BASIC ELECTRONICS
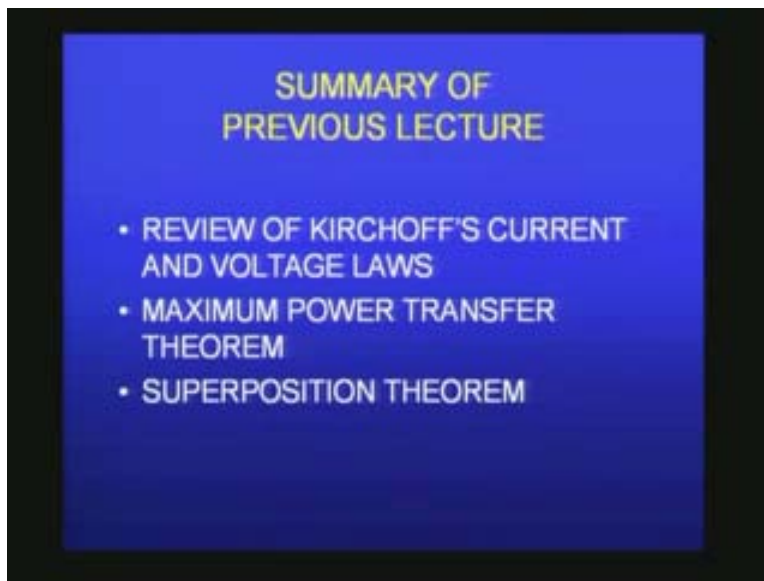**PROF. T.S. NATARAJAN**
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LECTURE-5
SOME USEFUL THEOREMS IN
BASIC ELECTRONICS

Hello everybody! In our series of lectures on basic electronics let us now move onto the next lecture. Before we do that let us recall what we discussed in the previous lecture.

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In the previous lecture we were looking at some of the well known theorems and laws which are very useful in electronics. We just reviewed the Kirchoff's law of current and voltage and then we also looked at some detail the maximum power transfer theorem which says when maximum power will be transferred from a given circuit to the load. We found that when internal resistance of the source is matched by the external load resistance there is maximum power transfer. We also saw some demonstration of the same. Lastly we also saw the most important network theorem that is superposition theorem. When we have more than one source, current sources or voltage sources how do we solve for a current or voltage across any of the given resistors. We saw the conditions to be satisfied, how the whole thing has to be looked at as a superposition. So this superposition theorem is very useful in solving network problems.

Today we will look at two more very important theorems of network basically Thevenin's theorem and Norton's theorem. These two are also very, very useful in simplifying very complicated circuits and trying to understand the working of different circuits in electricity and electronics. Let us now take first Thevenin's theorem. We

actually had a brief idea about Thevenin's, Norton's theorem in the previous lecture at the end of the lecture. Thevenin's theorem is very useful by which a complex circuit can be reduced to an equivalent series circuit consisting of a single voltage source which is called V Thevenin's and a single series resistance which is called R Thevenin's resistance of the Thevenin's and a load resistance R_L which any way is there in the circuit.

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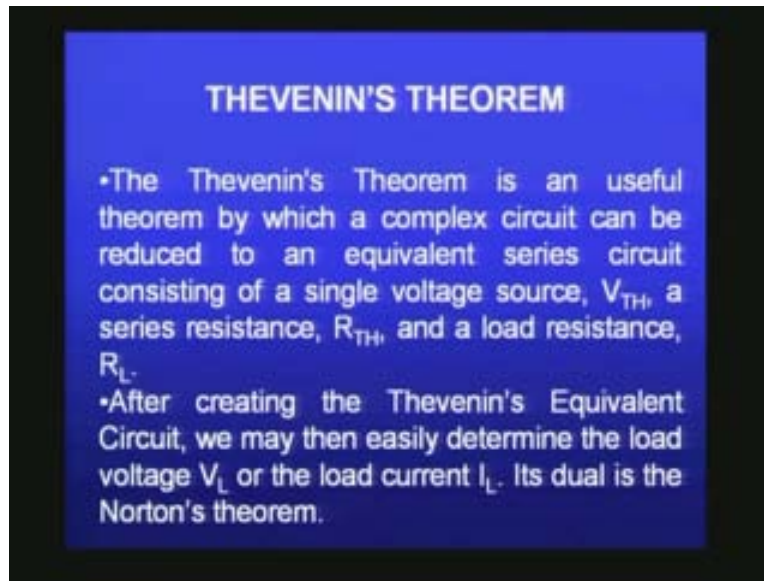
So any complicated circuit having any number of sources and resistors can be simplified by just having only one Thevenin's source, a voltage source and one Thevenin's resistors equivalently. So that becomes much simpler to solve once we have this type of an arrangement and you can see that it becomes very simple to solve such a theorem. There is also another theorem, the second theorem which is called the Norton's theorem which is a dual of Thevenin's voltage theorem. In the Norton's theorem instead of looking at voltage sources which we will do in Thevenin's theorem, we look at current sources. That means any complicated circuit can be equivalently considered as having one single Norton's current source and Norton's resistance. So these two theorems are very useful in solving many problems in electronics and electricity.

On the screen you can see there is a black box where there could be any circuit with number of DC sources and resistances and that is connected to one R_L, the load resistance at the terminals A and B output terminals of this black box. What Thevenin says is that the entire set of resistors and sources that you have in this box can be equivalently considered with only just two devices. One is Thevenin's voltage source V_{TH} and other is the Thevenin's resistance R_{TH}. One has to obtain the value of V_{TH} and value of R_{TH} corresponding to any given circuit and then the simplified circuit will just have only three components; the Thevenin's voltage source, the Thevenin's resistance and the external R_L that is being connected.

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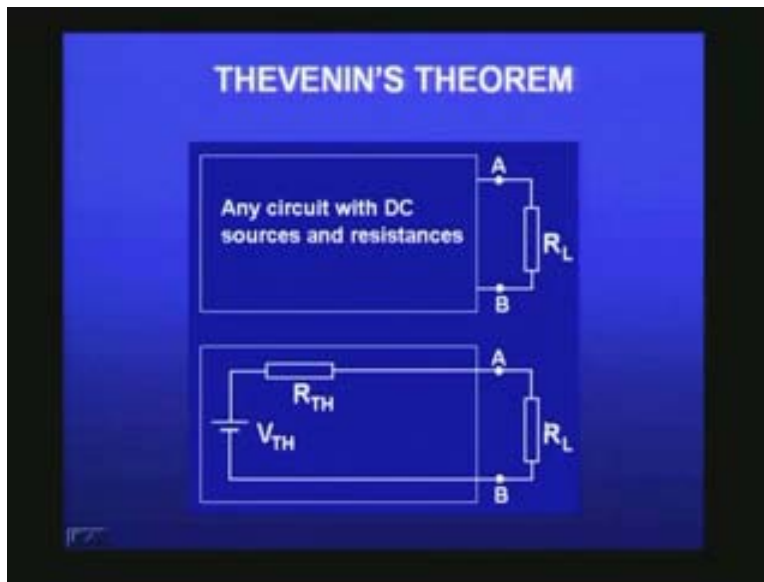
Then it becomes very simple. It becomes a simple potential divider. If you want to know the voltage across R_L, it is just a question of finding out what percentage or what proportion or what fraction of voltage V_{TH} is appearing across R_L which is a very simple problem which we have already solved.

