Introduction to Electronic Circuits.
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Lecture-4.
Network Theorems (Thevenin's and Norton's).

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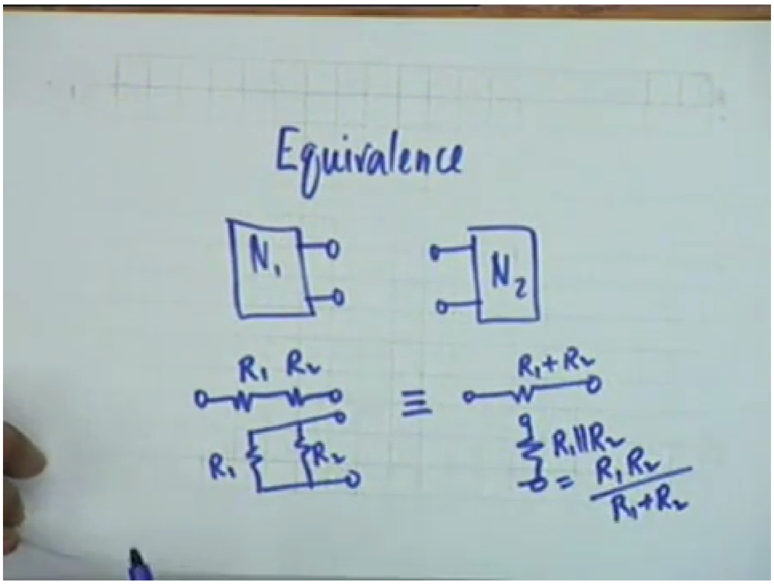

Professor: This is 4th lecture and the topic is network theorems. In particular today we propose to talk about Thevenin's and Norton's. We started in a very simple manner in the last lecture stating the Thevenin's theorem, we want to go today in a more comprehensive manner. Both of these theorems Thevenin's and Norton's have something to do with equivalence of networks. That is 2 networks N1 and N2, 2 networks N1 and N2 are said to be equivalent if their terminal behaviours as the same. Networks as you know terminal behaviour of a network is characterised by its voltage current relationship.

If the voltage the relationships of 2 networks N1 and N2 at the terminals are the same, then the networks are said to be equivalent. In particular Thevenin's and Norton's theorems have to do with one port equivalence. Equivalence one port networks, that is one port means the network contains only 2 terminals. Very simple one port can be thought of, can be thought of like this. Let us say 2 resistance is R1 and R2 in series, then you know that this one port is equal into a single resistance of value R1 + R2, agreed. On the other hand if I have one port in which 2 resistances are in parallel, then you know that a single resistance is equivalent to this, whose value is R1 parallel R2 is given by R1 R2 divided by R1 + R2, these are examples of very simple equivalences.

To take this further, we know that if 2 inductors are in series, then a single inductor whose value is equal to the sum of the 2 inductors is an equivalent network. If 2 capacitors are in series, C1 and C2, then the equivalent network consists of a single capacitor of value, C1 C2 over C1 plus C2, capacitors add when they are connected in parallel, all right. Now Thevenin's and Norton's theorems go beyond this.

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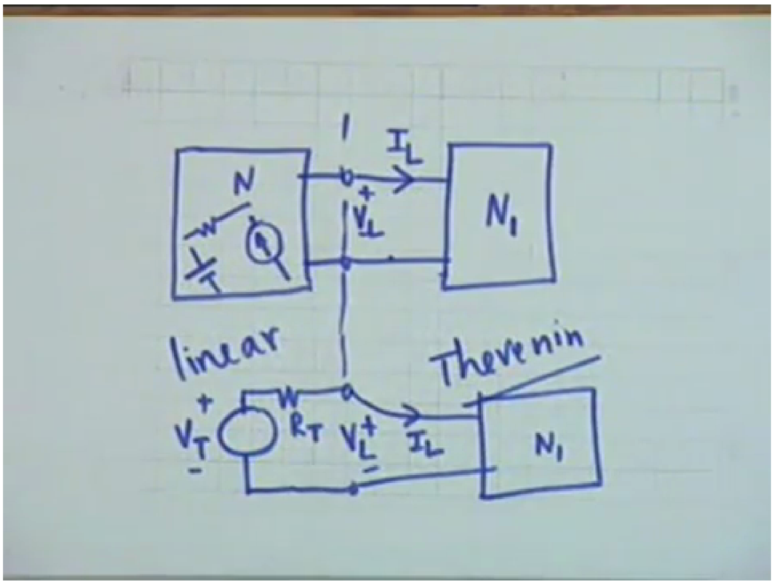

They say let us consider a network N which not only contains resistors, we are considering basically resistive networks, linear resistive networks along with DC sources. This is our consideration at the present moment, we are not admitting inductors and capacitors. Suppose we have a network N which not only contains resistors but also contains voltage sources and current sources, all right. So we are considering a composite one port which contains resistors, voltage sources, current sources and these sources could be either independent or dependent.

What we mean by dependent, we will consider a little later. That is what we are considering either one port network N which contains resistors and sources, let us use a single term sources, sources could be voltage or current, sources could be dependent or independent. And the meaning of dependent sources as I said we will illustrate 1st, then we shall go into the explanation. What is important is that you understand the concepts. Thevenin's is theorem says that if there is a network N which is linear, connected to another network, another network let us say N1 which could be either linear or non-linear, it does not matter.

N1 is an arbitrary network which is also one port and capital N is the one port which drives N1. That is capital N is the driving network and N1 is the driven network, this is driving and this is driven. Then as far as the current injected into N1 is concerned, insofar as the load or the driven network is concerned, the network N or the driving network can be replaced by an equivalent network. And this equivalent network consists of a voltage source VT, an ideal voltage source in series with the resistance RT, this is Thevenin's theorem.

Thevenin's theorem says that if a linear network drives a load, this load could be linear or non-linear, it could be any combination of resistors and sources but the driving network has to be linear and the driving network insofar as the load is concerned, insofar as the current injected into the load or the voltage appearing across the load terminals is concerned, the driving network can be replaced by a very simple equivalent network which consists of a series connection of a voltage source VT and a resistance RT. The subscript capital T is for Thevenin, it is the 1st letter of Thevenin, THEVENIN.

Student: Sir this is only for resistive…?

Professor: We shall we shall extend it to inductive and capacitive network later. But let us understand the concepts regards to, with reference to a resistive network. We shall require slightly different techniques for networks containing inductors and capacitors which we shall consider later. Now to be able to understand this a little more in the perspective, let us say that under the actual network connection, let us say the load current I L. If I L is going, then I L must come out also, all right, this current, current coming out must be IL. Let us say the current IL, then Thevenin's theorem says that if this equivalent network is connected to the same network N1, then the current here will also be IL.

