**Basic Electrical Circuits**
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**Lecture – 3**

Definition of a linear element; Elements in series and parallel; Superposition in linear circuits; Extreme cases open and short circuits; Parallel/series connections of a voltage source and a current source

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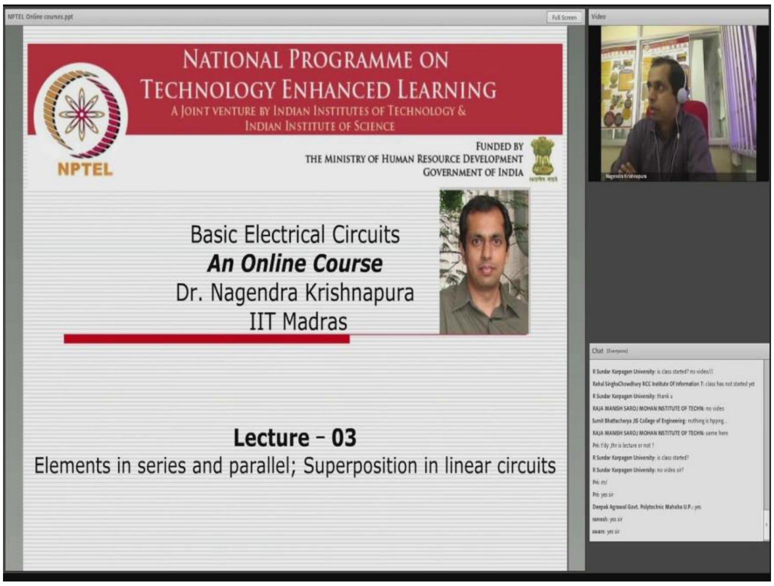


Welcome to the third lecture of basic circuits, basic electric circuits. And in the last class, we looked at some basic elements, which were linear elements and also independent voltage and current sources. We will continue from there in this class, ok.

Now, as this title says, it talks about elements in series, in parallel, in superposition and so on. So, like I had said, we will also go by how fast we are going in each class and then ((Refer Time: 00:40)) it in the previous class and so on, so that we do not lose continuity. So, what we will do is, we will look at the elements in some more detail and then see what happens when we connect them in series and parallel, ok.

So, before I start any questions about the previous class, there is a question from Vishal Goswami. What was the question? Hello, what is the question?

Now, what I will do is, I will go to my notes and then start sharing that, ok.

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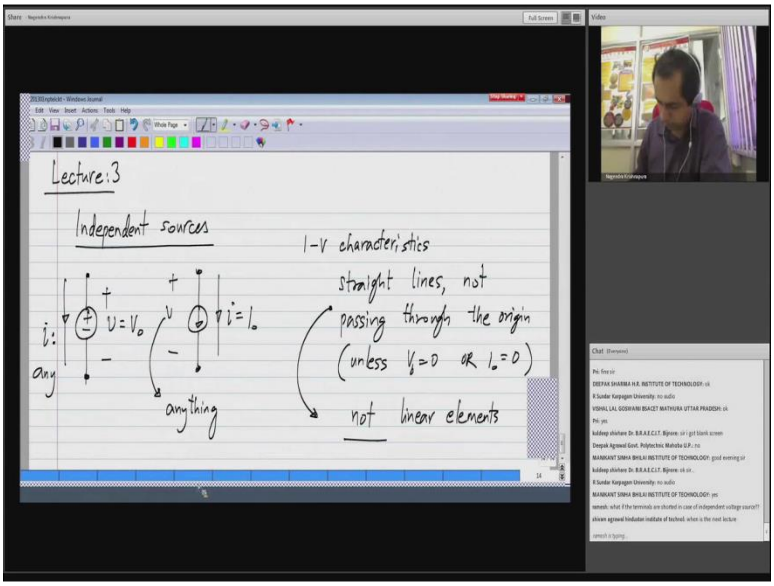


In the previous lecture we discussed independent sources. Independent sources, one of which was the independent voltage source, what it does is to maintain a given voltage, V naught, across its terminals and it can carry any currents. This, what it means is the voltage source itself will not impose any restriction on the current. The restriction will come from whatever circuit it is connected to, that is the property of an independent voltage source. And the independent current source will maintain a current flow of a given value through itself and the voltage across that can be anything, ok.

So, we looked at these and these have I-V characteristics, which basically means, that if I draw I versus V, which are straight lines not passing through the origin unless co-incidentally the voltage source value or the current source value happens to be 0, unless that happens the straight lines are not passing through the origin, which means, that these are not linear elements.

Now, what is the definition of linearity? We said that linear elements obey superposition. In that sense, they will not obey superposition because clearly, the voltage across at voltage source will be equal to V naught, no matter what current flows through it. So, clearly if you have two different values of current and then you add up the voltage source values, your voltage values will not get the resultant voltage when the sum of currents is passing through the voltage source, ok. Similarly for the current source.

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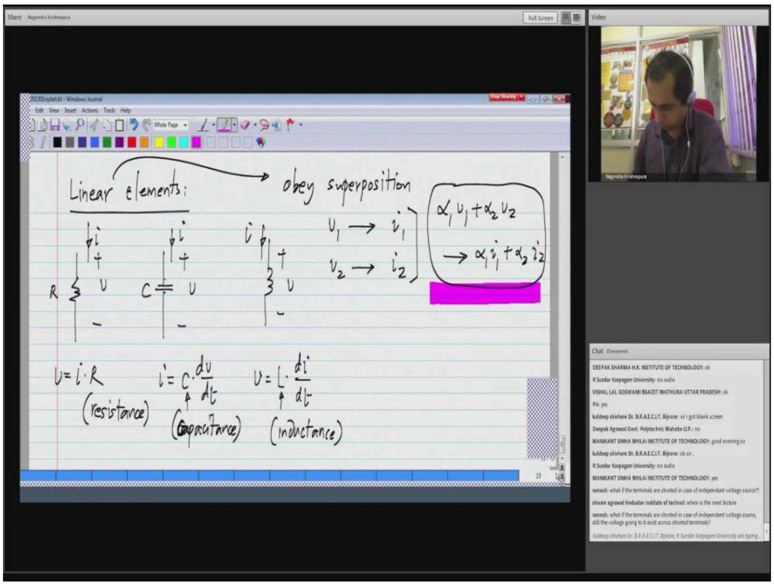


Now, in addition to this we also looked at a certain number of linear elements and this means, that they obey superposition. Now, in case of electrical elements the variables of interest are voltage and current. So, if V 1 gives you a current i 1, V 2 gives you current i 2, then what superposition says is, that alpha 1 V 1 plus alpha 2 V 2 will give you a current alpha 1 i 1 plus alpha 2 i 2. So, this is what is meant by superposition. And this has to be true if the element has to be linear. And also, if this is true, the element is definitely linear.

Which are the linear elements we looked at? The resistor r whose voltage and current are related by a proportionality constant R, which is the resistance and a capacitor C was voltage and current related by time derivative and the C is the capacitance. And finally, the inductor was voltage and current are related by the time derivative, but in the opposite direction and this l is the inductance ok.

So, now all of these are linear elements. In case of the resistance it is pretty obvious why it is linear, it is proportional, the relationship is proportional and that will give you linearity. Now, in case of capacitance and inductance this time derivative is the linear operator and hence, these elements are also linear, which means, that they will follow this principle. It can also be in the other direction, that is, if i 1 gives you V 1 and i 2 gives you V 2, alpha 1 i 1 plus alpha 2 i 2 will give you alpha 1 V 1 plus alpha 2 V 2. So, that is essentially what we discussed in the previous lecture. Now, what we will do now is to consider some simple interconnections of these elements and see what the result is.

