Diploma of Audio Production Name________________

Analogue Fundamentals (Audio Knowledge)

Module 11

Topic 1: Capacitors and DC
Topic 2: Testing of Capacitors with a Multimeter.
Topic 3: Capacitor Values and labeling.
Topic 4: Capacitors and charging circuits.
Topic 5: Timing Circuits and Time Constants.
Topic 6: Capacitors in series & parallel.

Topic 1:

So far all our dealings have been with resistive circuits but there are many other electronic components that are used in all avenues of electronics and audio/music industries.
Two of the more common are Capacitors and Inductors. Lets deal with Capacitors first and leave the Inductors to another lesson..

So what is a Capacitor? Didn't the Professor talk about a "Flux Capacitor" in the motion picture "Back to the future"? Well I have no idea what a flux capacitor is, however a capacitor is basically a device for storing energy. It also has many useful offshoots of this characteristic.
Now energy can be stored in many forms but a capacitor as used in the electronic industry stores electrons. A bit like a battery but a capacitor is a temporary storage device.
For a capacitor to have energy stored it must have an unbalance of the electron distribution between two terminals.

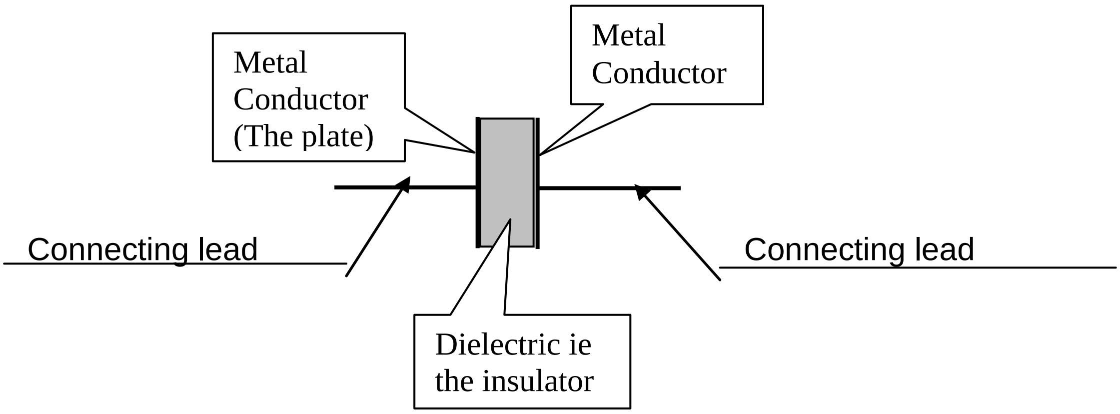
Where are capacitors used in the electronic and in particular the audio industry?

- In power supplies as an energy reserve and filter.
- As coupling for AC signals whilst blocking DC
- In "EQ" circuits
- In timing circuits
- Speaker crossovers networks
- In radio equipment to make "Resonant Circuits.
- This list could seemingly be endless so I think you have the general idea.

Basic Construction

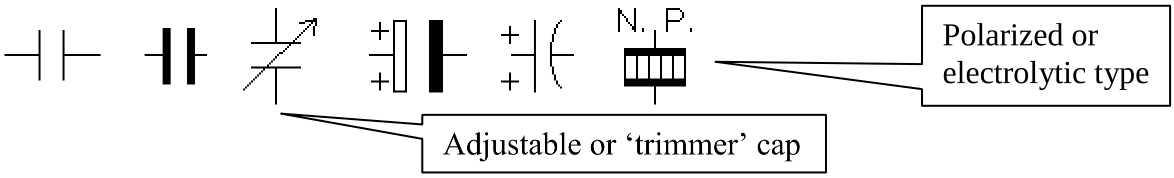
The basic construction of a simple capacitor is 2 metal plates, Conductors, separated by an insulating material such as air or plastic etc. This insulating material is known as the **Dielectric**.

eg:



The symbol is really how the capacitor is basically constructed.

ie;



The symbol indicates that we have on open circuit and that current cannot flow and this is true as the conductors are separated by an insulator.

