Circuit Theory
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Lecture - 24
The Hybrid and Transmission Parameters of 2-Ports (Continued)

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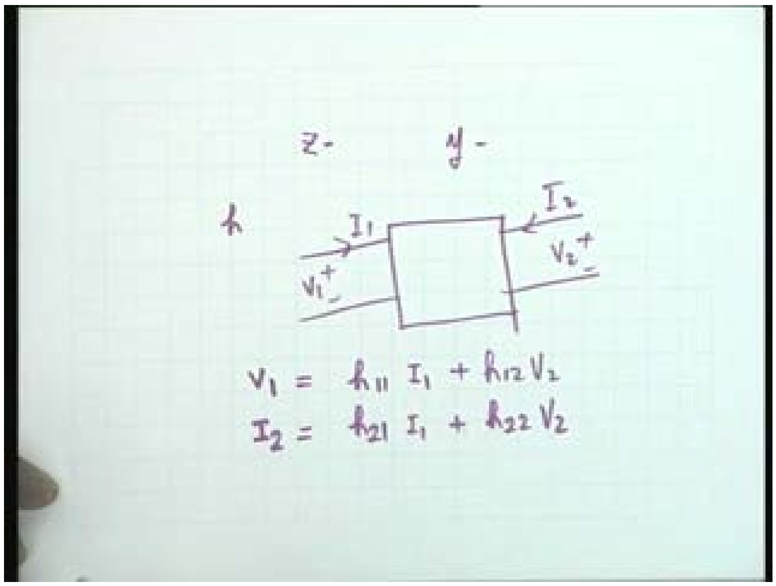

This is twenty-fourth lecture and we are going to discuss the hybrid and transmission parameters of 2-ports. We have already discussed the open circuit z parameters and the short circuit y parameters. The hybrid parameters or h parameters are defined like this; our convention for the 2 ports is the same V 1 I 1, V 2 I 2 conventions are the same and the quantities that we take as dependent variables are 1 voltage and 1 current, V 1 and I 2 and this should tell you why the parameters are called hybrid. They are not both voltages, they are not both currents, 1 voltage and 1 current. Not only that, the voltage and current are not at the same port.

There are different ports so there is a hybridization of all kinds and the quantities are written as h 1 1 I 1, the independent parameters are I 1 and V 2, so h 1 2 V 2, h 2 1 I 1 plus h 2 2 V 2, these are the 4 parameters and if you look at the definition, which I shall repeat and the next slide.

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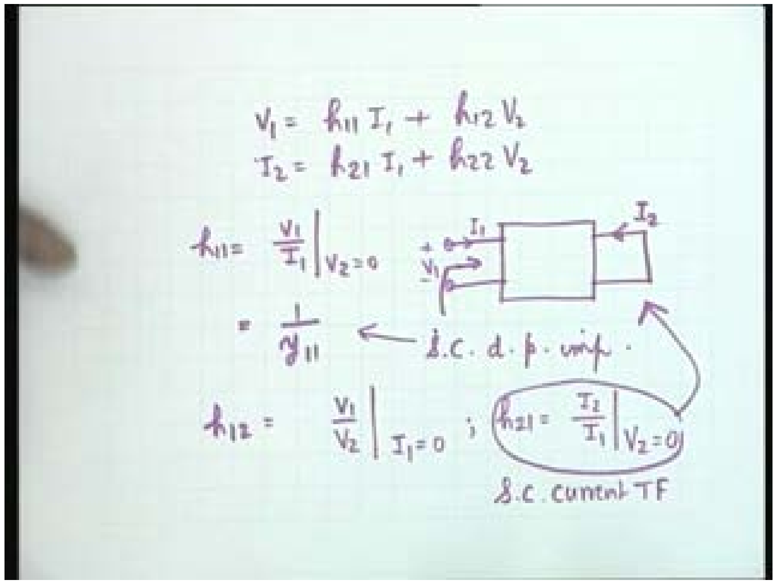

V 1 equal to h 1 1 I 1 plus h 1 2 V 2 I 2 equal to h 2 1 I 1 plus h 2 2 V 2, the thing to remember is, it is the input voltage or voltage at port 1 and current at port 2. Now if you look at the definition, h 1 1, obviously is V 1 by I 1, with V 2 equal to 0, the output short circuited. Let us look at, we will go very slowly, let us look at the condition V 2 equal to 0, means, if this is short circuited, this is the current I 2 which is not of interest. What is of interest is V 1 by I 1 and therefore, it is the input, V 1 by I 1 is the input impedance under short circuited output.

So what is the admittance? By definition, this admittance is y 1 1 and therefore, h 1 1 is simply related to divide parameter y 1 1. It is input impedance under the output short circuited, output short circuited gives the input admittance as y 1 1 and therefore, h 1 1 is y 1 1 and this is a short circuit driving point impedance, short circuit driving point impedance. Let us look at h 1 2. By definition, h 1 2 is V 1 by V 2, under the condition, I 1 equal to 0. But before you take this, let us take the other one. h 2 1 is equal to I 2 by I 1, under the condition V 2 equal to 0.

So h 2 1 can be calculated from this diagram. Under the condition V 2 equal to 0 find the ratio of I 2 to I 1 and that shall be h 2 1 and as you see, h 2 1 is a current transfer function, agreed? It is a dimensionless quantity current transfer function that is the output current divided by input current with the output short circuited. So this is a short circuit, s c short circuit current transfer function.

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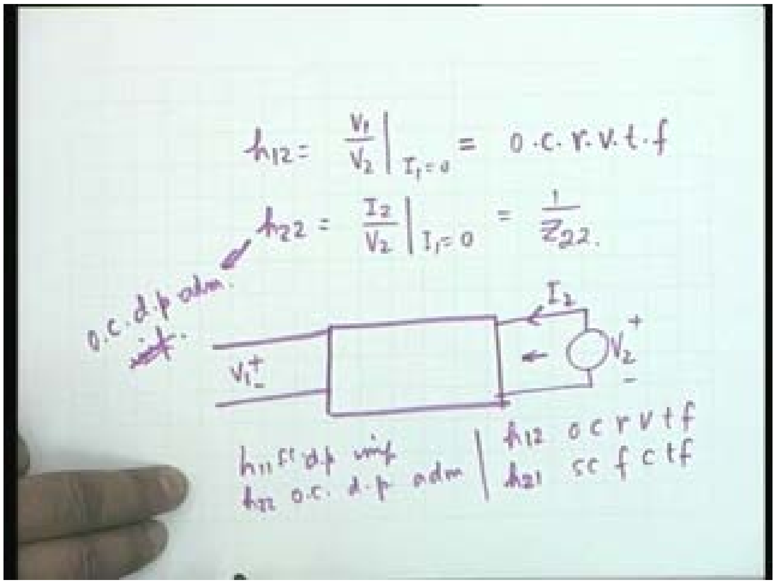

Now let us look at the other 2 parameters, namely h 1 2 is equal to V 1 by V 2 I 1 equal to 0 and h 2 2. If you see, it is I 2 by V 2 with I 1 equal to 0, and I 1 equal to 0 means open circuit at port number 1. So let us draw the circuit, let us draw the block. Port number 1 is open circuit and therefore, no current. The only thing you can measure is the voltage, and port 2 there is a voltage excitation v 2. Obviously, the excitation cannot be at port 1, why not?