Now let me take an example of a circuit which has got three internal resistors R_1, R_2 and R_3 and R_L is the external resistance between the terminals A and B.
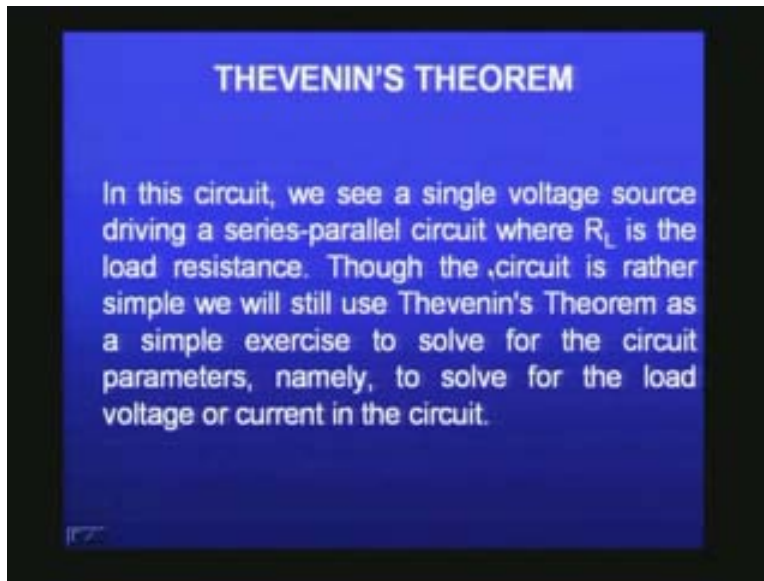
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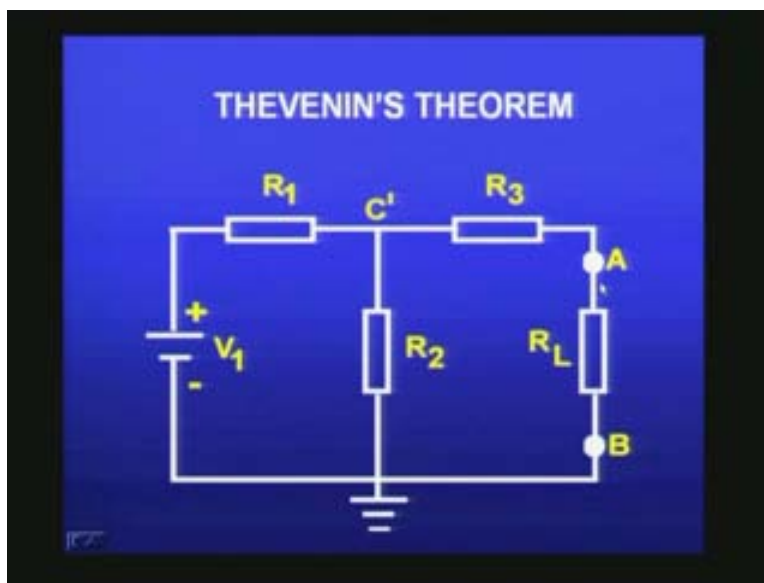
You have only one source because to start with the example will be very simple with one voltage source and just three resistors connected as shown in the figure. Our job is now to

find out how to solve these using Thevenin's theorem so that we should be able to obtain ultimately an equivalent Thevenin's voltage and equivalent Thevenin's resistance which will replace all these voltage sources V_1 and R_1, R_2, R_3 combination. We will see what the theorem says. The theorem says that you can measure the Thevenin's voltage in two ways.

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One is by actual measurement. The other one is looking at it in an analytical way. Let us see how we go about doing this. The first thing is we want to find out what is V_{TH}.

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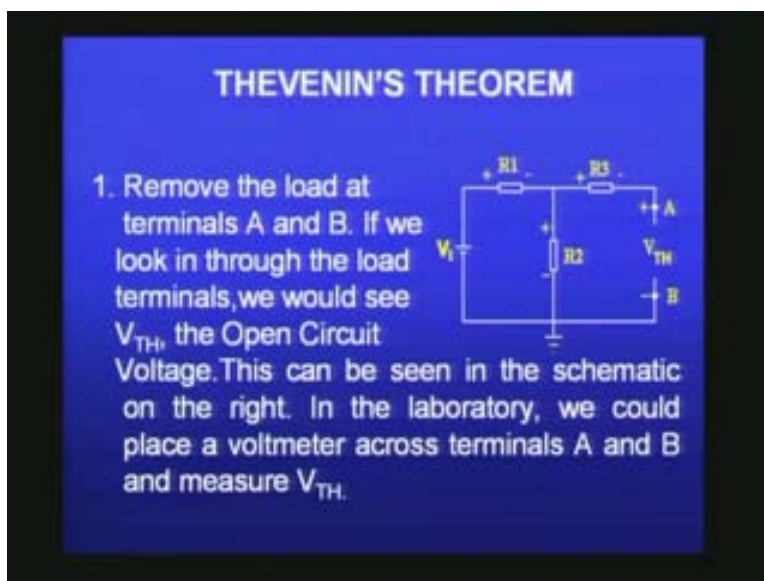
Then all that we have to do is remove the load. That is what you can see in the picture now. The load R_L is removed here and you just connect the terminals A and B to a voltmeter and measure the open circuit voltage. It is an open circuit now because the circuit is open at this point. You have removed R_L. So the circuit is open. That means infinite resistance here and if you measure using a digital multimeter the voltage between the points A and B is the effective Thevenin's voltage appearing at the output. So if you want to measure it is very simple. Open the circuit. That is remove the R_L from the circuit and use a multimeter to measure the voltage across the output terminals A and B under open condition. That gives you the V_{TH}.

Let us look at analytically how we calculate the Thevenin's voltage.

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Since the circuit is open between A and B you can see there will not be any current through the resistance R_3 because the circuit here is infinite resistance. The entire current will be flowing only through R_1 and R_2 and therefore whatever voltage you want between A and B will be the same as the voltage across R_2, for example. The voltage across R_2 will therefore be the voltage Thevenin, V_{TH}. That is what shown is shown here on the screen. V_{TH} is equal to V_{R2}, the voltage across R_2. This we can easily calculate from this circuit because you can see you have a voltage source, you have two resistors and you want to find out what is the voltage that has to be developed across one of the resistors.

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It is a simple potential divider and therefore you know V_{TH} will have to be V_1 multiplied by R_2 divided by $R_1 + R_2$ which is nothing but a simple potential divider arrangement and you are trying to measure the proportional voltage across R_2, one of the resistors.

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So we can see this is the V_{TH} and this will be the effective equivalent voltage source that we should ultimately use after we simplify the circuit. We have now got V_{TH}. Next step is to obtain R_{TH}. How do we get R_{TH}? R_{TH} can also be easily measured by just measuring the resistance across the output terminal with R_L removed; that is the open circuit resistance. How do we do that? Before you measure the resistance, remove all source voltages and replace them with a short while retaining any internal source resistance.

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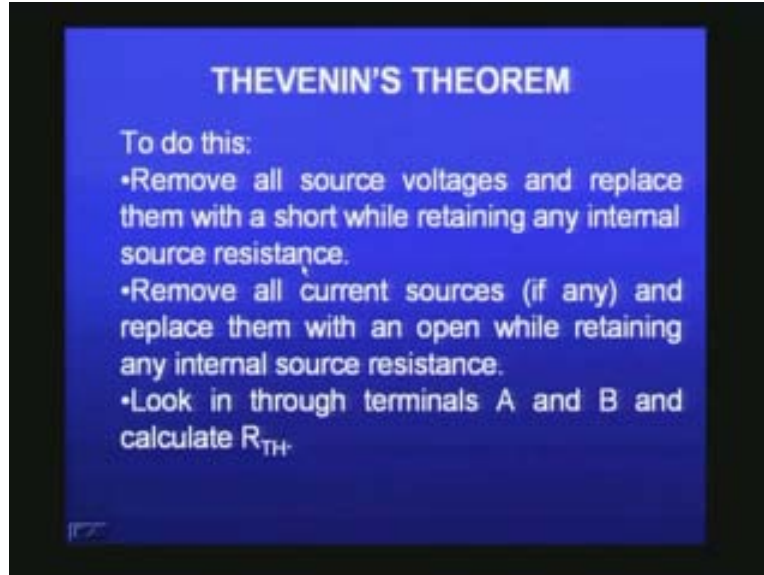
So if you have a voltage source, you just remove the voltage source from the circuit; connect a short in its place or because we assume the voltage source to be ideal if the voltage source you know has got an internal resistance then include only the resistance and remove the voltage source. Similarly if it contains current sources then you have to open the current source and if the current source has got internally very large resistance include the resistance in the circuit. So you will have only resistances in the circuit. You would remove all the sources, whether it is voltage source or current source. After removing all the sources look in through the terminals A and B, the output terminals, where the load was and measure the resistance. That resistance is equivalent to R_{TH}, the Thevenin's equivalent resistance. You can see in the circuit that is what I have done. I have removed the voltage source which was here previously and I replaced it with a short. So this point is connected to the ground because we assume that voltage source is an ideal voltage source; almost nil internal resistance and therefore you are left with only the three resistors R_1, R_2 and R_3 and R_L is removed here and you have A and B terminal which is an open circuit situation and therefore now if I measure using a multimeter, the resistance between the two terminals A and B, that resistance will be the equivalent Thevenin's resistance.

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We have seen how we can measure the Thevenin's voltage and the Thevenin's resistance. We can also calculate in this simple circuit which contains only three resistors R_1, R_2 and R_3 the equivalent resistance. I am sure every one of you knows about it. You can see R_{TH} is actually R_3 plus the parallel combination of R_1 and R_2. Let me go back and show you, you can see R_1, R_2 are now coming in parallel because these ends are the same for the two resistors; these ends are also the same R_1 R_2 are coming in parallel, R_3 is in series with this combinations of R_1 and R_2. The equivalent Thevenin's resistance can now be written R_{TH} is equal to R_3 plus R_1 multiplied by R_2 divided by R_1 plus R_2.