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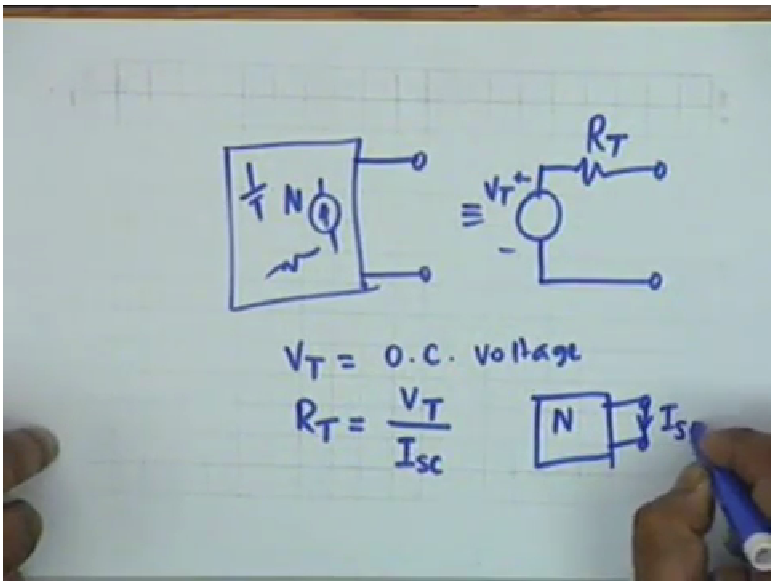

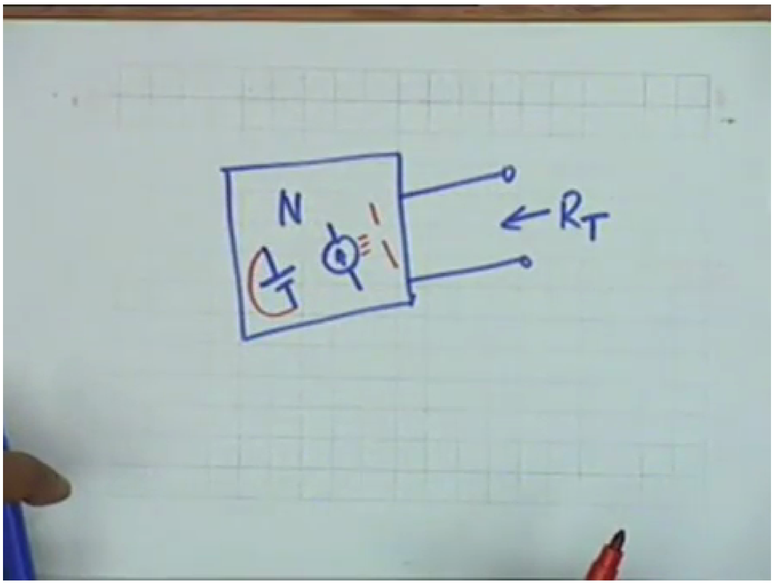

Since what equivalence means, equivalence means that the terminal behaviour is the same, that is if this voltage is VL, then this voltage shall also be VL, this is what equivalence means. All right. The interpretation of VT and RT as follows. We have taken a network N which contains resistance, voltage sources and current sources and you want to find out its equivalent, you want to find out its Thevenin equivalent VT plus - and a Thevenin equivalent resistance RT. VT is simply the voltage appearing at the terminals of 1 port with one port open circuited.

In other words no current, the one port N does not drive any current, under that condition whatever the voltage is called VT. So it is VT is the open circuited voltage, that is when it is not connected to any resistance, the resistance is infinite between the 2 terminals, the voltage that appears across this is the VT. And RT is the ratio of VT to the current that flows when these 2 terminals are short-circuited, that is N, the terminals are short-circuited, so this is ISC, the short-circuit current. The ratio of the open circuit voltage to the short-circuit current is RT. This is one interpretation of RT.

The other interpretation is that RT is the resistance looking back into N, RT is the resistance measured across this one port with the voltage sources short-circuited, that is voltage source is replaced by a short-circuit and current sources replaced by an open circuit, that is like this. That is open current sources and short voltage sources inside N, under that condition whatever resistance is measured across the port is RT. And this is the interpretation of RT and this is where the concept of dependent and independent sources arise.

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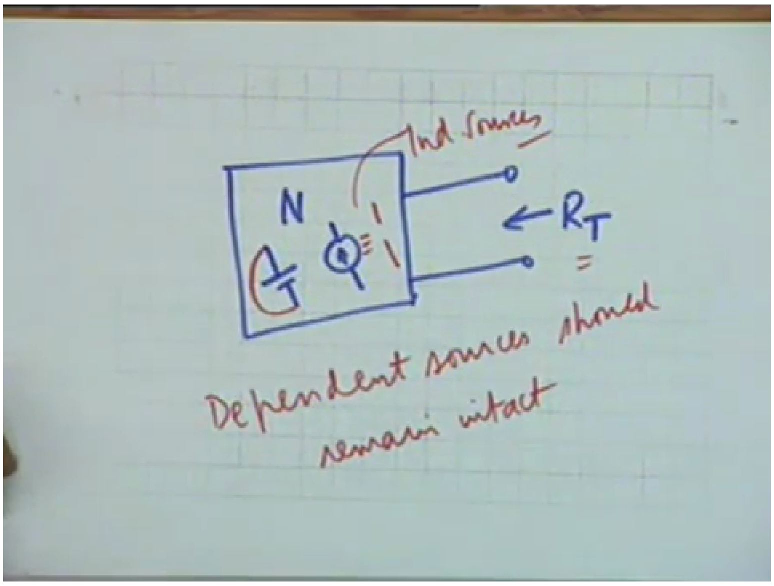

Let me make a formal definition, a dependent source is one, now we are talking of dependent and independent sources. What I have said about short-circuiting this source and open circuiting a current source applies only to different sources. In finding RT, dependent sources should not be touched, dependent sources should remain intact. Question is what is a dependent source, a dependent source is one whose voltage or current, a source is either a voltage source or a current source. A dependent voltage source is one was voltage depends on some current or voltage at some other point in the circuit, all right.

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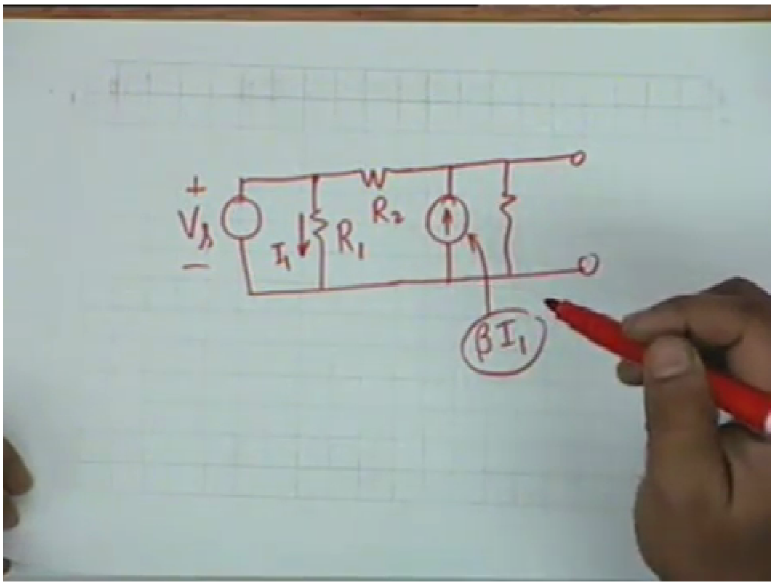

A dependent source is one whose voltage or current depends on some other voltage or current in the circuit, that is a simple definition of a source, a dependent source. For example, for example, if I have let say a voltage source VS in parallel with the resistance let us say R1, then we have another resistance R2, then I have let say current source, another resistance. Suppose this is my circuit where this current is I1 and this current source is let say beta times I1, agreed, beta times I1. Then this current source is not an independent current source because the current generated by this beta I1 depends on the current at some other point in the circuit, it depends on the current through R1, you understand this?

This voltage source let us VS for example is an independent voltage source because it generates a voltage VS irrespective of what happens to the rest of the world, it does not care. Whereas this current generator is not so independent, its current, the current generated by this source depends on another current at some other point in the circuit, that is I1. You understand what is meant by dependent and independent sources? A dependent source generates a voltage or current irrespective of what happens to the rest of the world, a dependent source is not as free as this, its current or voltage depends on some other current or voltage.

It is not necessary that a current source should depend on another current, it could depend on another voltage. As you can see here I can write I1 as VS by R1 and therefore I can write this as gamma VS, where gamma is beta by R1. And therefore this current source could depend on either the voltage or the current. Similarly a dependent voltage source could depend on either a voltage or a current.

