Circuit Theory
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Lecture - 2
Review of Signals and Systems (Continued)

Second lecture on circuit theory and the topic is review of signals and systems continued. We did some in the last lecture and we ended up in the definitions of passivity, a passive network and then we also discussed what we mean by a linear network. The next concept that we talk about is bilateralness, bilateral or unilateral. This refers, this term refers to a 2 terminal element, a 2 terminal element, a network element which has only 2 terminals or 1 port and therefore, all you can do is connect a voltage source, measure the current, or connect a current source and measure the voltage all right. Now a device, a 2 terminal element is called bilateral if it can pass current equally well in both directions. That is, if you connect a voltage source here, with this polarity, current passes like this and let this current be capital I then, if you interchange the polarities that is, if you change the polarities to, let us say, this is minus and this is plus then the current will pass in the other direction and the same current should pass, then it is called a bilateral element, bilateral, the term bilateral refers to a 2 terminal element.

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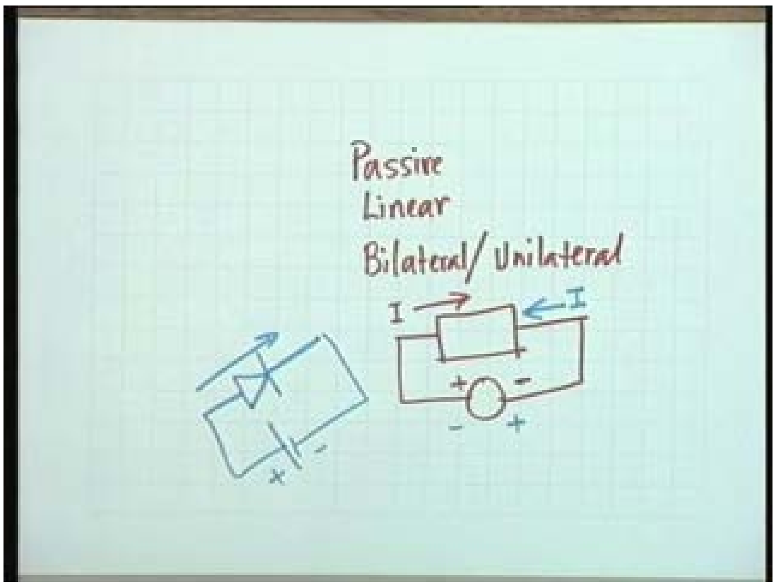

Student: Sir, this is applicable for both active and passive circuits?

Sir: both active and passive circuits. Yes.

Student: And this is for when you connect a voltage source.

Sir: Or a current source. If you connect a current source here then there is a polarity of voltage. If the current source is reversed the polarity of the voltage should reverse the magnitude should remain the same. This is called a bilateral element. On the other hand, if it does not happen, if on changing the polarity of the voltage, the current polarity changes but the magnitude also changes then, it is called a unilateral element and the most common example of a unilateral element is a diode. A diode as you know, conducts very well in the forward direction, that is, if there is a voltage source connected like this, it conducts as if it is a short circuit, an ideal diode. On the other hand, if this polarity of the voltage source is reversed then it acts like an open circuit, the current almost reduces to 0. The diode is an example of a unilateral element. If I now make a statement whether, if I now ask you a question, whether a transistor is unilateral or bilateral, your answer should be the question is, question is Ill-posed, because it is a 3 terminal element, all right? But if I say, between emitter and base, is it unilateral or bilateral? Yes, it means, it makes sense it is unilateral. What about between collector and base?

Students: Unilateral.

Sir: Okay, collector and emitter?

Students: unilateral.

Sir: Unilateral, and what is the reason? Because the surface area of the emitter and the surface area of the collector are quite different and therefore, the amount of current that flows when the battery is connected in one polarity will be quite different from the amount that happens if the battery polarity is reversed. This is because of the change of surface area. Therefore, you understand what is unilateral and what is bilateral.

A network, a multi terminal network instead of 2, 3, 4, 5, 6 or n number of terminals having a number of cores, if it consists of unilateral elements only, then such a network is called a reciprocal network.

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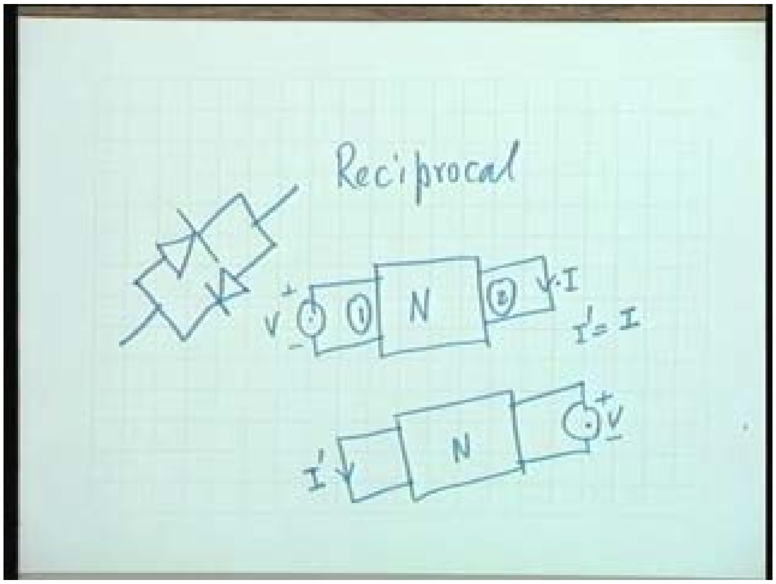

If a network consists of unilateral elements only, then it is called a reciprocal network and the reciprocity is formally defined like this. We will come to the fine details of reciprocity a little later but reciprocity is formally defined like this; that if the cause and effect are interchanged, a reciprocal network is one in which, if the cause and effect are interchanged, the relationship between cause and effect does not change. Let me repeat, a reciprocal network is one in which if the cause and effect, we have given different terms to cause and effect we have said cause is an excitation and effect is a response. So let us redefine it in terms of excitation and response. A reciprocal network N is one in which, if the excitation and the response are interchanged, the relationship between them does not change. For example, if you connect a voltage source here and measure, let us say, the short circuit current I. This is port 1, this is port 2 and then, if you take the same network and interchange the excitation and the response, that is, connect the voltage source here V and measure the short circuit current here. Okay? Same voltage, the network would be reciprocal if I prime is equal to I. The relationship between them does not change, that is, if it is the same source then the response should be the same. Now, if the source is doubled, let say the source is not the same, if it is doubled, then, the current should also be doubled. In other words, the ratio of the response to excitation remains the same and this is what we mean by the relationship between the excitation and the response. Yes? What is the question?