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This is the effective resistance of the parallel combination of R_1 and R_2, to add it along because it is in series with R_3 this effective resistance is added with R_3 to obtain the total effective Thevenin's resistance, R_{TH}. This can be also be measured by using a multimeter. We would see that later on. Let us take an example. On the same circuit I have just given some values to the various resistors. For example R_1 is 3.9 K; that is 3900 ohms. R_2 is 8.2 K ohms, R_3 is 4.7 K ohms and R_L is 3.3 ohms and V_1 the voltage source is 10V.

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I have just given some numbers for the resistors and the voltage. We will now try to solve numerically what will be V_{TH}, what will be R_{TH} and with the R_{TH} and V_{TH} position let us draw a simplified diagram and calculate what will be the output voltage across the load V_L. So that is what we are going to now do as an illustration. So you can see the circuit diagram now with all the values shown. R_1 is 3.9K, R_2 is 8.2K, R_3 is 4.7K and we want V_{TH}. Therefore you know what we have to do.

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We have to just bring voltmeter and connect between A and B and measure if you have got a voltmeter. Otherwise we can also do by actually working out, calculating the V_{TH} by the method that we already mentioned to you.
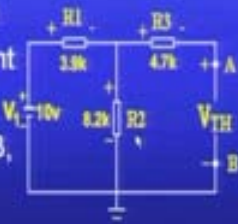
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If you want to calculate the V_{TH} at the output, you know R_3 will not contribute anything because this is in series with an infinite resistance here because you have now open circuit. R_L is not there and therefore the voltage across R_2 is the Thevenin's voltage with V_1 connected to R_1 and R_2 in series and therefore all that you have to calculate the V_{TH} which is equivalent to the voltage across R_2.

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Let us do that. V_{TH} therefore will be equal to V_1 the applied voltage which is here 10V multiplied by R_2 divided by $R_1 + R2$ because $R_1 R_2$ form a potential divider and so V_{TH} is equal to 10V because V_1 is 10V and R_2 is 8.2 K. Therefore 8200 divided by 3900 which is the value of R_1 plus 8200 which is R_2 and if you simplify this we get V_{TH} to be 6.78 V.

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You can verify it with a calculator. So V_{TH} we have calculated to be 6.78 for this circuit which contains a very simple scheme of three resistors and a voltage source. Now that we have got the V_{TH} we should now measure or calculate R_{TH} which is the open circuit resistance across the load.
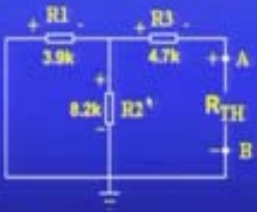
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For this, what we have to do? I have already explained to you. Replace the voltage sources with the short, current sources with open and include any internal resistance that may be present along with the voltage source. We generally assume the voltage sources to be ideal for this case and therefore just remove the voltage source, connect a short and there you have a very simple scheme of only resistors and we will now calculate the effective resistance, R_{TH} between the two terminals A and B at the output. That is exactly what we have done here. You can see on this picture, R_1 is3.9 K, R_3 is 4.7 K and R_2 is 8.2 K. We have replaced the voltage V_1 by a short.

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We want to measure what is this? You can measure by using a multimeter in ohms range that will directly give you the Thevenin's resistance. The other way to do is to calculate

from this circuit. This circuit is a very simple circuit. Again you can see R_1, R_2 are coming in parallel and the combination is coming in series with R_3. Therefore Thevenin's equivalent resistance can be very easily calculated. It is shown on the screen. R_{TH} is equal to R_3 plus R_1 into R_2 divided by R_1 plus R_2; we have already seen that.

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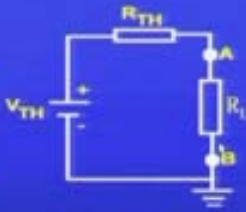

In this case R_3 is 4700 ohms, 4.7K plus R_1, R_2 combination is 8200 multiplied by 3900 divided by 8200+3900 and the effective resistance when you do simplification is around 7.3K. So this is the R_{TH}. So we have calculated V_{TH}. We have also calculated R_{TH} once we do that we can simplify the original circuit by just having the V_{TH} here as you can see and you have the R_{TH} which you have now calculated for this example and just you have connect the R_L which is the alternate load resistance we want to apply.
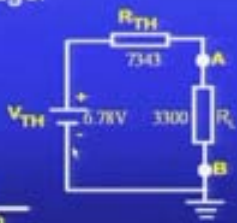
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You can see all the complicated circuit has been removed and replaced with a very simple scheme of one source and one internal resistance of the source which can be equivalently ..... (19:12). Now we have to calculate the voltage across the load; that is what the problem started with. So you can again see because you have only two resistors now R_{TH} and R_L with one single voltage source the problem becomes very simple.

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We have to just look at the voltage across the R_L. V_L is therefore V_{TH} multiplied by the potential divider arrangement R_L divided by R_{TH} plus R_L. With the values substituted V_{TH} we calculated to be 6.78 multiplied by 3300 which is the load resistance 3.3K divided by the Thevenin's resistance 7.3K plus 3.3K of the load resistance and when you simplify this you get the value of about 2.1V.

You can see we have simply replaced very complicated circuit with a Thevenin's equivalent circuit and that becomes very simple to solve. Let us try to simulate this whole measurement. I am going to show you on the screen a simple simulation of the experiment. You can see a breadboard coming over here and the same circuit is put there. There is one 3.9K; there is another 4.7K which is R_3 and the R_2 is 8.2K and your load resistance is 3.3K. That is connected to a voltage source on this side and the output is connected to a multimeter on this side and the circuit also for reference is shown here at the bottom corner.

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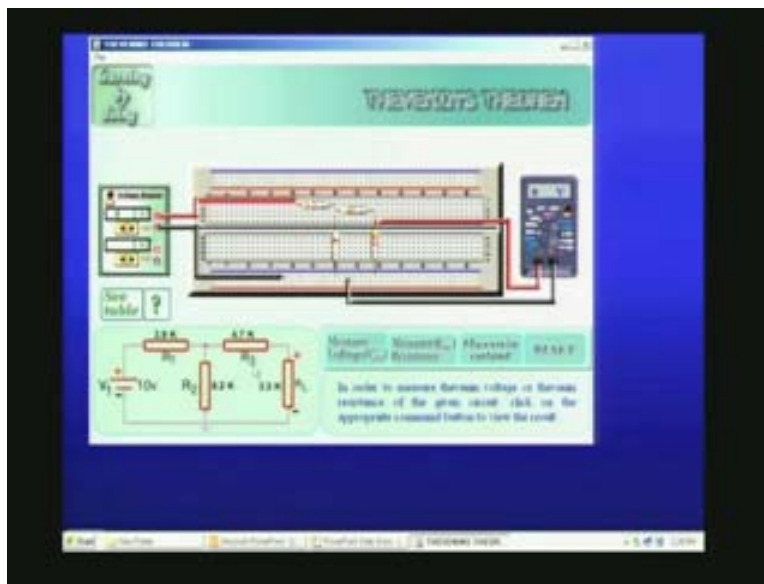
Now you have to measure the Thevenin's. We will do both. We will measure and we will also calculate. Let us measure Thevenin's voltage. Once I click you know what we have to do. We have to open circuit. That means we have to remove the R_L. So I go there and click on the R_L, R_L is gone. Now I will have to measure the voltage using the voltmeter. Before that I should switch on the power supply. So I switch on the power supply; switch on the multimeter. Now start applying voltage by using this increase button. I will apply 10V because that is what we started with. I apply now 10V for this circuit and measure the voltage across the load terminal after removing the load and you can see the voltage on the multimeter is 6.78 which is what we calculated in the previous slides. So the Thevenin's equivalent resistance is very simple. Just remove the load, connect a voltmeter; switch on the power supply and measure you find it is 6.78. If you want to see how it comes you can go and look at here; you can see the whole thing. If I apply 5V, the Thevenin's equivalent voltage will be 3.39. When you apply 10V the Thevenin's equivalent is 6.78.

Now you will switch off the voltage sources. We will go ahead to measure the Thevenin's resistance, R_{TH}. We will have to calculate R_{TH}. We know the rule. The rule is replace the power supply with a short. So when I click here you find this point is connected to the ground by using a shorting wire and the power supply is disconnected.

Now I have only the three resistors. The R_L is removed; under the open circuit condition I will measure the resistance here.