Student: Open.

Sir: It is open and therefore, any source that you connect will drive a current and therefore, the source must be V 2, I 1 equal to 0 and all that you calculate now is V 1 by V 2. V 1 by V 2 is the actual transfer function. So this is the reciprocal, no, I beg your pardon; this is an open circuit, not V 2 by V 1. You see, V 2 is the excitation and V 1 is the response. So it is correctly V 1 by V 2, this is therefore, the reverse voltage transfer function, but also open circuit reverse voltage transfer function. Reverse because it goes from port 2 to port 1. Our convention is that power or energy travels from port 1 to port 2.

This is another way of obtaining a transfer function. This is an open circuit reverse voltage transfer function and if you look at h 2 2, h 2 2 is I 2 by V 2 with I 1 equal to 0 and therefore, I 2 by V 2, h 2 2 therefore, is an open circuit driving point. I 2 by V 2 is admittance and therefore, this would be simply equal to 1 over z 2 2, agreed? So h 2 2 is driving point open circuit, driving point impedance function, no, admittance function. Now let us look at the dimensions, h 1 1 was impedance and it is driving point and it is short circuit. h 1 1 is short circuit driving point impedance h 2 2 is open circuit driving point admittance, h 1 2, h 1 2 is open circuit reverse voltage transfer function and h 2 1 is short circuit is it a forward or reverse? Forward.

Student: Forward

Sir: Forward current transfer function. Now you see the hybridization, it is a mixture of all kinds of things. Impedances, admittance, current transfer function, voltage transfer function, under open circuit or short circuit reverse or forward and that is why these parameters are called hybrid parameters and they have very important application in dealing with transistor circuits. As you know the hybrid phi equivalence circuit is the most universal and the most desirable kind of equivalence circuit for a transistor and they originate from the h parameters h parameter model of a general 2 port.

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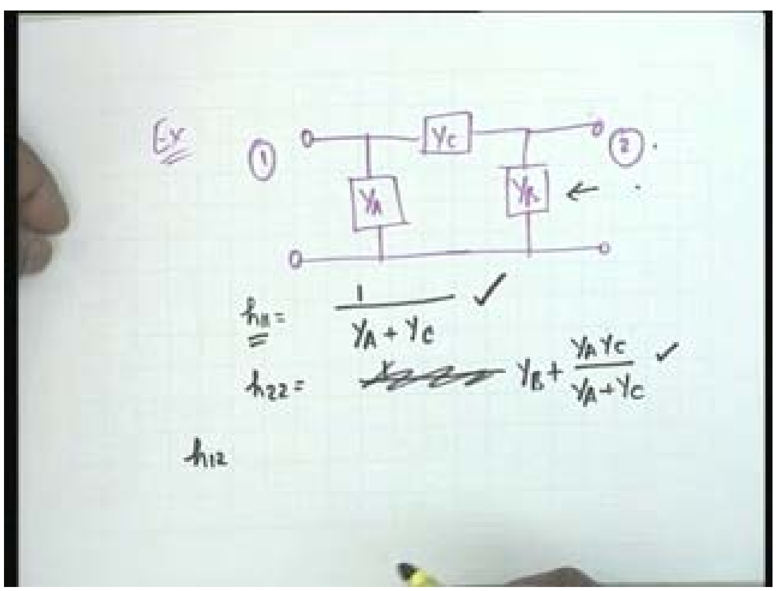

Let us take an example suppose i have you take the familiar phi network; YA YC YB. This is port 1 and port 2. The first thing we do is, h 1 1, as you know, h 1 1 is 1 by y 1 1. h 1 1 is the impedance.

Student:

Sir: Okay, 1 by, impedance looking here with this short circuited. So it is simply the parallel combination of YA and YC. So 1 over YA plus YC, it is an impedance. It is the input impedance so the output short circuited. In a similar manner, h 2 2 would be the impedance measure from here with port 1 opened and therefore, it would be 1 over, is that right?

Student: (..)

Sir: 1 over z 2 2, agreed? 1 over z 2 2. Now, obviously h 2 2 an is an admittance, is not that right? So the admittance measured here would be YB plus the admittance of the serious combination of this 2, which is exactly equal to YA YC divided by YA plus YC.

Student: Should not h11 be 1 by YA plus 1 by YC?

Sir: No, h 1 1 is an impedance.

Student: Yes sir.

Sir: Consisting of consisting of YA and YC in parallel. So the total admittance is YA plus YC and therefore, the impedance is 1 by YA plus YC, is this result correct? Let us find out the other 2 parameters, that is, h 1 2 and h 2 1. h 1 2, for example, for finding h 1 2, what we have do is YA, let me draw the network first, YC and YB. h 1 2 by definition is V 1 by V 2 with I 1 equal to 0. It is open circuit reverse voltage transfer function.

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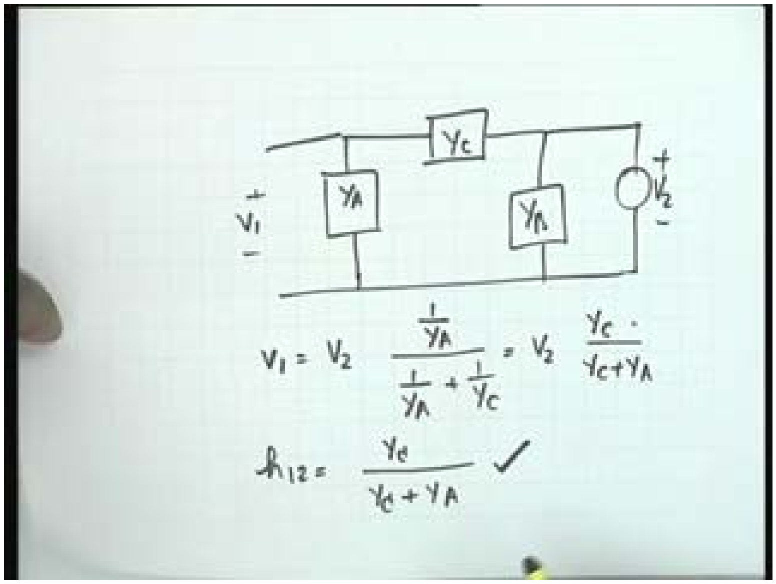