Student: Sir, the network should consist of unilateral elements or bilateral elements?

Sir: I am coming to that question later, but let us make a definition first of reciprocity. I repeat, a network is reciprocal if an interchange of excitation and response does not change the relationship between the excitation and the response. If it does not happen, then it is non reciprocal. The question that was asked is; if the network N consist of unilateral elements only then it is definitely reciprocal. On the other hand, if it contains bilateral elements, if it contains, I am sorry I made a mistake. If the network contains only bilateral elements, then it is definitely reciprocal. If the network contains only bilateral elements there is no question of non reciprocity, the network shall be reciprocal. On the other hand, if the network contains some unilateral elements, there is a possibility that the network may be non reciprocal. It is not necessarily non reciprocal. For example, if you have 2 diodes connected back to back; identical diodes, this contains 2 unilateral elements, but as a whole, this is a bilateral network because it passes current equally well in both directions.

Student: Sir but as a whole if we see it, it is a unilateral, bilateral.

Sir: That is what I am saying.

Student: So, then, suppose it is a network in a black box, then we cannot say that whether it contains any unilateral part or not.

Sir: Correct. If it is a black box like this, the only test that you have to do is to connect an excitation, measure the response, then interchange the 2. But this is the way of testing also.

Student: Say so for multi terminal if, suppose, we will be saying that, for it being a bilateral, there if 1 terminal must be bilateral with respect to all other terminals?

Sir: For a multi terminal network the question is, for a multi terminal network how do you establish reciprocity? You shall have to test all the ports. It is not sufficient to test 1 excitation and 1 response. You will have to go round and test for all of them. The network at, is at a couple of ports may be reciprocal. It may not be so at another couple of ports. Therefore, the question has to be answered very carefully. Let me repeat, if a network consists of bilateral elements only, it is definitely reciprocal. If a network contains in addition unilateral elements also, it may be reciprocal, it may not be reciprocal. It is only by carrying out the tests or by looking at the internal construction. Suppose we have 2 identical diodes back to, back to back, like this, not back to back, connected in parallel in opposite direction then, definitely, it is a bilateral network, bilateral network, okay? Bilateral element and if a network contains such a pair, you can say yes, it is a reciprocal network so one has to be careful about the definition of reciprocity.

Student: Excuse me sir, in a multi port network say, if it is true for, if it is reciprocal for only 1 pair of ports but not for the others, then can we call it as reciprocal?

Sir: We have to make it conditional. You have to say N is reciprocal with respect to ports i and j otherwise, we cannot say. We have to be very guarded. We cannot say anything otherwise, all right? We have to we have to qualify this.

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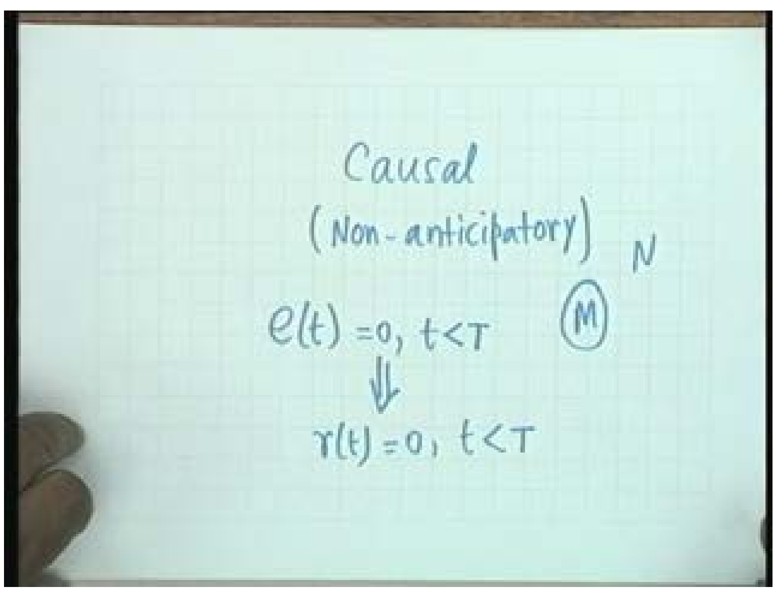

Next term that we apply, this is the kind of network that we shall study causal. Causal is a word which has been defined in signals and systems and the other name for causal, the common name for causal is non anticipatory. That is, it is a network which cannot anticipate, in mathematical terms if e, e of t, of the excitation, this excitation could be a single excitation or an excitation vector; if it is a multiport. Let us say an N port M of which are excited, then small e can stand for a vector, e 1 t, e 2 t up to e n t. So if the excitation is equal to 0 for t less than capital T, if the excitation is 0 for up to an instant of term capital T, then a causal network is one in which the response, which could also be a scalar or a vector response, is also 0 t less than T. This is called a causal network or an non anticipatory network. In other words, the output cannot precede the input. If the input is 0, the output has also to be 0, output cannot precede the input or the network cannot anticipate what shall be applied to its input in future.

Student: Sir, cant it even be a constant, the response?

Sir: The response can be a constant but if the excitation is 0 then, it is not a causal network. Okay?

Student: Sir, would not this be in the case only of linear networks?

Sir: Only in the case of? No. Non linear networks can anticipate, can also be subjected to such definition; non linear networks can also be causal.

Student: Yes sir, but then do we have the restriction that if e t is 0 then r t also has to be 0?

Sir: It has to be 0 even if it is non linear; this is the strictest, strict definition.

