BASIC ELECTRONICS
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LECTURE-3
ELECTRONIC DEVICES -II
RESISTOR SERIES & PARALLEL

Hello everybody we are doing a course on basic electronics by the method of learning by doing. We saw in the previous lecture about different types of resistors; fixed resistors, variable resistors which are also called potentiometers and some special type of resistors which are called for example LDR light dependent resistors whose resistance depends on the amount of light falling on it.

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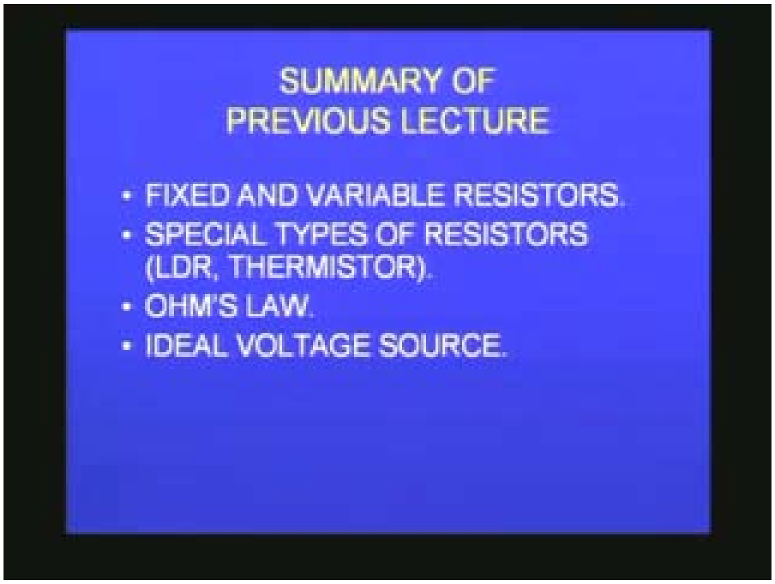

We saw another different type of resistor which is called thermistor which really is a resistor whose value depends on the amount of heat or temperature. Next we also saw basic law of electronics, which is ohms law which says the current in a given conductor is proportional to the voltage applied across its terminals. This is one of the very fundamental laws of electricity and electronics and if one knows this very well then you would be in a position to understand the working principle of several circuits. Then we also saw about ideal voltage source. Voltage source will always have an internal resistance which will normally be very small but still it exists and therefore when you draw current from a voltage source you would always find that some voltage is dropped across the internal resistance and thereby the exact voltage available for you at the terminal of the voltage source will be less than what you otherwise expect. Ideal voltage sources are characterized by zero resistance. So these are very important concepts in the whole idea of electronics and we also saw the actual practical experiments relating to all these things. We saw the LDR, we saw the thermistor and we saw the voltage source. Today in this lecture we will look at the combination of resistors. How resistors can be combined to obtain different values as well as how to divide a given voltage source to any required magnitude by using couple of resistors which is basically called a potential divider because it divides a potential.

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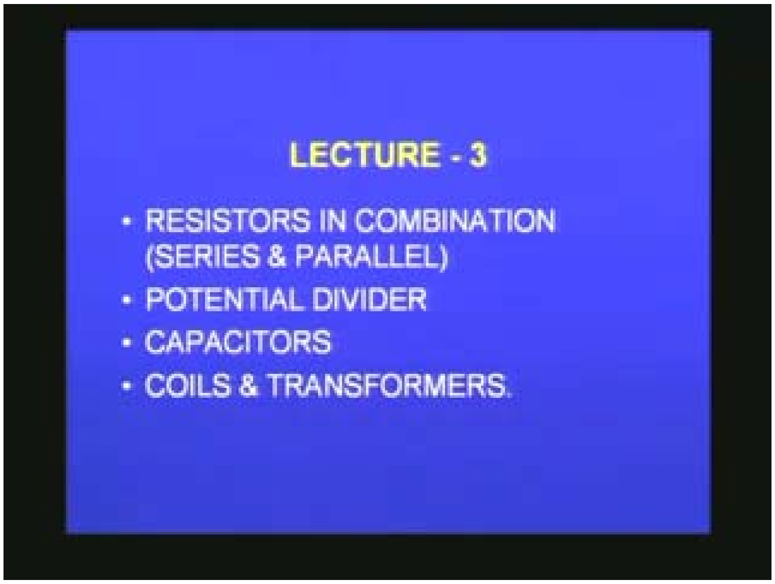

Then we will also see the next type of components that we would be making use of in electronics namely capacitors and lastly we will also see some basic idea about the coils, the inductances as we call it and transformers which also form a very important part of learning electronics. When we have only one particular value of resistor and you want to have a larger value of resistance, then what do you do? If I have 1000 ohms with me, quite a large number, but I want to obtain a 3000 ohms resistance. I don’t have 3000 ohms resistor; I must be able to obtain 3000 ohms resistance with the available 1000 ohms resistor. How do I combine them? Is there a way I can combine the different resistors to obtain a larger value of resistance or is these are the way to combine different resistors to obtain a value which is smaller than the value that I have? So these will have to be discussed. There are two different ways of combining resistors in a given situation. These are called series combination and parallel combination. Some of you may be familiar with series combination and the parallel combination. You come across this type of concept in several other similar situations also. I would draw your attention to the circuit that I have drawn.

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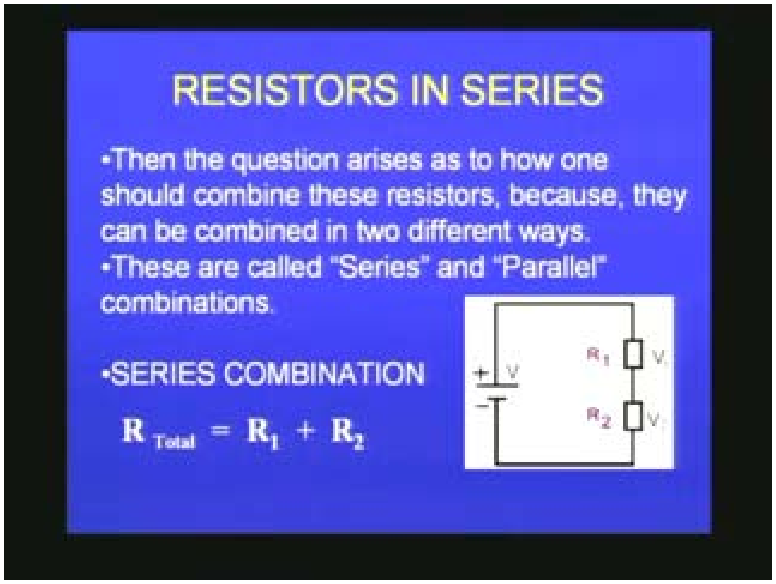

You can see that it's a very simple circuit which makes use of a voltage source which is shown in the form of a battery with a plus and minus sign and a V that is the magnitude of voltage and that is connected to two resistors which are R_1 and R_2 as you can see on the screen. So when the R_1 and the R_2 are connected one after another this way, it is called series connection. A series connection is characterized with the same current flowing throughout the circuit. You can see a current if it starts from the plus terminal of the voltage source, it goes along this wire and into this resistor and comes out of this R_1 and goes again into the next resistor R_2, comes out and completes the circuit.

So if a current is the same going through all the resistors connected in a given circuit, then that combination is called series combination. So series combination is characterized by a same current flowing through all the resistors forming the combination. So in that case what will be the total resistance in a circuit? It is very easy because the total resistance is just the sum of the individual resistors. So in this example that I showed you, the total resistance R is equal to R_1 plus R_2 because we have used only two resistors, the combination is the sum of two resistors R_1 and R_2 okay.

So calculating the value of two or more resistors in series is very simple because you just have to add them all together.

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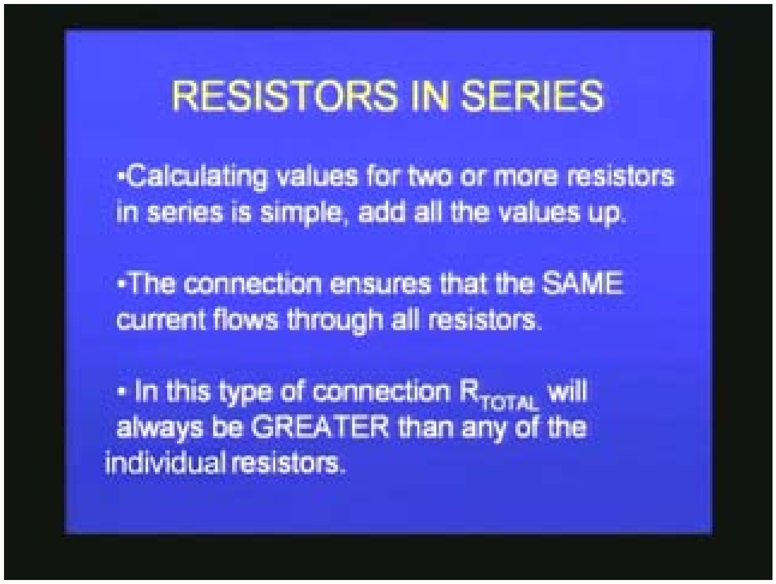

The second point which I already mentioned to you is that in this type of connection, the same current flows through all the resistors. This is the second important point. The third point which we should always remember in series connection is that in this type of connection the total resistance will always be greater than any one of the individual resistances because the total resistance is obtained by summing all the resistances and therefore any resistor will have value less than the total resistors or in other words the total resistance will always be larger than any of the individual resistances. This is one of the very important ideas in series connection.

Because I showed circuit with only two resistors, R_1 and R_2 you should not conclude that we can have only two resistors in combination. As a mater of fact you can add any number of resistors in series; R_1, R_2, R_3, etc and the total resistance will always be given by R_1+ R_2+ R_3+ etc as many resistors as you have connected. So it is always possible by having a set of resistors, same value resistor for example I gave you the number 1000 ohms.

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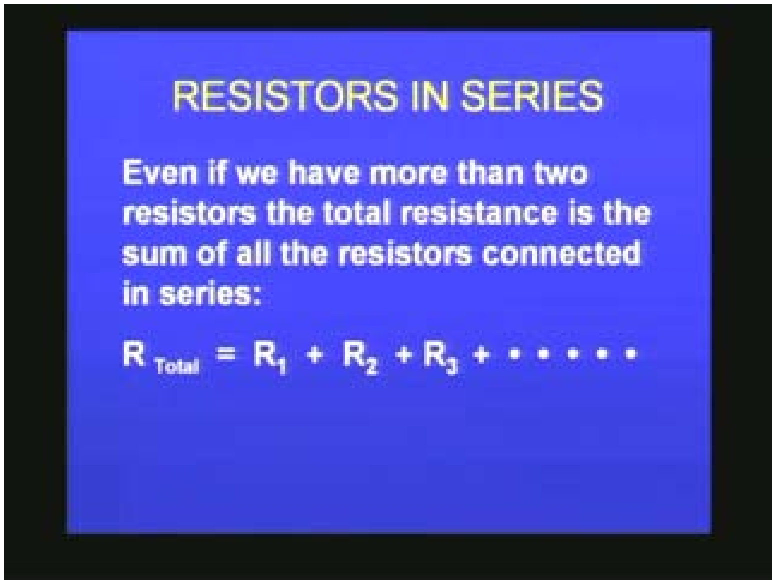

So if I have only 1000 ohms it is always possible that you can combine them and get the value of resistors which is larger than any of the value of resistors that you have for example 1000 ohms. You can easily form for example 3000 ohms resistors by combining three 1000 resistors in series. Like that, you can have any value larger than the value that you have. I just mentioned how this happens. Let me just explain to you how this could be understood in a very simple way.

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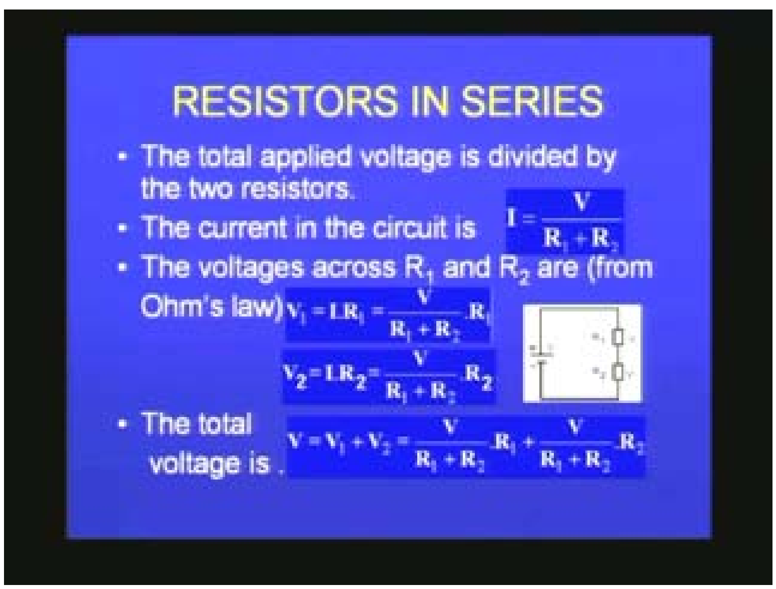

If you see on the screen, the total applied voltage is actually divided by the two resistors R_1 and R_2. How is that? We can have a look at that. All that we need to know is the simple law of ohms. So now you can see what is the current in the circuit that I showed you? I have given that circuit once again in this frame. You can see there is a battery R_1

and R_2 connected in series. So if I want to measure the current in the circuit, you know by ohms law current is equal to voltage by total resistance. The voltage here is V and the resistance here is the combination of the two resistors R_1 and R_2 and therefore current I is given by V/ R_1+R_2. I am sure every one knows this.