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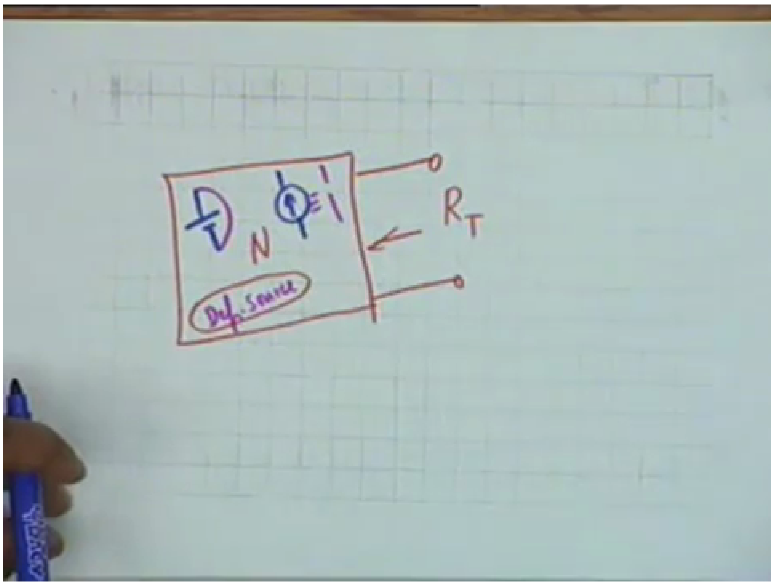

And the important point that we are mentioning is that in finding RT, the Thevenin equivalent resistance, as I said it is the resistance looking back into N, the network which you are trying to replace with the following modifications. That is if you have a voltage source, you short-circuit this, if you have an independent voltage source, you short-circuit it, which means that physically remove the source and put a short-circuit. If you have a current source, and independent current source, you replace this by an open circuit, so that what you really do is physically replace, physically remove this current source.

Whereas if you have a dependent voltage source, dependent sources do not touch, they are protected by a shield, you do not touch them, they remain as they are, all right. This point has to be borne in mind, this is the most important point. This is where most of the circuit analysis, particularly by non-electrical engineers goes wrong. And therefore you must remember this very carefully, dependent sources cannot be touched, they are barred. Yes?

Student: Can you give us an example of independent current source?

Professor: Independent current source, that is very simple, transistor output is behaves like an independent current source. Well, we will come across circuits which can be considered as current generator, all right, electronic circuits basically. It is not as simple as a battery.

Student: Previously while discussing Kirchoff's law, you had given current source in the sense of (())(17:14), that is independent?

Professor: That is independent but suppose it was 3 times V1, where V1 is some other voltage somewhere else in the circuit, then it would have been a dependent source. A current source is not available in the laboratory, in laboratory what you get are the batteries ormains voltage source, these are all voltage sources. Fortunately or unfortunately the generators that one make in practice I would take generators. But one can make current generators and we shall come across circuits in future, well indeed with transistor circuits which behave as current generators. We will consider them at a later point of time.

So the point that I have made is that the one port, a linear one port containing resistors and sources, sources of 2 kinds, current and voltage, sources of 2 different characters, dependent or independent, can be replaced insofar as the driven network is concerned by an equivalence circuit consisting of a simple series connection of a voltage source and a resistance. And we have called we have called the voltage as capital V subscript T and the equivalent resistance is capital R subscript T and capital VT is the open circuit voltage. And to determine RT, one can proceed in 2 ways, that is one can find out the equivalent resistance by making some changes in the sources, in the independent sources. That is independent voltage sources have to be short-circuited, independent current sources have to be opened, dependent sources not to be touched, to be left intact.

Then you measure the equivalent resistance, that is RT or the other thing you can do is forget about touching any of these sources, you simply find out the short-circuit current, then VT by ISC is RT. All right. Now before we take an example to illustrate this, I want you to understand the significance of RT in another way.

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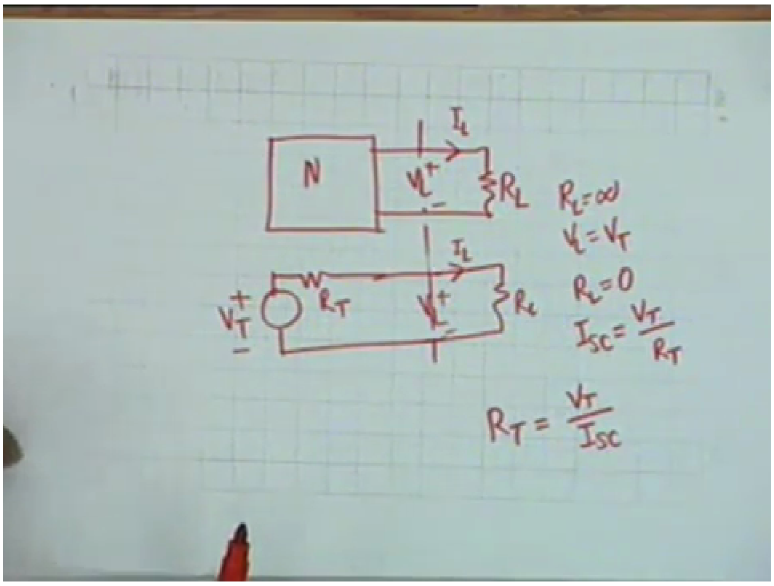

N can be connected to, N the network which you are trying to replace by a Thevenin equivalent can be connected to let say resistance RL, load. Now if N is equivalent to VT and in series RT, than the current in the load in either network should be the same. If this current is IL, then this current should also be equal to IL, all right. Now if I L is 0, under what conditions does that happen, if R L is infinite, that is if the network is open, then if RL is infinity, then you see the voltage VL let us say would be equal to simply, the open circuit voltage which by definition is VT, so VL is VT. Okay.

If RL is 0, that is if this is short-circuited, then the current in the original is ISC and in the Thevenin equivalent, what is the current? It is VT divided by RT because RL is 0 and therefore RT is simply equal to VT divided by ISC. This checks with our interpretation of RT. Ati can be measured in 2 ways, you can either find out the short-circuit current you can find out the equivalent resistance looking into this. To illustrate Thevenin here, if you have any questions are like to answer them now before I take the example.

Student: Sir does the load network has to be consisting of only resistances or it could consist of anything?

Professor: Well, broadly the constraint is it must pass the current, it should not be an open circuit, that is all constraint. It could be linear, it could be non-linear, it could contain resistance, inductors, capacitors, I do not care. But since we are considering direct current sources, DC sources in which there is an inductor, the inductor behaves as a short-circuit, if there is a capacitor, the capacitor behaves as open circuit. So basically with DC sources under equilibrium condition it behaves as a resistive network. We shall extend all these concepts to RLC networks at a later point of time. But we would like to grasp these concepts with resistive network 1st. Any other question? The examples as we are about to do we have already done in the last lecture when we solved a network containing a voltage source and a current source, we find out the current in all the branches and so on. The same example we will take and we shall solve by applying Thevenin's theorem.