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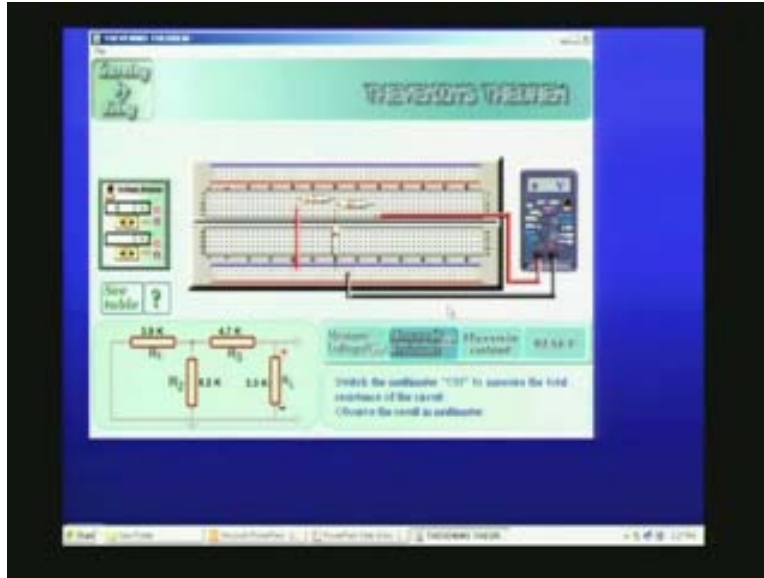
I will switch on only the resistance. I will switch on the multimeter. Immediately you can see it comes into resistance mode and it measures about 7.343ohms. So this is the Thevenin's equivalent resistance and the calculation is shown here. R_{TH} is nothing but R_3 and R_1R_2 in parallel combination. So now we have measured both the Thevenin's resistance and Thevenin's voltage. Now we have to measure the Thevenin's output across the load. The circuit now is simplified. You can see the voltage is connected here and there is only this 7.343 that is the Thevenin's resistance; this is the Thevenin's voltage source. Now we will have to set it for 6.78V. This is the load resistance 3.3K. Now we will switch on the power supply source and then you will increment. Immediately voltage comes out to be 6.78 which is the Thevenin's voltage we have set; we have measured and therefore I set this for 6.78 and I just measure the output voltage across the load to be 2.1V which is what we calculated in the previous example. You can see that the output voltage is also shown in the table. You can see that is about 2.1V.

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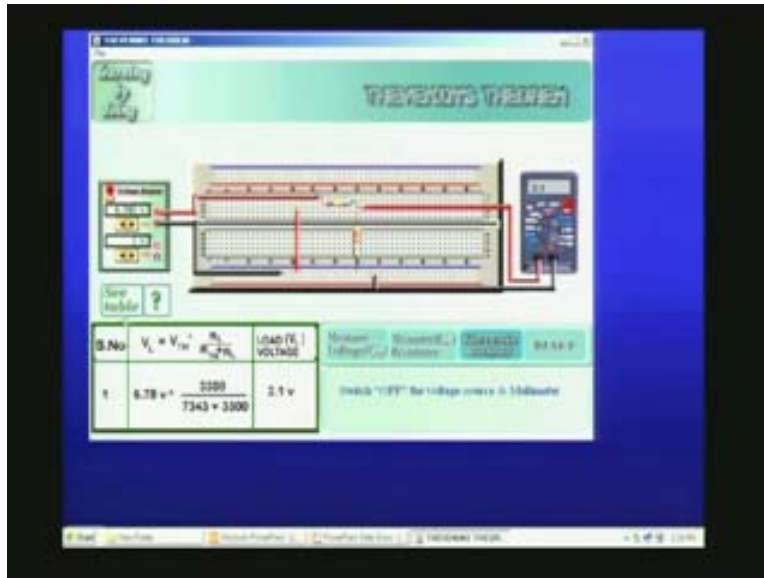
Now we will switch off the power supply and multimeter. We are ready to go and try the actual experiments. We will perform the experiment and then do the same measurement. Here I have the power supply. Red and black lines are connected to this circuit. For simplicity I have shown the circuit here. You have same circuit which we just now did. This is the voltage supply V_1. We will set up 10V here and the three resistors R_1 3.9K, R_2 8.2K and R_3 4.7K. The same resistors are shown here. This is R_1; this is R_2; this is R_3 and this is the load resistance which is 3.3K and this is the load resistance.

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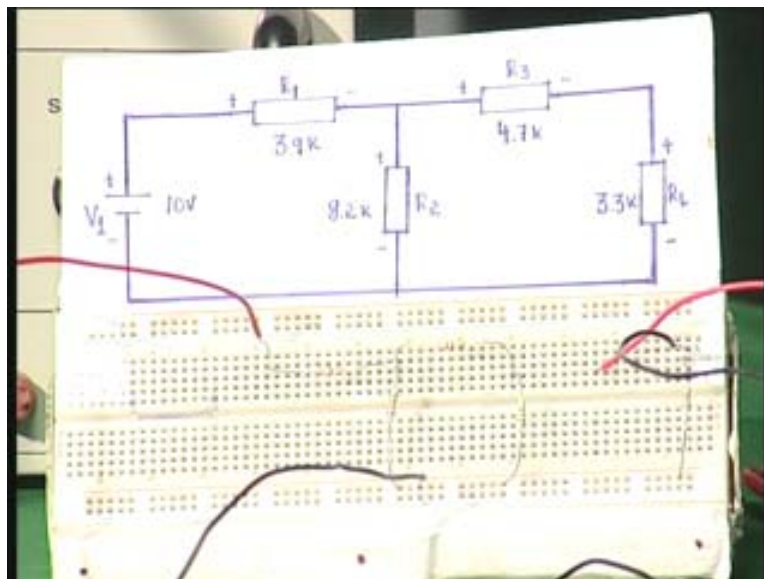
The red wire is connected to this end that is this point and the black is connected to the ground line, common line at the bottom and therefore the input is connected from the voltage source. I have to set this for 10V and I should remove this and measure the

voltage across this point using this multimeter in voltage range. Then I will be able to measure the Thevenin's equivalent voltage. Let us do that. For that I remove the load resistance. Therefore under open circuit condition I have the multimeter; I will connect the one end to the ground. I will take the other end and connect it to the point where R_3 is coming. This is the multimeter. I will switch on the multimeter to voltage range. I have connected to voltage range; put it in volts and connect it to DC. Now it is reading zero because I have not switched on the power supply. I am going to switch on the power supply and it is set for about 10V. So this is around 10V as you can see on the screen and 10V is applied with the three resistors. I have removed the load resistance and measuring the output voltage. Output voltage is around 6.89 or so. We actually calculated the value of 6.78. We see here it is around 6.9.

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The difference is because these resistors are not the exact values as mentioned here. They have some 5% or 10% tolerance and therefore the actual resistance value will be slightly different from the value that I have specified here and therefore you will get the actual voltage corresponding to this combination. But you can see it is very close to what we actually discussed and this is the Thevenin's voltage because I removed the load and measuring the voltage output using the multimeter. So this is the Thevenin's voltage V_{TH} that we have measured.

The next point is to measure the Thevenin's resistance. For that what we have to do? I will first switch off and I should remove the voltage source and connect it by short. I will take as small short wire. I will remove this red wire. I will connect that point where the voltage source is connected with a short. This is the shorting wire which has come in place of the voltage source and I have to now measure, after removing the load which I have already done, the resistance. I should now change the multimeter to resistance range and see how much is the resistance? I will move it resistance range; I will press here. Now I have done that. So three resistors are there and I am measuring the resistance using

this multimeter and I hope you can see the reading here is about 7.19K ohms or 7.2K ohms.

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We calculated something close to 7.3K ohms. We are getting here as 7.2 K ohms. That is why there was a difference also in the output voltage.

We have actually calculated the Thevenin's voltage; we have also calculated the Thevenin's resistance. Now I have to connect the load resistance and measure how much is the thing. So I will again remove this short. I will connect the load resistance 3.3K once again which I removed previously. Now I will connect the power supply back. I have connected the load resistance 3.3K. In the same circuit I have connected this power supply also back after removing the short. Now I switch on and measure the load resistance. I want to just measure the load resistance. I want to push it into voltage. I have connected voltmeter back to DC voltage and I have switched on. This is again around 10V and the output voltage across the load R_L, V_L is around 2.13V as you can see and therefore the load voltage is now 1.3V under the condition of all the resistors in place.