Now this comes in parallel with V 2, so it has no effect, so V 2, therefore divides, there is a potential division between YC and YA therefore, V 1 would be equal to V 2 1 by YA divided by 1 by YA plus 1 by YC, is that clear? This impedance, that is, z A divided by z A plus z C, not YA divided by YA plus YC. This is, in fact, this is V 2 YC divided by YC plus YA and therefore, h 1 2 is V 1 by V 2 therefore it is simply Y sub C divided by Y sub C plus Y sub A, is that clear? This is h 1 2. Now to find out h 2 1, h 2 1 is by definition I 2 by I 1 with?

Student: Short circuit current.

Sir: V 2 equal to 0 is that correct V 2 equal to 0 so let us see we have YA we have YC and we have YB, obviously, the excitation is I 1. There is a current source I 1, this is 0 and you are required to find out this current I 2, which is, obviously the current in Y sub C also, because this goes out of picture being short circuited and therefore, I 2 would be equal to I 1 minus I 1, then?

Student: (..)

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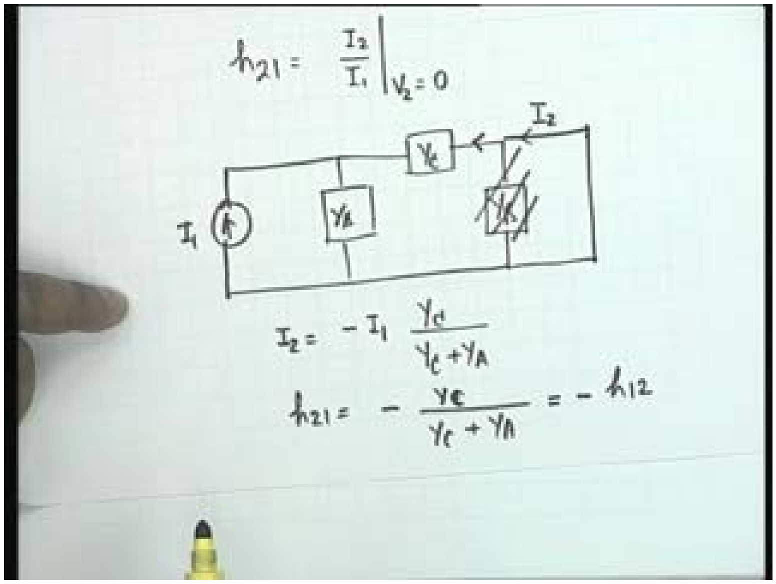

Sir: YC divided by YC plus YA, is that okay? And therefore, h 2 1 would be equal to minus YC divided by YC plus YA, and if you recall what is h 1 2, you see that this is exactly minus h 1 2 and what does this indicate? This indicates the condition for reciprocity. We assume that YA YB YC are bi-lateral elements that they pass current equally value in both directions, and therefore, what was z 1 2 equal to z 2 1 or Y 1 2 Y 2 1, in terms of z and Y parameters, now transfers into h 2 1 equal to minus h 1 2, this negative sign should be noticed, this is the, these 3 are identical conditions, that is, this condition equivalent to this condition and the whole thing is equivalent to the third condition. These are all conditions for reciprocity condition, reciprocity. Let us take another example.

Student: Sir the Negative sign comes in because one is a forward parameter, transfer function?

Sir: No, it is not because of that it is because of the directions of I 1 and I 2, both go in. so if there is a current I 1, if there is a current I 1 fitting here, the current threw I see must flow in this direction, whereas our convention is that I 2 goes in. That is why is sign is negative.

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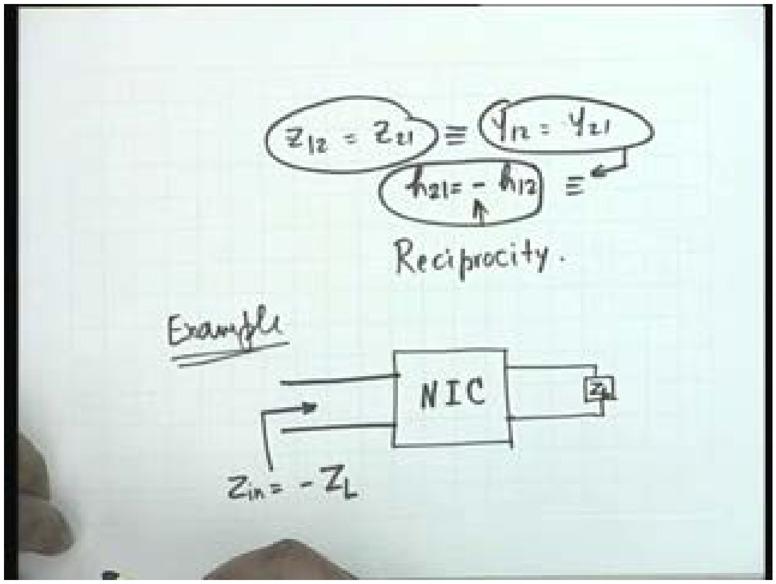

Student: Sir, this negative sign does not imply anything, for this current direction?

Sir: With this convention, with this convention h 2 1 must be equal to minus h 1 2, okay?

Student: Sir, if (..) h 2 1 equal to minus h 1 2, then we can say it is reciprocal?

Sir: It is reciprocal is a necessary as well as sufficient condition, yes, that is correct. In fact, this is a test for reciprocity. Let us take another example and this example is that of a 2 port having the particular property, that whatever you connect at port number 2, a load z L reflects at the input as the negative of z L, that is, z in equal to minus z L, which means that you have a, if you connect it, if you connect a positive resistance here, it will reflect as a negative resistance and this is the way to make the negative elements.

We have all ways talked a positive R L and C, there is a way of making negative elements and this is a 2 port which is not a dream 2 port, it can be realize in practice and such a 2 port goes by the name of negative impedance converter, NIC. Obviously, it converts a positive impedance into negative impedance and this is why it is called a negative impedance converter or NIC.