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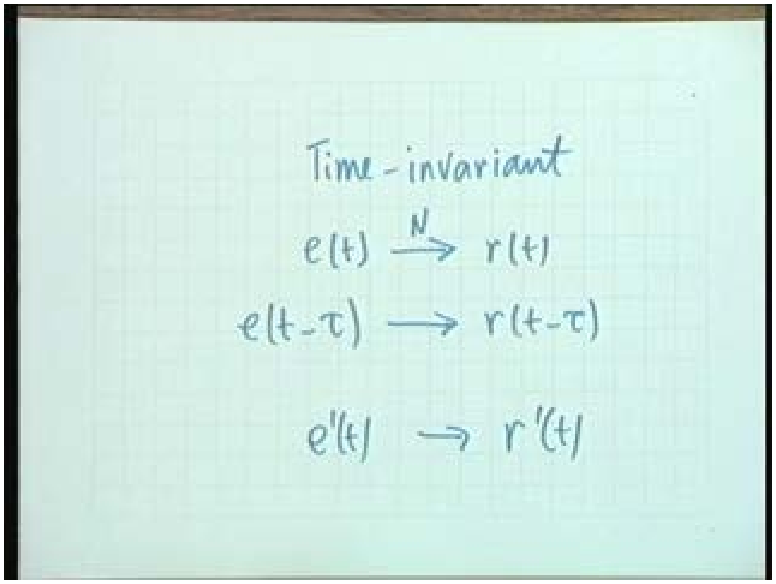

Then the other qualification of our network shall be time invariant. Time invariant network simply means that if e of t, by application to the network leads to a response r of t, then the delaying the input by an amount tau should delay the output by the same amount r of t minus tau. Okay? That is, that is, in popular words, it means that the shape of the wave form, shape of the signal clotted versus time, remains the same. Only thing that changes is the location of the response. Whether you see if e of t leads to r of t and e of t is a square pulse, r of t is, let us say triangular, then r of t minus tau is the response. If the square pulse is delayed, then it is the same triangle which shall be delayed. It shall be moved to the right by an amount tau, so the wave form remains the same; it is only the location that changes and one of the results of time invariance is that if e t leads to r of t then e prime t, that is, the differential coefficient of e t should lead to r prime t. This can be very easily proved, very easily proved and I would encourage you to undertake this proof if you can. So the kind of networks that we are going to discuss in this course will be linear, L for linear, this L we have not yet discussed, F we have not discussed, P we have discussed; P stands for passive and B stands for bilateral, bilateral.

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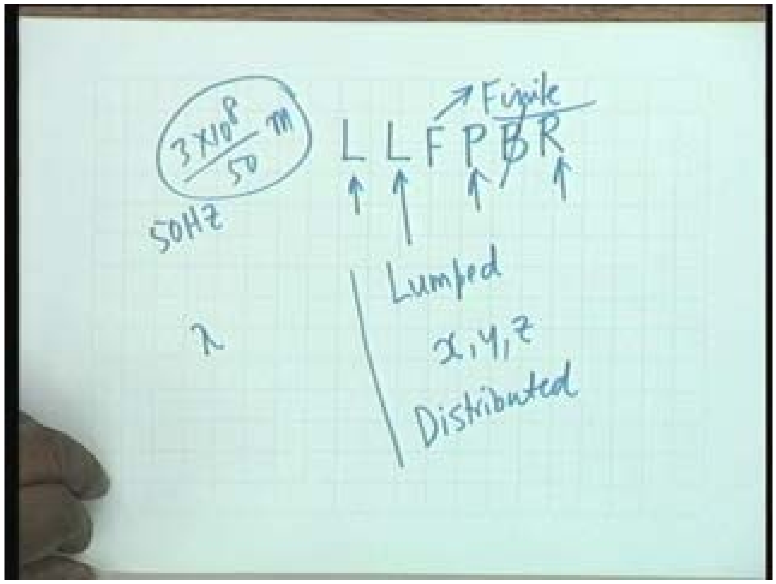

Now, it is in historical context that what B is there, it should actually be replaced by R, that is, we are going to talk of linear, passive and reciprocal network. This B stands for bilateral; it should actually be replaced by R because bilateral or unilateral refers to a 2 terminal element only. Now let us look at, let us look at these two. This L stands for lumped, lumped, this L stands for lumped, a lumped network is one in which the electrical effects can be thought to be concentrated at a certain point in space. A lumped network is one in which the space variable x, y, z are of no importance. The effect that is occurring is occurring at a certain point in space, space variable is not important. On the other hand, if the space variable is important then, it is called a distributed network, a distributed network. For example, the telephone line or the power transmission line, the power that comes from a grid to a substation. Well, it is a distributed network, the definitions of lumped and distributed strictly refers to the dependence or independence of, dependence on or independence from space variables. The other definition is, the other physical explanation is, that a network is lumped if the wave length of excitation is large compared to the dimensions of the network. For example, 50 hertz, if the frequency is 50 hertz; what is the wave length? 3 times 10 to the 8 divided by 50. So many meters and any circuit any power circuit, power supply or an electronic amplifier, whatever you make, is going to be very small compared to this, this dimension, and therefore the circuit can be thought of as lumped.

On the other hand, for a power line going from here to Karnataka, the distance may be comparable, will be definitely comparable to the wave length and therefore the space variable is also important. So, lumped and distributed means, a lump network is one in which the dimensions, physical dimensions of the network are negligible compared to the wave length of excitation. That is, the definition of lumped and then this F stands for finite networks. Being finite beings, we cannot think of infinite but there are infinite networks which, for which a different kind of theory is to be applied. For example, the ionosphere, the ionosphere over the earth, it is a network of charges. There are charges over the earth; ionosphere is responsible for reflection of radio waves and for long distance communication. Ionosphere for all practical purposes is an infinite network for us. We will not be concerned with infinite networks. We will be concerned only with finite network. So this is what we are going to discuss in this course L L F T B

