Module

2

AC Theory

Looking at Capacitors

Capacitors

What you'll learn in Module 2:

In section 2.1 Capacitors

Common capacitor types and their uses.

Basic Circuit Symbols for Capacitors.

In section 2.2 Charge & Discharge

How capacitors work.

What is charge?

Charge and discharge in a DC circuit

In section 2.3 Capacitance

What is capacitance?

Dielectric.

Permittivity.

Dielectric strength and maximum working voltage.

Calculating the charge on a capacitor.

In section 2.4 Capacitors in Circuits

Solving capacitor circuit calculations.

Capacitors in series.

Capacitors in parallel.

In section 2.5 Capacitor Quiz

Capacitor Quiz

Module 2 − Introduction to Capacitors

Capacitors

Capacitors are one of the most useful components in electronics, and after resistors are the most numerous components in circuits. This module introduces diffent types of capacitor and describes their basic operation. Later modules look at how capacitors are used in AC circuits where, together with inductors, they perform an important job in many circuits.

This is module 2 of 14 modules.

In this module what you will learn is listed in the grey panel. It tells you **"What you should know..." as a result of studying the complete module.**

Each module is divided into several smaller sections and you can check your learning with the "Module Quiz" at the end of the module.

Study each section (numbered 2.1, 2.2 etc) in order, and use the quiz questions to help check your understanding.

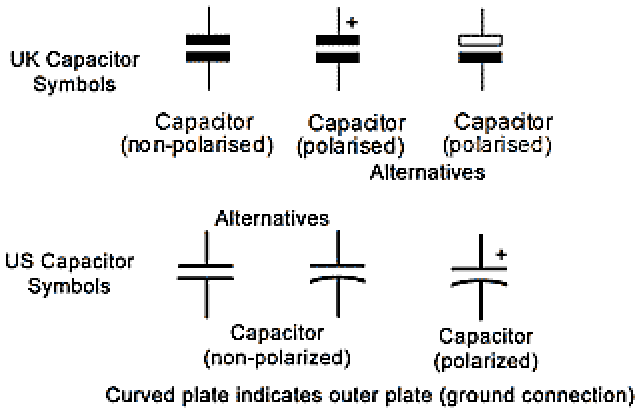
If you would like a PRINT version of other modules, go to the AC Theory section of www.learnabout-electronics.org click the PDF icon in the left column on the appropriate module, to download your copy.

Module 2.1 Capacitors

Capacitors (and inductors) have the ability to store electrical energy, inductors store energy as a magnetic field around the component, but the capacitor stores electrical energy directly, as an ELECTROSTATIC FIELD created between two metal "plates".

Fig 2.1.1 Basic Circuit Symbols for Capacitors

Fig 2.1.1 shows the UK and US circuit symbols for a variety of capacitor types. A basic fixed value type of capacitor consists of two plates made from metallic foil, separated by an insulator. This may be made from a choice of different insulating materials, having good DIELECTRIC properties. Some basic types of capacitor construction are shown in fig 2.1.2a.



Capacitors Have Many Uses.

Capacitors have many uses in electronic circuits. Each purpose uses one or more of the features described in this module. Fig 2.1.2 shows a variety of capacitors. Typical uses would include:

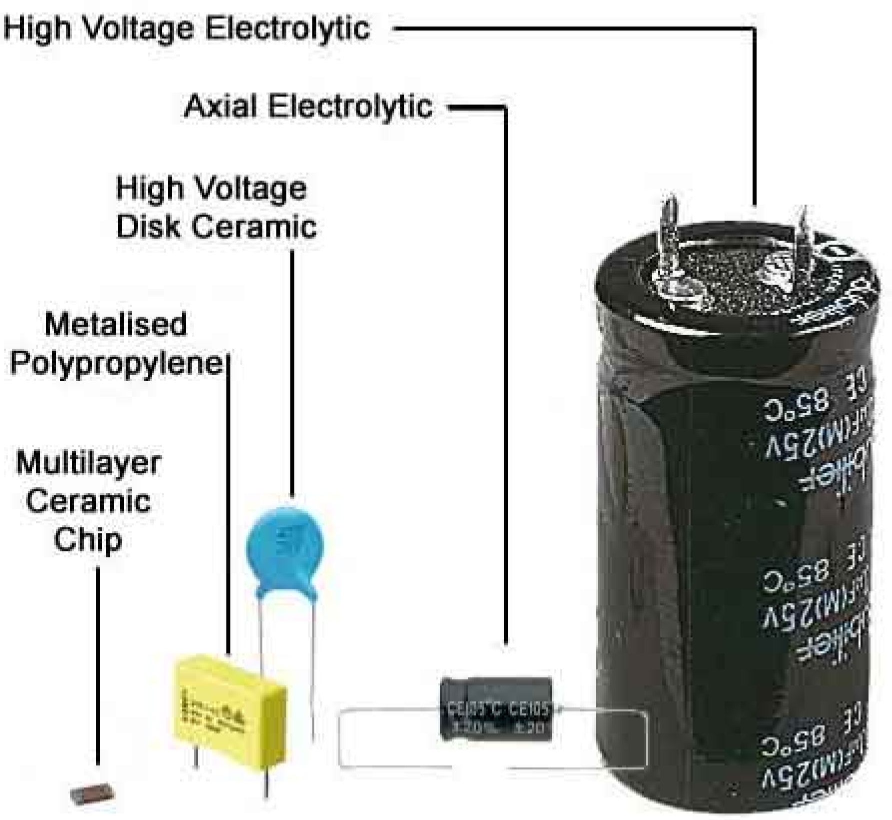


Fig 2.1.2 Images: Rapid Electronics Ltd Colchester UK

Capacitor types illustrated on page 3:

- **High Voltage Electrolytic** used in power supplies.
- **Axial Electrolytic;** lower voltage smaller size for general purpose where large capacitance values are needed.
- **High Voltage disk ceramic;** small size and capacitance value, excellent tolerance characteristics.
- **Metalised Polypropylene;** small size for values up to around 2µF good reliability.
- **Sub miniature Multi layer ceramic chip** (surface mount) capacitor. Relatively high capacitance for size achieved by multiple layers, effectively several capacitors in parallel.

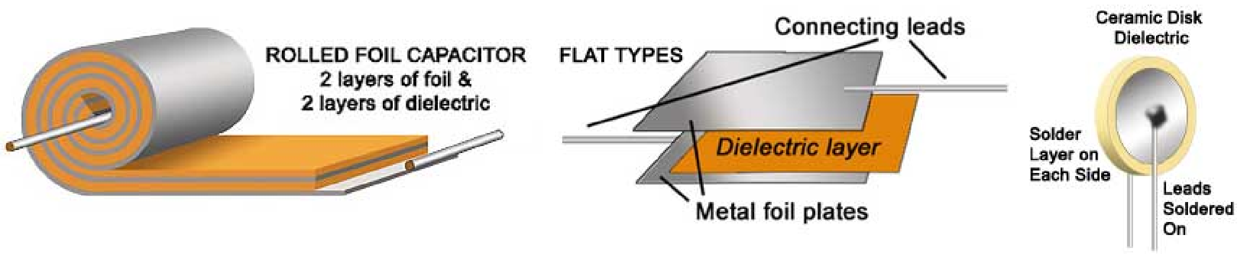
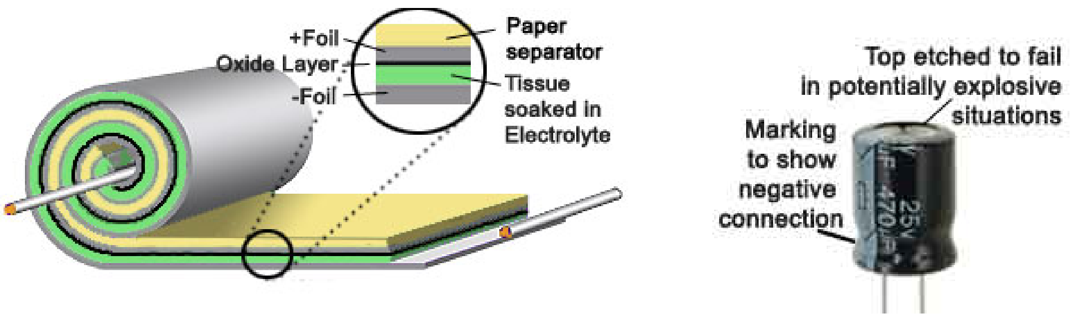


Fig. 2.1.2a Construction − Fixed Value Capacitors

The construction of non−polarized capacitors follows the same pattern over many types. Variations consist of the area of the plates and type of dielectric material used for a given capacitance; ideally the dielectric will be the thinnest material, with the best permitivity, that will also withstand the voltage required. Each of the basic types shown in Fig 2.1.2a will be coated with an insulating layer (often an epoxy resin).