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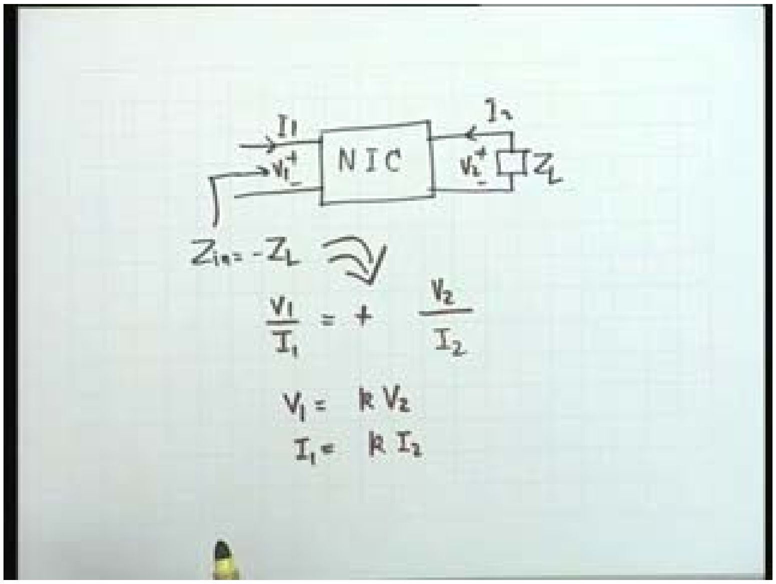

The NIC has the property that the impedance at the input is the negative of the impedance of the terminating impedance. Let us write it again, z in equal to minus z L. Now if I indicate the voltage is in currents, this is V 1 I 1 and V 2 I 2, you notice that z in is V 1 by I 1 minus z L is V 2 by by I 2, no. The relation between V 2 and I 2 is V 2 is equal to minus I 2 z L, is not that right? because the directions not agree and therefore the sign of the plus, is that okay?

z in equal to minus z L indicates that V 1 by I 1 is equal to V 2 by I 2. Obviously, this relation can be satisfied in many ways and the way that is usually, it is tried to be satisfied in an NIC is that V 1 is the proportional to V 2 and so I 1 proportional to I 2. If V 1 is k times V 2 and k is a constant, then I 1 must be equal to k I 2.

If I write these relationships, in the form of h parameters, that is, my NIC is characterized by V 1 equal to k V 2 I 1 equal to k I 2 and my h parameters relationship is between V 1 and I 2 as depended variables and I 1 and V 2 as independent. So h 1 1 I 1 plus h 1 2 V 2, I 2 is h 2 1 I 1 plus h 2 2 V 2. If I compared this relation with this relation, then obviously what I get is, h 1 1 is 0, V 1 equal to simply k V 2 and h 1 2 is equal to k, agreed? Is it okay? All right and I compared this relation with this but before that let me convert this as I 2 is equal to 1 over k I 1.

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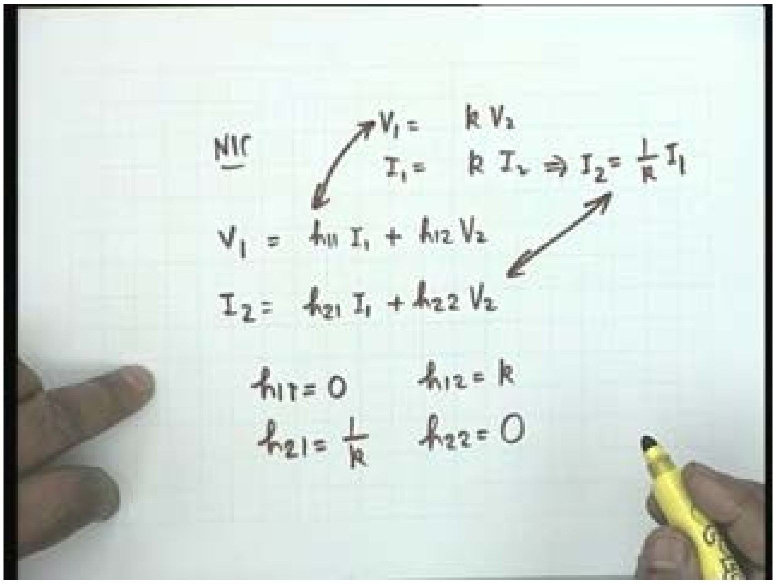

I can write it that way? Now I compare this with this. Then I get h 2 1 as 1 over k and h 2 2 is equal to 0, therefore,

Student: The assumption that V 1 is equal to k V 2 and I 1 is equal to K I 2, sir, have we taken it?

Sir: Pardon me.

Student: We assumed it, something?

Sir: No, I made a statement that this is the usual way 1 raised to satisfy the NIC condition. The practical circuits are build on this assumption. You can have other kinds of assumption also that V 1 equal to k I 1 and V 2 equal to k I 2, yes, you can do that. There are many other ways and

Student: Sir, we are not trying to synthesize the circuit? The NIC?

Sir: No, I am trying to show you an example of a 2 port, which is neither reciprocal nor passive and it is a circuit which can be made with transistors are (..) I am not synthesizing what is inside NIC. Inside NIC, we look at in a different course. What I am showing is that the NIC is an example of a 2 port, which is neither reciprocal nor passive. It is not reciprocal is obvious because h 1 2 is not equal to h 2 1, is it passive?

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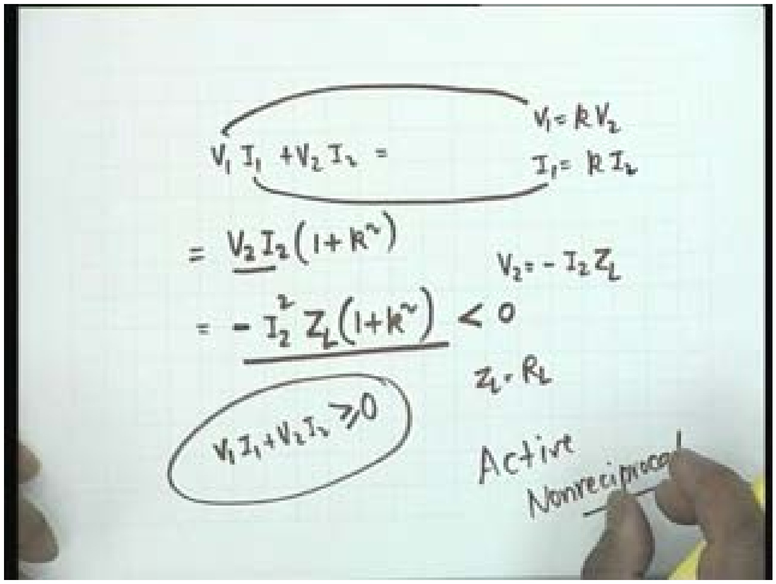

Well, for that, you see V 1 I 1 the total power that goes into the network. V 1 I 1 plus V 2 I 2, this is the total power that goes into the network and this is equal to, you see V 1 equal to k V 2 and I 1 equal to k I 2 and therefore, I can write this as V 2 I 2 1 plus k squared, agreed? V 2 I 2 1 plus k squared, also V 2 no V 1 I 1 is k V 2 multiplied by k I 2, so case

Student: (..)