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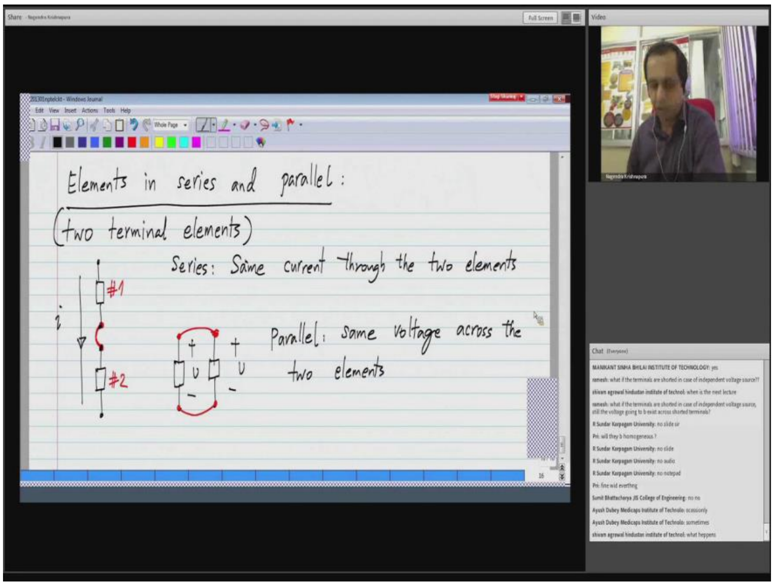


Now, first let us consider these elements in series and parallel. Now, what does it mean? We are, of course, talking about two terminal elements. Now, if you have two elements what is meant by a series connection?

Series connection means, that one element of one terminal is connected to, sorry, one terminal of one of the elements is connected to a terminal of the other element and nothing else is connected to this, ok. So, this one of the terminals of this element number one is connected to one of the terminals of element number 2 and to that point nothing else is connected. Now, what this enforces by Kirchhoff's current law is, that the same current is flowing through the two elements, ok. So, a feature of series connection is, that same current through the two elements.

Is there a problem with viewing the notepad again? It looks like most people are able to see the notepad, so I am going to continue. As I was saying, in series connection of two elements, you will have one terminal of one of the elements connected to one terminal of the other element with nothing else connected and what it enforces is the same current through both elements, ok. So, that a feature of series connections is, that the same current will flow through the two elements.

Similarly, what happens in a parallel connection is, that one terminal of the first element is connected to the one terminal of the other element and also, the other terminals are connected together, ok. Basically, some, one terminal of each is connected to one terminal of the other element and also, the other terminals are connected together. And what it enforces is an equal voltage across the two elements. Obviously, by KVL, the voltage across this and the voltage across that have to be exactly the same, ok.

If you consider this connection between two elements is a loop, then the voltage will be enforced to be the same by Kirchhoff's voltage law. So, for parallel connection we will have same voltage across the two elements. So, with this in mind we can see what happens to each element as we connect them in series or parallel.

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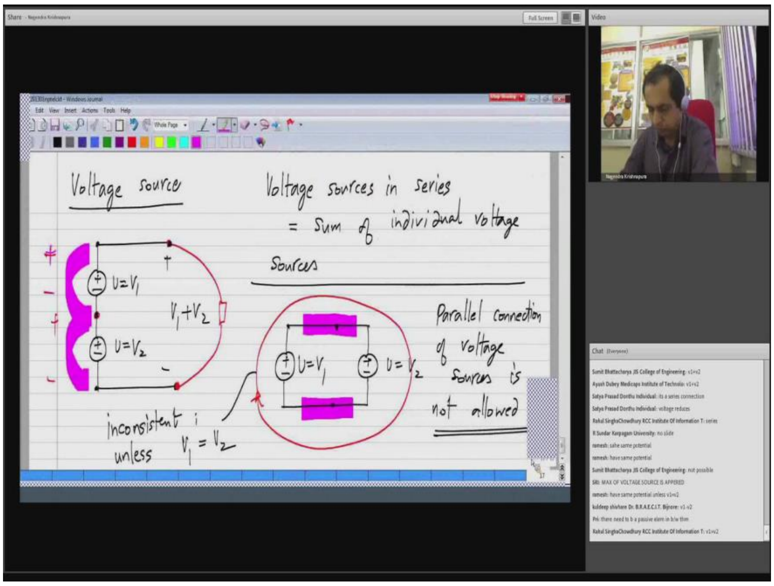


So, first let us consider the independent voltage source. So, let us say, I have a voltage source of a value V 1 and a voltage source of value V 2 and we connect them in series, that is, this node is the common node for one terminal of each element. And what I want to find out is, what does this entire thing looks like from these two terminals.

There is a question, what is the question? Hello. So, what is the, what does it look like looking from these two terminals. I would like answers from the participants. When we connect these two voltage sources in series, the middle voltage is, middle terminal is, middle node is common to, to the two elements. So, we have one terminal here and another one there. So, if you look at it, the entire thing looks like a single two terminal element.

So, what will it look like between these two terminals? So, as a couple of people answered, this will, the voltage across these two terminals would be V 1 plus V 2. So, now this is so simple, that I think all of you know the answer, but I will just show you how to do it formally.

You can imagine some branch completing this loop and you apply KVL across this loop. The voltage drop across this in this direction plus the voltage drop across this in the same consistent direction and finally, the voltage drop across this, and it has to be in the consistent direction, which is like that has to be 0, ok. So, that means, that in this polarity it will be minus V 1 minus V 2, or if I take the upper one, and the lower, upper one as plus and lower one as minus, it is V 1 plus V 2.

So, the bottom line is a series combination of voltage sources appears like a single voltage source of value equal to the sum of voltage sources, ok. And we can have more than one in or more than two in series. So, voltage sources in series equals sum of individual voltage sources. I think there is no confusion about this.

Now, the next thing is, that what happens if you connect voltage sources in parallel. What will happen, that is, I connect this voltage source and that voltage source in parallel again. I would like answers from the participants.

There are many answers and some of them said, this connection is not possible and that is correct. Many ways to think about it. Here, first of all, the first voltage source is enforcing a voltage V 1 between these two terminals and this voltage source is enforcing, trying to enforce a voltage V 2 between these two terminals, the same two terminals. Like, see clearly, there is a contradiction and that is not possible. Alternatively, you can think of this whole thing as a loop and write KVL around it and a sum of voltages would be V 1 minus V 2, which cannot be 0 unless V 1 happens to be equal to V 2, ok.

So, basically to resolve this, we say, that the parallel connection of voltage sources is not allowed. Now, this is, this gives you an inconsistent condition unless V 1 equals V 2. So, unless V 1 equals V 2, you cannot make this correct connection. So, you cannot connect voltage sources in parallel. So, I hope that is clear.

Professor: So, there is a question from Ayush Dubey, please go ahead.

Student: Yes sir.

Professor: Yes.

Student: Hello.

Professor: Yes, please go ahead.

Student: But practically, we can, practically we can connect to voltage sources in parallel. So, what is the result in practical?

Professor: So, the question is, in practice if I take two voltage sources and connect them in parallel, what happens? Now, first of all there are many manners to resolve this.

Student: Yes sir.

Professor: Whatever you get in practice, will not be an ideal voltage source, right. It will not be able to hold voltage of V 1 regardless of what current is drawn from it. So, what will happen is, if you connect two voltages, I mean, for instance, two batteries of unequal voltages in parallel, that way some current flowing, which will change the voltages of each battery. So, that is basically what happens. So, the bottom line is, there is no such thing as an ideal battery, ideal voltage source. So, you can connect things in parallel. There will be some current that is flowing and the voltage across each battery will be different from ideal value, ok. So, that is what happens.

Now, many of you also know, that if you have a real battery that will be modeled by just a voltage source, but a voltage source in series with a resistance. So, you really cannot have these independent voltage sources, which are ideal. This is useful concept in circuit analysis and a useful approximation in many cases, but you really cannot do that. Another way to think about it is, that you have this net voltage of V 1 minus V 2 across some wires, which have 0 resistance. So, that means, that if you have V 1 minus V 2, which is not 0 across 0 resistance. The current through the 0 resistance has to be infinite. So, if you do have infinite current, you can have some voltage drop.