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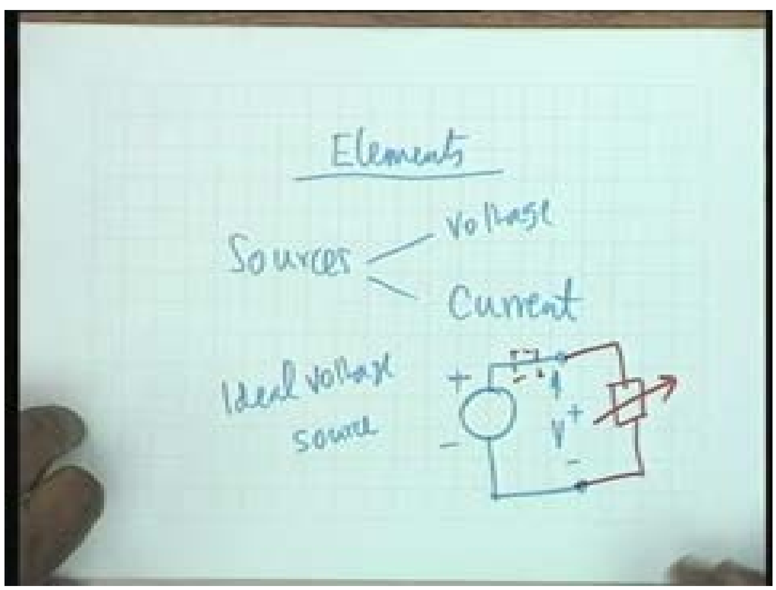

Now let us look at the elements, the circuit elements that we shall be considering, network elements or circuit elements. First we consider sources. As you already know, we can have voltage source or we can have a current source, that there are only two kinds of sources that we shall consider in this course and the description of voltage or current source always comes with an adjective, that is, ideal or non ideal and it is important to understand what is an ideal source. First let us consider an ideal voltage source. An ideal voltage source is one represented like this, with a polarity. An ideal voltage source is one which maintains its terminal voltage, terminal voltage V independent of what is connected as the load, independent of what is connected as the load. In other words, whatever be the current demand from the source, the terminal voltage remains the same. This is an ideal voltage source. An ideal voltage source, in theory, can supply any amount of current whatever the load, except for open circuit. Under open circuit of course, no current can flow. Except for open circuit, an ideal voltage source maintains its terminal voltage constant irrespective of what is connected to it.

On the other hand, if this voltage varies with load, if the terminal voltage varies with what current you are drawing from the source, then it is called a non ideal voltage source and a non ideal voltage source can always be taken care of by a series impedance, that is, an ideal voltage source in series with an impedance can account for a non ideal voltage source. In the case of a battery, it is an internal resistance of the battery. In the case of a general voltage source, it can consist of inductance, capacitance and resistance and therefore, we talk of an internal impedance instead of an internal resistance.

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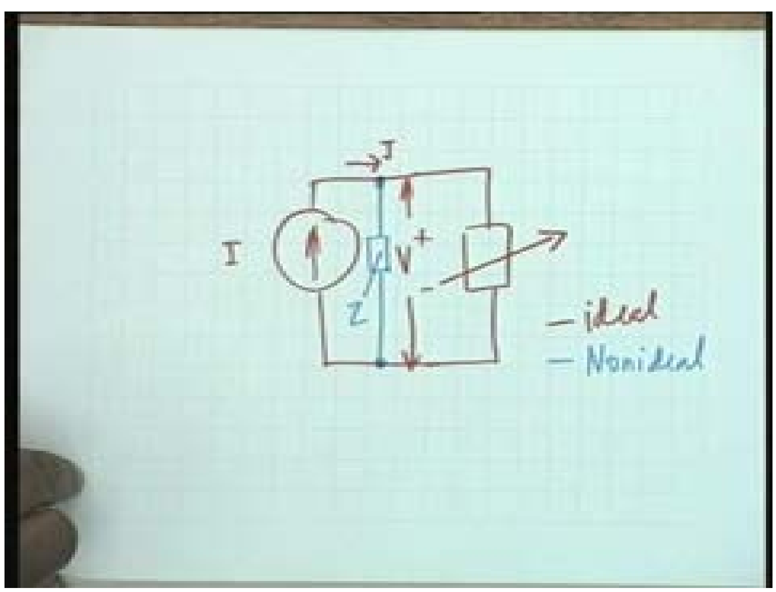

Similarly, an ideal current source is one which maintains the current delivered to a load constant irrespective of what the load is, that is, irrespective of what the potential drop or the voltage across its terminals is, it maintains a constant current. This is called an ideal current generator.
On the other hand, if this voltage changes with the load, that can be accounted for by a shunt admittance, by a shunt admittance which in the case of a resistive current source, will be a resistance and it can in general be an impedance. The blue colour takes care of non idealness, non ideal current source. A non ideal current source is an ideal current source, in parallel with an impedance. In the case of non ideal voltage source, it was in series and the red colour stands for ideal situation. You must be able to distinguish between ideal and non ideal sources. In reality there are no ideal sources. All sources have certain internal impedance or internal admittance. But for the purpose of theory many a times we shall talk only of ideal sources.

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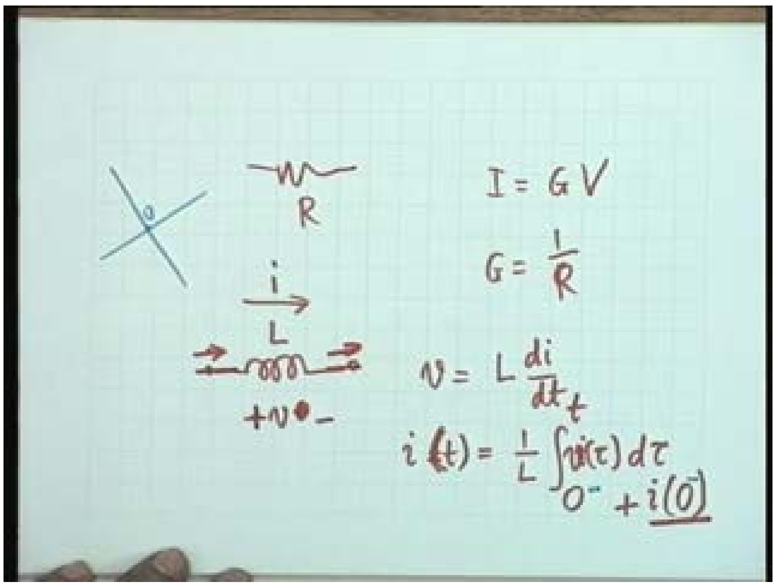