Sir: I do not understand why it is should be 1 minus k squared. I am substituting for V 1. I am substituting for I 1. k V 2 multiplied by k I 2 is k square V 2 I 2. I am writing this product in terms of V 2 I 2. I have a purpose, you see V 2 is equal to minus I 2 z L and therefore, this is equal to minus I 2 square z L 1 plus k squared. Therefore, the power that goes in can be negative, the sign negative. I 2 squared, if it is a resistive network, let us say, if z L equal to a positive resistance R L, then I 2 square is a positive quantity and therefore, the power that goes in can be negative, which means that the 2 port generates power. It does not observe power, it generates power.

A condition for passivity is that V 1 I 1 plus V 2 I 2 must be greater than or equal to 0. It must either absorb power or may not observe power, but it should not generate. If it is greater than 0 then the network we say is lossy, that is, a dissipate power then absorbs power. If it is equal to 0 then you say the network is loss less. On the other hand, what do you have here is negative and therefore, the network generates power, which means that the network is active and non reciprocal non reciprocal and obviously, if it is non reciprocal, it cannot be made out R L C elements positive R positive L positive C. We must have non reciprocal elements, non uni lateral elements like diodes or transistors are a combination of transistors to make an op amp.

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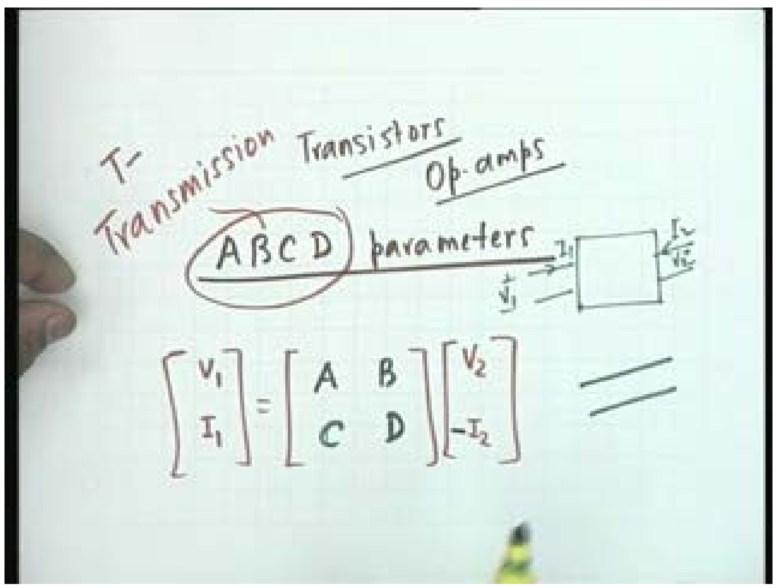

In fact, an NIC can be made with transistors and or op amps and simple circuits can be build to demonstrate the action of NIC. If you are interested, we shall look at some circuits at a later stage. Our next concern is the ABCD parameters, and you shall have very interesting examples of ABCD parameters also. ABCD parameters, as you know, are also known as transmission parameters and why they are so denoted? Why they are called transmission parameters, shall be obvious. They are also sometimes called T parameters, capital T we do not use a small t because small t we deserve for time.

Capital T, yes, you can use but in the literature right from the days of Lord Kelvin. Lord Kelvin was the originator of the transmission line concept, transmission line theory and he used ABCD parameters and therefore, we have respects for the older generation and we still call them ABCD. Although it is a bit messy, 4 things to be mentioned. But capital T, you see, has many other connotation is also used for time

Student: Temperature.

Sir: Temperature and what not. So we refrain from using all this. We will call them ABCD parameters and the relationship now is based on the input parameters being looked at as depended parameters V 1 I 1 and V 2 I 2 as the independent parameters, that is, in terms matrix notation, I will come to the actual notations later actual equations later and therefore, matrix notation, there is a 2 by 2 matrix which relates to V 2 and I 2 and one thing that must remember is Lord Kelvin used a negative sign V 2 minus I 2.

Student: (..)

Sir: No, they are dependent.

Sir: They are dependent. Did I say they are the independent? Well, then I made a mistake. One of the end mistakes that (..) does in the class, where and may be a large quantity but it is your responsibility to correct them. What I want you to notice is this negative sign. Well, if I look at the 2 port V 1 I 1 V 2 and I 2, what it means is that I 2, the output current is taken as going out of the network instead of coming in. If it is coming in, you should used a plus I 2 and Lord Kelvin argued that whatever you feed in, if I feed in a current in this direction, I will take it. Lord Kelvin's convention was that I will take it going out, the current going out. So this is why, to keep track with modern practices, in which a 2 port parameters is defined with all currents going in, I must use a negative sign and these parameters are A B C and D. These are the transmission parameters.

The negative sign must get imprinted in your mind this is the only set of parameters of before z y h and ABCD that we use a negative sign in front of a, negative sign appended to a current or a voltage. It is the current all right, this is only set of parameters.

Student: Sir, the current direction is taken to be outwards?

Sir: That is right, Lord Kelvin said I will take it out of the (..)

Student: Excuse me sir, at one time we cannot use both the current generator and voltage generator.

Student: Sir, 1 time we cannot use both the voltage generator and the current generator at the point.

Sir: Pardon me.

Student: Sir, at one time we cannot use both the current generator and voltage generator.

Sir: No, you do not.

Student: Sir, if you are taking v 1 and I

Sir: It just the variables it is not way of measuring. As you will see, measurement requires only one generator. It does not required 2. It is only a way of looking at. You see, I said out of 4 parameters, V 1 V 2 I 1 I 2 I can take any 2 as dependent, the other 2 as independent. I will not able to connect voltage generator and current generator in parallel, no.

Student: Sir but independent parameters are the forcing parameter

Sir: Right

Sir: Forcing parameters.

Sir: Right.

Student: So we want to force some voltage or some current

Sir: Okay.