Now, what it again really means in practice is, that if you take two voltage sources or two power supplies of unequal voltages and connect them in parallel, a very large current will tend to flow through them and possibly, damage the power supplies. There were other answers like the maximum of the two voltages will appear. No, that is not correct, you, this connection is simply not allowed.

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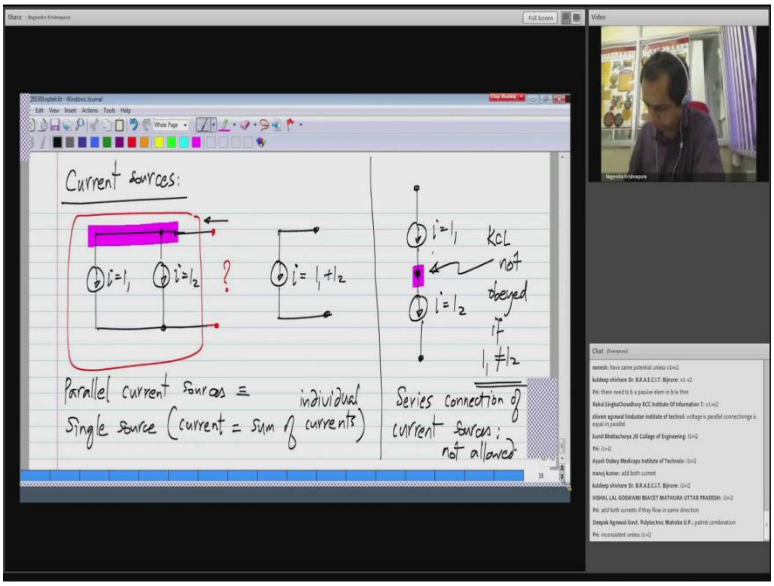


Now, we can look at current sources in a similar way. Let us say, I have a current i 1 and another current source of current i 2 in parallel, that is, both the terminals are common to the two elements. Now, again, we, this looks like some two terminal element here under. The question is what does it look like looking at those two terminals. Answers please quickly.

I think again, the answer is pretty obvious. This looks like a current source of value i 1 plus i 2. And it is very easy to see, basically want to find out what current is going there. And by Kirchhoff's law at this node, Kirchhoff's current law at this node, you see, that whatever is going in here has the equal current going in this plus the current going in that, ok. So, it forms a current source of value i 1 plus i 2. And you can have more than two current sources.

So, if you have multiple current sources in parallel, it is equivalent to single source with current equal to sum of individual currents. And we can quickly look at what happens if we have current sources in series or just like with the voltage sources in parallel, you see, that unless i 1 happens to be exactly equal to i 2, KCL at this node, at this middle node is not valid, is not obeyed. Here, i 1 is not equal to i 2. So, we say, that series connection of current sources is not allowed, ok.

So, unless i 1 happens to be equal to i 2, you cannot connect current sources in series and you can see, that it is complimentary to what happens in a voltage source. You cannot connect voltage sources in parallel, you can connect them in series and you cannot connect current sources in series, you can connect them in parallel.

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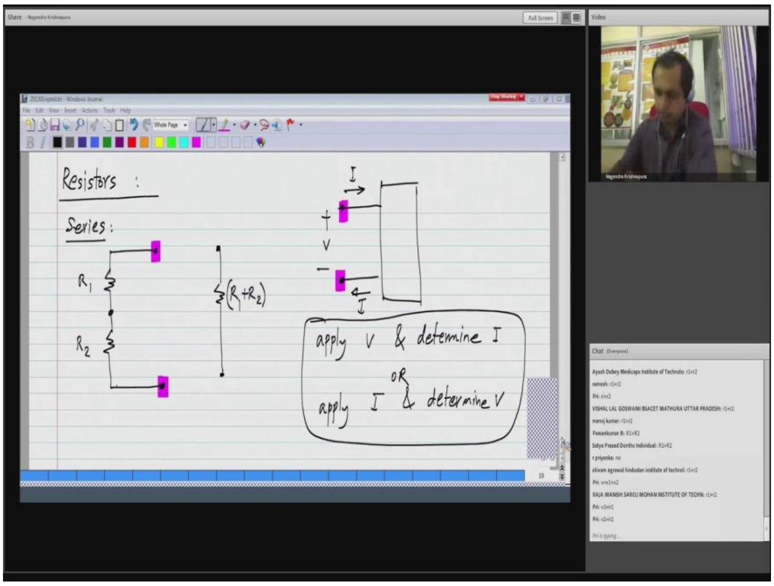


Next, let us look at resisters in series and parallel. So, if I look at series connection of resisters, I have R 1, R 2. And the question is, what it looks like from between these two terminals? Answers please. Again, the answer is known to a lot of people and it is, that it is equivalent to a single resistance of value R 1 plus R 2, ok.

So, while this answer is known, it is also important to be able to derive this by yourselves. Again, this is a very trivial derivation, but those of you who do not know, I will do it here and show it because anything that you calculate, you should be able to do with confidence. You should be able to say why it is R 1 plus R 2 and from the basic circuit laws and the definition of resistance, we will be able to do it. The various way to do that is, I want to find out what happens between these two terminals.

Now, one general thing is, that let us say you are given a box with two terminals. We are talking about electrical circuits. Internally, there are some circuits and two terminals are exposed to the outside and you are asked to find out what is inside. The only way, the only thing you can do is to find the i-V characteristics. You define i and V correctly, V with plus on top and i going into the upper terminal. Obviously, the same i will come out of the lower terminal because there is no net charge accumulation inside this element. So, you have to determine the i-V characteristics and that will tell you what this element is, what it behaves like and so on. And to do that you either apply a voltage source with the value V and determine i or apply i and determine V. So, this is the systematic procedure that you will use reputedly.

So, in this course, later you will see, you will be asked like what is the equivalent of this circuit or that circuit and the way to find out is by applying the voltage and determining the current or applying a current and determining the voltage. So, now let us do that for our combination

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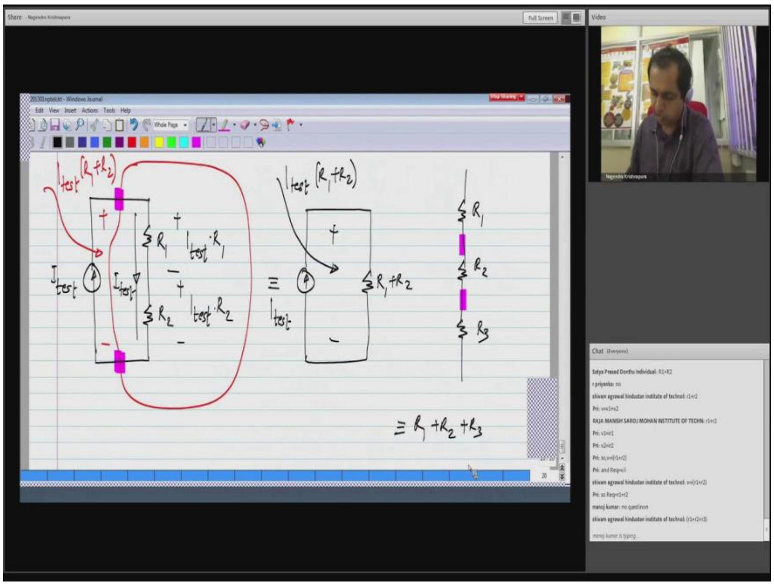

In this case, what I will do is apply a current i, I will call it i test because we are using to test what is happening between these two terminals. And it is clear, that this i test will go through R 1 and R 2 because there are no other place for, there is no other place for current to go. We do not have nodes with more than two branches, so there is no other place for the current to go. So, a current i test flows here and the current i test is flowing through R 1. It will have a voltage i test times R 1. Current i test is flowing through R 2, it will have a voltage of i test times R 2.