If I know the current, then it is a simple matter to obtain the voltage that is developed across each one of the two resistors that I have in the circuit. If I want to find out the voltage across R_1, you can immediately see that voltage, if I call it as V_1, V_1 by ohms law is given by current into resistance. Current is I, resistance is R_1 and therefore instead of I, I write, V/ R_1+R_2 which we know as current in the circuit. Therefore V_1, the voltage across resistance R_1 is given V/ (R_1+R_2). R_1 corresponding to I into R_1. Similarly is the voltage across $V_2$and the resistance across R_2.

So the voltage across the resistance R_2 is given by I into R_2, where I is again given by V/ R_1+R_2 because it is the same current which is going through both the resistors and therefore V_2 is given by V/ R_1+R_2 times R_2 and therefore we have seen there are two voltages V_1 and V_2 developed across the two resistors and what will be V, the total voltage. That will be equal to V_1+ V_2 as we all know and if I now put the expressions that I got for V_1 and V_2 namely V/ R_1+R_2 into R_1 plus V/ R_1+R_2 into R_2 for the second resistor you can see that V/ R_1+R_2 is common which I can take out; then you would find R_1+ R_2 will be the one which will be available and that $R_1$and R_2 will cancel with R_1+ R_2 at the denominator and so I will again get back V, the total voltage. So what do we understand from this? We understand that when I connect two resistors in series they divide the voltage, the total voltage V. So in this case the total voltage is divided as V_1 and V_2 where V_1 you can see is proportional to R_1 because it is I .R_1 and V_2 is proportional to R_2 because it is again I.R_2 where I is a constant which flows through both the resistors and therefore you can see the series resistors divide voltage that is what we want to understand from this.

I will try to explain to you with a typical example with numbers. Let us assume that we have a voltage source, V of 6V and the two resistors let them be 1000 ohms each or 1K as I have shown here. Then the total current in the circuit as you know is given by voltage divided by total resistance. The voltage here is 6V and the total resistance because I have used two resistors in series the total resistance is 2000 ohms or 2K. So 6V/2K gives me 3 milli amperes. The K in the denominator will go in the numerator as ten power minus three and therefore 6/2 is3; 3 into ten power minus three amperes and ten power minus three amperes is known as milli amperes. So current in the circuit with one 6V supply and two 1000 ohms resistors connected in series will be 3 milli amperes. If we know the current then immediately we can obtain the voltage that is developed across each of the two resistors. All that I have to do is multiply the current by the corresponding resistance. The current is 3 milli amperes and the resistance is 1K. So I should multiply 3 into ten power minus three amperes by 1000 and 1000 is nothing but one into ten to the power three and therefore you can see the ten power three and the ten power minus three will cancel and I will be left with 1 into three; it is 3 volts.

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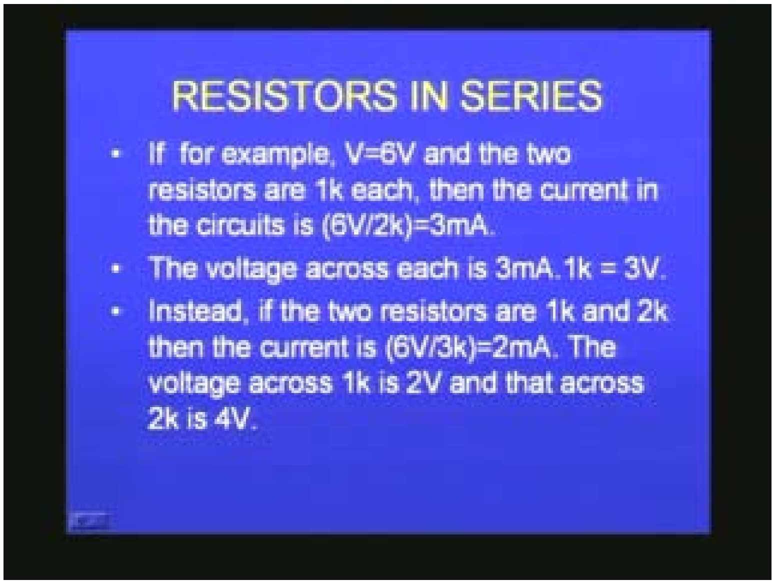

So the voltage across the resistor R_1 which is 1000 ohm is 3V. By the same reasoning you can immediately guess the resistance across the second resistor which is also 1000 ohms will be another 3 volts. So the total voltage therefore will be 3+3, 6V which is the voltage of the power supply and therefore you can see the total voltage of the power supply which is in this case 6V is divided equally by the two equal resistors 1000ohms each.

If I do not have equal resistors; for example one resistance is 1000 ohms and the other resistance is 2000 ohms. Then you would find that the total voltage will also be dividing proportionally to the resistance. That means across the 1000 ohms there will be less voltage and across the 2000 ohms there will be more voltage. In this case because it is 2+1= 3000 ohms I have in the circuit, if I have 6V, 6V/3000 ohms gives me 2 milli amperes and that means the total current in the circuit is 2 milli amperes in this case and the voltage across 1K therefore will be 2 milli amperes into 1K which is 2V and that across the second resistor 2K is 2K into 2 milli amperes which is equal to 4V as you can see and therefore series resistors have same current flowing through them and they divide voltage. These are the two important points that we should always keep in mind. Thus I have summarized here the series connection is characterized by: 1) the same current flows through all the resistors connected in the series and 2) the resultant resistance is the sum of all the resistances connected in series and lastly series resistors divide the total applied voltage proportional to their magnitude.

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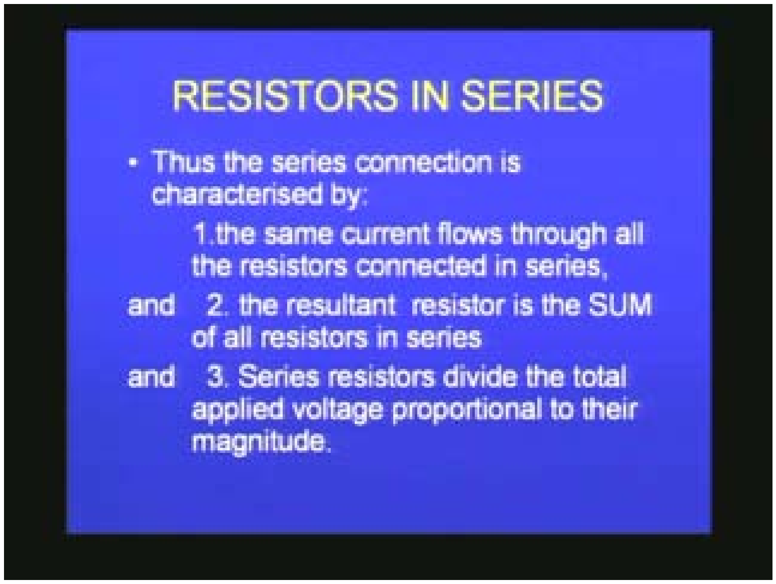

Having learnt about the series combination let us move on to the next which is connecting them in parallel. When I connect them in parallel, you can see in the circuit I have shown on the screen that both the resistors are connected across the voltage source.

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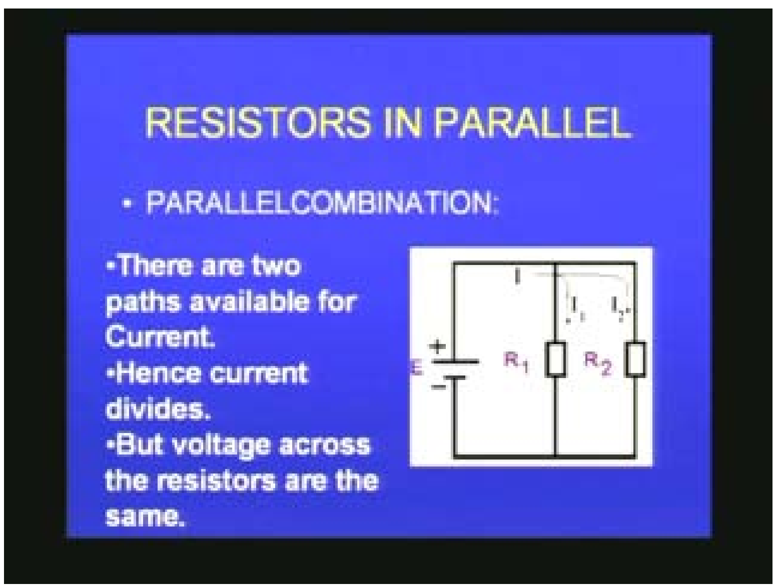

That means if I call this as the head, this I call as a tail of the resistor, you can see the head of one resistor and head of the other resistor are connected together and the tail of one resistor and the tail of the other resistor are connected together and both of them are connected to the power supply in this direction. So this is characterized by a parallel combination and immediately you can imagine what is happening to the current. The current which comes from the voltage source will have to divide here because there is a junction here and so current divides and you get different current flowing through the two different resistors R_1 and R_2 and then they come again together, add together and come out as the total current I. So what you can see in a parallel combination is that, the current divides. But something else is constant. Just as in a series resistor combination the current was a constant here some thing else should be a constant. What is constant in a parallel combination? You can immediately see the voltage applied across each of the resistors is a constant you can see the same voltage E or V is applied across this resistor R_1 and it is also applied in this resistor R_2. Therefore parallel combinations are characterized by same voltage appearing across all the resistors and secondly the current divides in a parallel resistor. So this is important. How do I obtain the total resistance or the combination resistance in the case of resistors which are connected in parallel?

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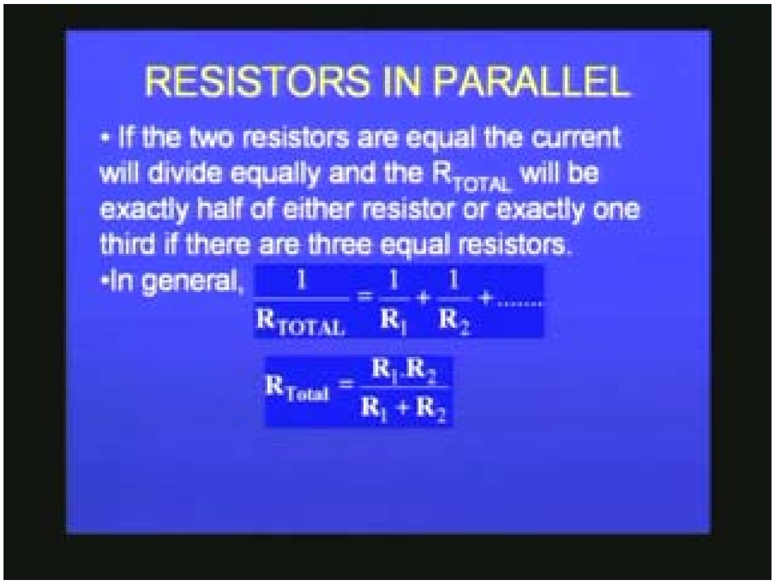

I have given the formula on the screen. If two resistors are equal, because they are equal they will have equal current flowing through them and therefore when the current divides, you would also see their resistance will also be half of the full value that you can think of. That is R_{Total} in general, the formula is given by $1/R_{Total}$ is equal to $1/R_1 + 1/R_2 +$ etc., depending upon how many resistors you connect in parallel. So if I have this complicated relationship, in terms of reciprocal can be looked at easily by taking $R_{Total} = R_1.R_2/R_1+R_2$, in the case of two resistors R_1 and R_2 connected in parallel. So the formula for total resistance of two resistors connected in parallel is very simple. You find the product of the resistors and divide it by the sum of the resistors and that will give you the resultant of combination of two resistors connected in parallel.

Let us again take a numerical example as before. Let us assume that we do have the same 6V power supply and for simplicity again we assume the two resistors which are connected in parallel are 1000 or 1K each. Because each resistor is connected to 6V supply independently in parallel, the current through the resistor will be therefore 6V by 1000 ohms or 1K corresponding to one resistor and that is equal to 6 milli amperes as we have seen before.