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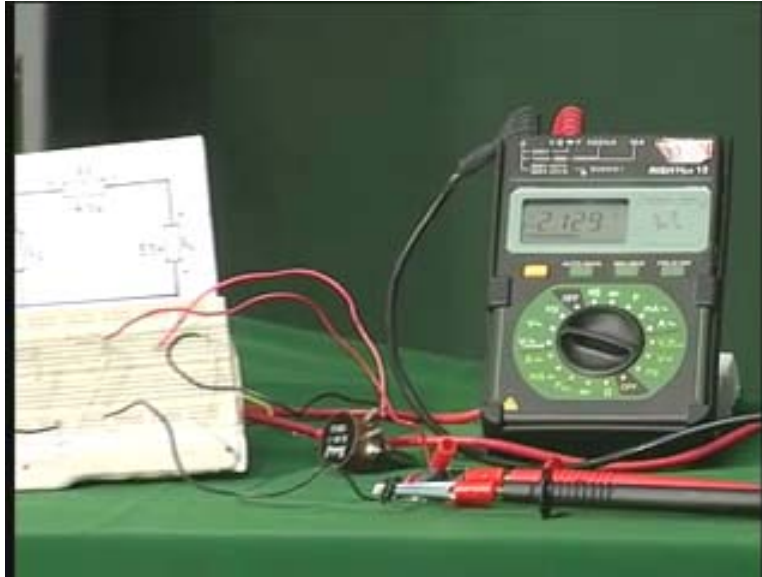
We have calculated V_{TH}; we have calculated the R_{TH}. Therefore now I am going to introduce the V_{TH}, R_{TH} only and put the load resistance and measure the output voltage. If again I get 2.1 then we have solved the circuit. So let us now try to do that. What I am going to do now is take this power supply out and set here 6.2V. I have set it up. I have here a resistor which is a potentiometer, a variable resistor. Let us first measure the resistance of that potentiometer. I will take the multimeter in resistance mode and calculate the resistance. Now it is around 7.8. I can adjust it to some smaller value. So it is around 7.5K. We calculated the Thevenin's resistance to be 7.3 or so. Let us make it to 7.3 by moving the potentiometer knob. So it is around 7.3K; right. We have now set Thevenin's resistance by using a potentiometer. We have set the voltage source to give an output voltage which is equivalent to Thevenin's voltage. Now I will connect this across the simplified circuit and now I will measure the output voltage using the voltmeter. I have connected the voltmeter across the load 3.3K. This is the Thevenin's resistance; this is the Thevenin's voltage source. I have discarded the original earlier circuit and I have got only two resistors; one is the potentiometer which I have set equivalent to Thevenin's resistance near about and this is the load resistance which is again 3.3K and voltage source which is 6.2.

Now we will have to measure the voltage. You can see the voltage is around 2V. We calculated it to be 2.1V in the actual situation and therefore it comes very close to that and I already explained to you that the difference is because these resistors that we have used are not exactly equivalent to whatever the color code says. There is a tolerance variation. Therefore you can see the Thevenin's equivalent circuit also gives about 2V; this circuit also gave 2V when I applied 10V here and then measure the voltage across the load and therefore you can see the whole circuit can be replaced by an equivalent Thevenin's resistance and Thevenin's source and we will be able to simplify the whole circuit in an easy way.

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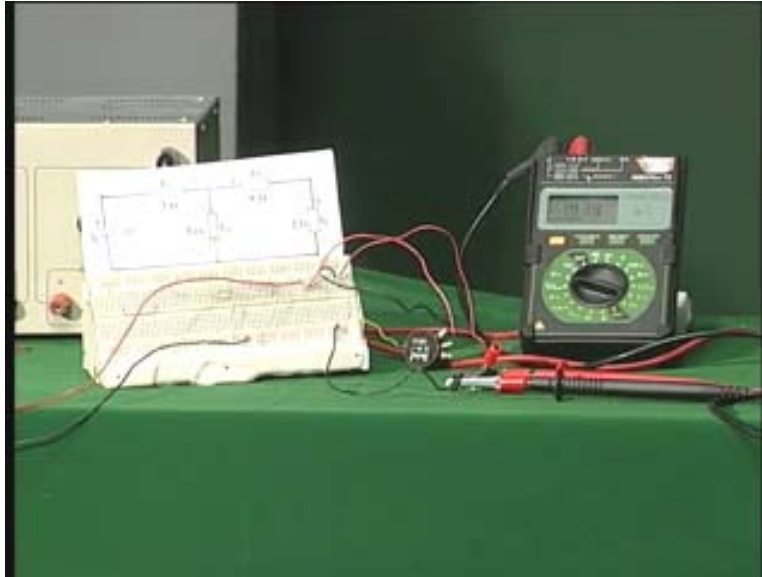
We have seen a very simple scheme in which I have used only one voltage source and three resistors. We can also take examples which involve more than one voltage source and several resistors. So I have now considered the second example which is more complicate as you can see here. It has got two sources.

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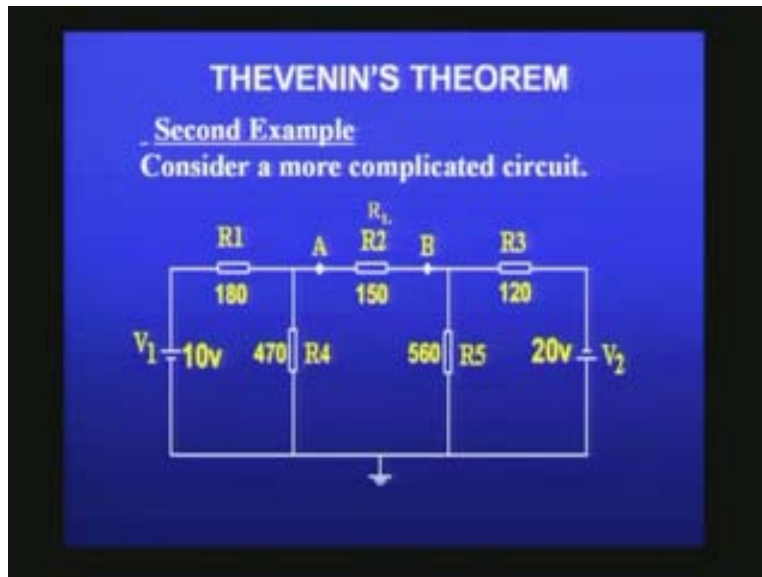
There is V_1 here 10V and V_2 here 20V and you can see the polarity is also changed here and you have number of resistances R_1, R_2, R_3, R_4 and R_5 and this R_2 is actually R_L I assume. Therefore what we want do to now is find out the voltage across R_2, A and B. R_2 is our R_L; I have shown here. We want know the voltage across this. That means I have to replace the entire block around this R_2 by simply using two devices. One is V_{TH}, the Thevenin's voltage and R_{TH}, the Thevenin's equivalent resistance. That is what we

should do. How do we go about it? There are number of ways to do that. You find with reference to R_2 there is some circuit on the right side with one voltage source and two resistors and on this side there is another voltage source and two resistors. If you look at this side you can see it is similar to what we saw in the previous example and there are two parts of the circuit; the left part and the right part. So we can try to see whether we can solve the Thevenin's equivalent circuit for the right side of the circuit and for the left side of the circuit and then combine them together and then find the total equivalent Thevenin's circuit. That is how we will do that.

What we have to do is we have to remove the load. I have removed the load here; open circuit condition and I should measure using a multimeter in the voltage range the voltage between terminals A and B. That will give me the Thevenin's equivalent voltage. By measurement it is very simple. Just remove the load; measure the voltage across the terminals of the load using a multimeter. That is all. That is the Thevenin's equivalent voltage and similarly measurement of Thevenin's resistance also is very simple. Remove the voltage source by a short, this voltage source also by a short and measure the resistance between A and B using a multimeter in resistance range. As simple as that.

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We will go ahead and then try to see how we can measure? I have already mentioned to you that we will consider this in two parts, left part and the right part. Let us look at for example V_{TH1} corresponding to the left part, V_{TH2} corresponding to the right part. Consider together separately and then combine the two together. Now you have here the left part alone, left half of the circuit and so now you can immediately see V_{TH} can be obtained because there are only two resistors; they are forming a potential divider. Therefore I can calculate the V_{TH} corresponding to this simple circuit on the left side. V_{TH1} is equal to V_1 which is 10V in this case multiplied by R_4 divided by R_1+R_4 because R_1, R_4 forms the potential divider arrangement. When I put the value of resistor 470 ohms, 180 ohms and 470 ohms I get a Thevenin's equivalent voltage of 7.23V.

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So this is the Thevenin's equivalent voltage for the left side. Now we have to find out what is the Thevenin's equivalent resistance R_{TH1} for the left side. For that we remove the voltage source; replace it with a short and measure the resistance. You can see in the circuit shown I have removed the voltage source and connected with a simple wire and I just have only two resistors and these two resistors are coming in parallel and therefore R_{TH} is nothing but a parallel combination of R_1 and R_4.

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So R_{TH} is equal to R_1 multiplied by R_4 divided by $R_1 + R_4$ and by substituting the values 180 ohms and 470 ohms and simplifying you can see R_{TH} is about 130 ohms.

