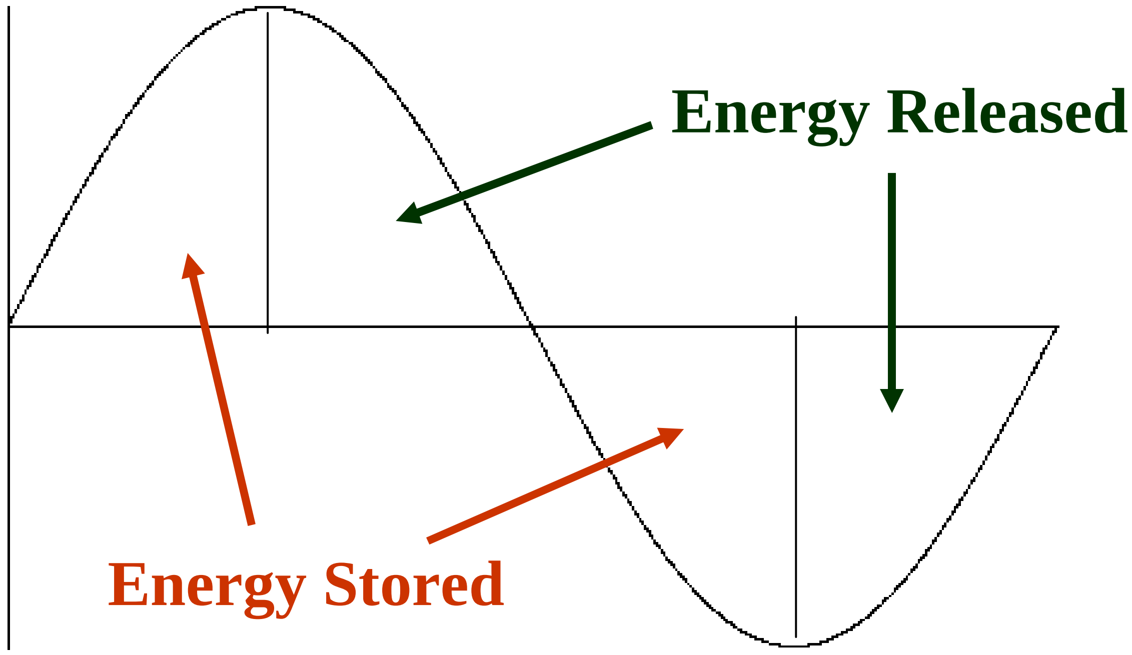
Capacitive Reactance

- **Capacitive Reactance** is the **opposition** to the **flow of AC by capacitance.**
- As the **frequency of the AC increases, Capacitive Reactance decreases.**
- The **Symbol** for **Capacitive Reactance** is $\mathbf{X_C}$**.**
- $\mathbf{X_C}$ is expressed in **ohms.**
- Even though it is expressed in ohms, **power is not dissipated by Reactance!** Energy **stored in a capacitor** during **one part of the AC cycle** is simply **returned to the circuit** during the **next part of the cycle!**

Capacitive Reactance



Energy Storage and Release



Energy Released

Energy Stored

Capacitive Reactance

$$X_C = \frac{1}{2\pi f C}$$

- Where:

F = frequency in Hertz

C = capacitance in Farads

π = 3.14

Capacitive Reactance

$$X_C = \frac{1}{2 \pi f C}$$

However, Farads and Hertz are **cumbersome units,** so we can use other units:

F = frequency in Megahertz (MHz)

C = capacitance in Microfarads (µf)

π = 3.14

Capacitive Reactance Example 1

- What is the capacitive reactance of a 470 pf capacitor at a frequency of 7.15 MHz?
  - Remember that 470 pf = 0.000470 μf.

$$X_C = \frac{1}{2\,\pi\,f\,C}$$

$$= \frac{1}{2\,\pi \times 7.15\ \text{MHz} \times 0.000470\ \mu\text{F}}$$

$$= \frac{1\,\Omega}{0.0211} = 47.4\,\Omega$$

Capacitive Reactance Example 2

- What is the capacitive reactance of that same 470 pf capacitor at a frequency of 14.29 MHz?
  - Again, remember that 470 pf = 0.000470 μf.