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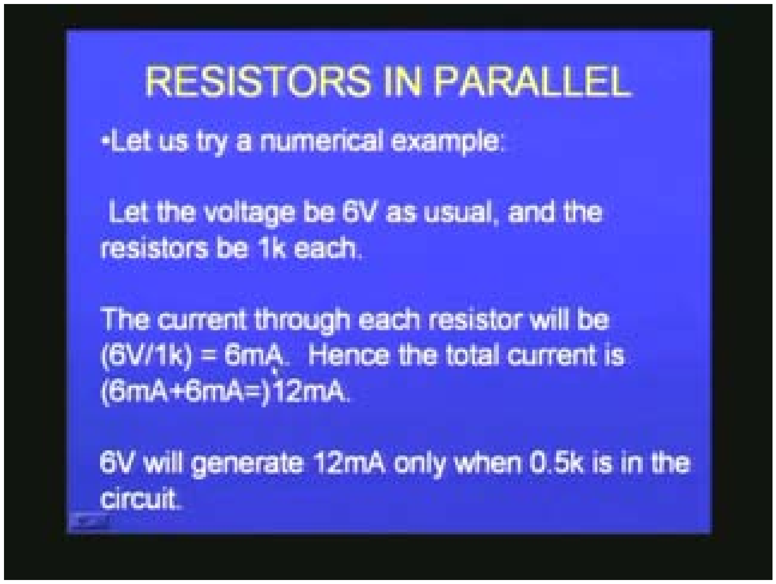

So 6 milli amperes of current flows through R_1. Again 6 milli amperes of current flows through R_2 and therefore you can see the original current which divided into the two resistors will have to be 6 + 6 or 12 milli amperes. What resistance when I connect across 6V power supply will give me 12 milli amperes of current is a very simple problem. Only if I have1/2K resistors that is 500 ohms is equal to 0.5K, then 6V/0.5 is twelve and therefore the total current will be 12 milli amperes. That means what is the effective resistance of two resistors 1000 ohms each I connected in parallel and the effective resistance as you can see is five hundred ohms or 0.5K.

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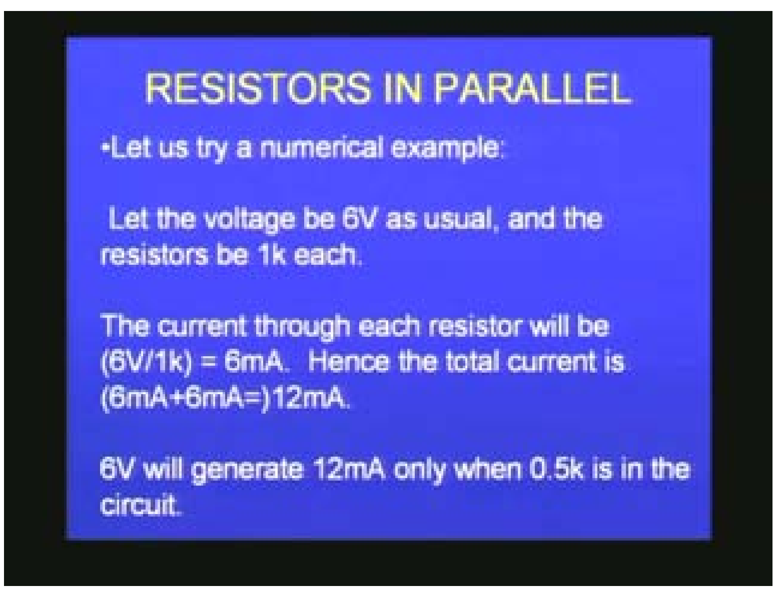

So when I connect the two resistors in parallel, the effective resistance becomes less. In this case 1/2 because I have used two equal resistors. If I have more than two resistors connected in parallel you can imagine that the effective resistance will still be lower. For example if I use three equal resistors in parallel combination, the effective resistance will be 1/3rd. So 1K, 1K and 1K connected in parallel, the effective resistance will be 1/3x 1000 ohms or about 330 ohms. Here I have shown when I connect the two 1K resistors, I can also use the formula to obtain the effective resistance or total is given by, as I already mentioned to you, $R_1.R_2/R_1+R_2$.

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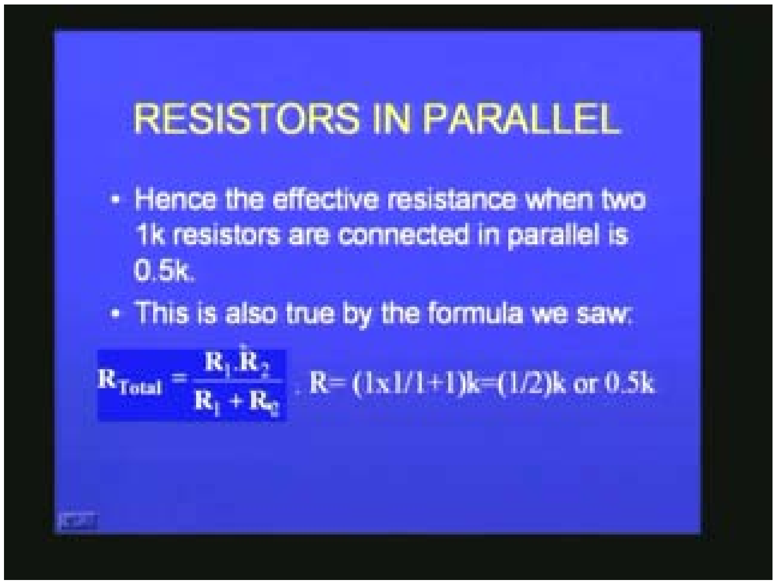

In the equal resistance case, I have 1000 ohms into 1000 ohms or here 1K. I have done everything in kilo ohms. So 1 into 1 divided by 1+1 kilo ohms and that is nothing but ½ kilo ohms or 0.5 kilo ohms. Instead of using equal resistors for R_1 and R_2 if I use different resistors, R_1 is different from R_2 then the single current which divides as I connect them in parallel will also be different. In the previous case the two currents were equal because I used equal resistors. So different resistors divide current differently and you know how it will divide. If the resistance is more, the current will be less. They have inverse proportion. If the resistance is less, the current will be more. If I have two resistors R_1 and R_2 and if R_1 is larger than R_2, then the current through R_1 will be less compared to the current through R_2 but still the total current will be the sum of these two currents which will be the one coming out of the power supply.

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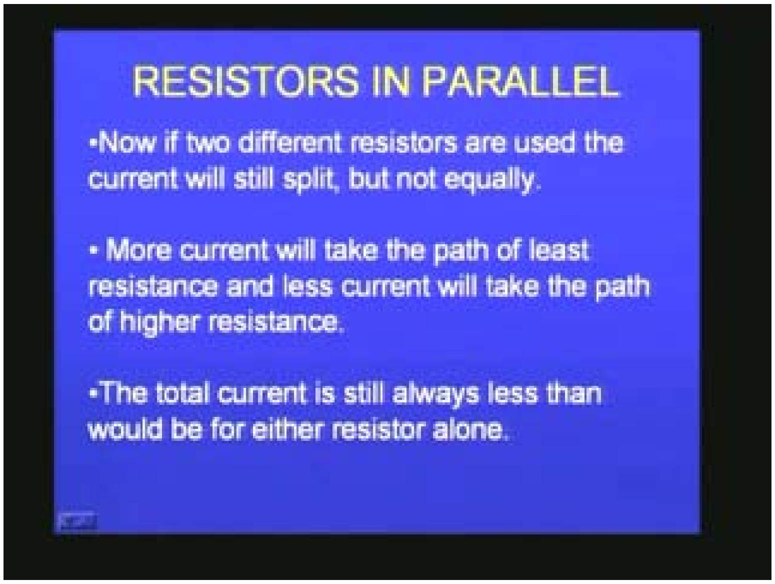

Now we summarize the various important points that we should remember when we have resistors connected in parallel. The same voltage exists across all the resistors connected in parallel that is one important point that you have seen there already and the reciprocal of the resultant resistor is the sum of the reciprocals of all resistors individually taken in the case of the parallel resistors and the last point is parallel resistors divide the total current in an inverse proportion to their magnitude; larger resistors provide less current, smaller resistors divide larger current.

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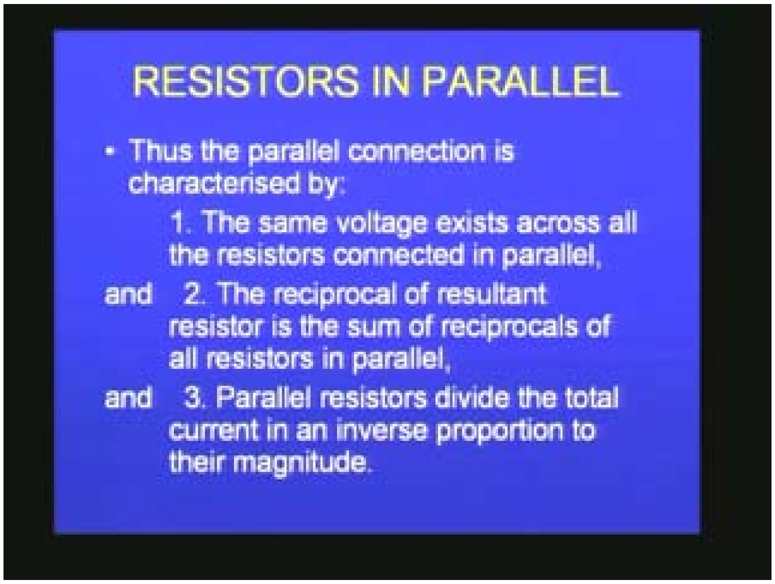

Another very important point with reference to resistors when connected in parallel is that the effective resistance of such a parallel combination will always be smaller than the smallest of the resistors that we have used in the combination. For example if I use 1K in the parallel combination we have seen already that it is 0.5K. It divides by two because I have used two equal resistors. Instead for example if I use 1K and 10K, that is 1000 ohms and 10,000 ohms then the resultant is 10 into 1 by 10+1. That means 10/11 is equal to 0.9K and that means smaller than the smallest of the two resistors that I used in the circuit which in this case is 1K. 0.9 is less than 1K.

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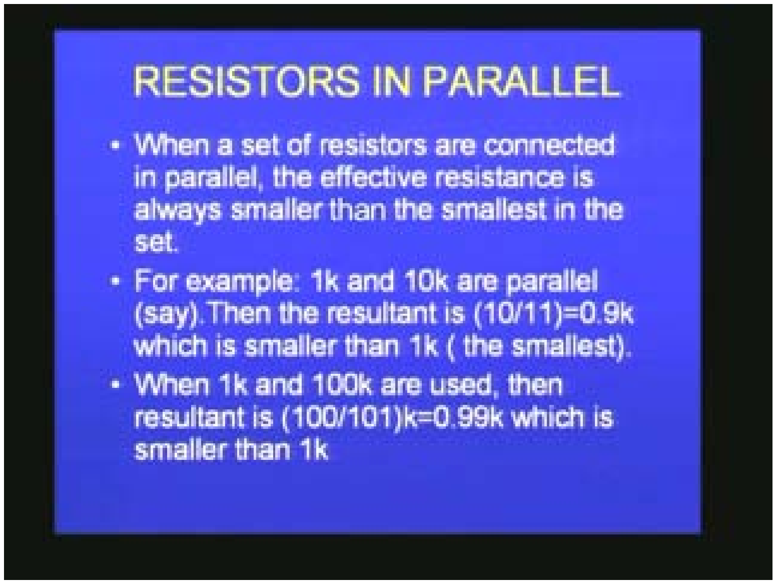

If I use 1K and 100K in parallel combination then the resultant you can immediately find out will 1into 100 divided by 1+100 and that means 100/101 and the value is about 0.99K. So you can see if the two resistors are equal the effective resistance is half, if the two resistors are differing by large value then you find it is much closer to the smaller of the two, much closer to the 1000 ohms. When I use 1000 and 10,000 it is 0.9 and when I use 1000 and 100,000 it is 0.99. Therefore as I increase one of the values of the resistors to the larger and larger value, you would find that the effective resistance will be almost related to smaller of the resistors.

Now that we have understood this parallel combination and series combination, we will be in a position to apply these combinations in different situations. One immediate application that you can think of with series resistors is the concept that I have already mentioned to you that series resistors divide voltage. Because they divide voltage, if I have a power supply which is let us say 10V output but I have a circuit which I constructed that requires only 5V. Then what do I do? I do not have any other power supply. I only have a 10V power supply that is required to be used in a situation which requires only 5V. So what do I do? Idea is very simple. You can use the two resistors in series. You can connect the two resistors in series to the 10V and make sure the two resistors are equal. Then you know equal resistors connected in series divide voltage equally and therefore 10V will be divided equally. That means I will get 5V and 5V across each of the resistors.

So if I connect the output of one of the resistors, the voltage developed across one of the resistors to my circuit I will get 5V required for my circuit. But there is one important point which we should remember. You can always divide the voltages proportional to the resistance as I already mentioned to you and therefore depending upon whether you want 5V or 6V or 10V, you can divide the resistors, suitably select them and then obtain any divisions that you require. But unfortunately what value of resistors you will choose for making a potential divider? Because I said that to get half of the total voltage required, I require two equal resistors. The two equal resistors could be 100 ohms each, it could be 1000 ohms each, it could be 100,000ohms each; which is the best one to choose?

