

## UNIT 38 – ELECTRICAL and ELECTRONIC PRINCIPLES OUTCOME 2

Electric fields and capacitors

*Electric fields:* electrostatics, charge, electron movement in field, force on unit charge, dielectric materials, effect of dielectric materials on field

*Capacitors:* definition of capacitance, working voltage, permittivity, capacitor construction, multiplate, series, parallel, energy stored, potential gradient, electric field strength, flux density, constant of proportionality

*Circuits:* practical activities to include charging and discharging circuits, time constants; construct a basic capacitor, tests to verify a selection of parameters

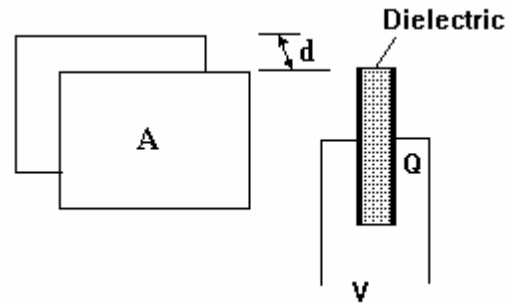
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Consider two plates each with an area  $A$  and separated by a distance  $d$ . The material between them is the dielectric. The charge  $Q$  stored on a pair of plates depends upon the voltage and the physical dimensions and properties of the plates and dielectric. For a given capacitor it is found that charge is directly proportional to voltage such that

$$Q = CV$$



The constant  $C$  is the **CAPACITANCE**. Capacitance is measured in Farads (F) but this is a large unit so we use the following multiples.

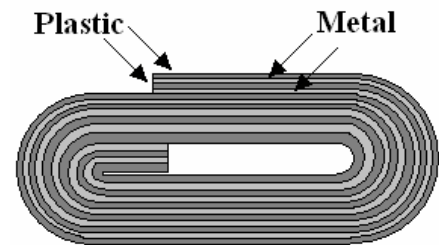
$$mF = F \times 10^{-3} \quad \mu F = F \times 10^{-6} \quad nF = F \times 10^{-9} \quad pF = F \times 10^{-12}$$

### 3. TYPES AND CONSTRUCTION

Some typical types of capacitors are shown below. Each capacitor has a maximum working voltage which if exceeded might cause the dielectric to break down and conduct.

#### 3.1 Paper and Plastic

The dielectric is made of paper or plastic, plastic being the more modern type. In the case of paper, two sheets of foil and two sheets of paper are interleaved and rolled into a cylinder. In the case of plastic, the plastic is coated in a metal film. The finished product is encapsulated in a plastic or metal tube with terminals connecting to the metal sections.



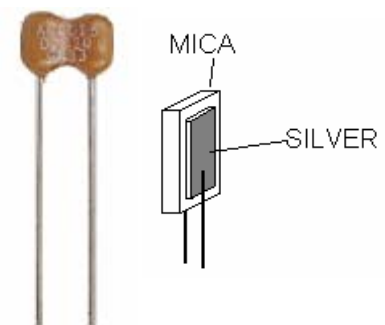
The capacitor may be made in box shapes in a similar way. The end connections are designed for mounting vertically or horizontally on circuit boards or between terminals.



The types of plastics commonly used are polycarbonate, polystyrene, polypropylene and polyester. The type used depends upon the intended voltage and accuracy.

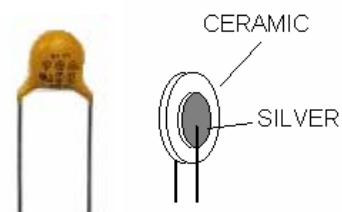
#### 3.2 Silver Mica

A piece of mica is the dielectric with silver deposited on each side to form the plates. They are encapsulated in wax impregnated with ceramic. They may be disc shaped or flat. Their advantage is high working voltage (typically 350V) and accuracy.



#### 3.3 Ceramic

These may be disc shaped, tubular or flat. The dielectric is ceramic and metal films are deposited to form the plates. They are encapsulated in resin or epoxy.



### 3.4. Tantalum Bead

Tantalum is used as the dielectric and produces a large capacitance in small volume but with low working voltages. These small capacitors are encapsulated in resin.