Storing energy:

Now remember that a material to be a conductor of an electric current has zillions of electrons that can easily be moved using a force (ie an ElectroMotive Force)

So a capacitor stores energy by removing electrons from one plate and depositing them on the other plate.

This means the plate that has a deficiency of electrons will have a net positive charge (ie more protons than electrons) And the plate that received extra electrons a negative charge.

The capacitor is said to be **charged** when we have this separation of electrons. For those of you who wish to dash home and make your own, here's the formula.

$$C = \frac{(8.85 \times 10^{-12}) \times K \times A}{d}$$

where: C = the capacitance in Farads

A = the plate area in square metres

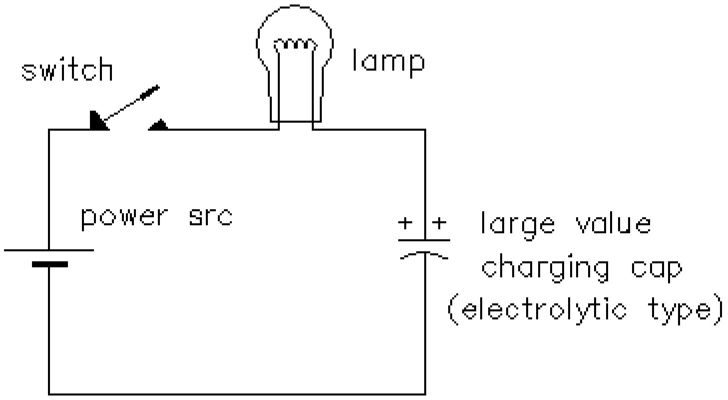
K = the dielectric constant

8.85×10^{-12} is a constant

d = the distance between the plates

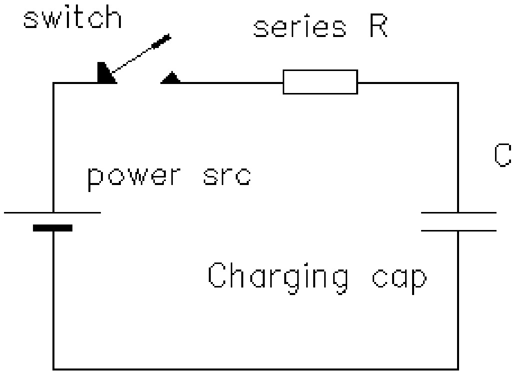
How do we charge the capacitor?

To enable a capacitor to store energy first we have to put energy in.
To do this we have to connect the capacitor up to a source of EMF. This EMF will take electrons from the “Plate” that is connected to the positive terminal and deposit them on the negative terminal. Now when the EMF is removed the capacitor stay “charged” as the electrons cannot go back as there is an insulator between the plates keeping them apart. We would normally include a series resistor to limit the “Charging Current” In the diagram below we have used a lamp to limit the current. As the capacitor charged up the flow of electrons to the plates causes the lamp to light.
We have to provide an external circuit to allow the flow of electrons back to whence they come from to discharge the capacitor.