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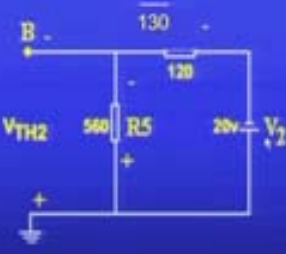
Therefore we have solved the left side of the circuit. R_{TH} is about 130 ohms and Thevenin's voltage is 7.23V. That is what we measured.

Let us move on to the right side. In the right you have R_3, R_5 and the 20V power supply.

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We have to calculate the equivalent V_{TH} and R_{TH} in this side. You can see that V_{TH} is again very simple because there are only two resistances R_3 and R_5 coming in the circuit and so V_{TH2} is V_2 into R_5 divided by R_3+R_5.

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This is -20V because the polarity is reversed compared to the other one; multiplied by 560 divided by 120+560. That is the potential divider arrangement we have and the value is around -16.5V. That is the Thevenin's voltage. To measure the Thevenin's resistance, again you go by the same rule. You replace the voltage source with a short and then calculate the resistance across the terminal where you connect the load. You can see in the circuit here I replaced voltage source with a short and I have to measure the resistance between these two terminals and this is nothing but the parallel combination of R_3 and R_5.

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R_3 is 120 ohms, R_5 is 560 ohms. So R_{TH2} for the right side is R_3 multiplied by R_5 divided by R_3+R_5.

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With the values of resistors substituted it comes to around 99 ohms. We have solved for the right side of the circuit the equivalent Thevenin's voltage and Thevenin's resistance. Now what we have to do to is we have to combine the two. Left side and the right side we should combine them together. So that is what we are doing here. Here you can see this is R_{TH1} and V_{TH1} and this side R_{TH2} and V_{TH2}. I combine them and that will be the equivalent Thevenin's circuit.

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V_{TH} is $V_{TH1}+V_{TH2}$; algebraically you should add. This is 7.23; this is -16.47 in this case. But they are actually aiding each other. It is like a series connection and therefore the total resistance will be 23.7 V. Similarly resistance I should connect them together; 130 ohms and 99 that correspond to 229 ohms.

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Therefore I can replace the entire circuit combination of both the right side and the left side with a very simple R_{TH} and V_{TH} resistors and this case R_{TH} and V_{TH} are 23.7V and 229 ohms. Finally to obtain the voltage across the load R_L, we will put all the things together; V_{TH}, R_{TH} and measure the voltage across AB.

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V_L the load voltage is equal to V_{TH} which is 23.7V multiplied by the potential divider R_L divided by $R_{TH}+R_L$ and when you do the simplification, it is around 9.38V. We can actually put the circuit on a breadboard and measure once again as we have done in the previous case. We have taken two examples; one a very simple example, another one slightly more complicated with two sources and multiple resistors and we have seen how the equivalent Thevenin's circuit can be obtained for this complicated circuit. This is the final circuit with the V_{TH} and R_{TH} shown.

We will move on to the next theorem which is Norton's theorem which is a dual of Thevenin's theorem. Only difference is you make all the complicated circuits of the network that you have got by replacing it with a current source instead of a voltage. In the case of Thevenin you replaced it with the voltage source. In the case of Norton's you replace it with an equivalent current source and there will also be equivalent Norton's resistance just as you have a Thevenin's resistance. I have shown on the screen any circuit with several DC sources and linear resistances. It can be simplified with a single current source I_N corresponding to Norton's current source and a resistance R_N which in this case is connected in parallel. Therefore we look at it as conductance G_N if you want to consider.

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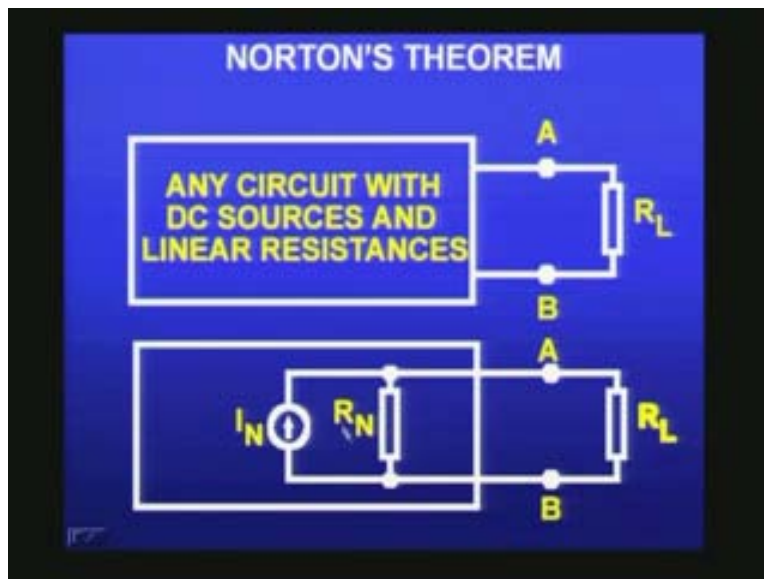
R_N is the resistance value of this parallel resistance and this R_L is anyway there. The problem now is how to get I_N and R_N by measurement and by calculation. I take a very similar example as we did in the previous case with three resistors R_1, R_2, R_3 and one current source IS_1 to start with.

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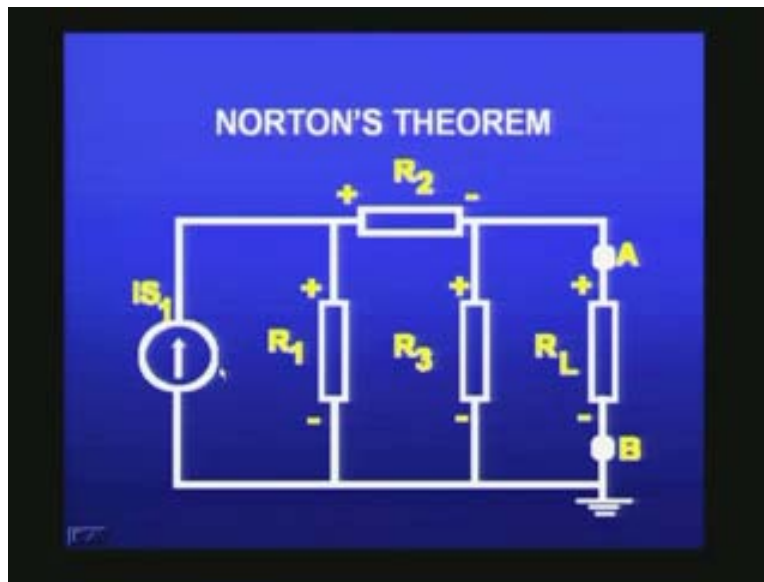
You have R_L here connected between the terminals A and B. How do we apply Norton's theorem and obtain the equivalent Norton's circuit.

What do we do? In this case if you want to measure the equivalent Norton's current source all that you have to do is remove the load resistance and connect it with a short and measure the short circuit current. Therefore what we have to do is remove R_L and connect a current meter in its place. The current meter will measure the current flowing through that terminal now. Because there is no resistance it is called a short circuit. Current meters are assumed to have zero resistance and therefore what you measure is the short circuit current across the load terminal and that gives you the Norton's current. In
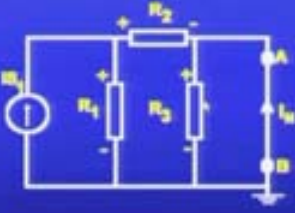
the other case, in the Thevenin's case you will measure the open circuit voltage across the load terminal after removing the R_L. Here you remove R_L, connect it by a short and measure the current flowing through that short and that is the Norton's equivalent current source. If you want to measure the resistance all that you have to do is open circuit R_L. Remove R_L and measure the resistance across the terminals. That means R_N is equal to Thevenin's resistance, R_{TH}. Both are equal. R_{TH} and R_N are equivalent because method of measurement is also the same.

In this circuit I have short circuited the load. I have removed the load and connect it with a short wire. We have to find out the current here. Because I have shorted here this R_3 is parallel to R_L. Because I have got a short here R_3 will have no current at all.
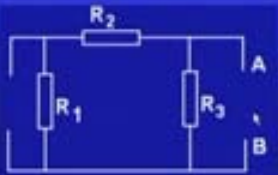
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All the current will go through the zero resistance path rather than the R_3 and therefore R_3 is not to be considered at all. Because R_3 is not effectively in the circuit you find IS_1, the Norton's current source is actually dividing here into two current components; one here and one here. The parallel resistors divide current and that is what we see here. I have written the equation here and so you can calculate the short circuit I_N which is actually the Norton's current source is obtained from the IS_1, the source multiplied by R_1 divided by R_1+R_2. This is the equivalent Norton's current. If this is called I_N, this current will be IS_1- I_N. Whatever is the difference that will be flowing here multiplied by R_1 the voltage across this should be equal to the voltage across R_2 and R_2 is I_N multiplied by R_2, that is the voltage across R_2. From this simplification you get I_N is equal to IS_1 into R_1 divided by R_1+R_2 by using the current divider theorem if you wish to remember that. Parallel resistors divide current. So we have now got Norton's equivalent current and we must measure Norton's equivalent resistance or conductance. For that what we do? We open circuit all current sources and short all voltage sources. We do not have any voltage sources in the circuit and measure the resistance across the terminal R_L after R_L is removed, A B.