Electrolytic Capacitors

The construction of electrolytic capacitors is similar in some ways to a rolled foil capacitor. Except that the layers between the foil are now two very thin layers of paper, one that forms an insulator separating the rolled pairs of layers and the other, a layer of tissue between the foil plates, soaked in an electrolyte that makes the tissue conductive!

It would seem from the previous paragraph that the soaked tissue places a short circuit between the plates. But the real dielectric layer is created after construction is complete, in a process called "Forming". A current is passed through the capacitor, and the action of the electrolyte causes a very thin layer of aluminium oxide to build up on the positive plate. It is this layer that is used as the insulating dielectric. The capacitor therefore has a very thin and efficient dielectric, giving capacitance values many hundreds times greater than is possible with a conventional plastic film capacitor of a similar physical size.

The down side with this process is that the capacitor is polarised and must not have reversed polarity voltages applied. If this occurs the insulating oxide layer is stripped away again and the capacitor may pass a large current. As this occurs in a sealed container, the "liquid" electrolyte quickly boils and expands rapidly. This can lead to an explosion within seconds! **NEVER connect an electrolytic capacitor the wrong way round!**

Variable capacitors

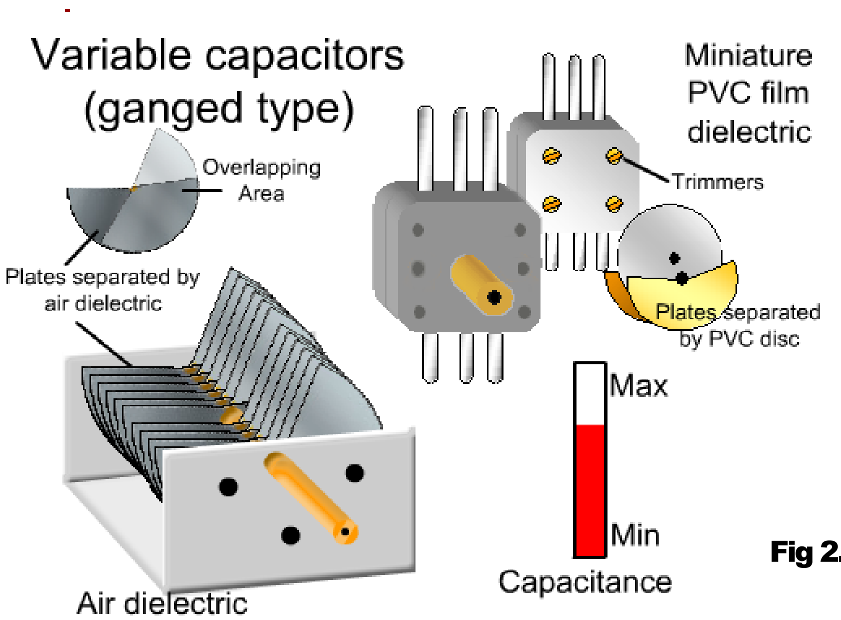


Fig 2.1.3

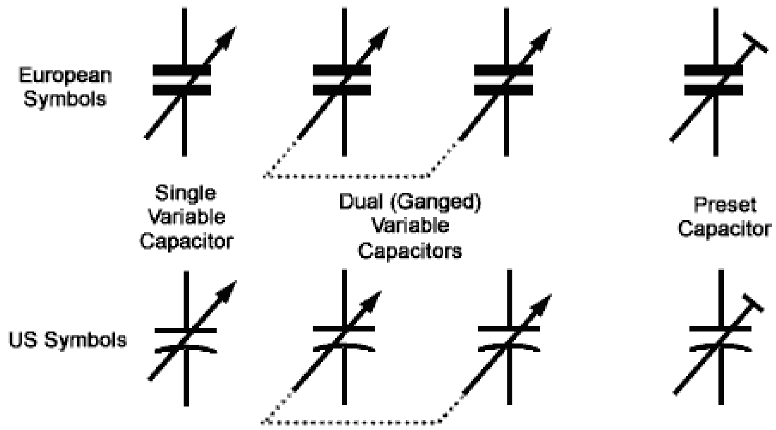