$$X_C = \frac{1}{2\,\pi\,f\,C}$$

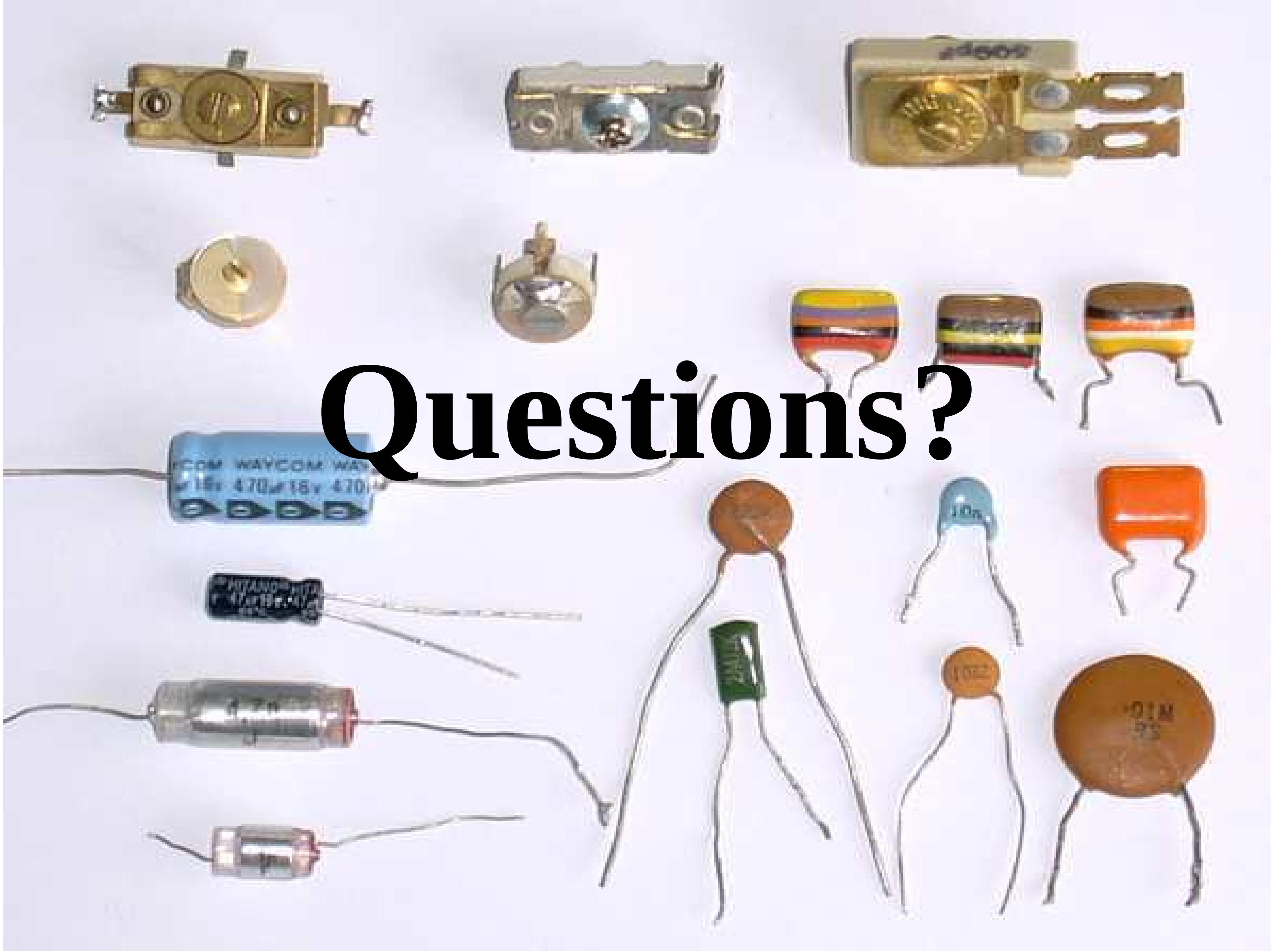
$$= \frac{1}{2\,\pi \times 14.30\ \text{MHz} \times 0.000470\ \mu\text{F}}$$