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This is equivalent to the earlier Thevenin's consideration. That is what we have done now. We can see R_1 R_2 are coming in series and it is parallel with R_3.

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The equivalent resistance therefore will be R_3 multiplied by R_1 R_2. They are coming in series therefore together I should take them, divided by $R_1+R_2+R_3$. This is the equivalent Norton's resistance. We have determined Norton's resistance, Norton's current source and therefore we can put the R_L and complete the whole circuit. We can calculate the load current when R_L is also in place.

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That can again be obtained by the current division. I_L is actually coming from I_N through resistances. Two resistances is coming in parallel R_N and R_L and therefore I_L is I_N into R_N divided by R_N+R_L by the current division theorem or I_L is I_N into G_L by G_N+G_L which is using the conductance, the reciprocal of the resistances.

We will take an example which will perhaps illustrate this very simply.

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I have taken R_1 to be 270 ohms, R_2 is 220 ohms, R_3 is 100 ohms and IS_1 is 10 milliamperes. I_N we know is IS_1 into R_1 by R_1+R_2. If you substitute the values 10

milliamperes multiplied by 270 divided by 270 ohms + 220 ohms gives me an I_N of 5.5 milliamperes. This will be the short circuit current across the terminals of the circuit where RL was originally. We have to find out R_N.

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For finding R_N, you know R_3 and R_1+R_2 together in series are coming in parallel. Therefore R_3 multiplied R_1 plus R_2 divided by R_1 plus R_2 plus R_3 and if you substitute the values of resistances we have taken in example you get an equivalent resistance of about 83 ohms. I have now got the equivalent Norton's circuit. The Norton's equivalent current is 5.5 milliamperes, we have calculated.

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The Norton's resistance is 83.4 ohms that is connected in parallel to the current source and R_L is also connected in parallel to the entire circuit. RL is 100 ohms. We have to calculate the load current, load voltage, etc.

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NORTON'S THEOREM

Now using the values of I_N and R_N we have to find the load current. The formula is

$$I_L = I_N * \frac{R_N}{R_N + R_L}$$

$$I_L = 5.5mA * \frac{83.4\,\Omega}{83.4\,\Omega + 100\,\Omega}$$

$$I_L = 2.50\ mA$$

Thus the load current value is obtained using Norton's theorem.

Again by using the current division I_L is equal to I_N into R_N by R_N+R_L. We know all the values 5.5 milliamperes is Norton's current multiplied by 83.4 which is the Norton's equivalent resistance divided by 83.4 plus R_L which is 100 ohms here and the current is 2.5mA. Thus the load current value is obtained using Norton's theorem. This is the actual final circuit where I have shown the value of the Norton's current source 5.5mA, Norton's equivalent resistance it is 83.4 ohms and the load resistance R_L and I_L flowing through the load is 2.5mA. Out of 5, 2.5mA flows through that; rest of the 3mA will flow through that. So if 2.5mA is flowing through the load resistance R_L you can also calculate the voltage across the load which is nothing but the product of these two and the product is about 2.5 into 100 which is 2500mV. Because it is milliamperes it is equivalent to 0.25V.

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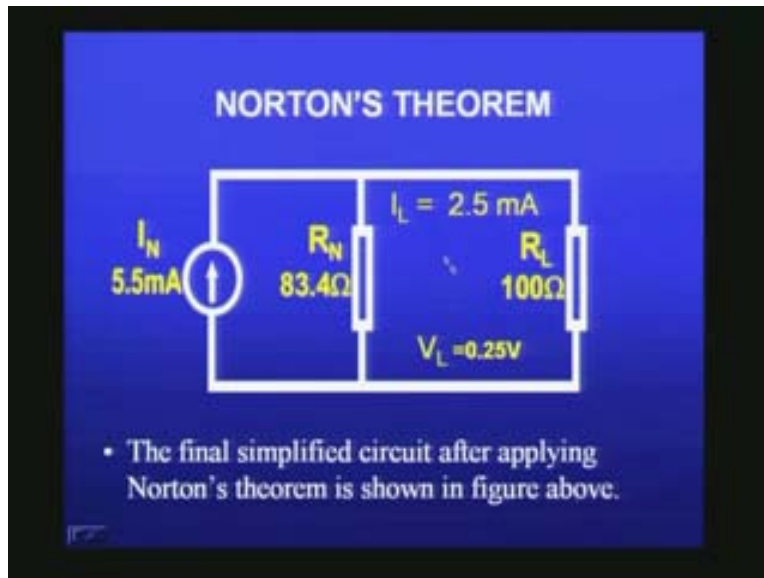
So you can calculate the voltage across the load, the current through the load and all information regarding the circuit. It is very easy by using Norton's theorem.

Let me quickly go through the simulation for this. Here I have the same circuit. You have different resistances. 270 ohms; here you have 220 ohms; here you have 100 ohms R_3; this is your R_L 100 ohms. You have a multimeter, you have a current source here and the circuit is also shown here.

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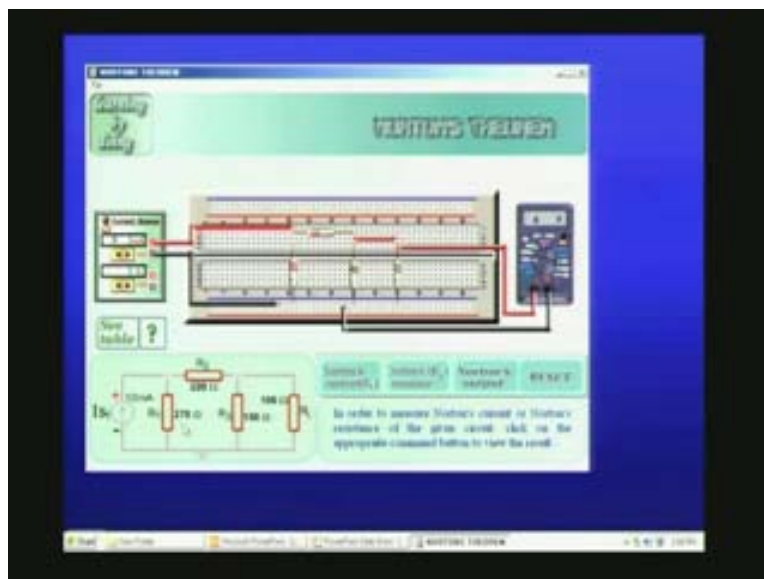
We have to measure the Norton's current which is the short circuit current and the Norton's resistance. We will do that in the simulation. To measure Norton's current we have to short the load. Therefore we remove the load. Click here, the load is removed