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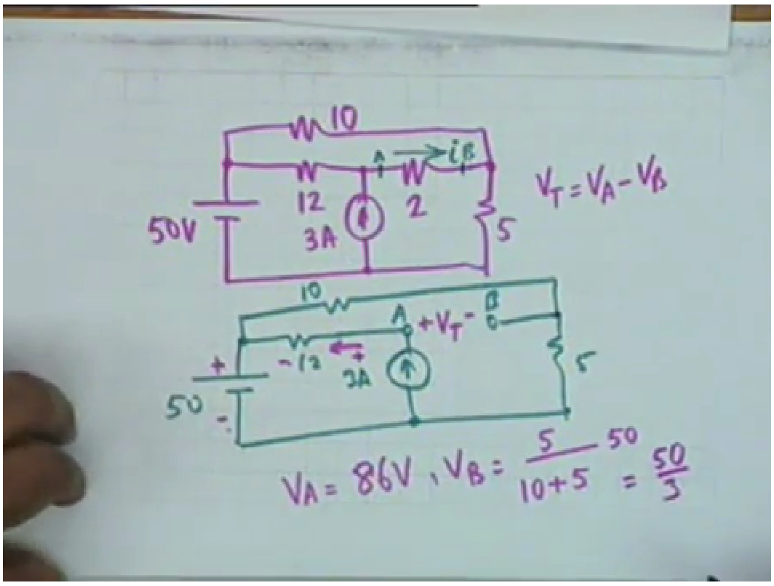

And it is not a trivial exercise, though I would like you to follow the steps very carefully. The circuit is the following. Given a 50 volt source, 50 volt source along with 2 resistances 12 ohms and 2 ohms, the 3rd resistance 5 ohms and the current generator of 3 amperes here. Then there is another resistance here of value 10 ohms, this will be one circuit. And to make things a bit more complicated, to make it look really complex, let us find out the current process 2 ohms and let us call this current as i. Now it is the same exercise that we have taken to illustrate KCL, KVL, Loop analysis and node analysis. We want to solve it by applying Thevenin's theorem, all right.

Now the 1st thing we do is to find out the Thevenin's equivalent, we call these points as let us say A and B. To find out Thevenin's equivalent, we would like to find out VT and RT. To find VT, we must open this half, in other words our new circuit to find VT shall be like this, 50, 12, then A and B, these are open, then 5 ohms and you have 10 ohms here, in addition you have a current generator of 3 amperes here. What is VT, VT is the voltage difference between A and B. If we call this voltage as Va and this voltage as VB, then VT is this difference with this polarity.

Why this polarity? Because the current I have assumed from left to right, so this is the polarity. If you connected 2 ohms here, obviously current will go from left to right, as the point here? We are going to calculate now VT. Obviously VT as I said is equal to VA - VP, so let us find out what is VA. You see that in calculating VA, we have a current source here, 3 amperes, what can this current source do? It can only drive a current through the 12 ohms here, it cannot throw in any other direction, the only freedom it is left with. And therefore it will cause a voltage drop across 12 ohms of 36 volts, 3 times 12, 36, with what polarity, plus here and - here, right.

The polarity will be plus here and - years and this battery is glacier and - here. So can you tell me what VA is? Its VA is obviously 36 +, +50 or - 50? Plus - plus -, so 86 volts, okay, VA is 86 volts. Now I come to VB, VB is the voltage across this 5 ohms resistor. Agreed. And you see the configuration, this can be done by Inspection, 50 volts is connected through a series combination of 10 ohms and 5 ohms. So very simple for television takes place and it is 5 divided by 10 +5 times 50, agreed. Is this point clear?

50 volt appears across a serious connection of 10 ohms and 5 ohms, remember this is opens, so the rest of the circuit does not interact that at all. So 10 ohms and 5 ohms, what we are trying to find is the drop across 5 ohms. And obviously voltage division R2 over R1 plus R2 multiplied by 50, is this point clear? How much is this, 50 divided by 3, agreed.

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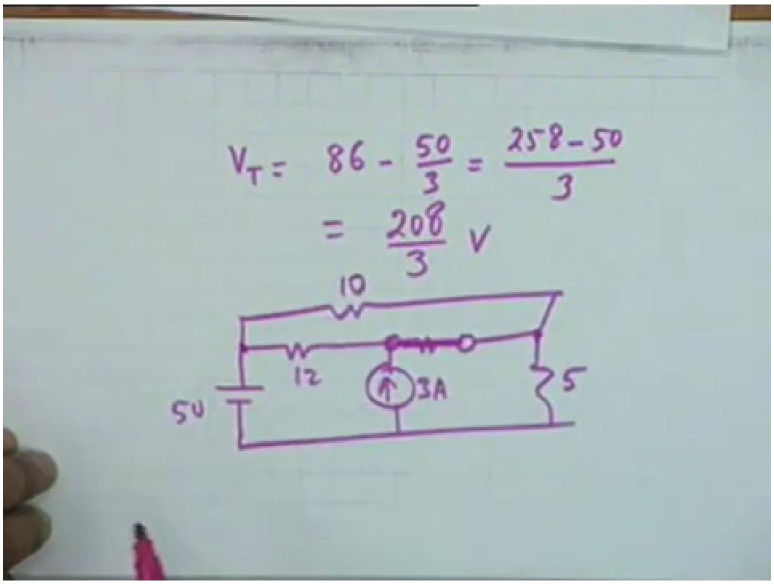

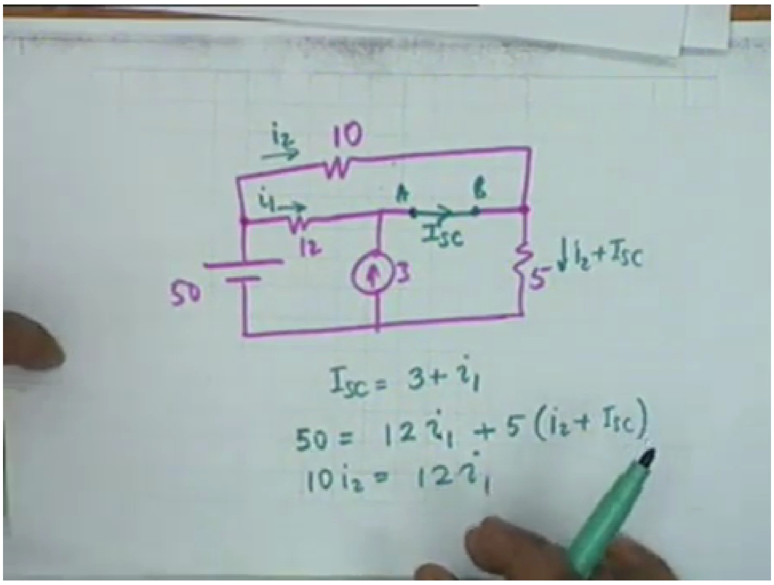

And therefore and therefore VT, our Thevenin's equivalent is simply 86 - 50 divided by 3 which is equal to 3 times is 18, 1, 258 - 50 divided by 3, is equal 200 divided by 3, I beg your pardon, 208, this is VT. Now we want to find out RT. Let us find out RT, let us find RT by both ways, both interpretations. That is by finding the short-circuit current and also by measuring the resistance, equivalent resistance. It turns out that the 2nd approach, namely finding out the equivalent resistance by killing sources, that is by killing which sources? Independent sources, independent sources, that turns out to be easier as we shall see right away.

Our circuit was 50 volts, 12, I beg your pardon, this will be short-circuit now, 2 ohms will be a short-circuit, here 3 amperes source here, 3 amperes source, then you have 5 ohms and a 10 ohms here. Let me draw it again (())(29:05). I have 50, 12, 3 amperes and this place of 2 ohms which I have open circuit for finding VT shall now be short-circuited. This is A, this is B and this current is the current that we are interested in finding out, ISC, all right. Then I have the 5 ohms resistance and this resistance is 10, all right. I can find that ISC like this, suppose I consider this current as I1, this current as I1, then ISC obviously shall be equal to 3 + I1. By which Law have we applied?

Student: KCL.

Professor: KCL, all right. We also have to know this current, let us call this as I 2, all right. Then how many unknowns are there?

Student: 2.