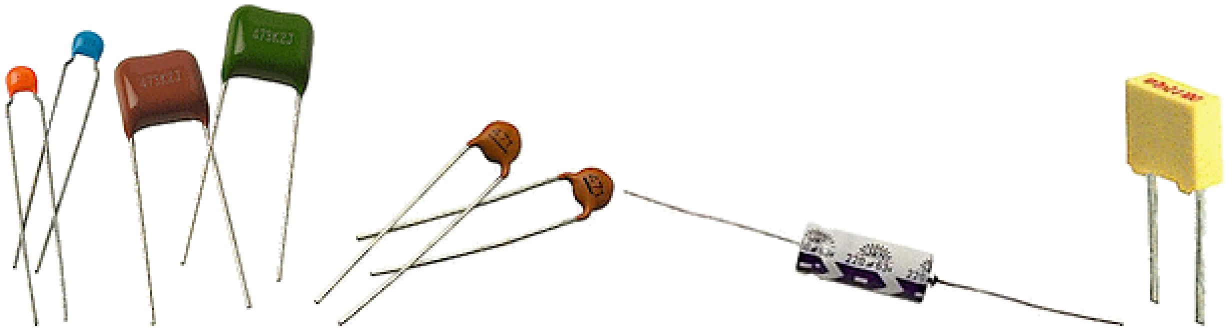
Charging circuits

When a capacitor charges, it starts off at a fast rate. This is because in the uncharged state, it does not oppose the flow of current into (and out of) the plates. After some time it has charged the maximum charge it will hold at that voltage. In the circuit below, a resistor is used to “slow” the rate of charge.



Now what do these “Capacitors” look like?

Well they come in all shapes and sizes from as small as a pinhead to the very large devices like the ones you stick in the boot of your car to help in the operation of the car Amplifier. (ie; a cylinder around 300mm long and 75mm diameter) Rather annoyingly, unlike resistors there is no firm standard for value marking.



The Value for capacitors is stated in “Farads” after the scientist Faraday. We will look at this in more detail next lesson.

2nd Prac exercise for the day.

Aim: To measure the DC resistance of a Number (3) of Capacitors and to write down the information written on them. Draw a small picture of each capacitor and include as much info as you can.

Topic 2:

In the last lesson we found out that the capacitor measures infinity and therefore is an open circuit to DC which we would have expected..
However testing with an analog meter may give an interesting result. If we put the meter on the ohms x 1k range and place the leads across the capacitor we may see that the meter needle first deflects towards the zero ohms end and then go back to infinity. This is of course the capacitor charging using the voltage in the meter as the source of EMF. Reversing the leads will result in the meter needle being deflected again before the meter settles at the infinity reading. If the meter responds in this way it is usually a good indication that the capacitor is OK. However if the capacitor is a very small unit it may fail to deflect the needle at all.
Try going to the next higher resistance range as this places a higher resistance in series and will “slow” down the “Charging” process.
Well what about using the DMM? A DMM will give confusing results as the display seemingly outputs random figures however most DMM’s now have a “Bar Graph” which can be used in the same way as a normal analog meter.

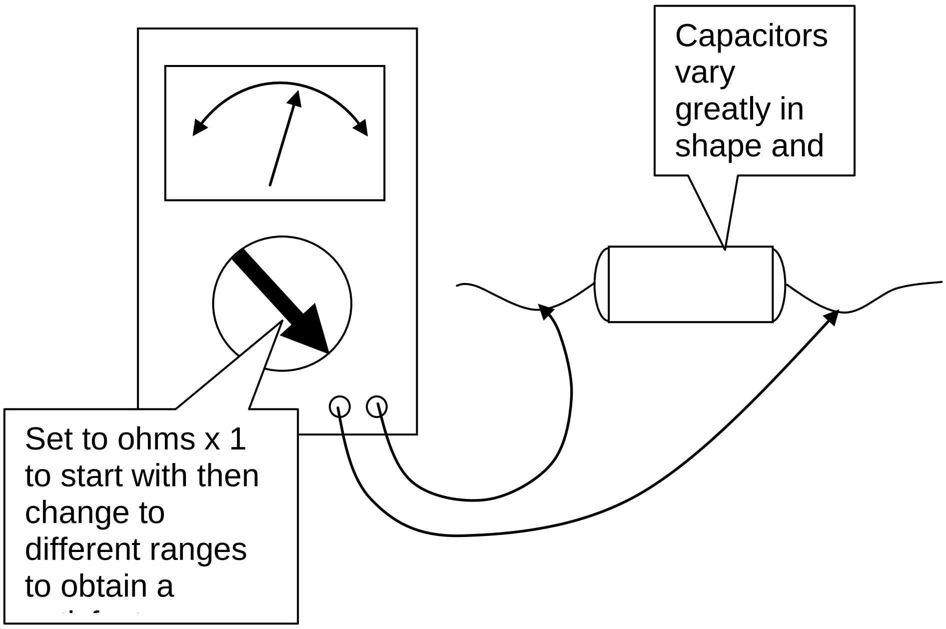
OK well now it’s time to again test some capacitors using both analog meters and DMM’s.