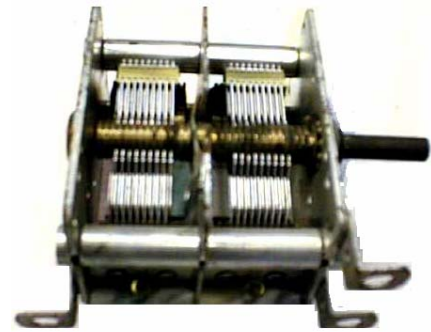
### 3.5. Electrolytic

The construction consists of metal foil and impregnated cotton gauze layered and rolled up into a cylinder. The dielectric is a chemical film formed by electrolytic action between the gauze and the foil. Very large capacitances are possible. The dielectric is broken down by reversed current so they cannot be used with A.C. and polarity of the terminals must be observed. Sizes range from less than 1 micro-Farad to many thousands of micro-Farads. The physical size also depends upon the working voltage.



### 3.6. Variable

The picture shows a multiplate air spaced variable capacitor. There are two sets of metal plates or vanes, fixed and moving. The fixed vanes are all attached to the frame. The moving vanes are attached to the spindle. The plates are made to interleave and the area common to both sets of plates is varied by rotating the spindle. The dielectric is air or plastic. The dielectric is air. If plastic is used between the plates, they may be made more compact. These mechanical designs are expensive and for many applications they have been replaced by a device called a varicap diode. A typical use is in radio tuners.

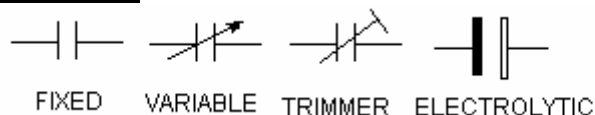


### 3.7. Preset or Trimmers.

These are small variable capacitors designed to be adjusted only occasionally. When a capacitance value is critical, a trimmer may be used instead of a fixed type so that the exact capacitance may be obtained. One design uses interleaving plates that rotate. Another design uses two metal plates that are squeezed onto a mica sheet by turning a screw.



## 4. CAPACITOR SYMBOLS



## 5. ELECTROSTATIC THEORY

Each electron carries a negative quantity of energy of  $160 \times 10^{-21}$  Joules per volt. If a plate has excess electrons it has a negative charge and if it loses electrons it becomes positively charged.

Plates which have opposite charge attract each other. Plates with a similar charge repel each other. These forces are electrostatic forces.

### 5.1 ELECTRIC FIELD E

The electric field strength is defined as  $E = V/d$  Volts/metre

### 5.2 ELECTRIC FLUX

Electric flux is the charge that exists in common between two plates. It is expressed as the charge per square meter of common plate area. It is defined as follows.

Electric flux density =  $D = Q/A$  Coulombs/m<sup>2</sup>

### 5.3 RELATIONSHIP BETWEEN ELECTRIC FIELD AND FLUX

It is found that for a given capacitor, the electric flux is directly proportional to the electric field.

$D = \text{constant} \times E$  and  $D = Q/A$   $E = V/d$  so substituting we get:-

$$D/E = \text{Constant} = (Q/A)/(V/d) \quad \mathbf{Q d/A V = \text{constant}}$$

The ratio or constant is changed if a different dielectric is used. If a vacuum separates the plates it is found that  $D/E = Qd/AV = 8.85 \times 10^{-12}$

This constant is called the ABSOLUTE PERMITTIVITY of free space and is denoted as  $\epsilon_0$ .

$$\mathbf{\epsilon_0 = 8.85 \times 10^{-12}}$$

For other materials the constant is different. In order to take this into account the following formula is used.

$$D/E = Qd/AV = \text{constant} = \epsilon_0 \epsilon_r$$

$\epsilon_r$  is a multiplier which states how many more times the constant is than when it is a vacuum.  $\epsilon_r$  is called the RELATIVE PERMITTIVITY. Here are some values of  $\epsilon_r$ .

MATERIAL	$\epsilon_r$
Free Space	1.000
Air	1.006
Paper	2 approx.
Glass	7 approx.
Mica	4 approx.
Ceramic	6 approx.
Plastics	various

We said that  $D/E = Qd/AV = \epsilon_0 \epsilon_r$  so it follows that the capacitance C is given by:

$$\mathbf{C = Q/V = (A/d)\epsilon_0 \epsilon_r}$$

We put this in more simple terms by saying that capacitance is directly proportional to area but inversely proportional to the gap d. It also depends upon the relative permittivity of the dielectric.

#### SELF ASSESSMENT EXERCISE No. 1

1. Calculate the charge stored on a capacitor of value 200  $\mu\text{F}$  when 50 V are applied to the plates. **(0.01 Coulomb)**
2. Calculate the value of a capacitor which stores 5 Coulombs at 20 V. **(0.25 F)**
3. Calculate the Voltage required to store 20 Coulombs in a capacitor of value 50  $\mu\text{F}$ . **(400 kV)**
4. An overhead cable is 30 m from the ground at a potential difference of 20 kV to the ground. Calculate the electric field strength and the theoretical voltage at a height of 2 m from the ground. **(666.7V/m and 1333 V)**
5. Calculate the capacitance of two parallel square plates 50 mm x 50 mm when separated by 2 mm of glass. **(77 pF)**  
The plates are charged to 100 V and left isolated. the glass is removed and air replaces it. What happens to the voltage on the plates?