So, between these two terminals I will have a voltage, which is this plus that form KVL because this voltage plus that voltage minus this voltage taken from bottom to top, that will be 0. So, the voltage in this direction would be i test R 1 plus R 2. So, the voltage drop is proportional to i test and proportionality constant is R 1 plus R 2. And if you know, that if you have this resistance, the voltage across that will be i test R 1 plus R 2.

Now, this looks like lot of work for designing something so simple, but everything that you do, everything about complicated derivations will be things like this. It will be based on a systematic application of Kirchhoff's current law and Kirchhoff's voltage law and also the relationship that governs each element. So, that is why, I showed this to you. Yes, please go ahead with the question. What is the question? Please go ahead with the question, Manoj Kumar, ok.

So, a series combination of resistors will give a, will be equivalent to a single resistor whole value equals to the sum of resistors. So, you can have many resistors in series, R 1, R 2, R 3, etcetera. When you have things in series, these intermediate nodes should not have any other connections. This point should have only two elements, R 1 and R 2, like here this has R 2 and R 3 and so on. If you have something else is going here, you cannot say, that R 1, R 2 and R 3 are in series. You also have to look at what is connected to this one. So, in this case, this is equivalent to a single resistance R 1 plus R 2 plus R 3.

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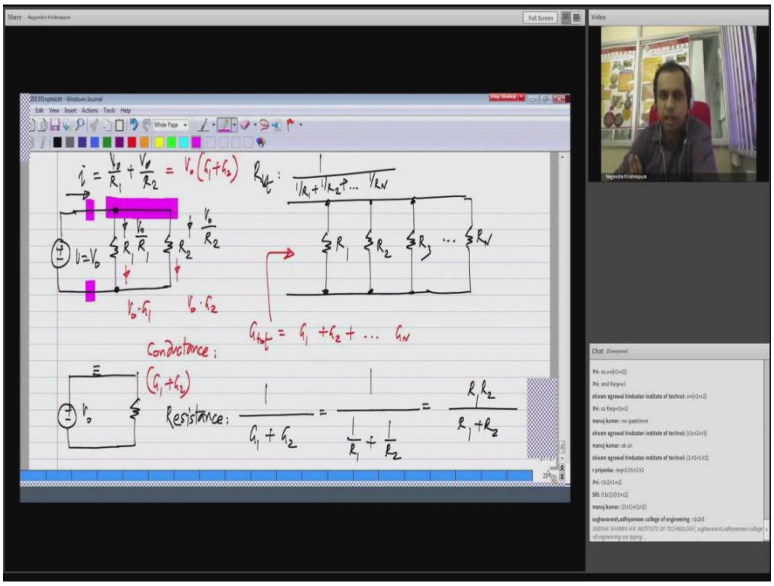

Similarly, if you have resistances in parallel we can determine what it looks like between these two terminals. And let us say, apply voltage V and I try to find the current. So, what I do is, I will connect a voltage source V equals V naught and find out the current. Now, it is clear, that this voltage V naught appears across R 1 as well plus across R 2. So, this current here would be V naught divided by R 1, the current through R 2 would be V naught divided by R 2. And by applying KCL here at a node, we get a total current to be V naught by R 1 plus V naught by R 2. So, the current is proportional to the voltage, which means, that it is a resistance or a conductance and the proportionality constant would be the conductance ok.

Now, if I write these in terms of conductances, the current here would be V naught times G 1, where G 1 is 1 over R 1 and the current here is G naught time G 2, where G 2 is 1 over R 2. The total current can also be written as V naught times G 1 plus G 2. So, this is equivalent to a single resistance whose conductance is G 1 plus G 2. When I write this, it means, the conductance is G 1 plus G 2 or the resistance is 1 over G 1 plus G 2, which is 1 over 1 by R 1 plus 1 by R 2, which gives you the well-known formula of two resistors, R 1 R 2 by R 1 plus R 2. For more than two resistors, formula will not look so simple.

So, it is much simpler to think of conductances when you think of resistances in parallel. The conductances will add up. And if you have more than two resistance in series, the resulting conductance will be the sum of individual conductances and from that you can calculate the resistance. So, let us say we had n resistances in parallel, the total conductance would be the sum of conductances, where G is 1 by R 1 and so on and total resistance would be the reciprocal of that.

So, this again is obtained by the simple experiment of connecting a voltage source and finding the total current. You can also find, apply a current source and find the voltage, will give you the same answer, but it will be slightly more cumbersome because when you have elements in parallel, the voltage is the same across the elements. It is easier to do it with the voltage source and when you have elements in series the currents are same through the elements. So, it is easier to apply a current source. Now, whether you apply a current source or a voltage source, you will get exactly the same answer. But I am just pointing out, that using the voltage source or the current source may be convenient in some cases.

Any questions on what we have done so far? Please go ahead. Any questions?

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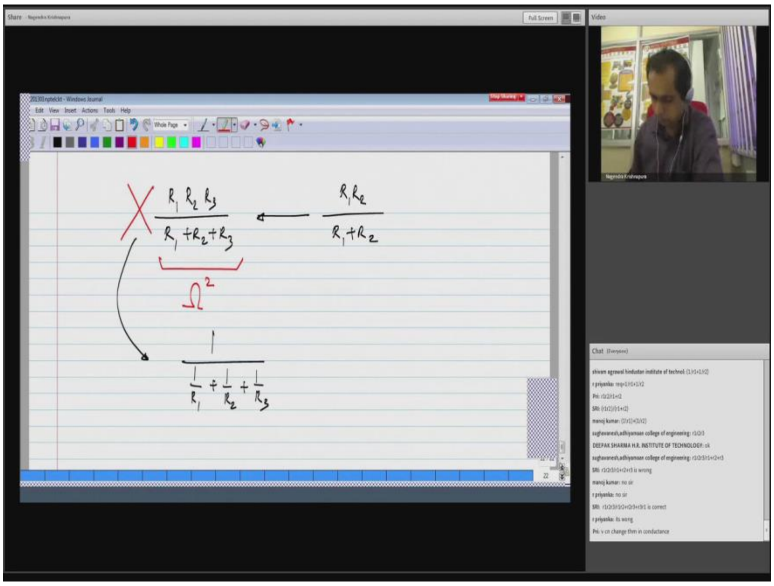

There were no questions, but somebody said if you have 3 resistances in parallel, the effective resistance would be R 1 R 2 R 3 by R 1 plus R 2 plus R 3. Now, I assume this person obtained this as an extension of R 1 R 2 by R 1 plus R 2. But our, somebody already responded this is not correct. In fact, this cannot be the formula for a resistance. If you look at the numerator, you have product of three resistances. So, the product is Ohm cube and bottom you have Ohms. So, this will have dimensions of Ohms, unit of Ohm square. So, this is not a resistance at all. So, you cannot extend it like this.

What is true is, that the resistance would be 1 by 1 over R 1 plus 1 over R 2 plus 1 over R 3. It will be R 1 R 2 R 3 divided by the pair wise product and sum of those things and this is very cumbersome to write. So, you may simply leave it as 1 by 1 over R 1 plus 1 over R 2 plus 1 over R 3. So, intuitively it is easy to see, that the conductances will sum up and it is the counter part of the series connection where the resistances will sum up. So, these are the elements we have considered so far.