and in its place I have got the multimeter in the milliampere range, in the current range and I have the current source here. Let us switch on the current source and the multimeter.
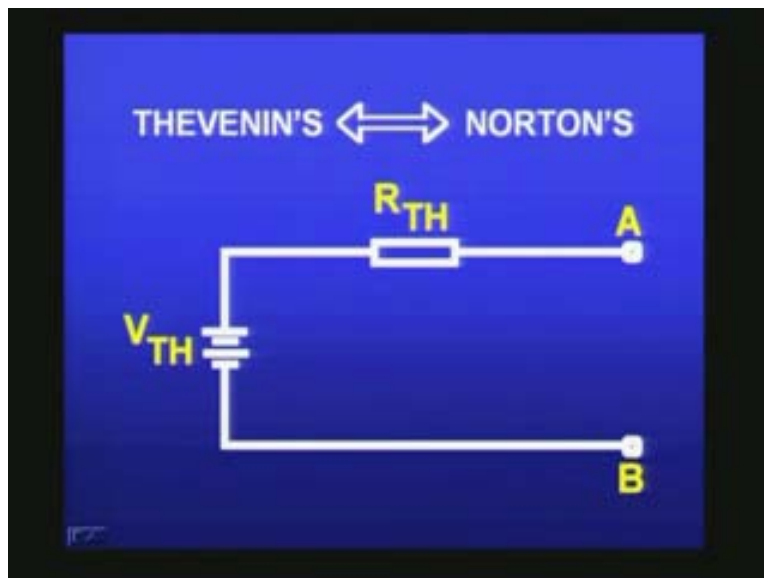
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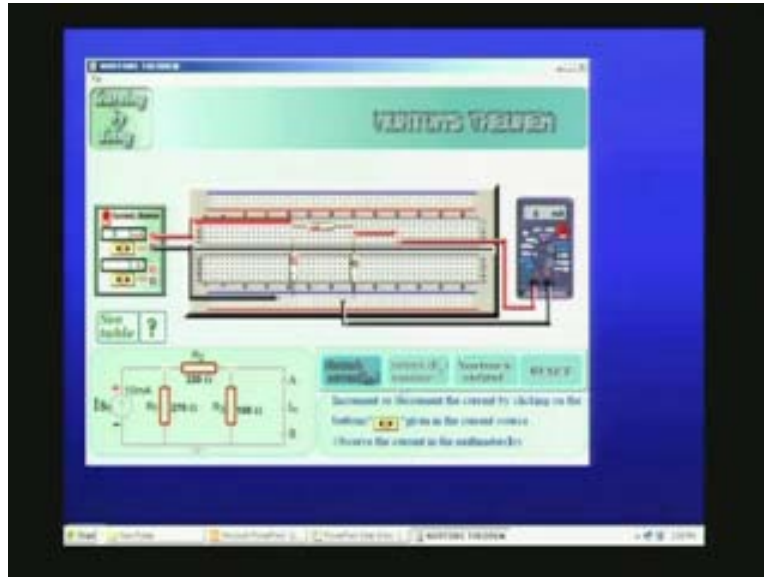
Increase the current to 10mA because that is the current value IS_1. Now I have 10mA current and you can see the short circuit current is 5.51 as measured by multimeter. If you want to look at the calculation it is shown here. I_N is IS_1 into R_1 by $R_1 + R_2$ which is 5.51, which we already calculated. We have obtained the Norton's equivalent current source. Now we have to obtain the Norton's equivalent resistance. For that if I have current source I should open circuit. Therefore when I click here the connection to the current source is removed. That means it is open circuit here and I just have the three resistors and I should make use of the multimeter in resistance mode and measure the resistance. Let me switch on the multimeter it comes in ohms range and it is measuring 83.4 ohms. So this is the Norton's equivalent resistance. If you want to look at the value you can see. R_3 coming in parallel to R_1 and R_2 and therefore the equivalent resistance is 83.4 ohms. We have calculated the Norton's current; we have calculated the Norton's equivalent resistance. Then we have to get the complete circuit with the load connected. This is the Norton's equivalent resistance 83.4. I will set here the Norton's current and I will measure the current through the load resistance. You can see the circuit here. Now I will switch the current source, I will switch the multimeter and you would find if I connect here I get 5.51milliampere as a source and the series current measured by this is 2.5mA which is the value we obtained previously. The calculation can be seen in the screen 5.51 multiplied by 83.4 divided by 83.4+100 ohms gives me 2.5mA. That is what we got. So by simulation we were able to do the Norton's equivalent circuit. This is the final circuit that we have got here.

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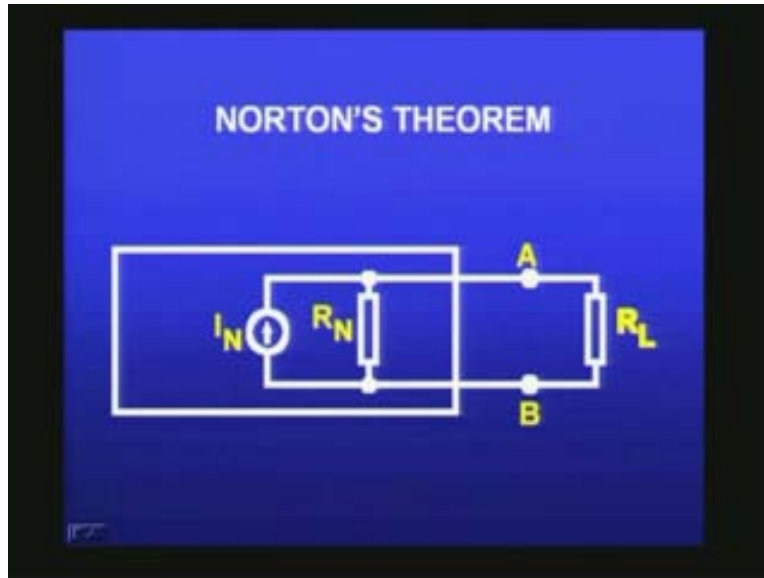
The entire block is removed and replaced by one Norton's source and one Norton's resistance and they are connected in parallel to R_L, the load resistance. We have already mentioned that the Thevenin's and Norton's are the dual of each other.

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In Thevenin's we have got the voltage source, V_{TH} and a series resistance R_{TH}. In Norton's you have got a current source I_N and a resistance R_N in parallel.

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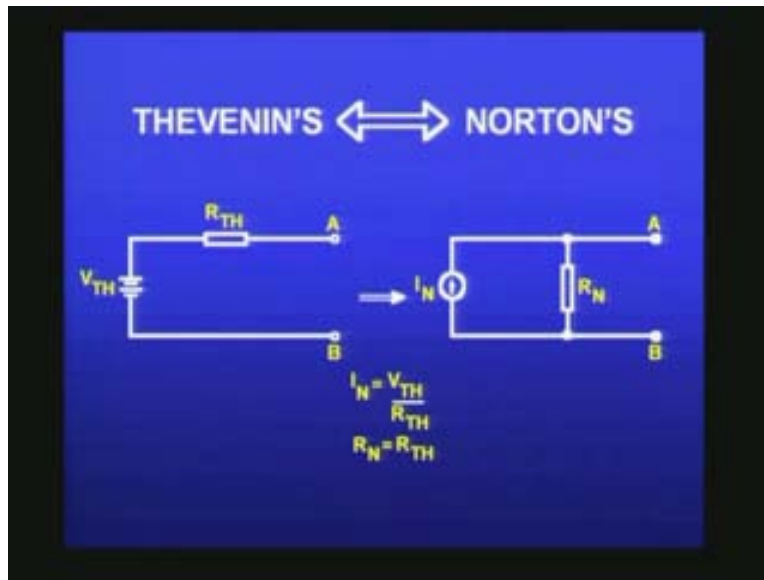
Now you can see how to convert from Thevenin's to Norton's and from Norton's to Thevenin's. Then you can see the relation between the Thevenin's and Norton's values. I_N is nothing but V_{TH} by R_{TH} and R_N is equal to R_{TH}. That I already mentioned to you. So the two circuits are equivalent. Similarly if I want V_{TH} if I know I_N and R_N I should multiply I_N by R_N. That will give me V_{TH} and R_{TH} is anyway equal to R_N. Therefore you can see the circuits are all equivalent.

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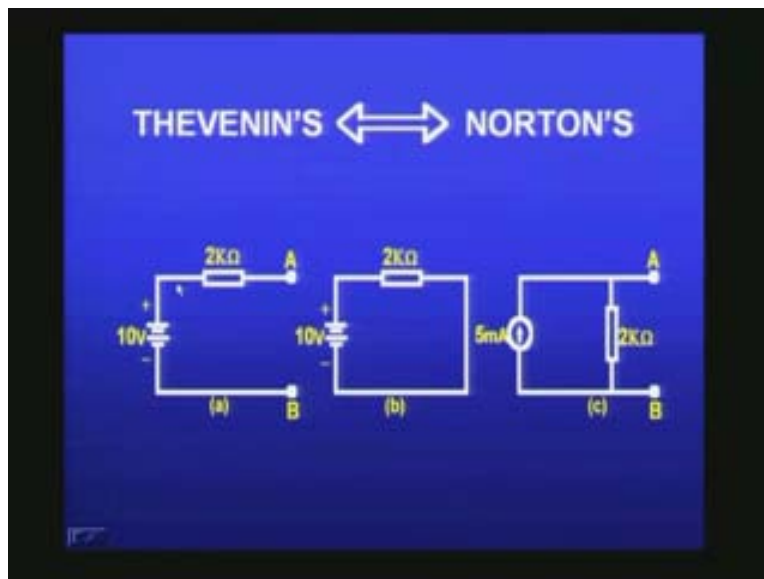
In our case for example if I have 10V and 2K then if I want the corresponding Norton's current I should short circuit and measure; 10V by 2K which is around 5mA.

So 5mA is the Norton's current and 2K is the Thevenin's resistance. That is what I have shown here. So Norton's and Thevenin's can be easily converted from one to the other and therefore both the theorems are very useful in solving different problems in networks.

We will conclude this lecture at this stage and we have seen two important theorems in this lecture. One is the Thevenin's theorem and the other one is Norton's theorem. In the next lecture we will look at one of the important passive devices namely semiconductor diode and it s different types and how it will be very useful in many applications in electronics. Thank you very much.