Professor: 2, just 2. So let us express everything in terms of ISC. And we write 2 Loop equations, all rights, 2 Loop equations. The 1st loop is 50, 12, 5, agreed, then I get 50s equal to 12 I1 plus what is this current, I2 + ISC, 5 I2 plus ISC. And the other loop equation is this, 10 and 12. Obviously 10 I2 shall be equal to 12 I1, is that easy to see? It is the same difference of potential, either we apply KVL or you argue like this is at the same two-point and therefore 10 I2 should be equal to 12 I1. Now I leave the algebra do you, I have done the algebra, and I leave the algebra to you, I will only give you the final result.

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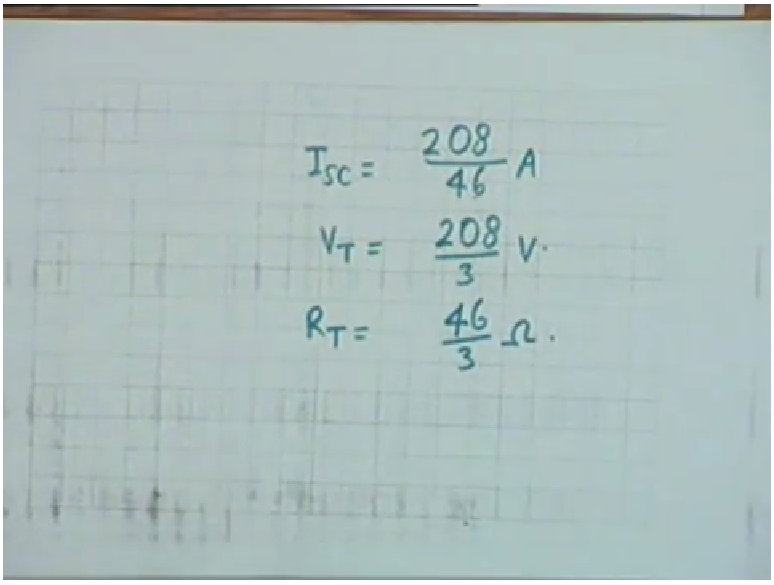

What you do is, you replace I1 by 3 - ISC and solve from, solve for ISC from these 2 equations, either by substitution or by Cramer's rule, I do not care. The final result is that ISC is equal to, I did it somewhere, 208, divided by 46 amperes, this is the final result. My VT was equal to, was equal to how much? 208 by 3 volts and therefore my RT shall be equal to what, 46 by 3 ohms, all right. Now if you ask me now what did we gain by Thevenin's theorem? It did not look like much simplified one because for ISC I had to solve 2 equations anyway, is not it.

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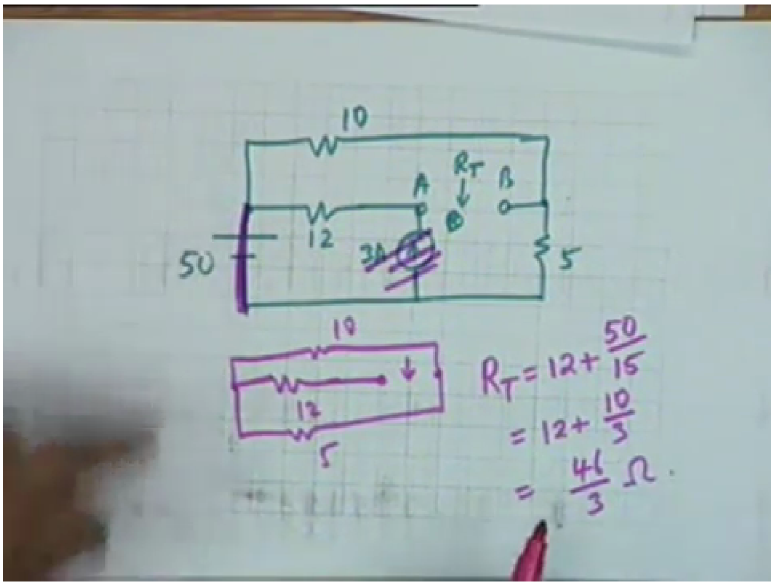

It turns out that the other method, instead of calculating ISC, the other method is a better choice here, that is finding out RT, let us see, let us see how that is a problem. What we had is 50, 12, A, B, this is where we have to measure RT between that A and B after killing the sources, means you have to kill them. This is 5, this is 3 amperes and there is a 10 ohms here. Okay. In the previous method what I did was I short-circuited this and found out I SC, the short-circuit current. Now we shall argue like this, that RT is the resistance between A and B, with independent voltage sources short-circuited, so this is replaced by short-circuit now.

And independent current sources open circuited, so break this up, remove this source physically. What are you left with? You are left with a 12 ohms in series with a parallel combination of 10 and 5, is not that right? What you have is 12 ohms, then a 10 ohms here and then a 5 ohms here. This is the equivalent circuit, you are measuring the resistance between these 2 points. So RT is almost obtained by Inspection, it is 12 + 10 parallel 5 which is 50 divided by 15 which is equal to 12 + 10 by 3 which is 46 by 3, this is what we had obtained after a bit long calculation in the ISC method, the short-circuit current method. Nevertheless the short-circuit current has its own importance as we shall see a little later.

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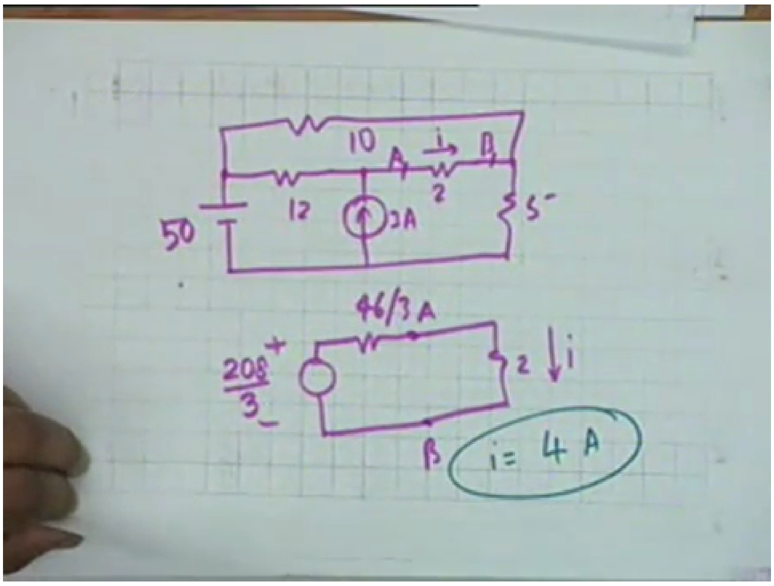

Now therefore our Thevenin equivalent circuit, you remember our original problem was this, 12, 2, 5, 3 amps, and 10, this was 50 volts, we were trying to find out I. This is my node and what I found out is that my VT is 208 divided by 3 and RT is 46 by 3, this point is A and this point is V, A and B. This is my equivalent circuit, then I connect the 2 ohms, the current through 2 ohms must be the same as in the original circuit. So what is the value of I? I is 4 amperes here, that is correct. And it checks with what we found out by Loop analysis or node analysis.

This is a known trivial application of Thevenin's theorem and I wanted you to know that even a complicated case like this where there is a voltage source, there is a current source and it is a fairly complicated 1, 2, 3, 4 resistors can be solved by simple application of Thevenin's theorem. Now next I shall take another example, which contains dependent sources and see how to apply Thevenin's theorem there. And this example as we shall see later is an equivalence circuit for a transistor. But just look at it the way I am drawing it now, forget about what it represents.