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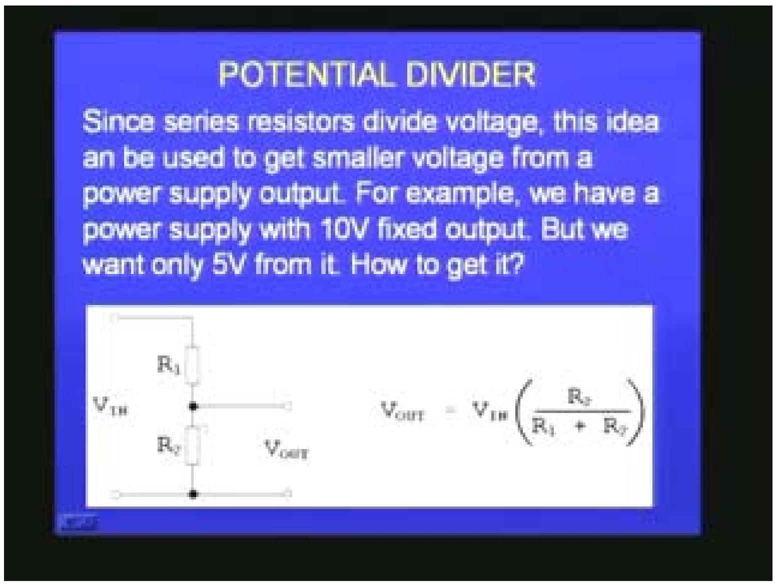

All these combinations whether I use 100 ohms and 100 ohms or 1000 K ohms and 1000 K ohms, whatever I use as long as I use two equal resistors the voltage will be divided equally. So in all the cases, the division of voltage will be the same but something else will happen. That you should remember. You are dividing the voltage because you want to apply a smaller voltage to a different circuit and that circuit for functioning, it requires a current. That means you must have enough current. Minimum current required to operate the circuit should be available from your power supply. I want to show you on the screen; you have got a voltage supply V_{IN} divided by two resistors R_1 and R_2 and apply the voltage across R_2 as V_{OUT}. I will take it for connecting to any other device. The equation that I have shown here is V_{OUT} is V_{IN} multiplied by R_2/R_1+R_2 which is a very simple relationship which you can obtain from ohms law but the point I want to tell you is when I want a load or some circuit connected across the output of R_2, you would find that the current for this circuit will have to come from your main power supply with V_{IN} through the resistor R_1 also. Therefore if R_1 is 100,000 ohms then a current which will come to the output circuit will be limited by the R_1 resistor which is coming in series and therefore you would find if I use very large resistors here I will not be able to get enough current for applying to different circuits that I have at the output. Therefore one has to choose reasonably small values of resistors for R_1 and R_2 two especially when you want potential divider. But how small? Can I put 10 ohms and 10 ohms and divide the voltage? Again it will divide equally. But because it is 10 ohms, I can get very large current. Therefore there is no problem. Yes you can certainly get very larger current using 10 ohms, 10 ohms combination; but you should always remember 10 ohms, 10 ohms will make a large current to continuously flow through the circuit and therefore there will be a large current flowing through these two 10 ohms resistors. That means there is a power loss in terms of the power rating of these resistors R_1 and R_2. There will be some heat loss in these resistors which will be unnecessary and therefore one has to have some via media in between. You should not use too large values; you should not use too small value and therefore you will use reasonably small values like may be 1000 ohms is a reasonably good value that you can think of.

In this screen I wanted to show you a relationship, how do I obtain an output voltage as R_1 by R_1+R_2 into V_{IN}. I is V_{IN}/R_1+R_2; that we already know. The total current is total voltage divided by total resistance and since this current flow through R_2, in this case I multiply by I into R_2 and that is V_{IN} divided by R_1+ R_2 into R_2 which I have rewritten as V_{OUT} is R_2 by R_1+R_2 into V_{IN}.

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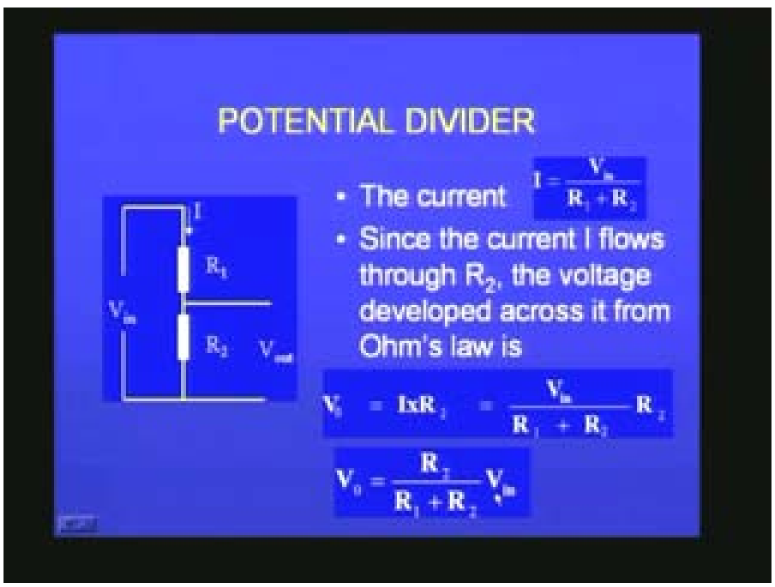

So this is a concept of the potential divider and I have given some examples. If the two resistors are equal then V_{Out} will be $V_{in}/2$; that we have already seen; equal resistors divide voltage equally.

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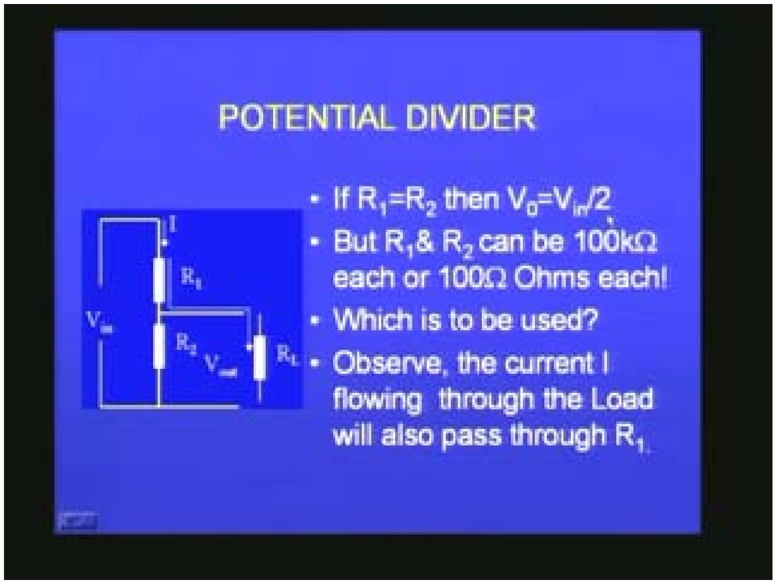

I also mentioned to you in the potential divider that the current flows through R_1 and therefore one has to choose carefully the value of R_1. We can also have the two resistors replaced by a variable resistor if necessary; that is also possible. And then the last point which is very important in potential divider is with reference to power dissipation.

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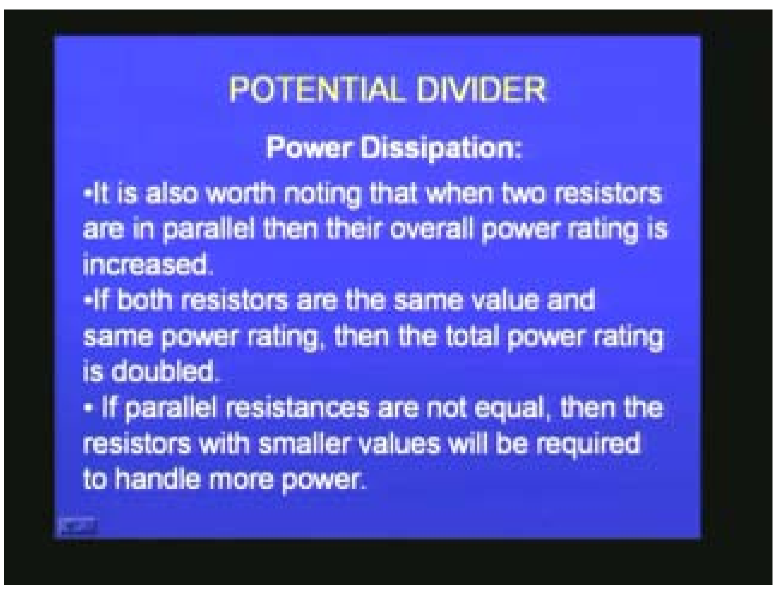

We should always use resistors which are not too small, resistors which are not too large but some thing in between. May be about 1000, 2000 ohms will be reasonable value of the resistors to be used in serial combination for obtaining potential dividers. I will just give one or two simple ideas. Four identical quarter watt resistors, 0.25 watt resistors can be wired in parallel to give a resistor of $1/4^{th}$ the value in ohms but four times the power rating because the current will be four times whereas the resistance value will be 1/4th because you have connected them in parallel.

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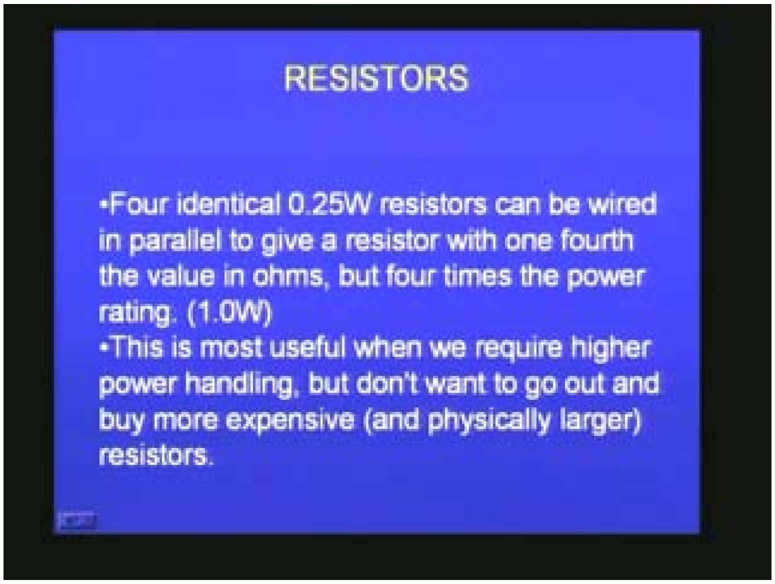

This is most useful when we require higher power rating resistors but we cannot buy them immediately by going over to the shop. You can use these simple techniques for obtaining larger power rating for your resistance. We have already discussed power is proportional to voltage into current and therefore we must make sure that when we connect resistors in parallel, parallel resistors require larger power rating and therefore carefully choose the combination so that there is no problem with regard to power rating.

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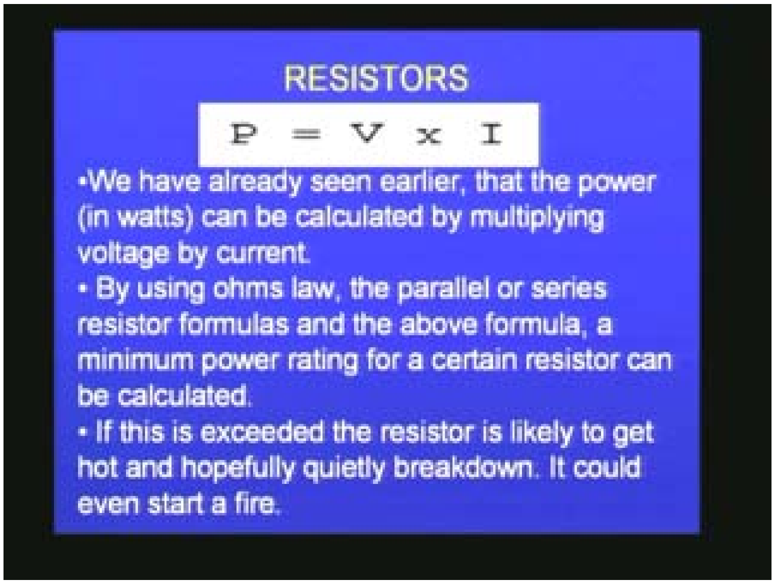

If you use a resistor which has got a lower power rating then the resistor will go back when you connect them in series due to the heat dissipated or it could also start a fire. Next this is about the voltages combinations in series and parallel. I will quickly go over to the experiment and show you the different ways of connecting the resistors in parallel and series and then let us try the experiments.

Here I have a power supply and the two wires from the power supply are connected to a breadboard which we have already seen and you can see I have connected two resistors here, each one of them is 1000 ohms.

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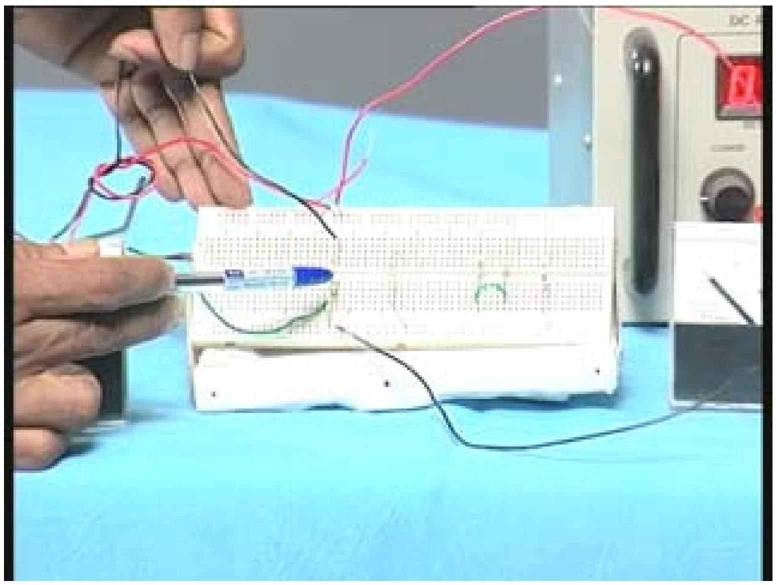

Some of you are familiar with the color codes which I already mentioned. You can see that it is brown, black, red and gold. Here again brown, black, red, gold. These are 1K resistors connected and the power supply comes here and I have connected a current meter, a milliammeter between one point on the power supply and resistor series combination. So I have connected this meter in series in the gap and the two resistors are also connected in series and the negative power supply goes back to the power supply. So the two resistors are connected in series I have about approximately 6V or so, 5.9V. So when I have 5.9V, two resistors equal to 2K, 6/2K is around 3 milliamperes. So you can see this bigger division is 5 milliamperes; so it is nearly six divisions that correspond to 3 milliamperes of current.