Then we talk of the three elements: the resistance, capacitance and inductance. Resistance as you know, a linear element, a linear bilateral resistance obeys Ohm’s law, that is, V equal to I R or instead of resistance, it can be described in terms of a conductance, its reciprocal, and you can write I equal to G times V. Where capital G stands for one by R and it is called the conductance. A resistance has no memory, it cannot memorize, it cannot hold charge, it cannot hold energy, it is in fact a dissipative element. In other words, if current passes through it, the resistance dissipates or absorbs energy. It is a dissipative element. On the other hand, if you take an inductance L and our notation would be, if this is V then, I beg your pardon, the notation is, if this is V with this polarity, then the current I is taken in this direction and the relationship between voltage and current, as you know, is V equals to L d i by d t, V equals to L d i by d t. Forget about the right hand, left hand and all those rules. They will determine in the case of an actual inductor, the sign of this voltage.

If you change the direction of ((…)) sign of this voltage can be changed, but this is a schematic description. I am not saying current flows clockwise or anticlockwise. No. What i am saying is, the terminal currents is, it enters in this at this terminal goes out at this terminal and this is the polarity of the voltage and V is equal to L d I by d t. This is Lenz's law and this is what determines the terminal relationship for an inductor and we naturally see. Yes?

Student: Sir, V is the induced voltage or the external applied voltage?

Sir: V is the total voltage across the element and it has to be equal to the external applied voltage. Whatever happens inside the inductor is a different story. We are only taking the terminal description. V equals to L d I by d t and therefore if I want to find the current I at time t, then obviously this will be 1 over L integral i tau, i beg your pardon, V tau d tau. I have changed the integrand, i am sorry, the variable of integration to tau. The question is, from what limit to what limit? Well, since I am finding out a t therefore, the upper limit must be t then lower limit can be, it has to be minus infinity but usually you see in electrical engineering or in any other engineering. We cannot go to minus infinity, we limit our range of vision to t equal to 0 and therefore, this is to be 0 to t and if it is 0 to t, then the previous current at t equal to 0 must also be taken account of. In other words, what we have to do is 0 plus i of 0 plus i of 0 because we cannot integrate from minus infinity to t, minus infinity to 0. We are accounting for an i of 0 which is called the initial condition and i integrate from 0 to t.

Now, in this in this, 0 has to be qualified, 0 has to be qualified. Is it 0 minus or 0 plus? 0 minus is before the excitation is applied, and 0 plus is after the excitation is applied. There is a difference between the two concepts. Although physically they mean the same point, 0 is a single point but

0 minus is a point which is infinitesimally close to 0, but not quite equal to it. Therefore, what we have to do is 0 minus to t and then this i has to be 0 minus. This is how we shall indicate i of t is 1 by L 0 minus to t V tau d tau plus i of 0 minus. Let me write it down.

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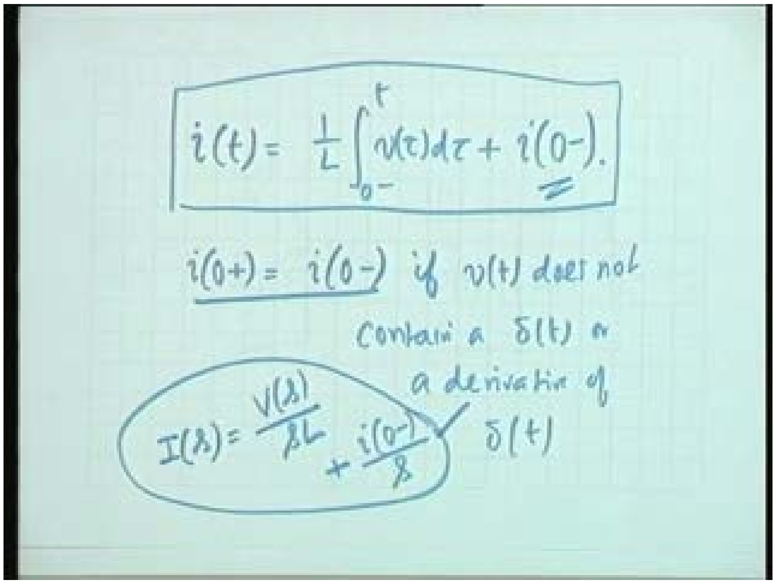

Again, i of t equals to 1 over L 0 minus to t V of tau d tau plus i of 0 minus.

Student: Sir, even zero minus is evident because we should not expect anything before zero we could just say zero plus and let the zero minus come in ((…))

Sir: There is a problem, the problem is if V of t, if V of t contains the impulse and things are quite different, if V of t contains an impulse or a derivative of an impulse, well, if V of t does not contain an impulse, that is, that is, V of 0 minus is the same as V of 0 plus. Then i of 0 plus would be equal to 0 minus to 0 plus integral of V tau d t that would be 0, if V of t does not contain an impulse and therefore, this would be i of 0 minus if V of t does not contain a delta t or a derivative of it. If that is the case, then i of 0 plus is equal to i of 0 minus which is another way of saying that the current in an inductor cannot change suddenly.

The current in an inductor at 0 minus and 0 plus should be the same, unless it is forced, unless it is forced by an avalanche of voltage. You see, integral V tau d tau if V tau is delta tau, then the integral is 1, from 0 minus to 0 plus, then of course it has to change. So, unless that happens, i of 0 plus is equal to i of 0 minus and as you know, the inductor stores energy in the magnetic field and the energy is half L i square and therefore, this is the another way of saying the conservation of magnetic energy, magnetic energy is an inductor or magnetic flux in an inductor cannot change suddenly, unless forced by an avalanche an infinite amplitude pulse, which is an impulse. If you look at this relation once more and suppose we want to be general, that is, we want to admit the existence, admit the possible existence of an impulse or its derivative, then you have to use this total relation and if you look at this relation carefully, you see that i of t is the sum of two currents. One is i of 0 minus and other is this integral.