Procedure:

With the meter on resistance measurements and say on ohms X1 test a number of capacitors (3) and note result. Change the range setting to ohms X10, ohms X100 etc and note the result as to speed of the pointer deflection.

Repeat using the DMM and check the numerical and bar graph readouts.
Don’t forget to reverse the leads once the resistance measures open circuit or infinity.

PTO for hook-up details.
Hook-up



Capacitors vary greatly in shape and

Set to ohms x 1 to start with then change to different ranges to obtain a

Topic 3: Capacitor Values and labeling.

Capacitors are rated in “Farads” and the higher the number the greater the charge it will store. Now for most applications the “Farad” is far too large a unit so we use sub-multiples.. That is microfarad (μF), nanofarad (nF) and picofarad (ρF). We tend not to use millifarad instead using multiples of microfarads. Eg 2200μF, 22000μF 5600μF etc. About the only application for very large capacitors around 1 to 10 Farads seems to be in the “Car Audio” industry where they are used for large energy reserves for the High Power Car Audio Amps that live in the boot.

Therefore a 1μF capacitor is 0.000001F and a 10nF is 0.00000001F and a 1.5ρF is 0.000000000001F so we can see it is much better to use the submultiples.
In the audio electronics area we tend to use μF and nF with the ρF mainly found in the radio or RF industries.

Now there seems to be a various ways to indicate the value of a capacitor.
A 10nF capacitor for instance, can be labeled as 10nf, 0.01uF or 103. OK we are cool with the 1st two but what is 103?
Well in the label “103” the 10 is the actual digits of the value of the Capacitor and 3 means 3 zeros which gives us 10000.. Now this refers to “picofarads meaning 10,000 picofarads. Therefore 472 means 4700 picofarad or 4.7 nanofarad and 224 would mean 0.22uF or 220000pF.

Complete the following table for a bit of practice.

0.33uF	330nF	334
		471
4.7uF		
	22nF	
0.1uF		
		333
	27nF	
	1nF	
0.047uF		
		152

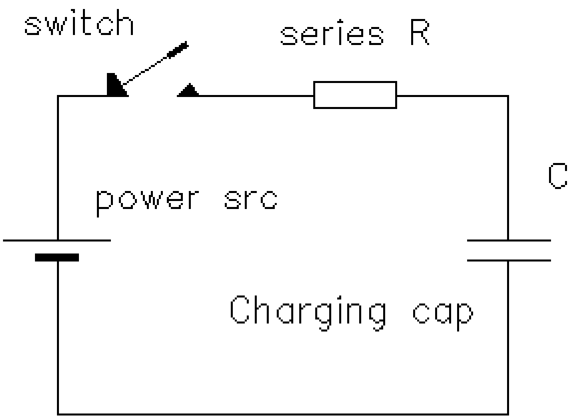
Topic 4: Capacitors and charging circuits.

As we stated in last weeks lesson for a capacitor to store energy we first have to “charge” the capacitor. Now the energy is stored in the form of “Static” electricity which results from the unbalance of electrons between the two plates. And therefore we have an “electric” field created between the two plates and this static field is a bit like that of a plastic comb which attracts hair or even small bits of paper when it is charged up.