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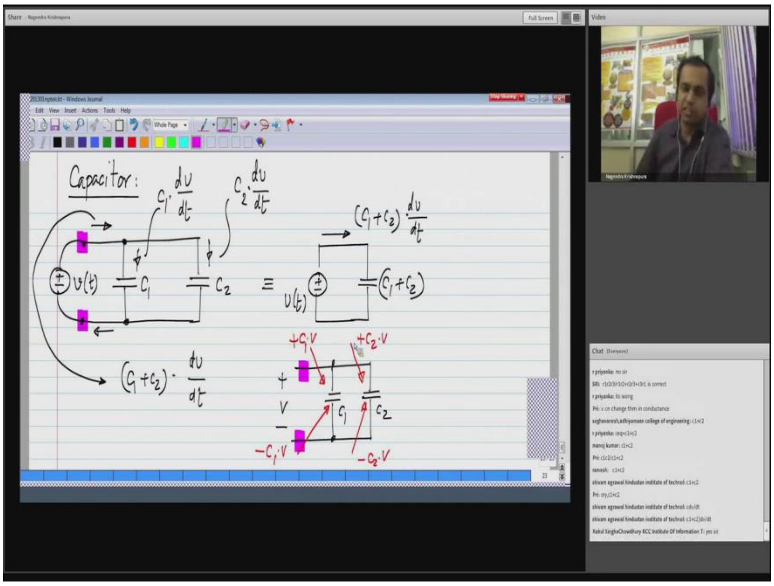


Now, next is, let us say we take a capacitor and we can connect them in series and parallel. So, let me first consider the parallel connection of capacitors C 1 and C 2. So, what will be the equivalent of this looking from these two terminals? In many people who answered this immediately, the answer is C 1 plus C 2. Now, we will see how that is. And again, if you use this procedure systematically, you will get the answer automatically without any confusion.

So, again I have choose to apply some voltage, V of t, by the way. And independent voltage source means, that the voltage value is independent of what current is flowing through it. The voltage value itself is dependent on time. Now, in the initial part of this course, we will by and large look into voltages, which are constant with time, but the voltage can be independent, the voltage can be dependent on time. And an independent voltage source really means, that the voltage value is independent of the current flowing through it.

So, here I have to apply a timer in voltage because if the voltage is constant, we know, that no current can flow through the capacitor. If I do that, C 1 has a current, voltage V of t across it and C 2 also has V of t across it, ok. So, the current through this would be C 1 times time derivative of V of t and the current here is C 2 times time derivative of V of t. So, the total current drawn from the voltage source is C 1 plus C 2 times time derivative of V of t. So, obviously this is exactly equal to having a single capacitor of value C 1 plus C 2. The current going in here will be C 1 plus C 2 times derivative of V. So, parallel connection of capacitors will give you an equivalent capacitance, which is the sum of all the parallel capacitors.

Another way to think about it is, if you have multiple capacitors with a voltage V, then on this capacitor you will have a charge plus C V on the upper plate and minus, sorry, plus C 1 times V on the upper plate minus C 1 times V on the lower plate. And on the second one, you have plus C 2 times V on the upper plate and minus C 2 times V on the lower plate. So, if you associate this terminal with one plate and this terminal with the other plate, you will see, that on the effective upper plate you have C 1 plus C 2 times V and that tells you the capacitance of C 1 plus C 2, ok.

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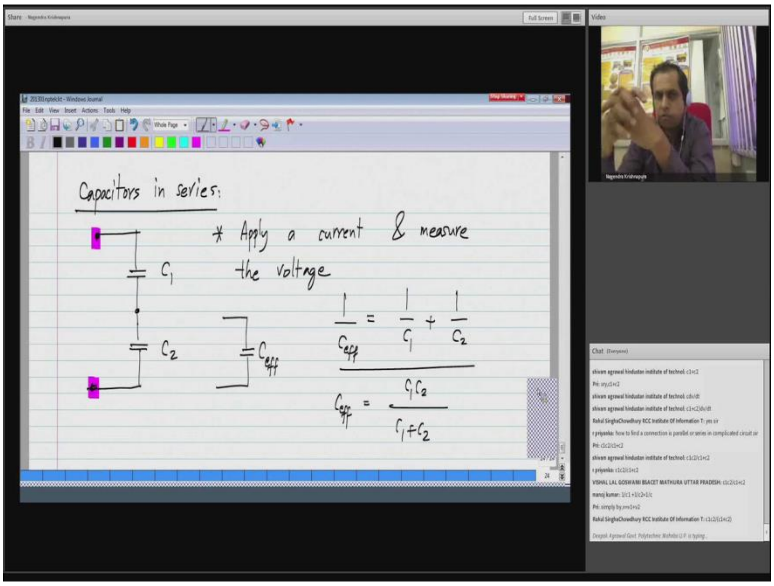


Similarly, if we have capacitors in series, what will be the equivalent looking into these two terminals? What is it going to be? I am not going to show this. If at all any of you is not clear about it, you can derive it yourself. Again, I will say, that you derive it while understanding every step of procedure. You apply current and measure the voltage. The result turns out to be a single capacitance C effective and 1 over C effective will be 1 over C 1 plus 1 over C 2, ok.

Or for two capacitors you can have this formula, C 1 C 2 by C 1 plus C 2. So, a parallel combination of capacitors, you get the sum of capacitance, a series combination of capacitance, you will get a formula similar to that of resistance in parallel. The reciprocal of the total capacitance will be equal to the sum of reciprocals of individual capacitances when you connect capacitance in series.

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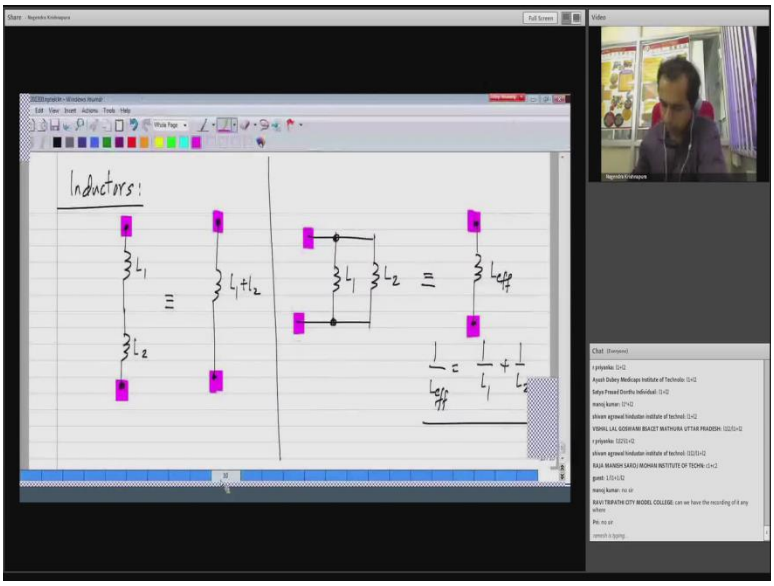


And exactly the same thing can be done for inductors. I will not work it out, I will leave it as an exercise to you. If you have any difficulty, try to work it out again following every step rigorously. If you have any difficulty, we can, you can raise the question and we can discuss in one of the following lectures, ok.

So, we have a series combination of inductors. What is this going to be equivalent to? As many answered correctly, this will be a single inductor of value L 1 plus L 2. And if you have 2 inductors, L 1 and L 2, in parallel, this will be equivalent to a single inductance, L effective and reciprocal of L effective, will be the sum of reciprocals of all these inductance values. So, you can derive these things on yourselves by applying a voltage or a current and finding the result in current or voltage through the combination.

When I say equivalent, there are these two terminals and these two terminals, and between them the electrical behavior is equivalent, that is, i-V relationship is equivalent. That is what is meant by equivalence.

Any questions so far?