The variable capacitors shown in fig. 2.1.3 are used as tuning capacitors in AM radios, although they have largely been replaced by "Varicap" (variable capacitance) diodes, but they can still be found in circuit diagrams and supplier's catalogues for replacement purposes.

Tuning capacitors have very small values of typically a few pF to a few tens of pF. Large air dielectric types, like the animated one on the left have been superseded by miniature types as shown top right (front and back to show the tiny trimmer capacitors accessed through holes in the rear of the case).

Trimmer capacitors

Small trimmer capacitors, adjustable with special trimming tools (DON´T use a screwdriver!) by technicians rather than the equipment user are available in a variety of very small designs. They work in a similar way to the larger variables, with tiny rotating plates and typically PVC film dielectric layers between. Their capacitance is only a few pico farads and they are often used in conjunction with larger variable capacitors (and even fitted inside the case of tuning capacitors) to improve accuracy.

Fig 2.1.4 Variable and Preset Capacitor Symbols

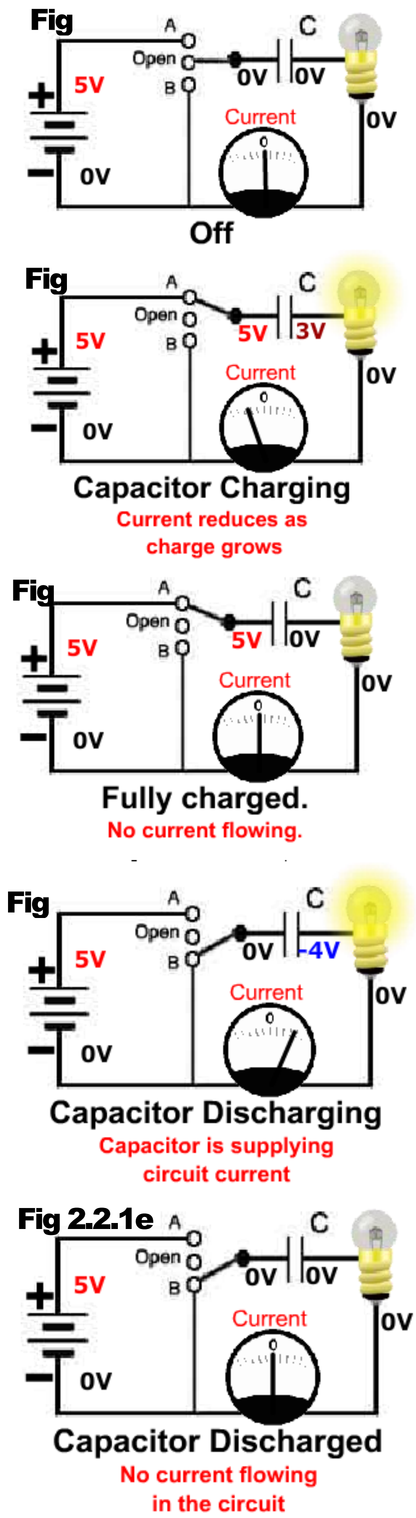


Symbols for variable capacitors are given in fig 2.1.4. Variable capacitors are often available as GANGED components. Usually two variable capacitors are adjusted by a single control spindle. The arrow symbol indicates a variable capacitor (adjustable by the equipment user, and the T shaped diagonal indicates a preset capacitor, for technician adjustment only. The dotted line connecting a pair of capacitors indicates that they are ganged.