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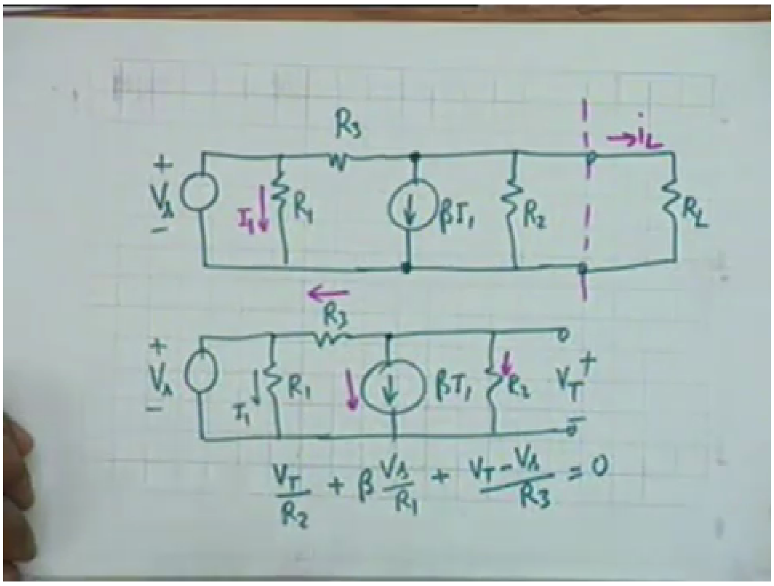

We are interested in solving this problem, there is a dependent current source beta I1 in parallel with a resistance R2 and this drives a load RL, all right. What we are interested in is let say the current in RL. If I know RL, if I know the current in RL, then I of course know the voltage in RL, all right. This is what I wish to find out, I come by application of Thevenin's theorem to that part of the network which is to the left of the dotted line, all right. I wish to find out the Thevenin's equivalent and for that the 1st thing I do is to find out VT, all right.

Student: (())(37:45).

Professor: I did not show I1, I1 is this current, I1 is this current. Thank you. Now obviously beta I1 is a dependent source, so let us see how we solve this problem. The 1st thing we do is to find out the open circuit voltage, let me draw the circuit again, this is R1 and this current is I1, R3, beta I1 and there is a resistance R2, this voltage is VT, open circuit, RL is disconnected, the super circuit. Now to find out VT, VT, what are you going to apply? There is a voltage source, there is a current source and to complicate matters the current source is a dependent one, it depends on another current and some part, some other part of the circuit.

The simplest method where you can think of loop analysis, node analysis, you can think of branch currents, loop currents and so on. The simplest method obviously shall be node analysis because this is only one voltage which is unknown and this voltage is, this node voltage, after all these 2 are the same nodes, so all that we have to find out is VT. So we write one KCL equation, that is, all these currents, leave this node VT. Obviously this is VT by R2, this is the current through R2 plus beta I1, beta I1 leaves this node but what is I1? I1 is VS divided by R1, so beta VS divided by R1, all right, plus VT, plus the current through R3.

There are 3 currents that you have to take care of, this one, this one and this one, these are the 3 currents leaving the node and sum of them should be equal to 0. So the 3rd current, the current through R3 is VT, this potential - VS divided by R3. So VT - VS divided by R3 and this should be equal to 0, which immediately gets you what is VT.

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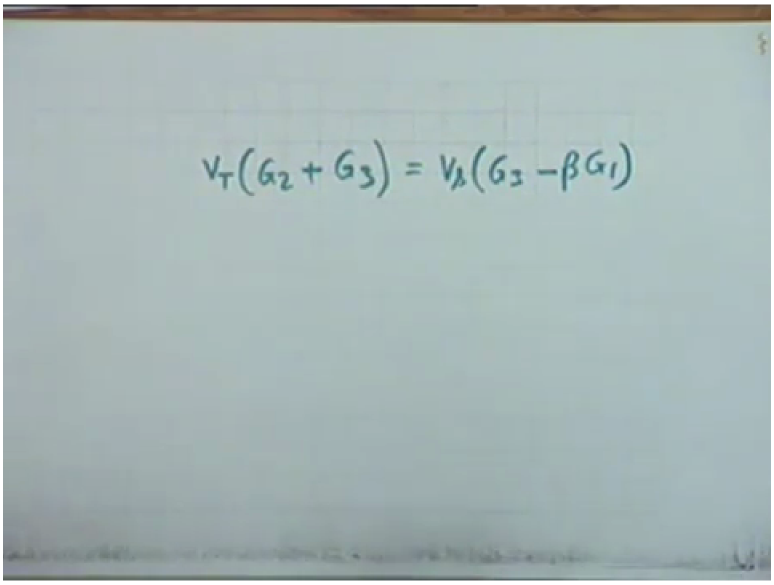

If I use the symbol 1 by R equal to G, capital G, then VT can be written in one stroke, that VT times G2 plus G3 plus shall be equal to VS, I take them to the right-hand side, G3 - beta G1, is that okay? Is that all right, when I have used GI as equal to 1 over R I, GI Obviously is conductance, what is the unit? Mhos, all right. The Americans pay for mhos because Siemens was a German. If Siemens was an American, they would have said Siemens, and you study American textbooks, Smith is an American tech books, so he writes mhos, all right, minor differences.

But obviously you can see that VT is given by VS, G3 - beta G1 divided by G2 plus G3. All that you needed in solving this problem, in finding out VT was KCL, KVL and commonsense which is the strongest tool of an engineer. And the other points, the other thing that has to be found is, is RT. I shall find out RT by both methods and then you decide which one is simpler.

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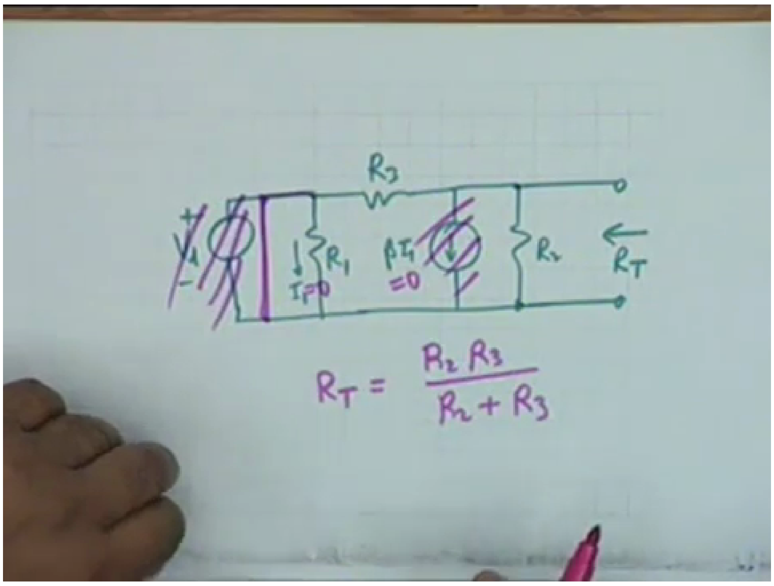

Let us look at the circuit again, what we had to do is VS, then we have R1, R3, beta I1, R2, let us find out RT by direct measurement across these terminals looking back after killing the independent sources, dependent sources should not be touched. So what I do is I short-circuit this, that is the only thing I have to do, I think it, this is the only independent source and killing it means that I short-circuit this. I do not touch, I do not touch beta I1, recall that this is I1. Now you see that as a result of shorting this, what is I1, I1 becomes equal to 0 and therefore beta I1 becomes equal to 0, which means that the current generator is not there, all right.

So what is RT then?

Student: (())(43:05). R2 R3 by R2 plus R3.