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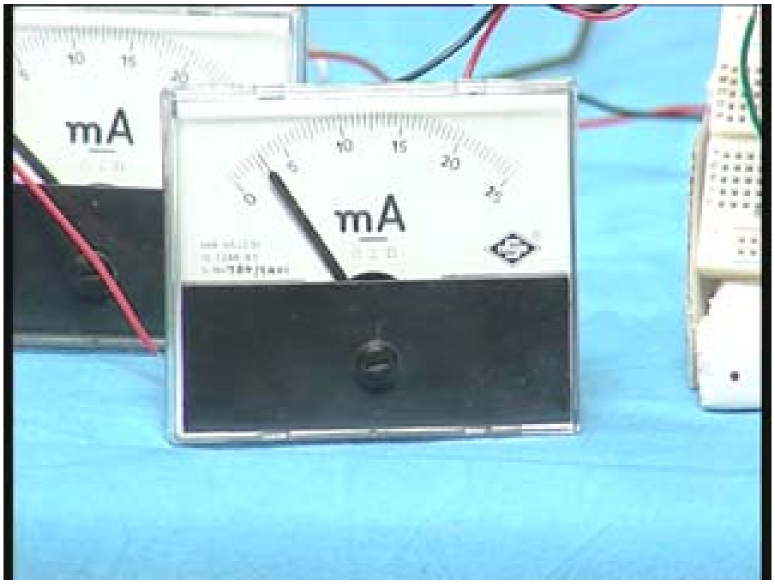

You can see again it is following ohms law and the two resistors have got the same current flowing through them which is given in this case as 3V. Now I have the voltmeter which I connected corresponding to the voltage and it is now measuring DC volts between these two terminals. Now I will use this to measure the voltage across one of the resistances. For example I will connect the bottom to the ground; I will take the other wire and connect it to the mid point. If it is connected to the mid point, then it is measuring the voltage across the lower resistance R_2 and you can see the voltage is 2.9 which correspond to really 3V approximately. Therefore when I connect 6V to two equal resistors the voltage across one of the resistors is found to be 3V. Similarly you can see the voltage across the other resistor will also be equal to 3V.

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Therefore total 6V is divided among the two resistors connected in series and therefore the concept that same current flows through both the resistors and series resistors divide voltage is very well understood by doing this.

Now what about their combination? I have used two resistors which in this case is 1000 each. Therefore the total resistance as you know is 1000 plus 1000, 2000 ohms and therefore now what I have done is I have connected here another resistor whose value is nearly 2000 which I got by, you can see, the color code. Three red strips, red, red, red which is equal to 2.2K or 2200 ohms very close to 2000. I am connecting that in the circuit and let us see what will be the current. Now you can see the current is same as what you measured before when I had two different resistors each of 1000 ohms now replaced by 2200 ohms and you can see the current is almost the same as the previous case.

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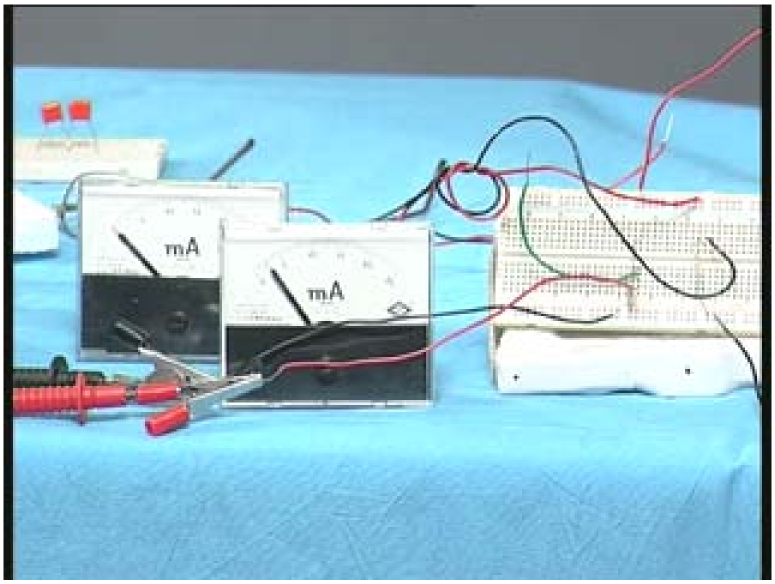

That means two, 1000 ohms connected in series is equal to one 2200 ohms nearly 2000 ohms resistor. Therefore the combination of resistors, when I connect them in series is just obtained by summing all the resistors. That is want I wanted to show you.

Let me go on to the parallel combinations. You can see here I have two resistors. Again they are 1000 ohms, 1K resistor. I have connected them together at the bottom and the top one I will connect to the power supply quickly. So I take the power supply, connect it at the top point and I want to measure the current flowing through each of the resistors. Therefore one end of the current meter I connect to power supply; the other end I connect to one of the resistors. Similarly I will take the other milliammeter also to the second resistor. Now I will connect the negative of the power supply. I hope you can see that. You can see this is nearly 6 milliamperes; this is also 6 milliamperes.

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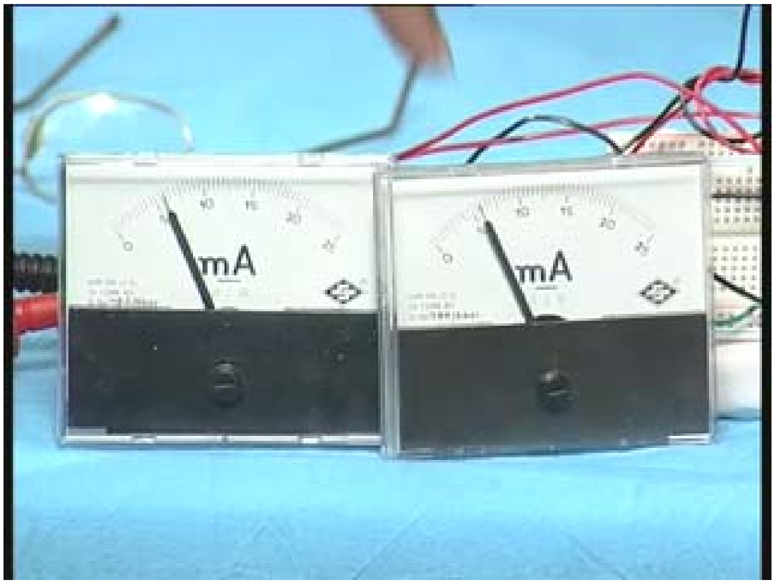

Therefore I have 6 milliamperes through one of the resistors, 6 milliamperes through the other resistors. The total resistance will be 12 milliamperes which I can actually monitor using this if necessary. So you can see because I have 6V appearing across both the 1000 resistors both resistors will generate 6 milliamperes independently and the total current will be the sum of the two currents. Therefore a parallel combination divide current and they have the same voltage 6V across them. 6V/divided by 1000 is 6 milliamperes; here also 6 milliamperes.

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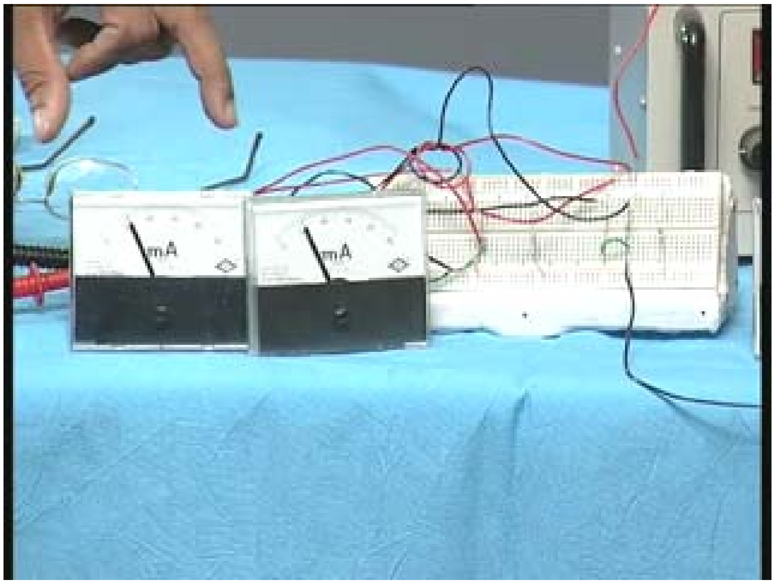

So we can see that parallel resistors divide current and they have a same voltage. That is what I just wanted to show you. So we have seen the actual demonstration of the series and parallel combinations of the resistors. Now we will move to the next component, which is capacitor.

So what is a capacitor? A capacitor is basically a device which has got, in general two parallel plates separated by an insulator or a dielectric.

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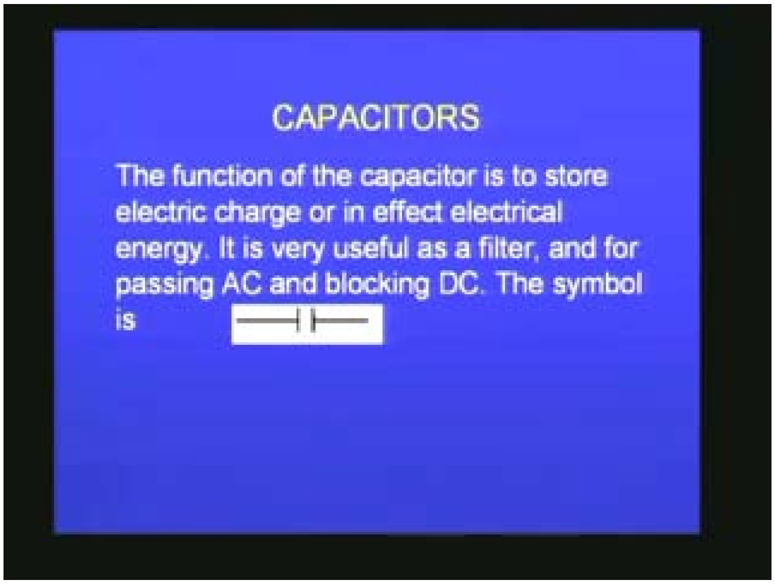

It is used for storing electrical energy and capacitor is characterized by very large resistance to DC or the direct current and smaller resistance for alternating current. I have shown the construction of a typical parallel plate capacitor which is a most popular one. You can see there is one plate here connected to a wire and there is another plate here connected to another wire and you have in between a dielectric which is basically air or any other insulator. These things you would have studied in your earlier classes; the value of capacitance is given by epsilon zero into epsilon r into A divided by d where A is the area of the capacitor, d is the distance of separation between the two plates and epsilon zero and epsilon r are constants. Epsilon zero is called the permittivity of free space, epsilon r is the dielectric constant or the relative permittivity of the media.

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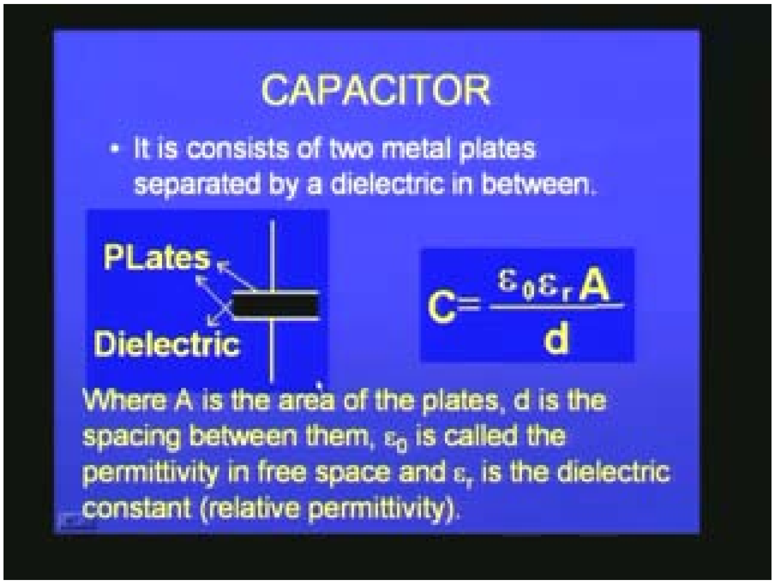

So you can see the capacitance of a capacitor is proportional to area because it comes in the numerator. It is inversely proportional to the spacing. That means smaller the distance between the plates, larger will be the capacitance and it also depends on the dielectric constant or the nature of the medium that I have in between the two parallel plates. So when a DC voltage is applied to a capacitor, the capacitor gets charged. The charges start flowing into the capacitors, they stay on the plates and thereby they get fully charged. Just as charges get accumulated on the plates, there will be a current flowing when I immediately connect a capacitor to a battery. But then this current will slowly come to zero as the charges accumulate on the plate and therefore finally when it is fully charged, the current flowing through the capacitor will be zero; there will not be any current at all in the circuit.