Module 2.2 Charge & Discharge

How a capacitor gets its charge

Fig 2.2.1 Charge and Discharge



When a capacitor is connected in a DC circuit as in Fig 2.2.1a, a large current will flow, but only for a short time. When the switch is closed to contact A and electrons begin to flow from the negative battery terminal, and appear to be flowing around the circuit. Of course they can't because the capacitor has a layer of insulation between its plates, so electrons from the negative battery terminal crowd onto the right hand plate of the capacitor creating an increasingly strong negative charge. The very thin insulating (dielectric) layer between the plates is able to efficiently transfer this negative charge from the electrons, and this charge repels the same number of electrons from the left hand plate of the capacitor. These displaced electrons from the left hand plate are attracted towards the positive terminal of the battery, giving the impression of current flowing around the complete circuit.

Why the current falls

After a short time (Fig 2.2.1b) however, a large number of electrons have gathered on the right hand plate of the capacitor, creating a growing negative charge, making it increasingly difficult for electrons flowing from the negative battery terminal to reach the capacitor plate because of the repulsion from the growing number of negative electrons gathered there.

Full charge

Eventually (Fig 2.2.1c) the repulsion from the electrons on the capacitor's right hand plate is approximately equal to the force from the negative battery terminal and current ceases. Once the battery and capacitor voltages are equal we can say that the capacitor has reached its maximum charge. If the battery is now disconnected by opening the switch, the capacitor will remain in a charged state, with a voltage equal to the battery voltage, and provided that no current flows, it should remain charged indefinitely. In practice a very small leakage current will flow across the dielectric, and the capacitor will eventually discharge. This process however can take seconds, hours, days, weeks or months, depending on individual circumstances.

Discharging the capacitor

Suppose that with the capacitor fully charged, the switch is now closed in position B. (Fig 2.2.1d) the circuit is complete once more, but this time consisting of a resistor and capacitor. Electrons will now flow around the circuit via the resistor as the charge on capacitor acts as the source of current The charge on the capacitor will be depleted as the current flows. (Fig 2.2.1e) The rate at which the capacitor voltage reduces towards zero will depend on the amount of current flowing, and thus on the value of the resistance in the circuit, in Fig 2.2.1 this resistance is represented by the lamp.

The indicator lamp

Using a lamp as a load resistance connected in series with the capacitor gives a useful indication of the operation of the circuit. Initially, as the capacitor begins to charge, the large current makes the lamp glow brightly. As the current reduces due to the build up of charge on the capacitor, the lamp dims and goes out once the capacitor is fully charged.

When the switch is in position B and the charged capacitor begins to discharge, the lamp glows brightly once more, dimming and going out as the current falls towards zero due to the diminishing charge on the capacitor. Notice that during discharge, the current is flowing through the lamp in the opposite direction to the flow during the charging period.

Module 2.3 Capacitance

The amount of energy a capacitor can store depends on the value or CAPACITANCE of the capacitor. Capacitance (symbol C) is measured in the basic unit of the FARAD (symbol F). One Farad is the amount of capacitance that can store 1 Coulomb (6.24 x 10^{18} electrons) when it is charged to a voltage of 1 volt. The Farad is much too large a unit for use in electronics however, so we more often find the following sub-units of capacitance more useful.

Sub unit	Abbreviation	Standard notation
micro Farads	μF	x 10^{-6}
nano Farads	nF	x 10^{-9}
pico Farads	pF	x 10^{-12}

Remember however, that when working out problems involving capacitance, the formulae we use need the values in the basic units of Farads, Volts etc. Therefore when entering a value of 0.47nF into a formula (and your calculator) you should enter it as; 0.47 x 10-9 Farad

Capacitance depends on four things;

1.The area of the plates

2.The distance between the plates

3.The type of dielectric material

4.Temperature

Of these four, temperature has the least effect in most capacitors. The value of most capacitors is fairly stable over a "normal" range of temperatures. Capacitor values may be fixed or variable. Most variable capacitors have a very small value a few tens or hundreds of pF).

The value is varied by either:

- Changing the area of the plates.
- Changing the thickness of the dielectric.

Capacitance (C) is **DIRECTLY PROPORTIONAL TO THE AREA OF THE TWO PLATES** that directly overlap, the greater the overlapping area, the greater the capacitance.

Capacitance is **INVERSELY PROPORTIONAL TO THE DISTANCE BETWEEN THE PLATES.**

i.e. if the plates move apart, the capacitance reduces.