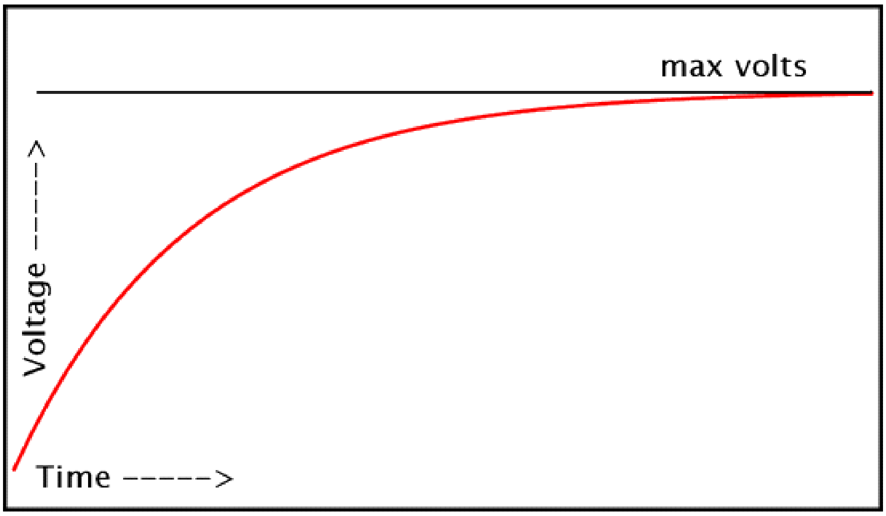
Does the lamp illuminate on charge and discharge? We hope so. Now in both cases the lamp starts off bright and then gets duller until it is not glowing at all.
The charging and discharging of the capacitor always follows a set behavior pattern. That is it seems to charge quickly at first then slow down until the capacitor is fully charged.

This pattern is referred to as the **exponential** charge and discharge curves for a capacitor. If we break this curve up into 5 equal sections on the horizontal axis the capacitor voltage will reach 63.2% of the power supply (applied) voltage by the end of the 1st section. Also the “charging” current falls to 36.8% at this same point.
These sections are known as **“<u>Time Constants</u>”** and the capacitor is said to fully charged after 5 of these time constants.

Some pictures here will hopefully give us an insight into this behavior.
As mentioned before, a capacitor charges at a rate that slows quickly with time. In the uncharged state, it does not oppose the flow of current into (and out of) the plates. As the cap “fills up”, the charging slows because the existing charged repels further charging with the electrostatic effect. This process follows what is called a Time Constant curve. Imagine what happens if we throw the switch on the circuit below.

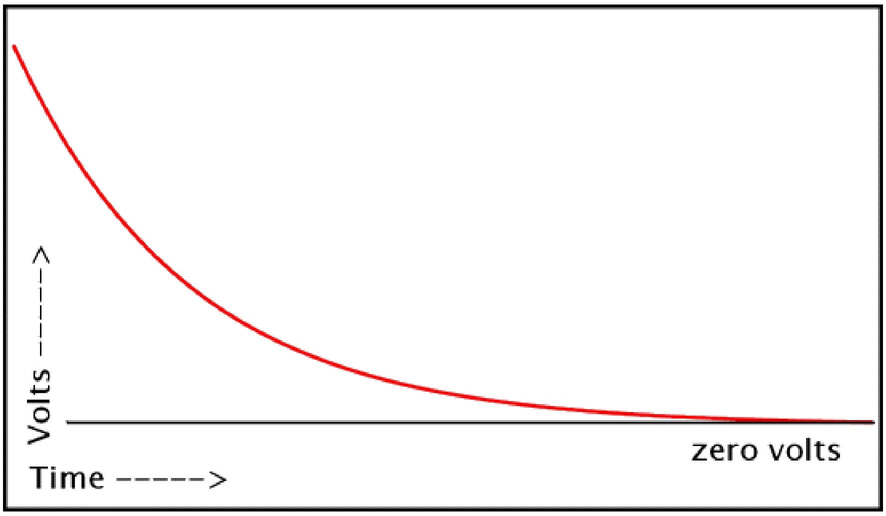


If we observed the voltage over the capacitor whilst it was charging, it would look like this:



This is because the effective resistance of the capacitor ***increases*** as it charges up to full.