Student: If we say that v 1 and i 2 are independent variables

Sir: As I say, this is only a semantics, this independent and dependent. Since I write V 1 in terms of V 2 and minus I 2, I say V 2 and minus I 2 are my independent parameters. It does not mean that measurements will also we made with 1 current generator and 1 voltage generator. You see, even in z parameters, y parameters, h parameters, there is only 1 generator at a time. If your notice, all the measurements are made with only 1 generator, not 2. So this independence, in the context of ABCD in particular, means that 2 parameters V 1 I 1 are expressed in terms of V 2 and minus (..), that is all. No other significance.

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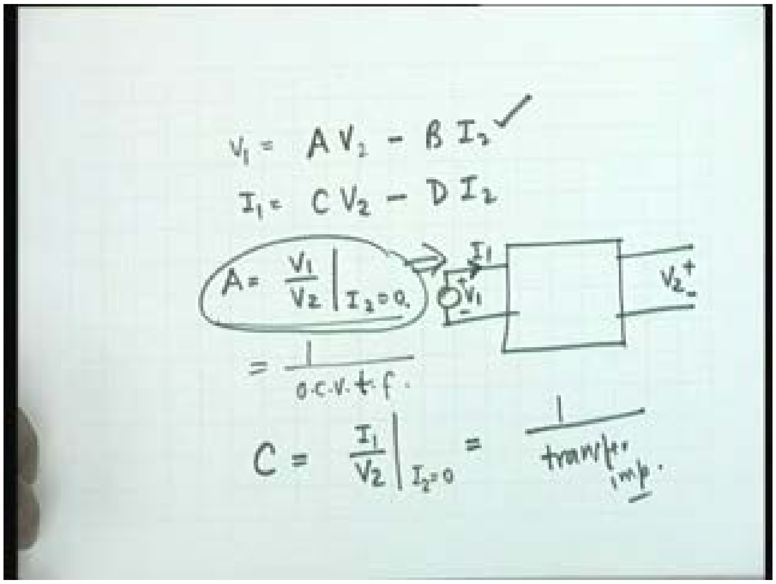

We will see how to measure them. If you write in full, then V 1 is equal to A V 2 minus BI 2, note the negative sign, and I 1 is equal to C V 2 minus D I 2 and therefore, we will see why they are called transmission parameters. Therefore, you see, A is equal to V 1 by V 2 with I 2 equal to 0. Now what does this mean? Let us draw the 2 port. I 2 equal to 0 means port 2 is open and therefore, the measurement is of V 2 with a V 1 here, which means that here, V 1 is the independent supply. Generator is V 1 not V 2.

So in terms of measurements, measurements have nothing to do it what we called independent parameters, independent currents or voltages. But you see, that A is obviously the reciprocal, you see here the transfer function open circuit voltage transfer function is V 2 by V 1, and A is the reciprocal of 1 by an open circuit voltage transfer function reciprocal of a voltage transfer function.

Student: We should have taken V 1 as the voltage generator and generator at the other end?

Sir: That is what I have done. V 1 is the voltage generator and V 2 is the, that is, I have unconstraint by this.

Student: Sorry sir, V 2 as the voltage generator.

Sir: I cannot, because I 2 is 0. If I connect a voltage generator here, it will definitely send a current, is not that right? And therefore, I am constrained by the definition to use a figure like this. You must remember these essential, important points and you cannot make a mistake because if you go back to the roots, if you go back to the definition, you cannot make a mistake. I 2 equal to 0 constrains means not to put a generator here. So generator must be here and this is why it is the reciprocal of an open circuit voltage transfer function. The reciprocal of an open circuit voltage transfer function may not be itself another voltage transfer function, it is the reciprocal.

Similarly, I can, another parameter that I can find out is C, from this network. C is I 1 by V 2 with I 2 equal to 0 and therefore, once again, my response shall be V 2, agreed, because I 2 equal to 0, response will be V 2, but this time the excitation is I 1 the current. So what we will do is, we will connect a current generator here or does not matter, we can also connect a voltage generator, that is not a problem. What we have to find out is I 1. I have to find out I 1 and V 2 this ratio and you see, this is the reciprocal of?

Student: (..)

Sir: No, reciprocal of a transfer impedance. You see, V 2 is the response, I 1 is the excitation, so 1 by a transfer impedance transfer impedance. C equal to 1 by a transfer impedance.

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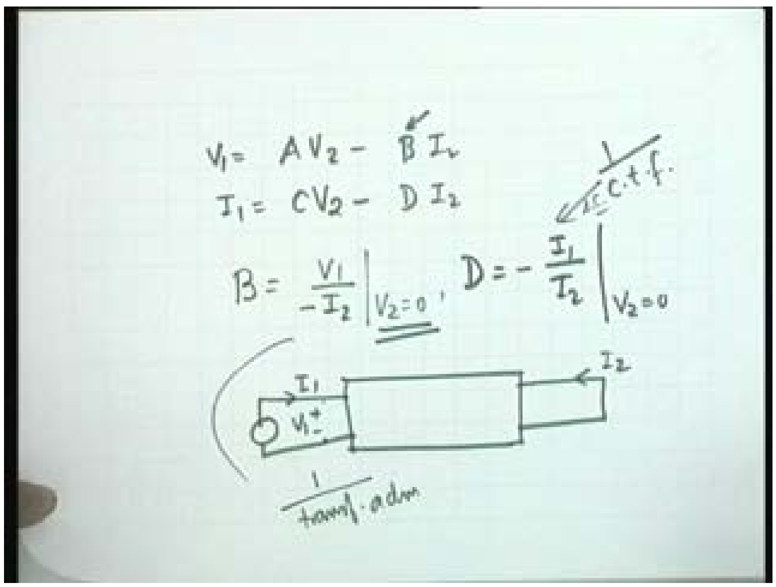

Next let us look at the interpretation of B and D. V 1 is equal to AV 2 minus B I 2. I 1 equal to CV 2 minus D I 2 and therefore, B is equal to V 1 by I 2 minus I 2. B is equal to V 1 by minus I 2, under the condition V 2 equal to 0 and D is equal to?

Student: Minus I 1 by I 2.

Sir: I 1 by, minus I 1 by I 2, under the condition? V 2 equal to 0. So let us make V 2 equal to 0. Obviously, I cannot connect a generator here, the generator has to be connected here. It is either a voltage generator or a current generator. Whatever be it, the voltage here is V 1 and the current here is I 1 and what is measured, V 2 is 0 and therefore, all that can be measure is I 2. The current, now if you take the ratio of this voltage to the negative of this current, which means, you will get B, so what is B? B is the reciprocal of reciprocal of?

Student: Transfer admittance.