The Dielectric

The electrons on one plate of the capacitor affect the electrons on the other plate by causing the orbits of the electrons within the dielectric material (the insulating layer between the plates) to distort. The amount of distortion depends on the nature of the dielectric material and this is measured by the permittivity of the material.

Permittivity

Permittivity is quoted for any particular material as RELATIVE PERMITTIVITY, which is a measure of how efficient a dielectric material is. It is a number without units which indicates how much greater the permittivity of the material is than the permittivity of air (or a vacuum), which is given a permittivity of 1 (one). For example, if a dielectric material such as mica has a relative permittivity of 6, this means the capacitor will have a permittivity, and so a capacitance, six times that of one whose dimensions are the same, but whose dielectric is air.

Dielectric Strength

Another important aspect of the dielectric is the DIELECTRIC STRENGTH. this indicates the ability of the dielectric to withstand the voltage placed across it when the capacitor is charged. Ideally the dielectric must by as thin as possible, so giving the maximum capacitance for a given size of component. However, the thinner the dielectric layer, the more easily its insulating properties will break down. The dielectric strength therefore governs the maximum working voltage of a capacitor.

Maximum Working Voltage (VDCwkg max)

It is very important when using capacitors that the maximum working voltage indicated by the manufacturer is not exceeded. Otherwise there will be a great danger of a sudden insulation breakdown within the capacitor. As it is likely that a maximum voltage existed across the capacitor at this time (hence the breakdown) large currents will flow with a real risk of fire or explosion in some circuits.

Charge on a Capacitor.

The charge (Q) on a capacitor depends on a combination of the above factors, which can be given together as the Capacitance (C) and the voltage applied (V). For a component of a given capacitance, the relationship between voltage and charge is constant. Increasing the applied voltage results in a proportionally increased charge. This relationship can be expressed in the formula;

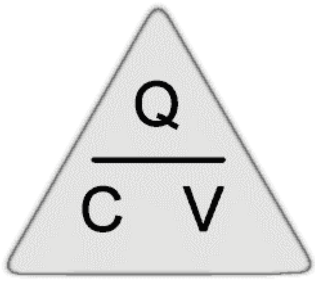
Q = CV

or

C = Q/V

or

V = Q/C



Where V is the voltage applied, in Volts.

C is the capacitance in Farads.

Q is the quantity of charge in Coulombs.

So any of these quantities can be found provided the other two are known. The formulae can easily be re-arranged using a simple triangle similar to the one used for calculating Ohm's Law when carrying out resistor calculations.

Maths Help

Want some help with electronics math? Download our helpful booklet from the "Downloads" page of www.learnabout-electronics.org with tips for buying and using a scientific calculator and for sorting out all those electronics values; invaluable help for the questions in our Module Quizzes and the examples in Module 2.4.

Module 2.4 Capacitors in Circuits

Capacitors in series.

Like resistors and inductors, capacitors can be connected in series, in parallel or in series-parallel. Placing capacitors in series effectively increases the thickness of the dielectric, and so reduces the total capacitance. Because the total capacitance is inversely proportional to the distance between the plates, the formula we use for capacitors in SERIES is;

$$\frac{C_1 \times C_2}{C_1 + C_2}$$

Note that the voltage across each capacitor will be inversely proportional to the capacitance, with the total voltage being shared out between the capacitors, the smallest capacitance having the largest voltage across it and the largest capacitance having the smallest voltage etc.

Capacitors in parallel.

Connecting capacitors in parallel effectively increases the area of the plates, therefore the total

$$C1 + C2 + C3 + \ldots\text{etc.}$$

capacitance is given by the sum of the individual capacitances.

Parallel capacitors all charge to the same voltage.

Note that when using these formulae the values must be put into the formula in their BASIC UNITS i.e. FARADS (not μF) Coulombs (not μC) and VOLTS (not mV).