If we measure the resistance of a capacitor, the resistance in this case will have to be very large or infinity because you have two plates; there is no electrical connection between them and apart from that you have introduced a dielectric either air or glass or mica. Therefore it will show infinite resistance. Hence obviously the capacitors will block DC, direct current. However when an AC voltage or current is applied, a capacitor will offer some reactance as it is called; it is not resistance, it is reactance because it is only responding to time varying signals of voltage and current. Therefore it is called reactance.

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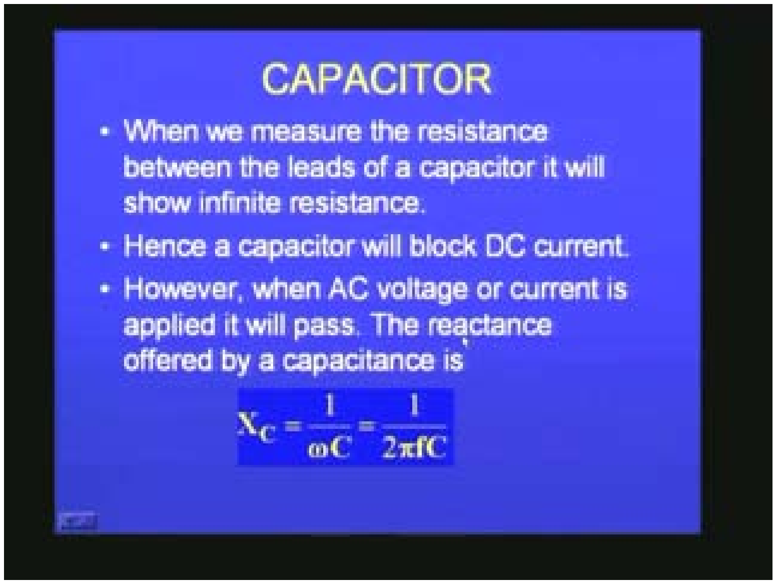

The value of Xc which is the reactance offered by a capacitance is given by one by omega C where omega is the frequency component. Omega is angular frequency which is given by two pi times f, the frequency of the AC and C is the capacitance in Farad. Usually the unit of capacitance is Farad. Farad is a very large value of capacitance and therefore only some super capacitors will have capacitance in the range of Farad. The normal value of capacitance is measured in microfarad which corresponds to ten power minus three farad or nanofarad corresponding to ten power minus nine farad and some times even picofarad which corresponds to ten power minus twelve farad.

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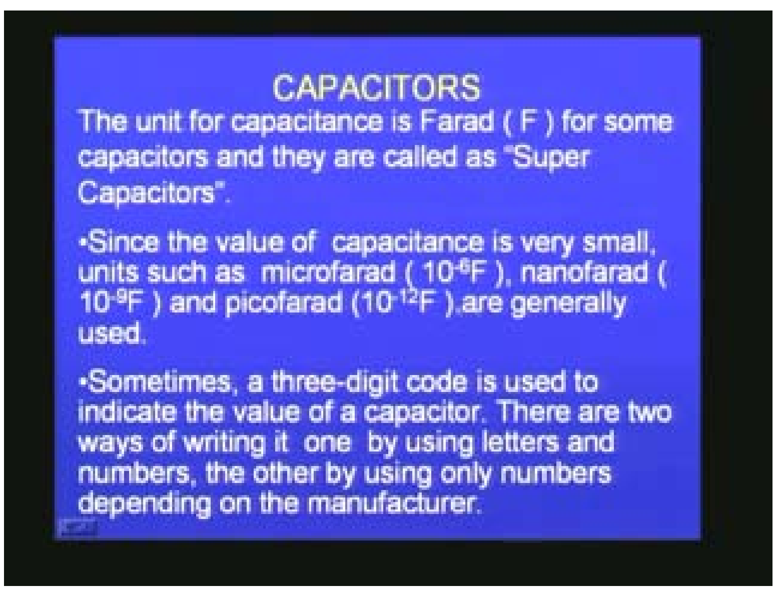

These are the scales that normally we use and we also use similar to the resistors a three digit code which indicates the value of the capacitors or some times they put in terms of some numbers on the capacitors, if it is possible. Just as resistors, capacitors can also be combined and you can combine them again in a similar passion in series as I have shown here. For example C_1 and C_2 are connected in series and if I connect them in series, the formula that you use is much more closer to the parallel combination of resistors. That is $1/C_{Total}$ is equal to $1/C_1 + 1/C_2$ and this is the formula we will use when you connect capacitors in series.

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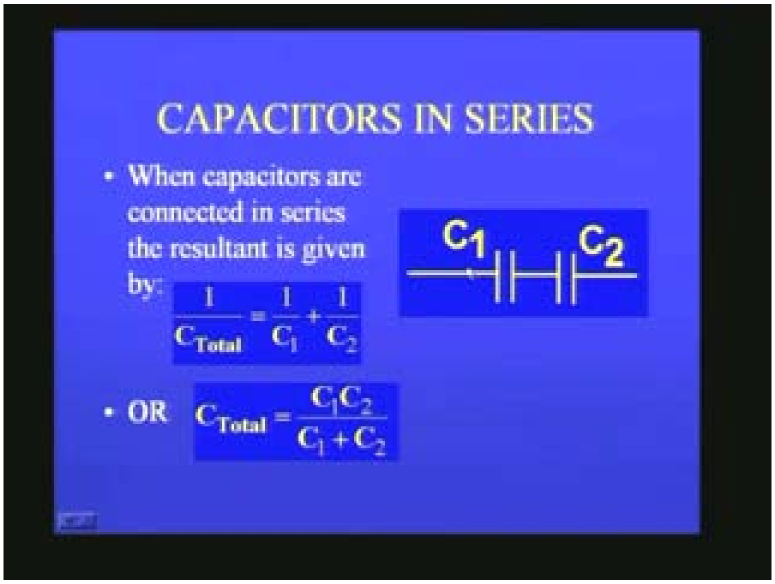

If I have only two capacitors then the total capacitance or the resultant capacitance is given by C_1C_2/C_1+C_2, just as we had a similar situation with reference to parallel resistors. If you connect the capacitors in parallel, then you can see they add as you are doing in the case of series resistors. So C_{Total} in the case of capacitors connected in parallel is nothing but C_1+C_2. So you should observe the difference between the combination of capacitors and the combination of resistors.

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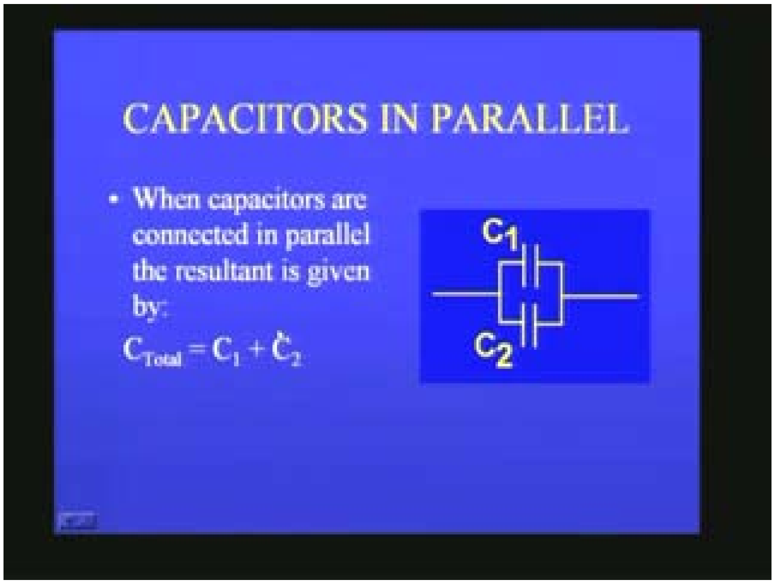

Just as resistors are characterized by a value and power rating, what wattage it can withstand, similarly capacitors are characterized by the capacitance in terms of farads or microfarads and also another important characteristic is the voltage; the maximum voltage that I can apply to the capacitor without breaking down the capacitor. If I keep on applying voltage and if I exceed the threshold then dielectric will break down making very large current to flow through that and that is what is called break down voltage. So breakdown voltage is another important characteristic of capacitors and therefore when I buy a capacitor I should specify the operating voltage. If I am going to operate the capacitors to 6V, 12V, etc., then I can go for 25V capacitors or 50V capacitors as the case may be.

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But if I am going to operate the capacitors in regions where the voltage could be as high as 1000V or 2000V then I should buy capacitors with very large break down voltages of the order of 5K or 10K, etc.

You also have different types of capacitors. The different types of capacitors come about because of the different types of dielectric material that you introduce between the two metal plates. So in the case of electrolytic capacitors which are widely used in different situations in circuits you would find the electrolyte is used as the dielectric. The dielectric in this case is an electrolyte and usually aluminum will be used as an electrode and the electrolyte will have some polarity consciousness. It has to be very carefully connected in circuit because they will be marked with very specific direction; plus and minus for the leads. If you interchange them, it will lead to difficulty because the current will flow in the opposite direction and it will evolve gases. Finally it may also explode sometimes.

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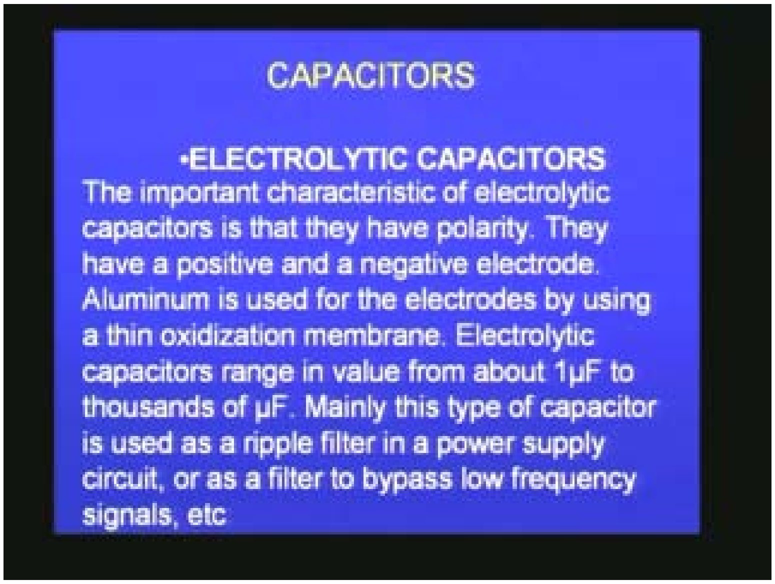

One has to be very careful when we use capacitors in the lab; especially in electrolytic capacitors you should look for the plus and minus sign and connect it properly in the circuit with the right polarity. Then you may be asking as to why we are using a polarized capacitor when it is said that capacitors will conduct only AC. There is no DC here. Only in DC we have plus and minus sign shown. Why in an electrolytic capacitors you still call it capacitors and than they must be you are marking plus and minus on the top? The reason here is the AC that you use in the case of electrolytic capacitors will be the varying DC. So you will have an average DC over which there will be a variation or an alternating voltage and therefore it is some thing like for example the ripple voltage in the case of a power supply. So electrolytic capacitors are always used under DC conditions but varying DC conditions and there is no harm. Still they will only take care of the alternating voltage that is being applied.

I have here some examples of electrolytic capacitors and the values also are shown. You can see this first one is 1 microfarad, the last one is 1000 microfarad and you can see the 50 V of operation. So all of them are characterized by a value of capacitance in microfarads and a value of voltage which is the maximum voltage I can use it under different conditions.

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So these are electrolytic capacitors and I will go on to show you the other type of capacitors. For example tantalum capacitors; Tantalum capacitors are also electrolytic capacitors. They use the material called tantalum for the electrodes and they are superior compared to the normal electrolytic capacitors. They have very high stability and they are used mostly in analog signal systems. I have given some examples of tantalum capacitors; 0.33 microfarad, 0.47 microfarad and 10 microfarad. You can see their sizes are also different depending upon the value but the voltage in all the cases is 35 V, which is the maximum voltage.

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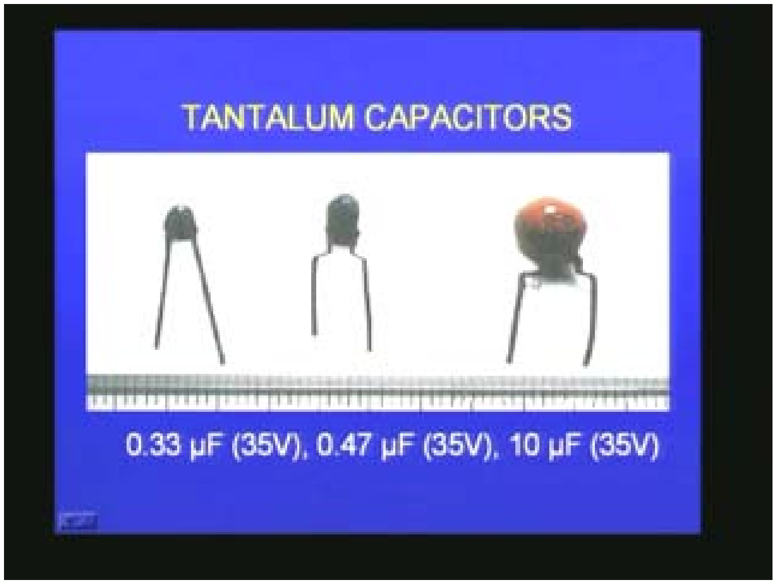

Then you have other type which is called ceramic capacitor and they have titanium barium oxide which used as the dielectric internally and they are used usually for high frequency applications. These are some of the ceramic capacitors.