Sir: Transfer admittance, well, negative or positive we will see. It is minus i 2, we will see if it comes negative will take this negative. But dimensionally, it is 1 by a transfer admittance and capital D, as you see, is the reciprocal of

Student: Transfer current function.

Sir: Current transfer function, 1 by current transfer function.

Student: Short circuit.

Sir: Short circuit, all right? But there something common between all these parameters, ABCD, there are all transfer parameters. None of them are driving point parameters. 1 is a voltage transfer function, reciprocal of a voltage transfer function, reciprocal of a current transfer function, reciprocal of a transfer impedance, reciprocal of a transfer admittance. The word transfer is common to all of them. In other words, the excitation and the response are a different ports and since every parameter has a transfer associated with it, they should be called either transfer parameters or, a better language, transmission parameters. This is the reason, yes?

Student: Sir, while calculating B, B is a short circuit at the second port and apply voltage source at first port, can we apply a current source at second port?

Sir: No, the constraint is that I have to make V 2 equal to 0. If I apply a current source here, I cannot guarantee that V 2 equal to 0, agreed? Any other question? Now without much of a discussion now, let us see if you can relate these parameters to the familiar ones, the z and y parameters for example.

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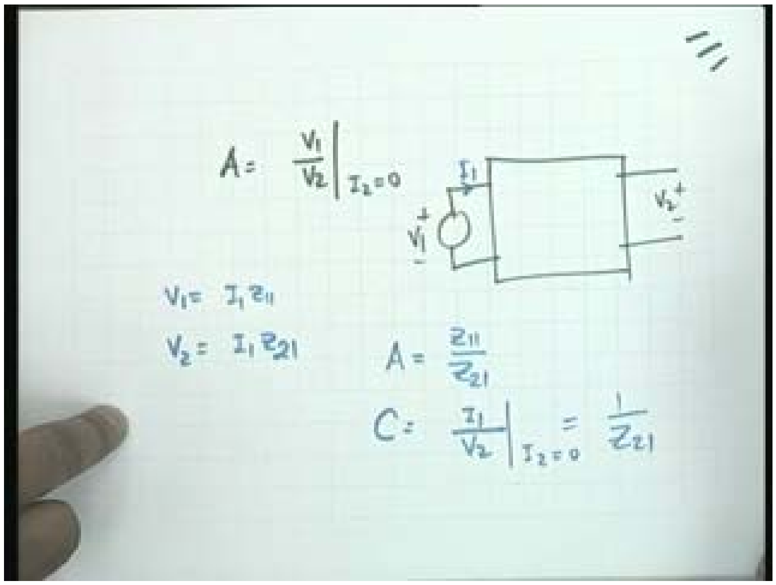

Suppose I consider A, the A parameter by definition is, if I remember, V 1 by V 2 under the condition I 2 equal to 0. Let us take the network, I have I 2 equal to 0, so the response must be here and this is V 1. Now, to find out the ratio of V 2 by V 1 and take the reciprocal, now if you recall, please do follow me, if you recall our z parameters definition is V 1 equal to I 1 z 1 1 plus I 2 z 1 2, I 2 is 0, so let me not write that, the other is V 2 equal to I 1 z 2 1, agreed? Therefore, my capital A shall be simply equal to z 1 1 by z 2 1, is that clear?

If you know the z parameters, I know the capital A parameters, the transmission parameters. Transmission parameter is simply the ratio of z 1 1 by z 2 1. The other parameter that we can find out from here is the C parameter. C is I 1 by V 2, if I am not mistaken, with I 2 equal to 0. So I 1 is this current and V 2, can you tell me what is, pardon me

Student: 1 by z 2 1

Sir: 1 by z 2 1, that is correct, 1 by z 2 1. Now I could relate this, I could relate A and C to z 1 1 z 2 1 because, very easily because, I kept this open and you see, open circuit, the z parameters are measured under open circuit conditions. On the other hand, the other 2 parameters are most easily related to the short circuit parameters, namely y parameters.

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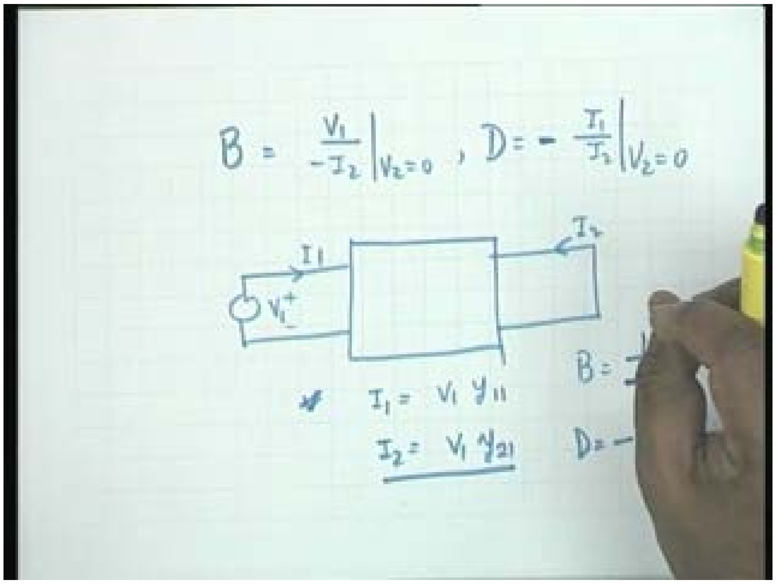

For example, the parameter B as I have said is V 1 divided by minus I 2, under the condition V 2 equal to 0, and the parameter D is minus I 1 by I 2, under the condition V 2 equal to 0. So let us take this network, V 2 equal to 0 is this. Only thing you can measure is I 2 and here, you connect either a voltage source or a current source but the net result is that the voltage is in current cell V 1 and I 1 and now what I have to do is, find V 1 by I 2 V 1 by minus I 2 or I 1 by minus I 2. Now, if I write the short circuit parameters, V 1, I am sorry, short circuit parameters I 1 is V 1 y 1 1, V 2 is 0, and I 2 is equal to V 1 y 2 1 because I 2 is 0, I am sorry, V 2 is 0, the second time I need not write. Is not it obvious that V 1 by minus I 2, that means, B V 1 by minus I 2 would be?

Student: Minus 1 by y 2 1.

Sir: Minus 1 by y 2 1, minus.

Student: No sir, current?

Sir: You see, this is the relation for this situation. I 2 equal to V 1 y 2 1 so V 1 y by minus I 2 would be minus y 2 1. Do not forgot this negative sign, it is extremely important. We will make a mess if this is not included and as for as D is concerned, for D you simply have to take the ratio of the 2 with a negative sign. So D would be minus y 1 1 divided by not quite, I am sorry, this is perfectly all right because the negative sign is there. Minus y 1 1 by y 2 1, is that clear?