If we observed the voltage over the ***resistor*** whilst it was charging, it would look like this.



This is because as the capacitor charges up, the amount of current flowing through the resistor starts off high, but rapidly ***decreases*** with time, and eventually there is no measurable voltage drop across the 'series R', because once the cap is charged up, the current flow through the capacitor (& the series R) ceases.

We can observe this effect when charging a capacitor through a reasonably high value resistor. Note: the higher the value resistor in the charging circuit the longer the capacitor takes to charge. i.e. it limits the amount of current available to charge the Capacitor.

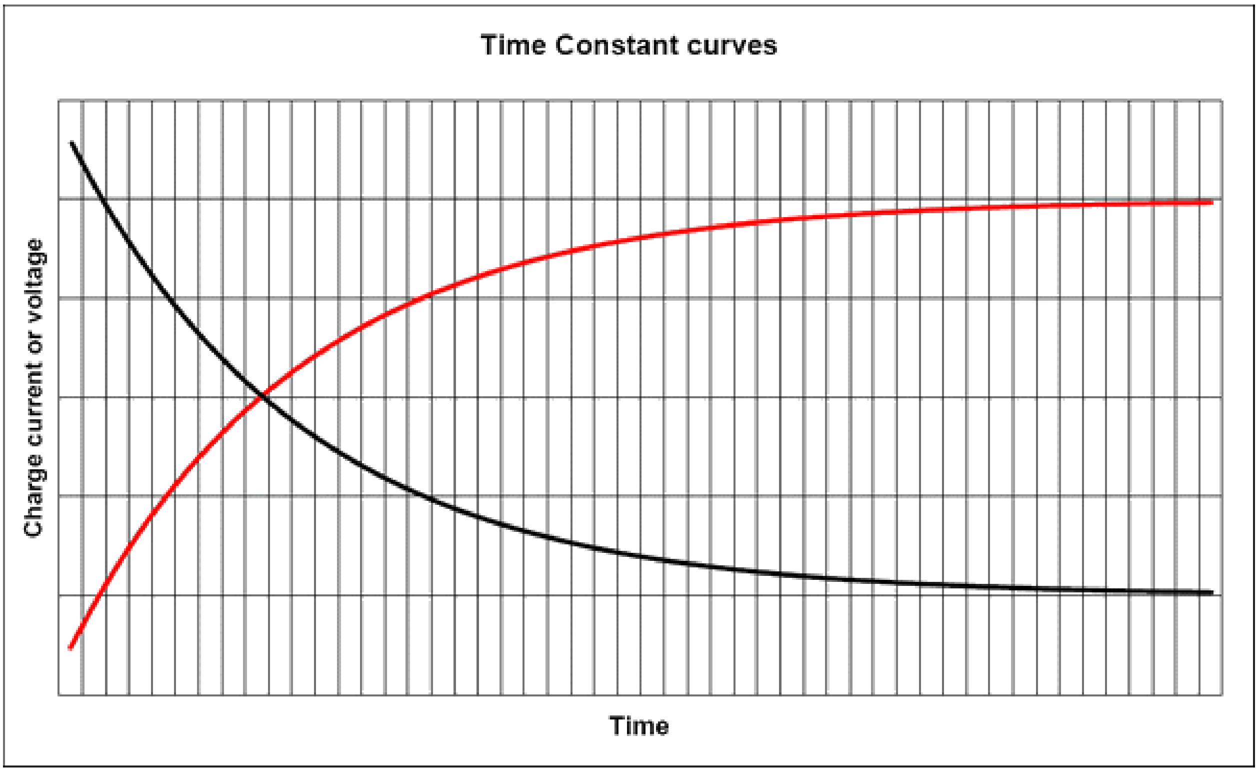
Topic 5: Timing Circuits and Time Constants.

Now if we know the value of the components in the Series Capacitor / Resistor Circuit we can reasonably predict how long the capacitor will take to charge.

The Formula (not another formula…..)