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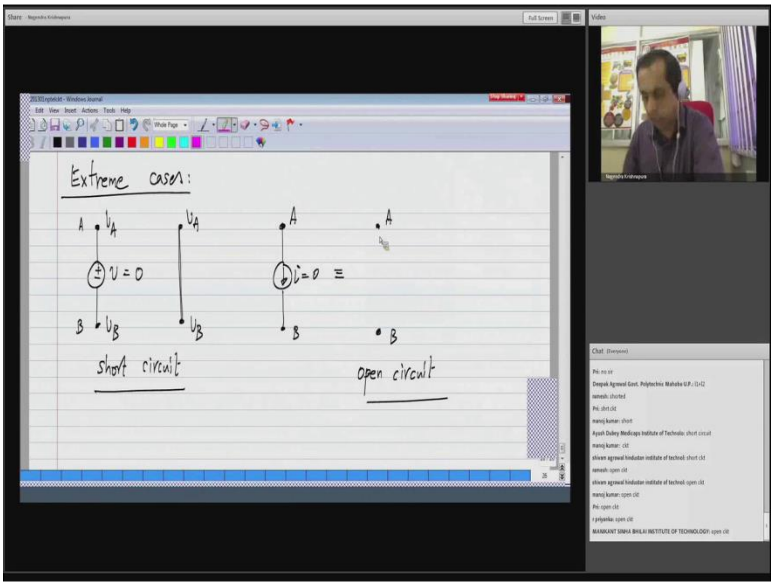


Now, we can look at certain extreme cases of element values. Now, let me start with a voltage source. Now, you can call these terminals A and B if you wish and I will say, that the independent voltage source value is 0. So, what will this be equivalently between A and B. My question is, we have an independent voltage source whose value is 0, so what is that equivalent to?

So, as many people mentioned, it is equivalent to a short circuit because again if this be equal 0, the voltage at node A has to be exactly equal to the voltage at node B, ok. So, that is like tying these two nodes together with a wire. So, this is a short circuit.

And similarly, let us have a current source whose value i equals 0. What is this equivalent to between A and B, nodes A and B? Again, the answer is pretty obvious. This is equivalent to an open circuit. An open circuit, by definition, does not allow any, any voltage, any current between them. So, if you have an open circuit between two nodes that means, no current can flow from A to B and this i equals to 0 means exactly that.

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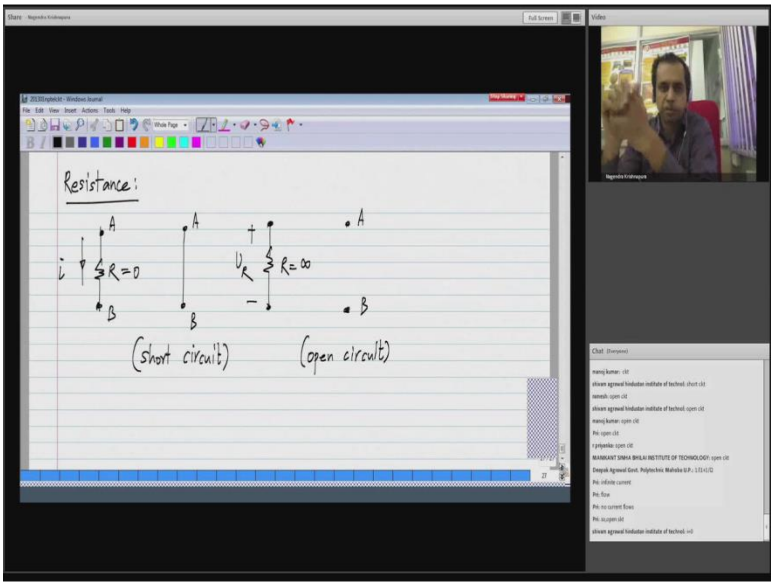


And similarly, for a resistance R, so let us say R equals 0 and the voltage drop will be i times R. If R equals 0, the voltage drop will be 0. That means, V A will be equal to V B and it is equivalent to a short circuit. So, resistance of 0 means, that it will short the two nodes between which it is connected.

And a resistance of infinity could mean, that it is an open circuit if the resistance of infinity. That means, whatever voltage you have across this, the current through this, which is V R divided by R as R tends to infinity will go to 0. That means, no current will flow through this nodes through this branch. So, that is an open circuit. So, an infinitely large resistance is like an open circuit.

Now, why are we looking at these things? Sometimes we have to evaluate these extreme cases. Sometimes also, we want to reduce the value of some elements to 0 or infinity and then see, what happens to the circuit, ok. So, if you know whether it is a short circuit or an open circuit, you can very easily evaluate.

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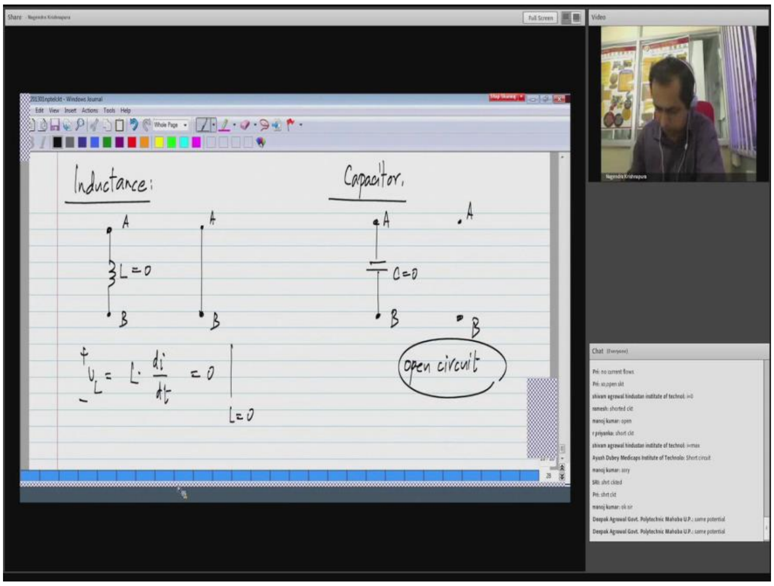


And let us say, I have an inductance L and L equals 0, and what would this be equivalent to? As many people said, this will be equivalent to a short circuit between A and B because the voltage across the resistor equals L times the time derivative of the current, and it will be 0 if L equals 0. So, regardless of the current, the voltage will be 0, that means, a short circuit. And similarly, if you have a capacitor which is 0, this is an open circuit.

So, we looked at extreme cases of certain elements.

Because of some problem, my browser closed instantly and because of that the connection got broken. But now it is back up, I believe.

We looked at extreme cases of these elements and in some cases they become open circuits and in some cases they become short circuits.

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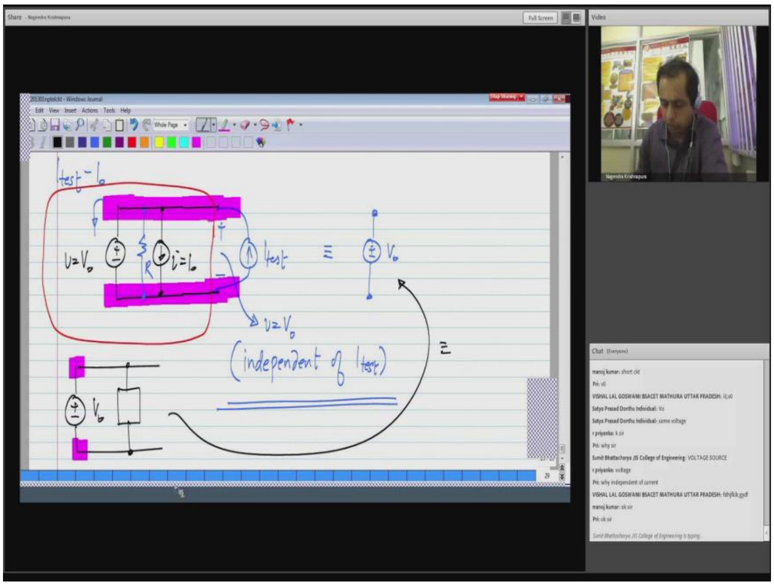

Now, we can look at couple of other special cases. So, let me say, that I have a voltage source V equals V naught and a current source i equals i naught in parallel. My first question is, is this connection allowed? For instance, we could not connect two voltage sources in parallel or current sources in series, now I have a voltage source and a current source in parallel, is this ok? Ok, looks like all of you agree, that it is possible.

Now, I have these two terminals here, what will it look like between these two terminals, this combination? They have a parallel combination of voltage source V naught and a current source i naught, so form the two terminals. What will the combination look like? Now, when I say what it looks like, you have to tell me if it looks like some simple element that we have already discussed. For instance, when we had two voltage sources in series, it still looks like a voltage source, but whose value was some of the individual values. Similarly, what will it look like here? I hope the question is clear.