$$= \frac{1\,\Omega}{0.0422} = 23.7\,\Omega$$

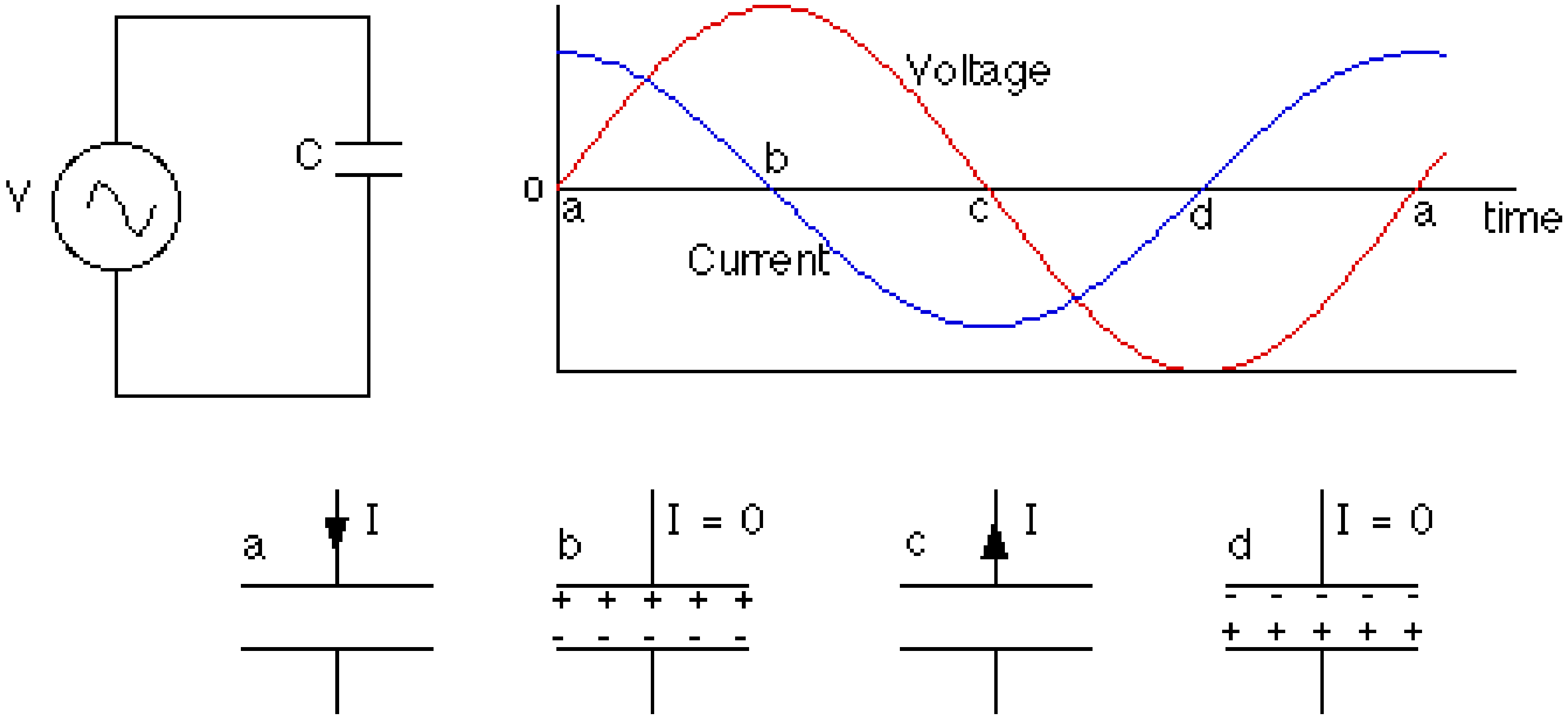
Capacitive Reactance Examples

- Note that as the **frequency increased** from 7.15 MHz to 14.290 MHz, the **Capacitive Reactance decreased** from 47.4 ohms to 23.7 ohms.
- **Remember:**
  - **Capacitors block DC;**
  - Capacitors **store energy** as an electrical charge; and
  - As the **frequency increases, capacitive reactance decreases (and vice versa!).**

Questions?



Current and Voltage



Inductive Reactance

$$X_L = \omega L$$

(units in ohms = Ω)

Capacitive Reactance

$$X_C = \frac{1}{\omega C}$$

(units in ohms = Ω)

Impedance

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$$

(units in ohms = Ω)

Phase Angle

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

Ohm's Law for A.C. Circuits

$$V = I Z$$