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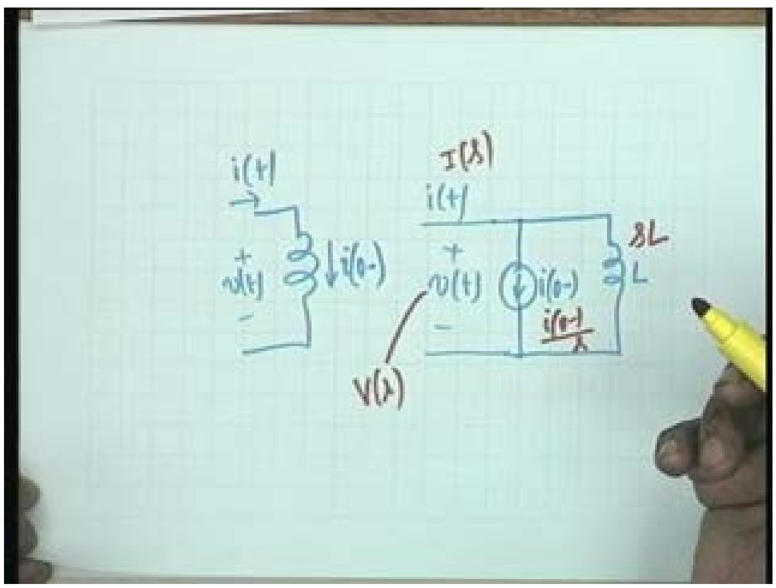

So one can represent an inductor which carries an initial current, let us say i of 0 minus. One can represent at t by means of an equivalent circuit, that is, I have i of t, I have V of t plus, minus. Equivalent circuit is it contains two terms, one is a current source i of 0 minus. So I indicate this as i of 0 minus and then an inductor which is initially relaxed, initially relaxed, that is, it carries no current. So a current carrying inductor can be represented by an inductor which has no initial flux in parallel with a current source. This is the equivalent circuit of an inductor.

Student: Sir does that imply that inductor is a non linear device?
Sir: No. It does not imply that inductor is a non linear device. Inductor is a linear device provided it is initially relaxed. If it is not initially relaxed, this constant may cause the inductor to be non linear. Yes, in the strict sense of the term but before I pass, before I pass to capacitor, can I also mention to you that an equivalent description of this relationship, in the frequency domain, shall be capital I of S equal to, as you know, integral, Laplace of an integral is division by S and therefore, it would be V of s divided by s L plus, what is the Laplace of a constant that divided by s, i of 0 minus divided by s.

So this would be the frequency domain description of an inductor, where if this current, if the initial current is 0, this is the term, this is the relationship that you are familiar, that is, current is equal to voltage divided by impedance of the inductor. But if the inductor carries an initial current, then this term is a must. We cannot ignore this and you see, in the equivalent circuit now, in the frequency domain, you shall have indeed a current source but the source is not i of 0 minus. It is i of 0 minus divided by s. So if this circuit is to be modified to Laplace transform domain, then this is V of s, this is I of s, this would be i of 0 minus divided by s and this shall be written as s L.

So in one stroke, we have done the time domain equivalent and also the frequency domain equivalent without any approximation, without any loss of generality. i can represent an inductor carrying an initial current, either the time domain or in the frequency domain by means of a parallel circuit and the parallel circuit consists of an ideal current generator. This current generated is ideal and an inductor which is initially relaxed.

In a similar manner, I can consider a capacitor C, which has an initial voltage. Let us say V c 0 minus and then I apply either a voltage source or a current source to charge or discharge the capacitor. Let the currents and voltages be V of t and i of t, then as you know, i of t is simply equal to C d v by d t. This is independent of initial conditions. However, if you want to find out V of t, then of course you shall have to integrate, that is, one by C integral i of tau d tau and the limits have now to be put carefully. This will be, upper limit would be t

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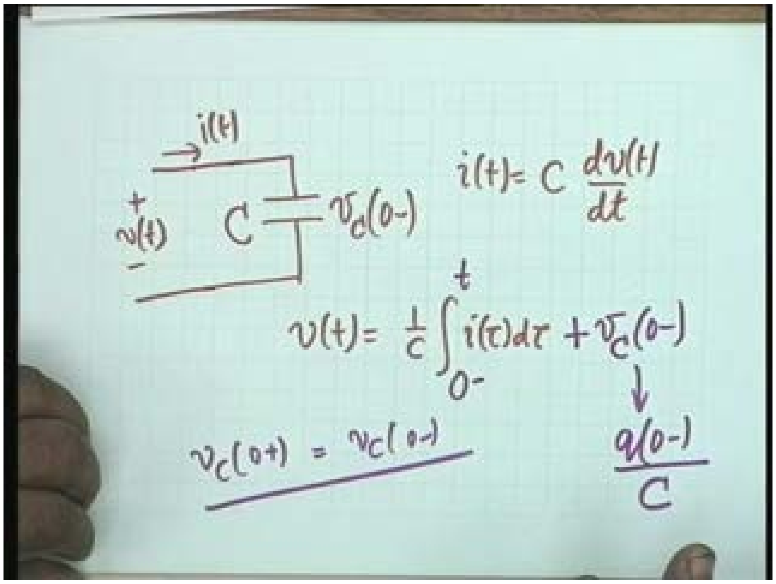

Student: Should not you denote it by V c of t because V of t you are using for ((…))

Sir: If the, if the voltage is the same, is the same across the capacitor, I can use, if you are so, for say, I will distinguish between them and write V of t equal to V c of t. Okay? So the lower limit should be 0 minus and then we must add V sub c of 0 minus, which as you can see, is the initial charge in the inductor q 0 minus divided by C. Now, if V sub c of 0 minus is 0, if this is 0 and i of t does not contain any delta function, you understand the conditions, then what would be V of 0 plus? Would be 0 which, amounts to the effect that a capacitor, an initially relaxed capacitor acts as a short circuit, voltage across it is 0 means it is a short circuit. Also, if i of t does not contain a delta function, then you see V c 0 plus shall be equal to V c 0 minus, which amounts to the law of conservation of charge, that is, the charge in a capacitor cannot change instantaneously, unless forced by an avalanche of charging, that is, if i of t, the current contains a delta or its derivatives, then this relationship shall not be valid. But in general if the capacitor is initially, if the capacitor is initially charged and charged or discharged by a current which contains no impulses, then V c 0 plus is equal to V c 0 minus and in this case, the integral relationship can be represented by an equivalent circuit in which, there is a source. You see, V t is the sum of V c 0 minus and the voltage across the capacitor initially relaxed.