Now, the way to answer this question is like you do for any other circuit. So, you have these two terminals and you have to either apply voltage and find the current. So, let me draw a box around this. What I am trying to find out is what the circuit looks like between these two terminals. What we have to do? We have to either apply a voltage and find the current, or apply a current and find the voltage, ok.

So, let me ask you this. If I apply a current i test and measure the voltage here that is developed, what will that be? Ok, looks like that the question was not clear. My question is, I have this voltage source and a current source in parallel and this is not very different from having, let us say, two resistors in parallel and so on, right. In principle, it is similar problem. You will end up with 2 terminals and you have to find out what the circuit looks like at those two terminals because I can have a box around this whole thing and I can call it two terminal element; there are only two terminals.

Now, the way to determine what any electrical two terminal element looks like is to either apply a voltage and find the current, or apply a current and find the voltage. So, in this case, I have also applied the current i test and I am asking you to find out what it, what the voltage developed is. So, what is the answer? Clearly, this voltage source will enforce the voltage between these two nodes to be exactly equal to V naught regardless of what current is flowing through it. So, the voltage across these two terminals will be equal to V naught and this is also independent of the current we have applied.

So, what does it mean? If the voltage value is independent of the current that is applied, that means, that what is the equivalent element. So, we have this voltage source here, what does it mean to have an independent voltage source? It means, that the voltage between its terminals will be always equal to V naught independent of how much current is flowing and those two terminals are exactly the same terminals that are coming out. So, between these two terminals here, we have V naught independent of i test, whatever current you apply.

By Kirchhoff’s law you know, that the current that is flowing through the voltage source is i test minus this i naught, but that is not relevant. How much ever the current is flowing through that, it will always maintain V naught. So, this entire thing is equivalent to a voltage source of value V naught.

Now, it does not matter if you connect a single current source or multiple current sources. I could also connect a resistor here. In fact, I can connect anything I want. I can have a voltage source and connect any other complicated circuit, I will not show what it is, but it is not relevant because this voltage source will say, that voltage between these two values is V naught, ok. So, this whole thing is equivalent to just a voltage source of value V naught. Any questions about this?

Now, somebody asked, if you measure the current will it become a current source? No, that is not the case because whichever way you measure it, first of all, because it appears like a voltage source, you will not be not be able to connect the voltage source and measure it. You will get an inconsistent condition. Now, this can sometimes happen. I said, that to test what a circuit looks like between two terminals, you can either apply voltage or apply current. And if you apply voltage, you measure the current and if you apply the current, you can measure the voltage.

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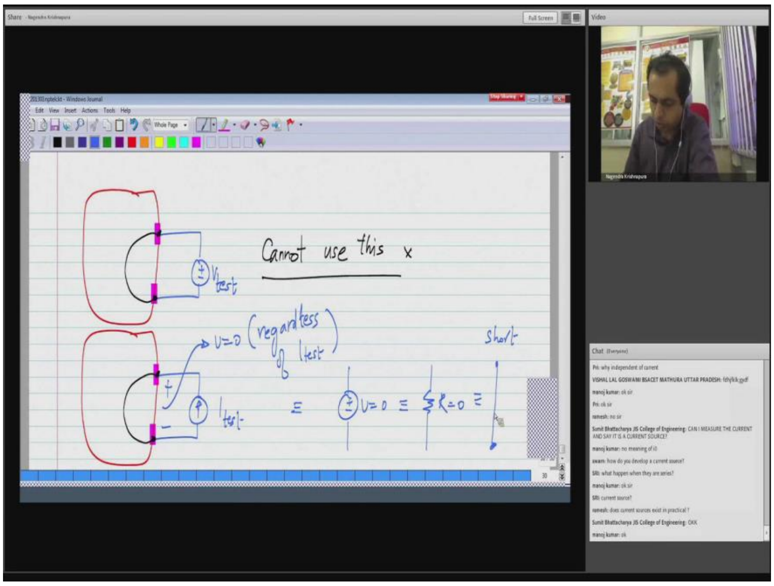


Now, there will be circuits where one or the other of these things will not be possible, that is, let us say, that I have this silly circuit inside a box. I have these two terminals and this is the black box. I will just close it and give it to you and I have a short circuit. Now, what happens? Clearly, you cannot apply a voltage to this. If you do this you will see, that you will get an inconsistent condition.

In fact, somebody asked this question right at the begging of the lecture. If you have a voltage source and you apply a short circuit across a voltage source what happens? You can see, that this is a sub case of having two voltage sources in parallel and one of the voltage sources being 0 because 0 volt voltage source is a short circuit.

So, what a source, which is short circuited, is equivalent to a voltage, two voltage sources in parallel whose values are not equal. So, that is not possible. So, in this can, you cannot find what is inside by applying a voltage source because that gives you an inconsistent condition. Now, this can happen many times. So, now, this circuit is so simple, by looking at it you say it is a short circuit. But in reality, the circuit that you are analyzing will not be so simple. So, it could be, that you apply a voltage source and go through the calculations and you will find, that you cannot, you will get some inconsistency or you will start getting ((Refer Time: 1:07:00)) in the calculation. In that case, you abandon that and you apply a current source and see what is happening, ok.

Now, for the same circuit if I apply a current, let me not say V naught, this was V test, what I applied to find out what is in the circuit, and I apply i test to find out what is inside. So, what it means is, what it says is, because it is a short circuit regardless of what current is flowing there, this node and that node will be at same voltage. So, this voltage will be 0 and this is 0 regardless of i test. So, what does it mean?

You can think of it as either 0 volt voltage source or a 0 resistance or a short circuit. All of these are anyway equivalent to each other; all of them are short circuits. So, that is why, in this particular example, we cannot apply a voltage source and find the current because there is already a voltage source inside. If you apply V test here and you work out the KVL equation, you will see, that the total voltage around the loop would be V test minus V naught, which is not necessarily 0, ok. So, that can happen.

So, it is not that you apply voltage here and find out the current, it looks like a current source. It cannot do that at all. I hope this last part was clear. What I was trying to say is, in principle, you can apply a voltage source, find the current or apply a current source, find the voltage. For some particular circuits, one or the other, these may not be possible.

Now, one of the other questions is, do current sources exists in practice? Yes, they do. Now, in this course we will not worry about how to make them, but those of you who take courses on analog circuits know, that there are elements known as transistors with which you can make some things, which are very good approximations to current sources. And sometimes some natural sources of signals like photodiode and so on, also behave more or less like current sources.

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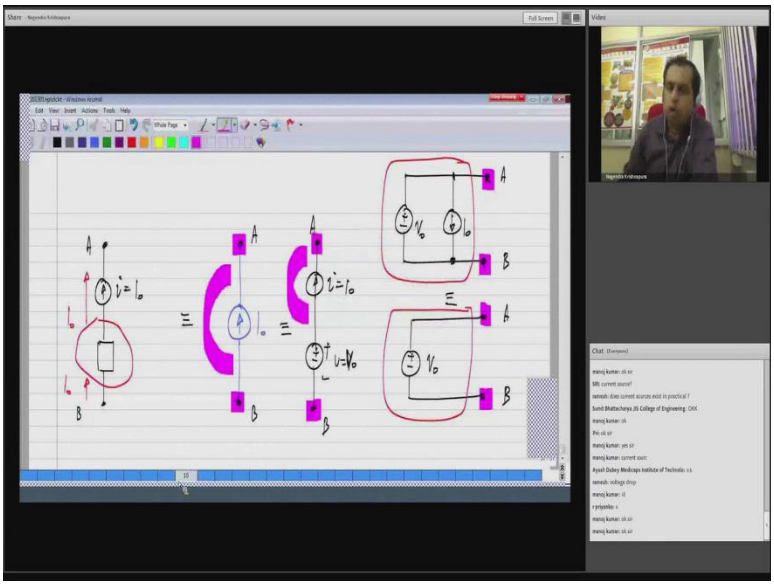

Now, the counterpart of this is a current source in series with some elements. What is this equivalent to? I think all of you should be able to answer this pretty quickly now. When I say equivalent to, between terminals A and B. So, again few of you have answered. It is very clear, that current i naught will be flowing here because of the current source and if you think of this entire boundary, the current i naught has have also to be flowing there because there is no local charge accumulation anywhere. So, the current cannot go off into some other place. So, between these two, it is equivalent to a single source of value V naught.