The time taken for the capacitor to reach 63.2% of the “Applied Voltage” is known as 1 Time Constant. After 1 x Time Constant (τ), the capacitor will have charged to 0.632 (63.2%) of the maximum charge it will hold at that voltage. After 5 x TC (τ), it is regarded as fully charged. In the circuit below, a resistor is used to “slow” the rate of charge. One TC is determined by the formula: $\tau = RC$ where C is the value of the cap in Farads, and R is the resistor in series (in Ohms) and the answer is in seconds.. Refer to the Universal Time constant below. Notice how the TC curves are the mirror of each other. Because of the way they behave, capacitors are called “reactive” components, because their effective resistance (known as ***impedance***) changes with the frequency of an AC signal applied. The impedance (Xc) of a capacitor is determined by the formula:

$$Xc = \frac{1}{2\pi FC}$$



Now it takes **5 Time Constants** for the capacitor to be fully charged. (or discharged)

So in our practical experiment we had a 22K res. and a 100µF capacitor.
The Maths

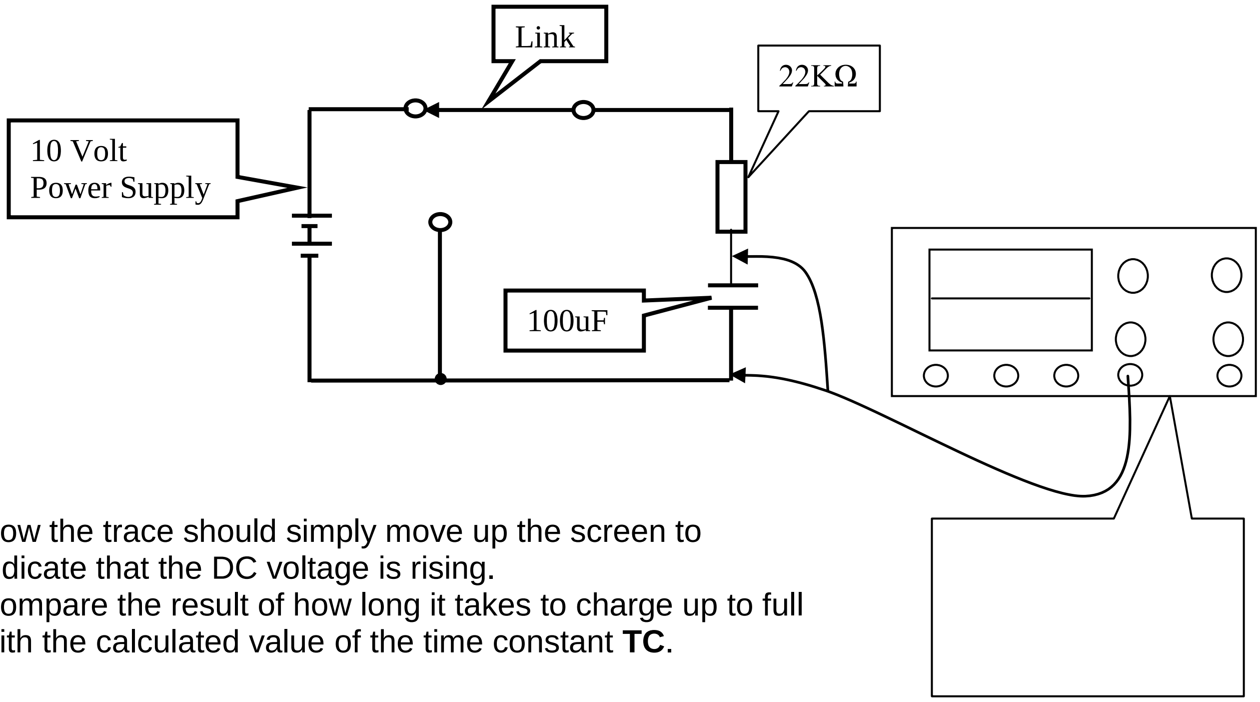
$$\begin{aligned}\text{Time Constant (TC)} &= \text{C x R}\\ &= 100\ \mu\text{F x 22K}\\ &= 100 \times 10^{-6} \times 22 \times 10^{3}\\ &= 2.2\ \text{Seconds}\end{aligned}$$

Therefore the Capacitor would have been fully charged in 5 x 2.2 seconds which is 11 seconds.. How did this compare to your prac?