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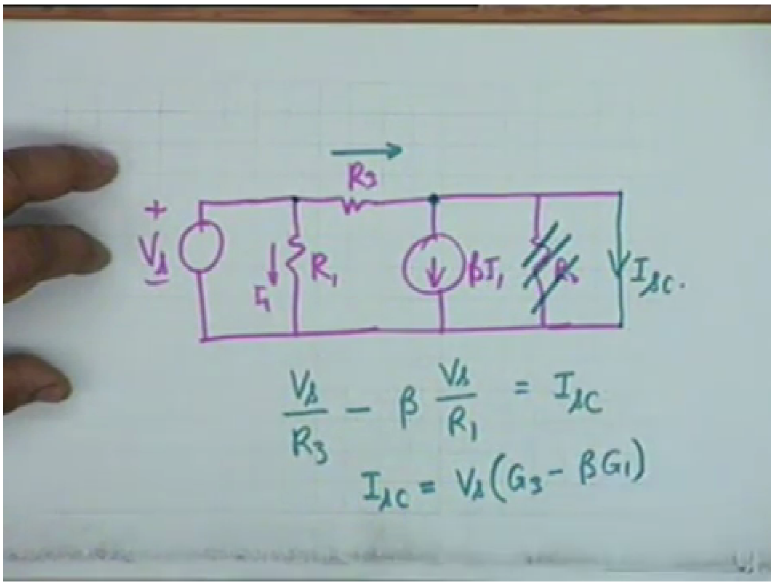

Professor: It is in parallel combination of R2 and R3 because R3 goes to short-circuit, R1 is ineffective. So it is simply R2 R3 divided by R2 plus R3. Okay. Now let us see, let us calculate it by other method, that is by calculating the short-circuit current. Our circuit if you recall is VS then R1, this is I1, R3, beta I1, R2 and I am going to short-circuit this, this is a current that I want to find out, ISC. Alright, if this is short-circuited, if this is short-circuited, then obviously ineffective, R2 is ineffective, no current in R2, all right. And therefore ISC shall consist of 2 components, if we apply KCL now here, then this current, this current - beta I1 should be equal to ISC, agreed.

If I apply KCL here, now what is this current, this voltage is VS, what is this voltage? 0, it is connected to ground, is not this voltage equal to 0, short-circuited and therefore the drop across R3 is simply VS. Therefore the current in R3 is VS by R3 - beta, what is I1, I1 is still VS divided by R1, this should be equal to ISC. That is ISC is equal to VS G3 with the same terminology, conductance, - beta G1. This is ISC, let us collect our, our equations. Is there any question here, this calculation? All you did was commonsense, one application of KCL and the other is commonsense, nothing else, we found that ISC.

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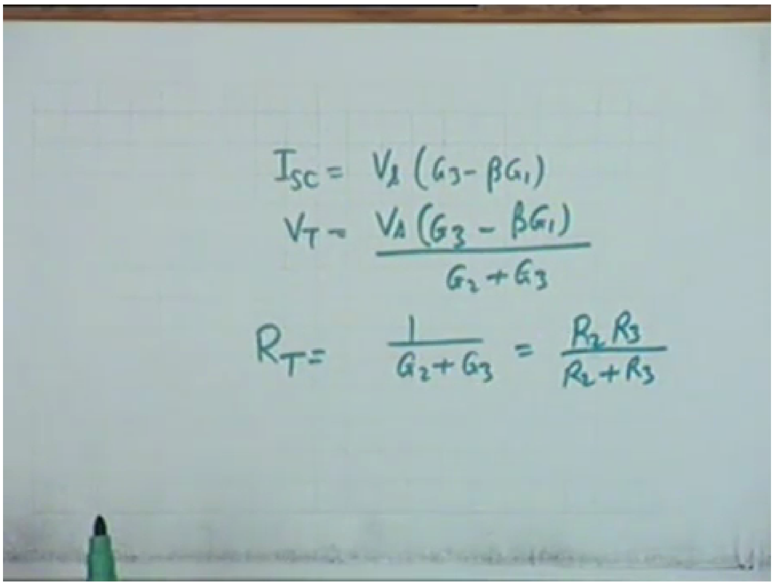

Let us write our equations again, ISC is VS G3 - beta G1 and what was VT? VT was VS G3 - beta G1 divided by G 2 plus G3. And by definition RT shall be the ratio of the 2. What does the ratio give, 1 over G2 plus G3, which is precisely equal to R2 R3 divided by R2 plus R3. So we have been able to find out the equivalent Thevenin's resistance by either method, now it is for you to judge which one, which method was better in this case. Which method was…? Direct calculation?

Student: Yes.

Professor: Well both of them are equally well.

Student: In the 1st one (())(46:49).

Professor: In the 1st one it was much easier, then it is a personal preference. I do not like green colour, some or somebody else likes green colour, so it is okay. To me both of them are equally easy. Once you see what is going on, once you see what the game is, then you can play the game according to the rules of the game, all right and hope to win, all right. So these 2 fairly involved examples should convince you about effectiveness of Thevenin's theorem. And along with Thevenin now… yes?

Student: The problem (())(47:35), if there is independent voltage source with voltage beta I1.

Professor: Yes, there could be a dependent would this source.

Student: What will be the equivalent resistance?

Professor: In the same example? You will have to work it out, beta I1 means beta VS divided by R1 and you will have to work it out. Alright, let us look at the circuit, it is not a bad question, it is a very good question.

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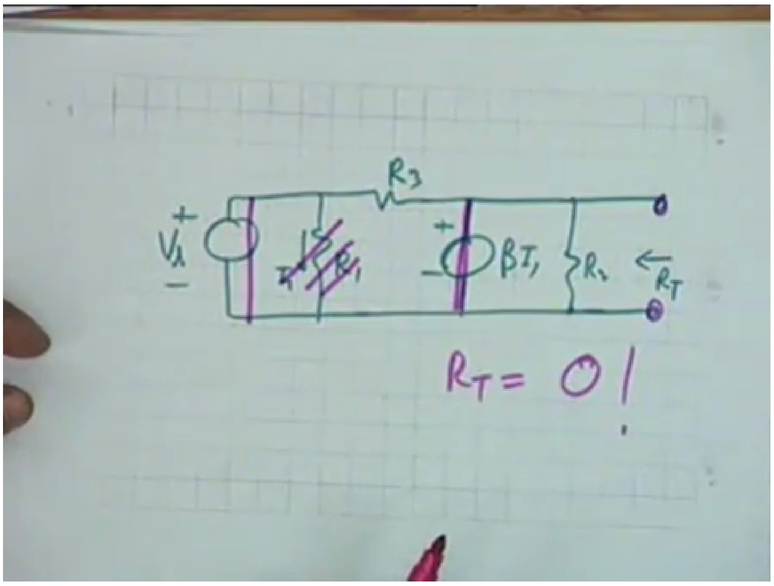

What he says is R1 some I1, R3 and he says let this be a dependent voltage source beta I1, instead of a dependent current source, then we have R2, what did you want to calculate? Thevenin resistance, now before that you also want to calculate VT, open circuit voltage. The open circuit voltage here obviously shall be equal to beta I1, all right. Now if you want to calculate Thevenin resistance RT, what you do is you short-circuit this, short-circuit this, so R1 is ineffective, R1 is ineffective and if R1 is ineffective, then what is I1?

Student: 0.

Professor: I1 is 0, if I1 is 0, then beta I1 is 0 - beta I1 is 0, what does it mean? It means an open circuit short-circuit? A voltage source if the voltage is 0, what does it mean?

Student: Open.

Professor: No, it is a short-circuit. There can exist a voltage across an open circuit but not across a short-circuit. So this is a short-circuit, so RT becomes identically equal to… What are you talking of? Who said 0? Who dares to say 0? I appreciate that courage because it is indeed 0. Because between these 2 points there exists a short-circuit, current has no compulsion to go any other way, it will go through the short-circuit, that is indeed the Thevenin resistance, all right. So the problem becomes much more simplified if it is a controlled voltage source, dependent voltage source instead of dependent current source in this situation, not necessarily in every situation, in other situations it may be more complicated.