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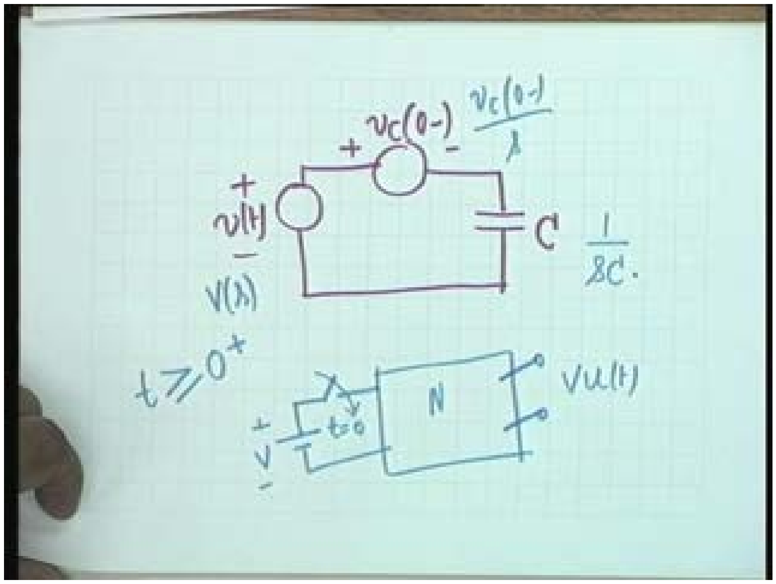

The equivalent circuit of a capacitor is therefore, the series connection of an ideal voltage source and an initially relaxed capacitor, I hope this is clear, by the same arguments, and if I want to change this to, let us say, the Laplace domain, then we have V of s. This will be V c 0 minus divided by s and this capacitor shall behave as an impedance of 1 by S C where S is the complex variable. This is the equivalent circuit of a capacitor. Any questions so far? A circuit containing initial conditions is an interesting circuit, is an interesting proposal but it does create complications unless you are very careful, unless you are very careful in solving. For example, in a typical situation, in a typical situation, you shall be given a network, some network and let us say, a voltage source V with this polarity is switched on at t equal to 0 which means that it is being excited by means of a step function.

The excitation, the switch can be replaced by u of t and therefore the excitation in effect is V times u of t and you might be asked to find the response at some port, at some port and the response to be either a voltage or a current. Then what you will have to do is, you will have to write the internal dynamics of the network N and the dynamics is represented by a differential equation or an integral differential equation, that is, an equation which contains integrals as well as differential coefficients. But in integral differential equation can only be reduced to a differential equation. Which is, go on taking the derivatives, differentiating till there are no integrals. So we simply say, write down the differential equation. Now, once you write down the differential equation, you can solve it by finding the complementary function and the particular integral and as you know the complementary function shall consist of undetermined constants and these constants have to be determined from initial conditions.

Now, in the context of network, since we are admitting an impulse function, we have to distinguish between conditions at 0 minus and 0 plus. For the network N, the solution have to be found out for t greater than equal to 0 plus, that is, after the application in the excitations and therefore, the initial conditions are to be taken as the conditions at 0 plus, not minus, 0 plus. How does one determine the initial conditions? If you, obviously for the network to be solvable, you will be given the conditions at 0 minus, that is, the condition of the network before the excitation is applied. From that either from the differential equation or from physical reasoning, you will have to find out what are the conditions at 0 plus. This is one of the problems of network analysis. The first problem is, is to find out the conditions at 0 plus. These are the initial conditions, what you shall be given is the conditions at 0 minus. Now, if there are no delta functions in the excitation, then of course your initial conditions are very easy. The inductor currents at 0 minus shall be the same as inductor currents at 0 plus.

The capacitor voltages at 0 minus, shall be same as capacitor voltages at 0 plus. So there is no problem. But if there are impulses, then you will have to be careful. You will have to find them out either from the differential equation and we shall show, we shall demonstrate how to do this or from physical reasoning physical arguments. So after you find out the initial condition, then you put down in the solution, determine the undetermined constants and that, that does the job. This is the time domain solution. Even if you want to determine things in the frequency domain, the initial conditions are important because you see, in the equivalent circuit; you do have current sources or voltage sources in terms of the initial condition. So that is absolutely important.
Now in the rest of the few minutes that are left, we will discuss two other terms which shall be important in the later part of the course.

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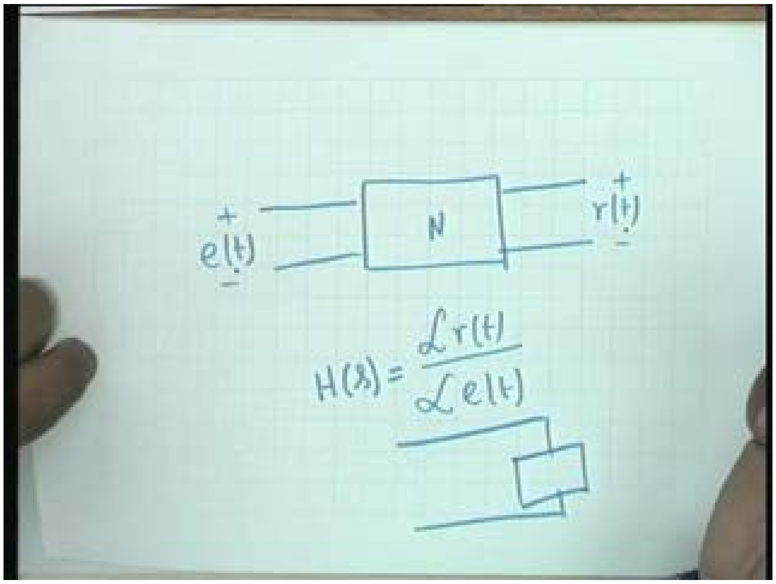