## 6. ENERGY STORED

A charge of 1 Coulomb carries energy of 1 Joule for each volt. The energy in a charge is hence  $QV$ . When a capacitor is charged, the voltage has to build up from 0 to  $V$  so the average voltage is  $V/2$ . The energy stored is hence  $QV/2$ . Substituting  $Q=CV$  the energy stored in a capacitor is hence

$$E = \frac{CV^2}{2}$$

## 7. NETWORKS

### 7.1 CAPACITORS IN PARALLEL

Consider three capacitors  $C_1$ ,  $C_2$  and  $C_3$  connected in parallel as shown. The voltage is the same on each one. The charge stored on each is

$$Q_1 = C_1 V \quad Q_2 = C_2 V \quad Q_3 = C_3 V$$

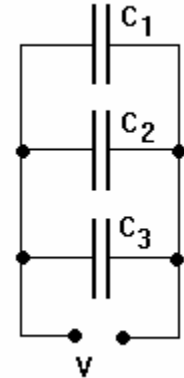
The total charge stored  $Q_T = Q_1 + Q_2 + Q_3$

$$Q_T = C_1 V + C_2 V + C_3 V = V(C_1 + C_2 + C_3)$$

We define  $Q_T$  as  $C_T V$  where  $C_T$  is the total capacitance so it follows that

$$C_T = (C_1 + C_2 + C_3)$$

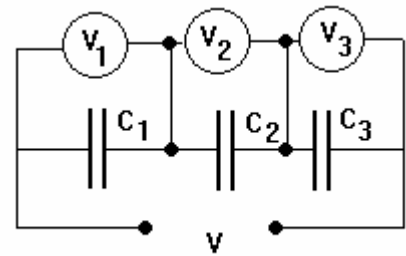
It follows that capacitors in parallel are added together.



### 7.2 CAPACITORS IN SERIES

Consider three capacitors in series with a voltage  $V$  across the total but the voltage on each one is  $V_1$ ,  $V_2$  and  $V_3$ .

Since the movement of electrons must be the same onto and off all the plates, the charge stored on each capacitor is the same and equal to the total charge.



$$Q_T = Q_1 = Q_2 = Q_3 = Q$$

$$V = Q_T / C_T \quad \text{and} \quad V_1 = Q_1 / C_1$$

$$V_2 = Q_2 / C_2 \quad \text{and} \quad V_3 = Q_3 / C_3$$

$$\text{Since } V = V_1 + V_2 + V_3 \quad \text{then}$$

$$Q / C_T = Q / C_1 + Q / C_2 + Q / C_3$$

Cancelling  $Q$  we have

$$1 / C_T = 1 / C_1 + 1 / C_2 + 1 / C_3$$

Hence

$$C_T = 1 / (1 / C_1 + 1 / C_2 + 1 / C_3)$$

Note that capacitors in series follow the same rule as resistors in parallel.

### 7.3 COMBINATION

Solving capacitor networks is similar to solving resistor networks. The following example shows this. Solve the total capacitance and the voltage across the  $20 \mu\text{F}$  capacitor.

First solve the parallel capacitors.

$$C_p = 100 + 70 = 170 \mu\text{F}$$

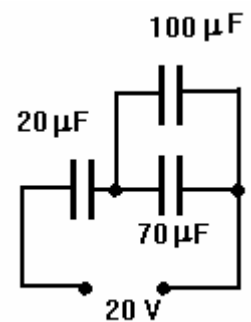
Next solve this in series with the 20.

$$C_T = 1 / (1 / 20 + 1 / 170) = 1 / 0.05588 = 17.89 \mu\text{F}$$

Next solve the charge  $Q = C_T V = 17.89 \times 10^{-6} \times 20 = 357.9 \times 10^{-6}$  Coulomb

The charge is the same on all series capacitors so the charge on the  $20 \mu\text{F}$  is the same.

$$Q = 357.9 \times 10^{-6} = 20 \times 10^{-6} \times V \quad \text{hence } V = 17.89 \text{ V}$$



**SELF ASSESSMENT EXERCISE No. 2**

Solve the total capacitance and the voltage on the  $30\mu\text{F}$  capacitor. (9.167  $\mu\text{F}$  and 6.11 V)