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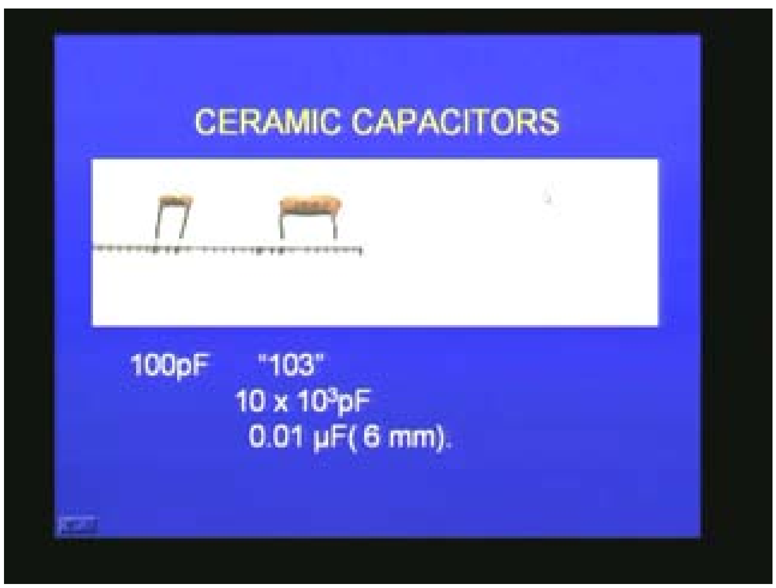

One is 1000 picofarad and the symbol they use is 103; first two digits corresponds to ten and three corresponds to ten power three picofarad which is equivalent to 0.01 microfarad You also have polystyrene film capacitors where polystyrene film is used as the dielectric and these type of capacitors are also used in different applications. I have given some examples of polystyrene capacitors here.

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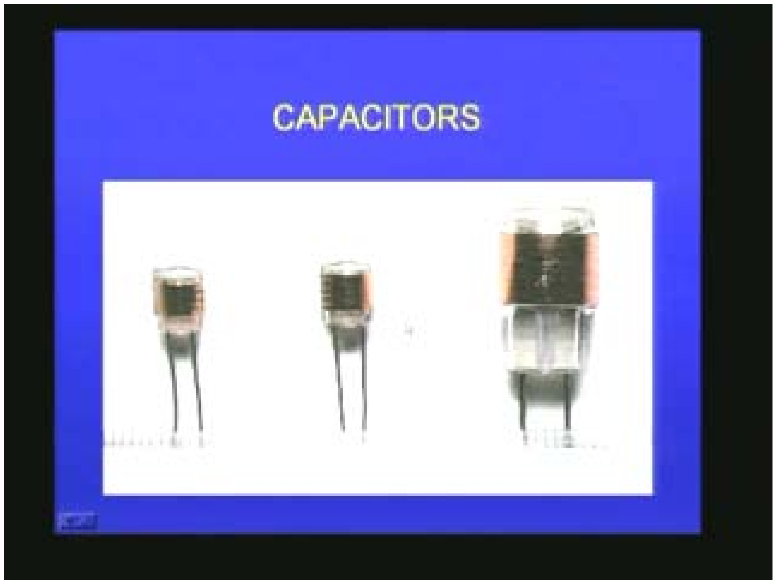

The nice brown color is due to copper being used as the electrode material. Then you have electric double layer capacitor which is called a “super capacitor” and the value of the capacitance is 0.47 farad. You should remember it is not micro farad; 0.47 farad. That means it is a very large value of capacitance. I will show you the picture. You can see here this is very large capacitor which has to be very carefully handled.

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You also have polyester film capacitors. Again you have the polyester used as the dielectric. They are very cheap. They have very reasonable tolerance in plus or minus 5% to plus or minus 10% and these are the polyester capacitors that I mentioned to you.

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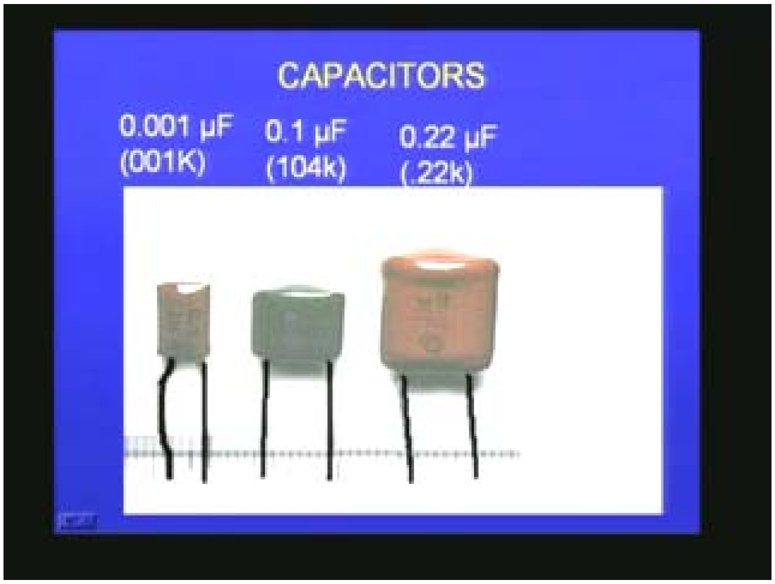

0.001 microfarad, 0.1microfarad and 0.22 microfarad, etc. Then polypropylene capacitors; again this is another dielectric that they use. Mica capacitors where mica is used as the dielectric material and it is used for high frequency and resonance circuits. They have very good insulations and you have dipped mica capacitors.

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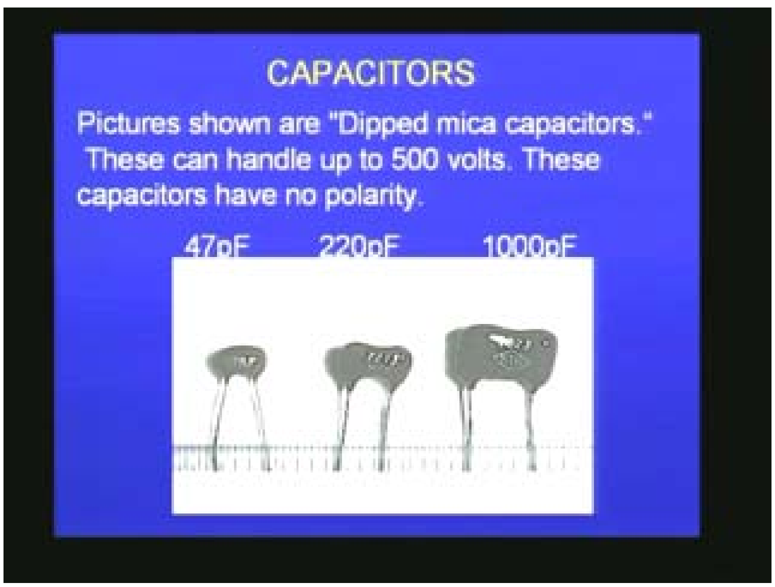

47 picofarad, 220 picofarad and 1000 picofarad are available. You also have metallized polymer film capacitors. They are much more rugged; they have no polarity and the figure shows such metallized capacitors.

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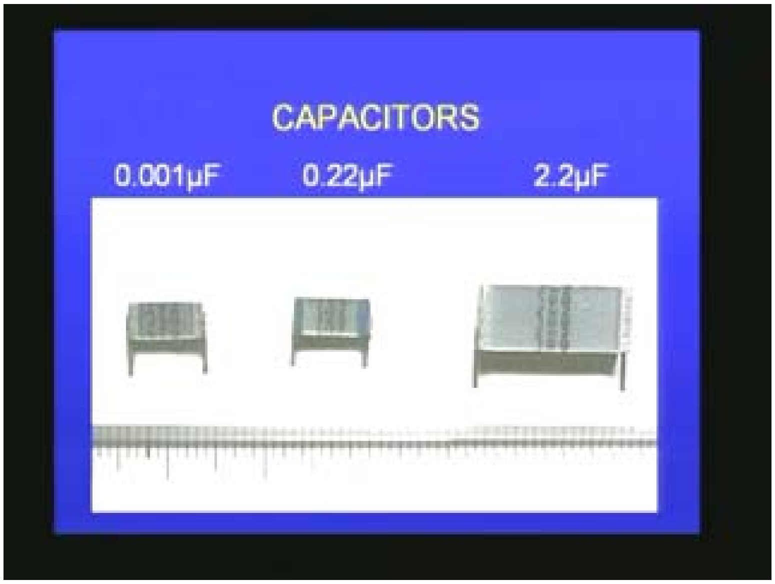

Just as you have variable resistors, you also have variable capacitors which are used for adjusting the frequency in a tuned circuit. You can use a special screw driver and vary. What is being done here is that the area of contact between the two plates will be changed; thereby capacitance will be changed. I have shown here pictures of variable capacitors. You can use the screw driver here and move this on top which will vary the capacitance from 3 pF to 27 pF, etc.

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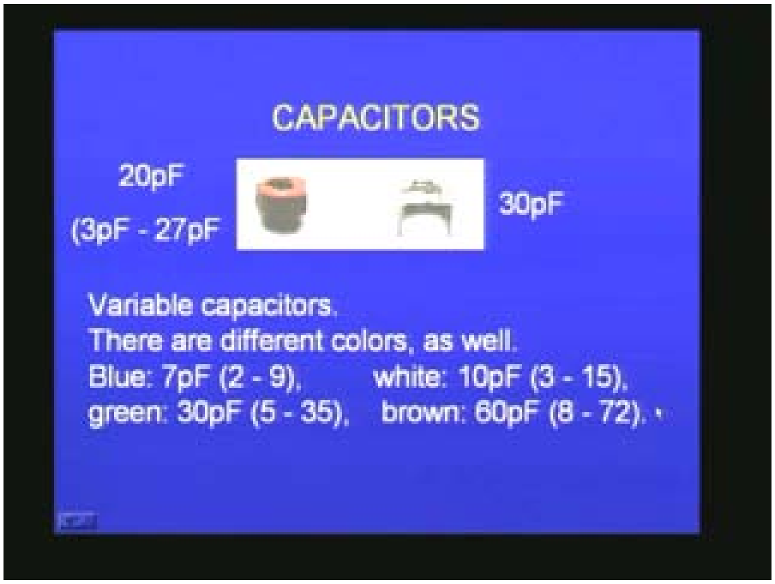

I have shown some more variable capacitors here. It is a ganged capacitor in the olden day radios, which makes use of these.

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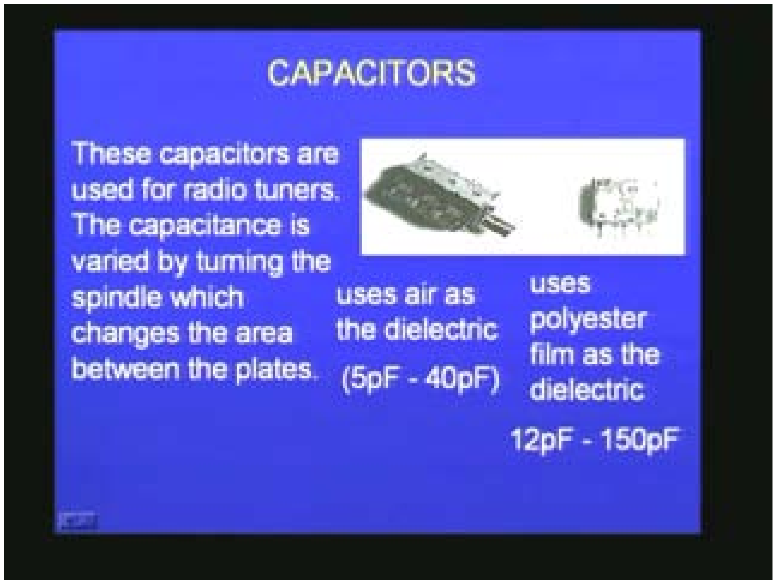

This is also a variable capacitor with a polyester film used as a dielectric. The variation is about 12 picofarad to 150 picofarad; very large values you can change.

Finally we will come to coils and inductances. These are also very useful in electronic circuits. We have a copper wire wound over a former which becomes inductors and the inductance is normally measured in units of Henry. The coils are also very useful in many circuits because you want to have resonance circuits.