I have told you that the synthesis problem network, synthesis problem is the reverse of analysis problem. In the analysis problem, the excitation e of t and the network N are given. You have to find out the response r of t. In the synthesis problem, the excitation and the response or a relationship between the two and typically the relationship that is given, is the ratio of the Laplace transform of the response to the Laplace transform of the of the excitation. This is what is given and this is usually denoted by H of s, usually denoted by H of s. H of s, in general terminology, is called a transfer function, in control, in many, in signals and systems and many other. But in the case of networks, we have to make a qualification; we have to make a qualification. We cannot blindly call it a transfer function. For example, if the network is a 2 terminal one, if the network is a 2 terminal network, well, then all you can do is; if the network is a 2 terminal one, all you can do is you apply a voltage and determine the current. So the function would be, the Laplace of current divided by Laplace of voltage or its reciprocal and it will have the dimension of impedance, it will have the dimension of impedance or admittance and as you, as you perhaps know, impedance and admittance are collected together in a single term, immittance. This part impedance or admittance is called, together is called an immittance and therefore, if the network is a 2 terminal network and there is only one port, then all you can do is find out the immittance function F of s which is either an impedance or an admittance.

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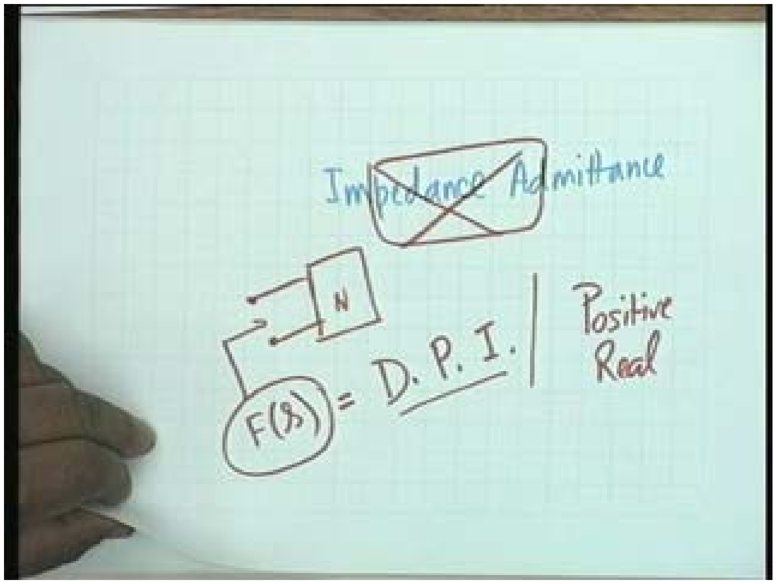

Suppose F of s is given. Well, this for reasons to be made clear in a few, in a few minutes. F of s, the immittance function, is called the driving point immittance DPI. Driving point immittance because it is the impedance or admittance measured at the port, at which you drive the network, at which you excite the network. So it is called a DPI, driving point immittance and if driving point immittance is given, how to find the network? As you know, the first task is the given, F of s. Is it realizable? Can I find the network? I have told you on the first occasion that it may be or may not be realizable. So the first question that one asks in synthesis is the given function. Is it realizable? If the answer is yes, then you go ahead with the synthesis.

Now in the case of DPI, we shall show at the in the later part of the course that it would be realizable if F of s is a special kind of function which goes in the mathematical literature by the name positive real functions, that is, if capital F of s is positive real, it is only then F of s is realizable. Now I used the word driving point, which means that there must be other types of network functions and this is the so called, so called transfer. As I said in network functions, have to be careful whether the, the term transfer must be used to denote difference between excitation and response ports, that is, excitation at one port and response at some other port. Only then the word transfer shall be used.

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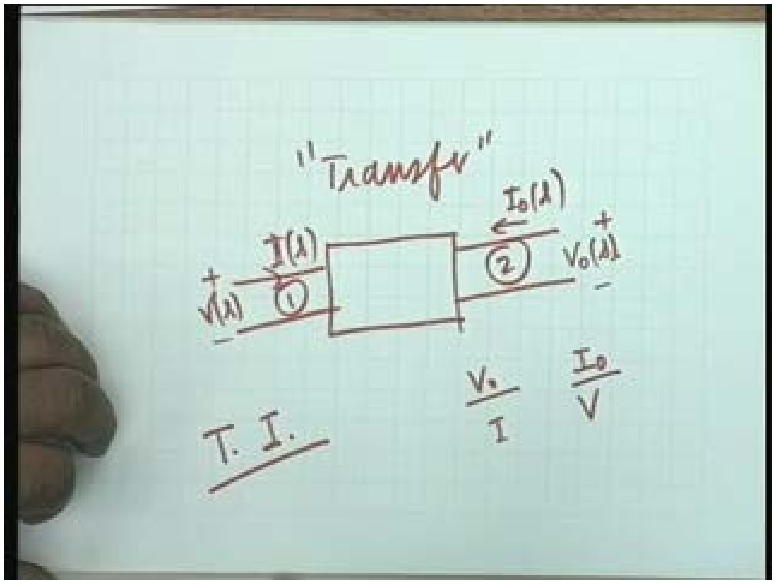

Now, suppose the currents and voltages at the excitation are V of s, I of s and the currents and voltages here are, let us say, V 0 of S and I 0 of S. This is port 1 and this is port 2. Now, the network function can be the ratio of a voltage to current or its reciprocal or it can be the ratio of, let us say, V 0 s to V of s. It can be ratio of voltages, it can be ratio of currents, and therefore, a transfer function can be either dimensionless or dimensioned. If it is a ratio of voltages then obviously it is dimensionless, if it is a ratio of currents it is dimensionless. But if it is a ratio of, let us say, V 0 by I, then obviously the dimension is impedance and then it is called transfer impedance. This is why we call the previous one driving point, to distinguish between transfer impedance and driving point impedance. Similarly, if it is, let us say, I 0 divide by V, then it is a transfer admittance and in this case, we define what is known as transfer immittance. It can be either an impedance or admittance, to distinguish it from driving point immittance. These terms are not important in general systems but in circuits, they are very important it, as usual, see the driving point synthesis problem is much easier than transfer function synthesis problem and this is where we close.