1. Draw the network and mark in the values

2. Add the two parallel capacitors 1uF+22nF
Using your calculator

C_{PAR} = 1 EXP-6 + 22 EXP-9 = 1.022 EXP-6

Note: / = divide, EXP =Exponent key, (and don't forget the brackets)

3. Use product over sum to calculate the two series capacitors

$$\frac{1uF \times 0.01uF}{(1uF + 0.01uF)}$$

C_{SER} = 1 EXP-6 x 0.01 EXP-6 / (1 EXP-6 + 0.01 EXP-6) = 9.901 EXP-9

4. Use product over sum again to combine C_{SER} and C_{PAR}

$$\frac{1.022\text{ EXP-6} \times 9.901\text{ EXP-9}}{(1.022\text{ EXP-6} + 9.901\text{ EXP-9})} = 9.806\text{ EXP-9} = \underline{9.806nF}$$

(Use pF, nF, uF etc. to keep your answer between 1 and 999)

Briefly 47nF; (nanoFarads) is entered as; 15 EXP -09 and 25mC (milliCoulombs) is entered as; 25 EXP -03 etc. This is easiest to do using a scientific calculator.

Now try calculating the total capacitance of some series and parallel circuits in the capacitors Quiz.

Module 2.5 Capacitor Quiz

What you should know.

After studying Module 2, you should:

Be able to Recognise common capacitor types and circuit symbols

Be able to describe charge and discharge in capacitors

Be able to describe dielectric strength and capacitance, and relate capacitance to charge.

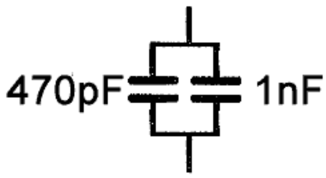
Be able to use appropriate units of capacitance, and to calculate capacitance in series and parallel capacitor networks.

Try our quiz, based on the information you can find in Module 2. Check your answers on line at http://www.learnabout-electronics.org/ac_theory/capacitors06.php

1.

What is the approximate total capacitance of this parallel circuit?

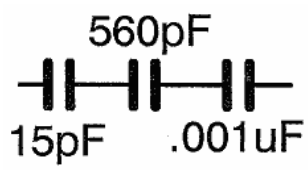
a) 320pF b) 147pF c) 3.2nF d) 1.47nF



2.

What is the approximate total capacitance of this series circuit?

a) 1.6nF b) 576pF c) 14.4pF d) 12pF



3.

When might it be necessary to use a 2 μF polyester capacitor rather than a 2 μF electrolytic capacitor?

a) When High Voltages are present

b) When the capacitor passes AC

c) In low temperature conditions

d) When small size is the most important factor.

4.

When a DC voltage is applied to a capacitor in its uncharged state:-

a) The capacitor voltage will be maximum but fall after a short time

b) The voltage will gradually rise at the same rate as the applied current

c) Maximum current will flow immediately

d) Maximum current will flow until the capacitor is fully charged

5.

Complete the following sentence: As a capacitor charges ..

a) Electrons gather on the negative plate and displace electrons from the positive plate.

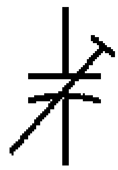
b) Electrons flow across the dielectric layer until the capacitor is fully charged

c) Electrons gather on the positive plate displacing electrons from the negative plate.

d) Current only flows through the capacitor for a short time.

6.

What type of capacitor does the component symbol (right) represent?



a) A preset capacitor

b) An electrolytic capacitor

c) A variable capacitor

d) A ganged capacitor

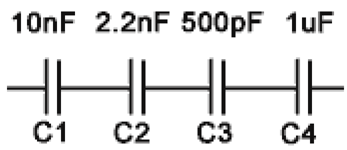
7.

Calculate the value of capacitance needed to store 1 µC of charge at 10V.

a) 10 µF b) 1nF c) 100nF d) 10nF

8.

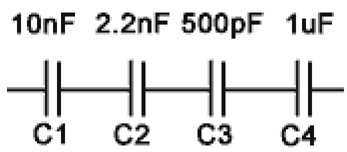
If a voltage is applied across the capacitor network shown, which individual capacitor has the largest voltage across it?



a) C1 b) C2 c) C3 d) C4

9.

What is the approximate total capacitance of the network shown?



a) 13.05nF b) 1.01uF c) 391pF d) 2.3nF

10.

Capacitance is directly proportional to:

a) The distance between the plates.

b) The area of the plates.

c) The dielectric strength.

d) The charge multiplied by the applied voltage.