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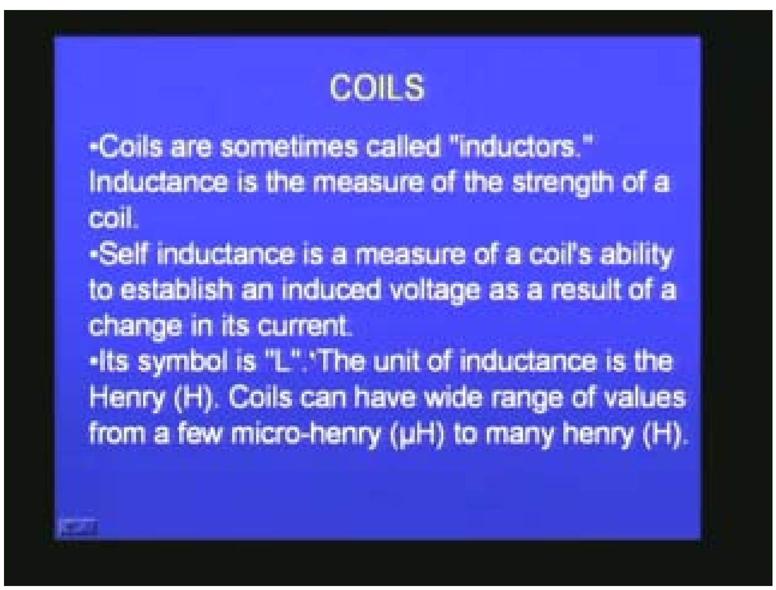

The symbol is L for inductance and the unit is Henry; usually we use micro Henry and milli Henry as units. The characteristic of the coils is that when current attempts to change then there is a reactance. In the case of capacitors whenever voltage changes there is a reactance. Here whenever the current changes there is a reactance and that is due to the electro magnetic effect that we know as "Lenz law".

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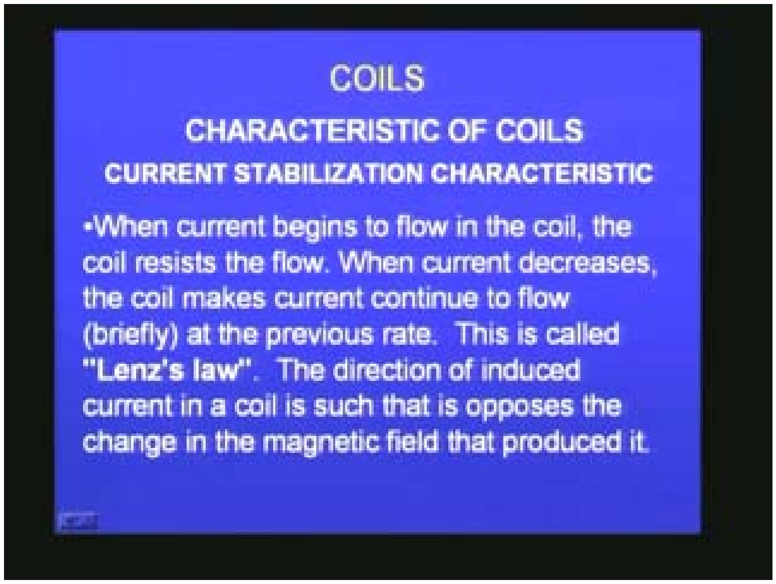

I have shown some simple examples here. This is a transformer where you have a primary and a secondary. When I apply an AC voltage to the primary due to the mutual inductance between the primary and secondary, there is a voltage also induced in the secondary and therefore they can be used to get smaller AC voltage from a larger voltage or a larger voltage from a smaller voltage.

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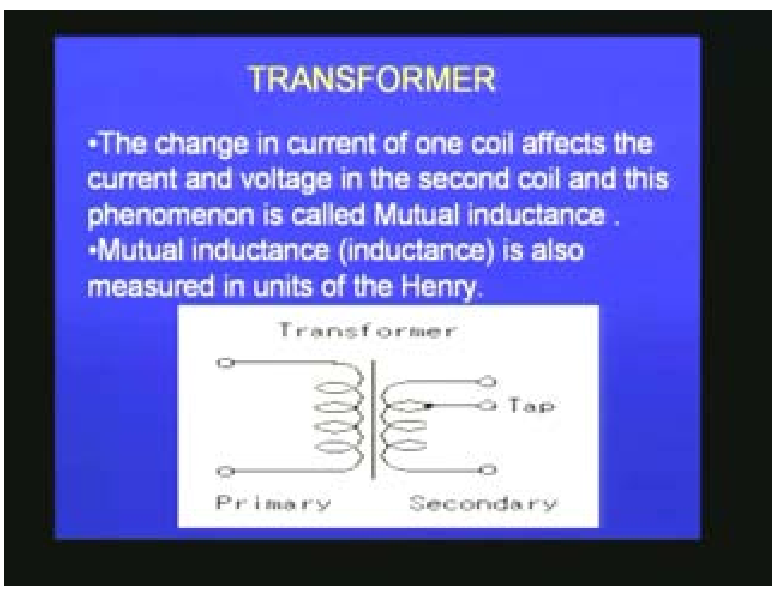

So transformers are very useful. Similarly coils are also used in electromagnetic relays to operate secondary circuits.

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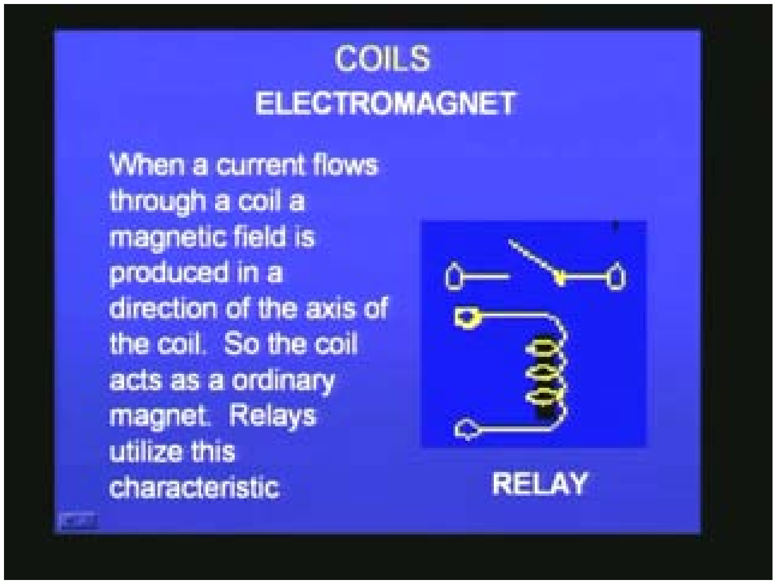

I have shown a simple circuit here. When current flows through this, the magnetic field will make the switch close and therefore you can switch on an independent circuit by using these relays. We will later on see demonstrations of such things and coils are also used in resonance circuits. This is a parallel resonance capacitance and inductance connected in parallel and the frequency of this parallel combination in one by two pi root LC where L is the inductance and C is the capacitance and this is something like a simple pendulum or a mechanical oscillating system. Here it is an electrical oscillating system. The capacitor gets charged and it passes a current through L.

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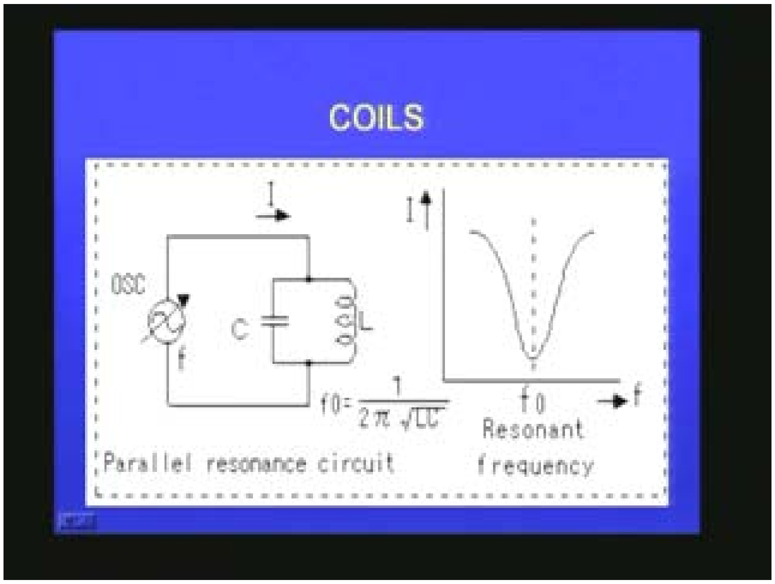

It produces an opposing back EMF that again charges the capacitor and so this goes on and on till all the energy is lost and this is the graph corresponding to the resonance circuit which is shown.

This is another circuit, which is a series resonance here.

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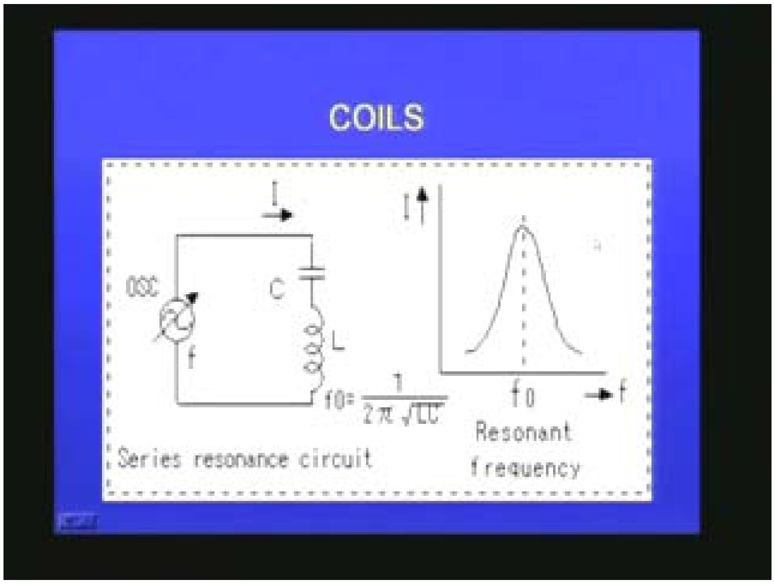

I have given some photographs of various types of inductances that we normally use in the electronic circuits. These two are actually transformers, high frequency transformers or intermediate frequency transformers.

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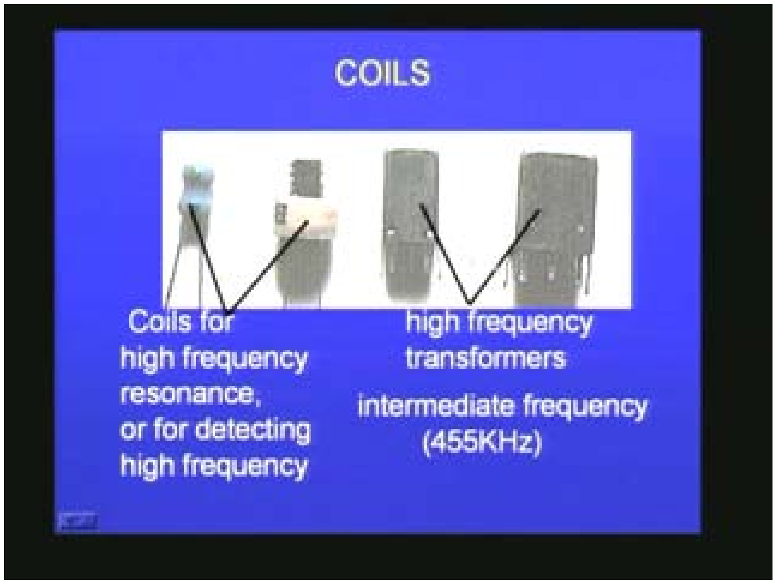

So you can adjust the value of inductance by using screw driver and vary the inductance value.

Finally let me just summarize the various ideas that we looked at today.

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We studied about resistors in combination, series and parallel and then we also saw how resistance can be connected in series to divide voltages as potential dividers and we also saw a demonstration of this series, parallel combinations and then we looked at different types of capacitors corresponding to different type of dielectric material that we use in them and how capacitors can be used in different circuits and then finally we saw about the inductance or the coils and the transformers. Transformers transform the voltages from one level to another level and they are very useful in high frequency as well as low frequency applications. For example every power supply that you think of in every electronic instrument, you would find there will be a transformer which is responsible for bringing down the 220V mains to some smaller value which can later be converted into direct current. So transformers are very, very useful in power supply circuits. Capacitors and resistors are very useful in several electronic circuits. In the next lecture we will try to look at a new type of device which is p-n junction diode and special type of diodes and applications of diodes.

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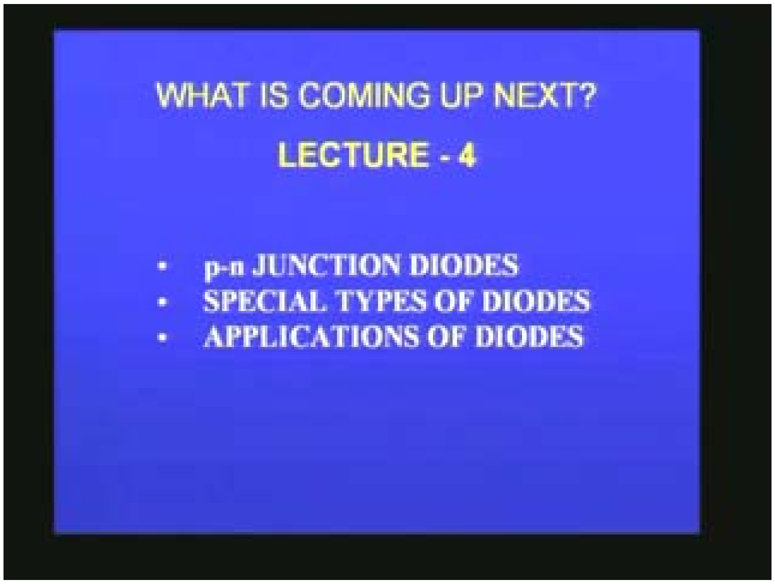

Thank you!