Calculating TC for the 100K resistor and the 100µF capacitor.
See how this figure tallies up with the prac below?

Practical:

Set up an oscilloscope in the following way to observe the rising capacitor voltage on the screen. Ensure the CRO input is switched to DC and you are on the 2 volts per division scale. The time per division switch should be set so as to give a continuous line on the screen.



Now the trace should simply move up the screen to indicate that the DC voltage is rising.
Compare the result of how long it takes to charge up to full with the calculated value of the time constant **TC**.

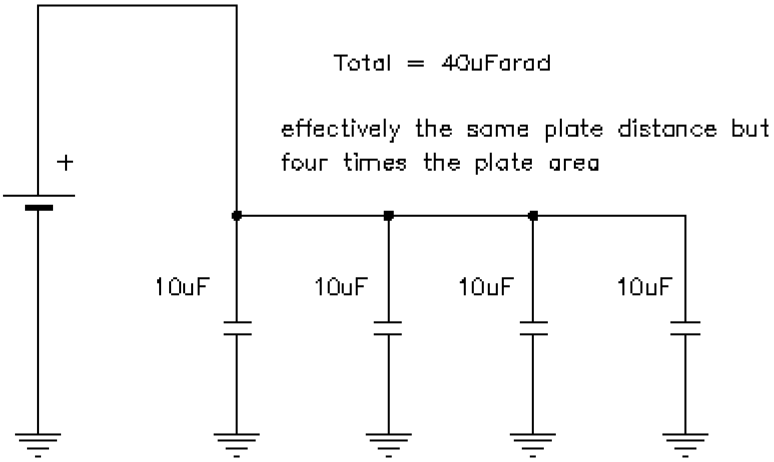
Timing circuits:

We can use this "delay" that the circuit gives to "time" or delay events. As an example if we wanted to leave a light on for a predetermined time or if we wanted to leave the turning indicators of your car on for a certain time we could use this delay that a CR circuit gives.

IN other words we could delay something happening until the capacitor voltage reached a certain voltage. I guess a good example in Audio would be how an Amplifier output is held off after switch on to avoid a loud "Thump" in the loudspeakers.

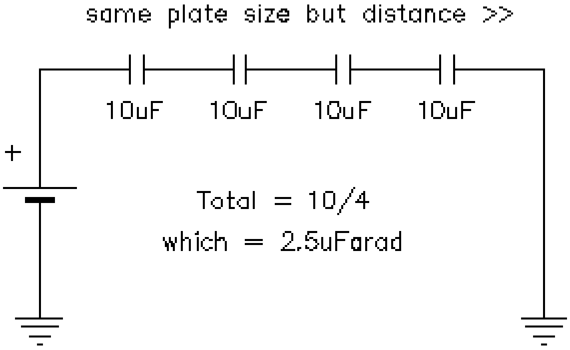
Topic 6: Capacitors in series and parallel

When capacitors are connected in parallel, the total amount of capacitance increases. This makes sense if you see that we are effectively increasing the plate area and therefore increases the amount of capacitance.
∴ the formula for caps in parallel is: **$C^T = C1 + C2 + C3 + C4$** etc



When capacitors are connected in series, the opposite is true. The total amount of capacitance decreases. This makes sense if you see that we are effectively increasing the distance between the plates. Below are examples:

∴ the formula for caps in series is: **$C_{Total} = \dfrac{1}{1/C_1 + 1/C_2 + 1/C_3 + 1/C_4}$**



Next week we will look at how these simple circuits can affect the tonal quality of the sound we listen to.