This is an example to show that all these parameters, whether h parameters, h parameters also related to the z parameters, did not we? We did not relate h 2 1 and h 2 and h 1 2. We will do that in a short while but any set of parameters can be converted to any other set of parameters, what is the reason? why can we do it? What is that facilitates this conversion? Because it is a set of linear equations, 2 linear equations, can be manipulated any manner you like, all right, without any problem.

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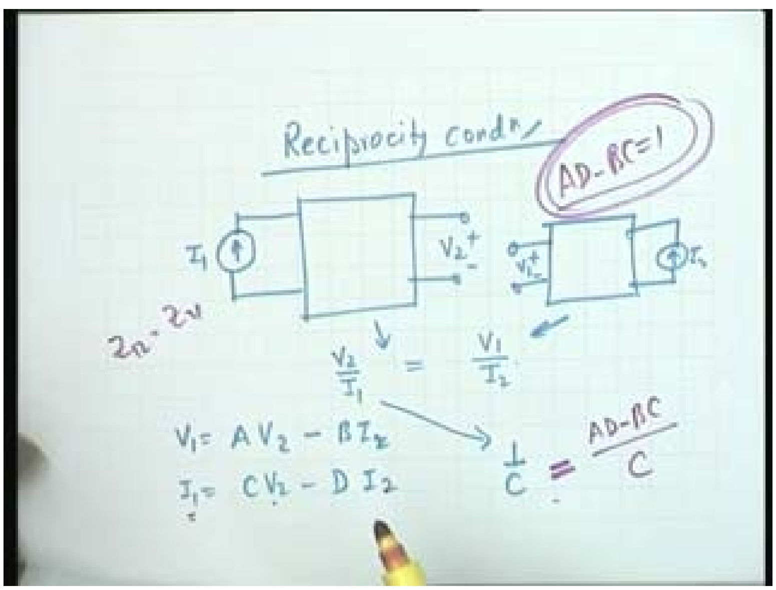

Let us take now another important derivation, that is, what is the reciprocity condition in terms of ABCD parameters? Reciprocity condition, in terms of ABCD parameters and for these we appeal to the network itself, that is, what you do is, we excite the network by a current and measure the voltage open circuit voltage V 2, agreed?

Now reciprocity demands that if the current source is taken to the right hand side and the voltage is measured under open circuit condition on the left hand side, the ratio should be equal. In other words, if I change my excitation and responses, I 2 and V 1, under these 2 conditions, the relation between V 2 and I 1 should be equal to V 1 by I 2, all right? V 2 by I 1 is measured from here and V 1 by I 2 from here. This is the reciprocity condition, this is the reciprocity theorem. Now if I appeal to my equations, you see, V 1 equal to A V 2 minus B I 2 and I 1 is C V 2 minus D I 2, then you see, under the condition that I 2 is 0, for this, I 2 is 0, what is V 2 by I 1? It is simply, yes? 1 by C.

And for the other condition, that is, I 1 equal to 0, you have to put this equal to 0. Let me indicate to you how it is done, I will skip the algebra. What we will do is, for finding out this V 1 by I 2, we have to put I 1 equal to 0. So if I put I 1 equal to 0, I get a relation between V 2 and I 2, all right? Then in the first equation, we have to find out V 1, so the place V 2 in terms of its value I 2, in terms of I 2. Then you can find out V 1 by I 2.

Student: (..)

Sir: Pardon me, say it again.

Student: AD minus BC by C?

Sir: AD minus BC by C, so these 2 should be equal, which means that AD minus BC should be equal to 1, if the network is to be reciprocal. We have proved it, how did you prove it? We applied the theorem itself, we went to the roots, but if you look at carefully, these roots mean nothing but equating z 1 2 2, z 2 1 what is this parameter? V 2 by I 1 with I 2 equal to 0? Obviously, it is z, no, not 1 2.

Student: z 2 1

Sir: 2 1 and this is z 1 2, V 1 by I 2, under the condition I 1 equal to 0 is z 1 2. So what have to done is, we have taken the condition z 1 2 equal to z 2 1 and then applied the definition of ABCD parameters, this is the condition for reciprocity.

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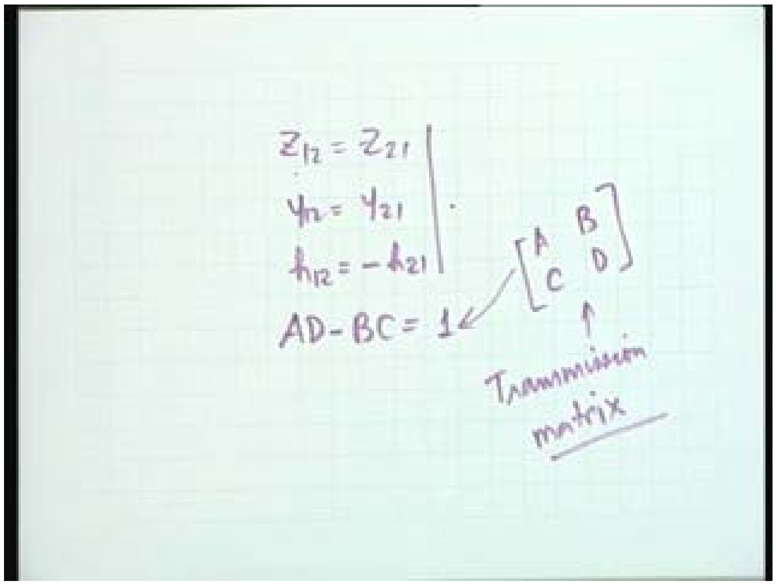

To summarize, our condition for reciprocity is z 1 2 equal to z 2 1 y 1 2 equal to y 2 1, this is fine, h 1 2 is minus h 2 1, there a negative sign, and in terms of transmission parameters it is AD minus BC equal to 1. You see that this is the only set of parameters in which all the 4 parameters are involved, that is, left hand side is nothing but the determinant of this matrix, the determinant of this matrix, where as the other 3 relate to the off diagonal parameters. Diagonal parameters are z 1 1, z 2 2, off diagonals are z 1 2, z 2 1. This is also off diagonal parameter, this is also off diagonal parameter. Only 2 of the 4 parameters are involved in reciprocity, if you describe the network in terms of z, y or h.

But if you take transmission parameters, then all the 4 are involved and it is the determinant of the transmission matrix, this is called transmission matrix. This is what will start from, in the next lecture.