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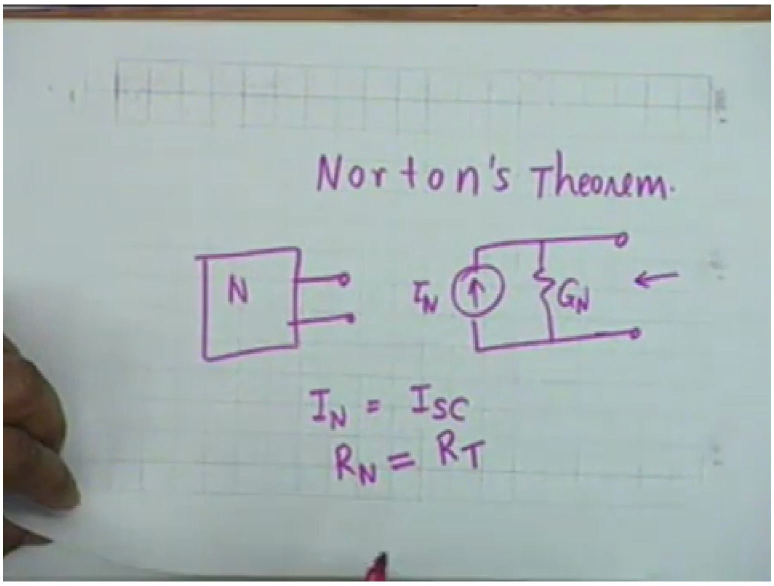

Now along with Thevenin comes the name of Norton, Norton was an American working in Bell Telephone laboratories and he enunciated a theorem which goes by his name Norton's theorem, which is precisely the dual of Thevenin's theorem, dual. That means what Thevenin enunciated in terms of voltage, Norton enunciated in terms of current. Thevenin's theorem says that the one-port N is equivalent to a voltage source in series with the resistance, Norton says that N can be replaced by a current source in parallel with the resistance, all right. Current source IN in parallel with a resistance which Norton prefers to call a conductance GN, all right.

And the interpretations of IM and GN, you can very easily see that IN is nothing but ISC, that is if you short-circuit these 2 terminals, the current that flows through the short-circuit is ISC and you can also see that RN is nothing but what? If you measure, if you measure the resistance looking from here, what resistance would you see? 1 upon GN, and therefore RN is simply equal to RT, it is clear to you? The Thevenin resistance, the Norton resistance is the same as the Thevenin resistance. You recall… Why is it so?

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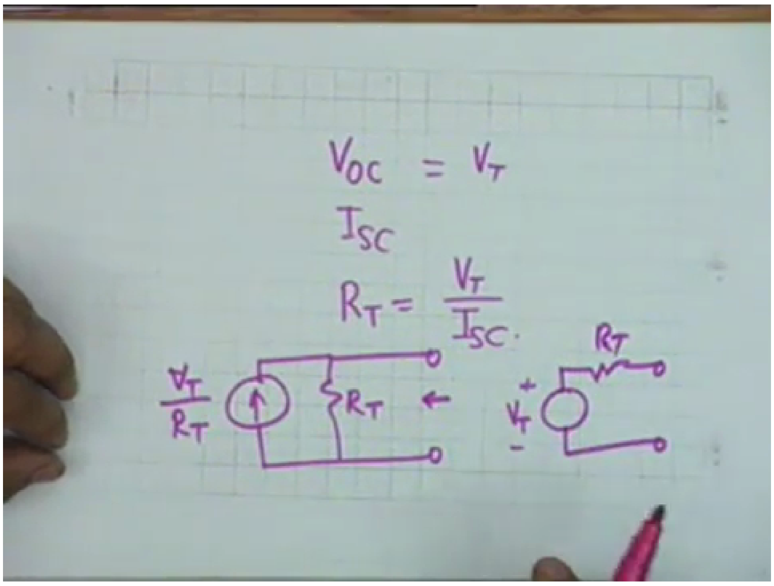

You recall that in finding out Thevenin equivalent, we found out VOC which is VT, we found out ISC and we find out RT as VT divided by ISC. What we are doing in Norton is simply, simply representing it in terms of ISC and an equivalent resistance. All right. Suppose, suppose I take ISC which is VT divided by RT, in parallel with RT and find the Thevenin equivalent of this. When the current source is parallel to the resistance, what is the open circuit voltage, simply VT. If this is kept open circuit, then this current flows through RT, so VT by RT multiplied by RT is VT and if you measure the resistance looking in this direction after killing the source, only source, this simply RT. So Norton, Norton's theorem is simply another way of looking at the Thevenin equivalent, all right.

What was considered as a voltage source by Thevenin is now being converted to a current source. So both of these problems that you solved also serves for Norton equivalent, because we found out RT, RT is the same in both, in one of them it is a series resistance, in Norton equivalent it is the parallel resistance. The source is ISC which we have to find for Thevenin equivalent also for Thevenin equivalent be found out VT and IFC. Question maybe that if I do not find the short-circuit current, I know the Thevenin equivalent, then all that you have to do is find, if you divide the open circuit voltage by the Thevenin resistance RT, whichever way you find, it does not matter.

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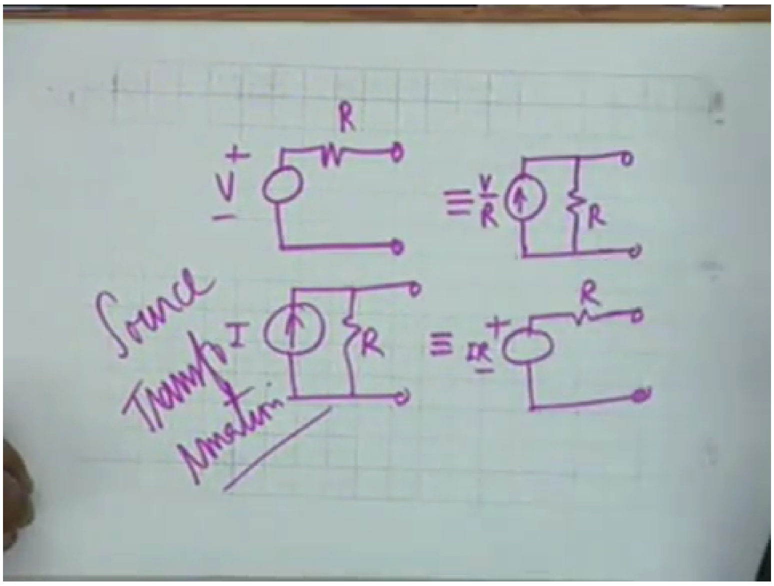

And therefore whatever we have done for the 2 examples in finding out the Thevenin equivalent also serves for the Norton equivalent. And this leads us to a more generalisation in the case of, a generalisation in the case of sources. That is if we have of course V, which is not ideal, which has a series resistance let us say R, then it is a non-ideal voltage source, this is equivalent to a non-ideal current source of current equal to V by R, short-circuit current and a parallel resistance equal to R. This is called source transformation, a big name but a very simple application of Thevenin's theorem.

Similarly if I have a current source I which is nonideal, that it has a parallel resistance R, then this is equivalent to a Thevenin equivalent, a voltage source, I times R in series with R. You will see that these simple transformations, the 2 transformations which go by the big name as source transformation shall be extremely useful in solving network problems without loop analysis, without node analysis. In fact Thevenin and Norton applied judiciously can save the labour of network analysis, however complicated its maybe. And we shall see some of the, some examples next time. Is there any question? All right, then next time.