So, as far as the terminals A and B are concerned, a current source, an ideal current source in series with something will look exactly like the current source. And this also applies to, if you have a current source and a voltage source in series, the equivalent is the current source just like when we had a current source and a voltage source in parallel, the equivalent was a voltage source. Is this clear?

Now, all of these things become useful. Sometimes what happens is, in circuits you will find these things in this fashion. The voltage source will be in parallel with probably a very complicated thing. You do not have to worry about all that complicated stuff. If all you are interested in is the voltage across the voltage source terminals, that will be equal to V naught regardless of what it connect to. Similarly, a current source will maintain a current flow of i naught regardless of what is connected to it.

Now, there will be some difference between these pictures, that is, when I say voltage source and current source in parallel. And let us say, this is connected to or let us say it is just not connected to anything else. Now, we know, that this is equivalent to the single voltage source. When I say equivalent, we have to be careful where they are equivalent. As far as these two terminals are concerned, A, B, they are equivalent. That is, if I gave you this whole thing in a box and this thing in a box, you will not be able to tell the difference without opening the box.

Now, there will be, I mean, something different, that is, for instance, let us say, nothing is connected to it in this particular, in the upper box. A current of i naught is flowing through V naught and here nothing is flowing through V naught. So, the internal details will be different. But as far as the terminals, the external terminals are concerned, the behavior will be exactly the same. So, when we say equivalent, we have to also be careful about what exactly is equivalent between the different circuits.

Similarly, if you have a current source, a current source and a voltage source, as you see from these two terminals, everything is exactly the same. What will be different is the voltage drop across the current source here and the voltage drop across the current source, there will be different. I hope this is clear.

So now we have extensively discussed what happens when you connect elements in series and parallel. Lot of this is very simple step and many of you already knew the expressions for many of them. But what I want to emphasize is, that everything can be derived from the basic laws of circuits, Kirchhoff's voltage law and current law and the behavior of each element. We have definitions of what is a resistor, what is a voltage source, what is a current source. From the basics you can derive all these other external, all these other additional stuff.

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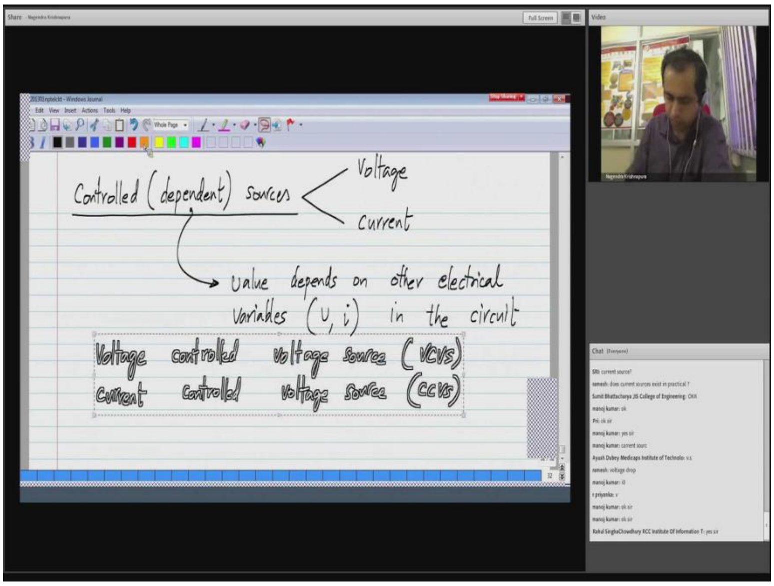


Now, before I end the lecture, let me just introduce you to a new type of element, which are known as controlled or dependent sources. We have looked at independent current and voltage sources. These controlled sources will also be either a voltage or a current source.

But what is meant by controlled or dependent is, that value depends on other electrical variables, that is voltage or current in the circuit, that is, let us say you have a controlled voltage source, its voltage value depend on some other voltage or some other current.

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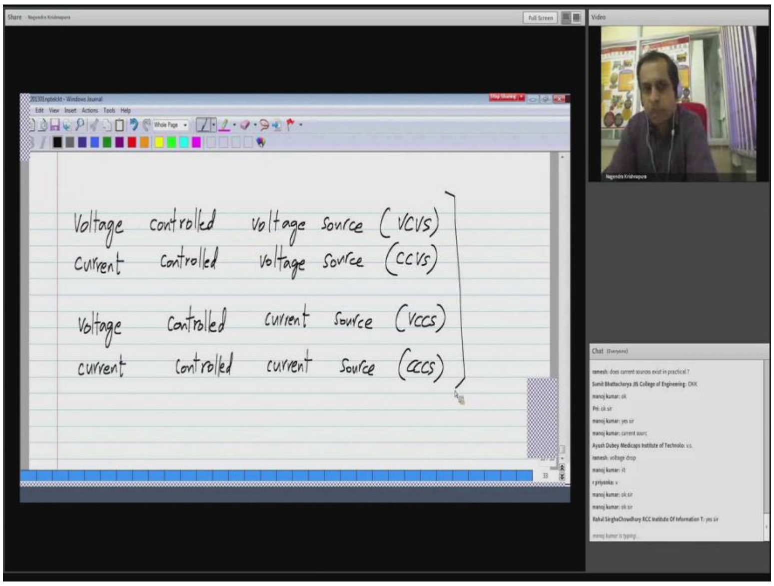

Now, based on what kind of source it is and what it is dependent on, we have four types of controlled sources. We have a voltage controlled voltage source, which means, that its voltage is dependent on some other branch voltage in the circuit, some other voltage in the circuit. And we have a current controlled voltage source, CCVS, which means, that the voltage source value depends on some branch current. And similarly, we have current sources, we can have voltage controlled current source, VCCS and a current controlled current source, CCCS.

Here was lost temporarily, that is why it was broken. But as I was saying, we will look at controlled sources in the next class, which is not going to be this Thursday, but next Tuesday. Now, are there any questions about this today's lecture? Yeah, there are questions about recorded session. Yes, the recorded sessions will be put up online. I think there was some delay in putting up the recording of the previous lecture, but everything will be up shortly.

Please go ahead. There is a question. Hello Pri, P R I, please ask your question. I think, there is a question from Priyanka. When is the test? It is not decided yet, but we will announce it sufficiently in advance. At the other terminal the network connectivity was lost, so I will try to answer some of the questions.

Now, I hope this, Swarna, I am not sure if you heard my answer. If current source and voltage source are in parallel, how do we calculate the current? Now, current source and voltage source in parallel, is exactly equivalent to a voltage source and the current will be determined by whatever circuit is connected to it, not by the voltage source. So, if you have details of that circuit, you can find out the current.

Then, let us see, what is the average current in a capacitor? Now, these are, I have to enforce some conditions on the operation, but you can consider the average current in the capacitor to be 0. Now, you can violate this by forcing non-zero average current into the capacitor, but we will not discuss those things here. There is something known as steady state. If you, if your circuit reaches steady state, then the average current in the capacitor will be 0.

Then, which book should be followed for numericals? I think book by Hayt and Kemmerly has very large number of example problems, I think you can use that, and the exact reference and the edition are given on the website. The next session will be on the next Tuesday, not this Thursday. Now, there is also another question, what will be i-V curves of practical independent voltage and current sources? We will take it up later, we will be able to do that.

Then, thank you all for attending, we will close for today.