Introduction To Electronic Circuits

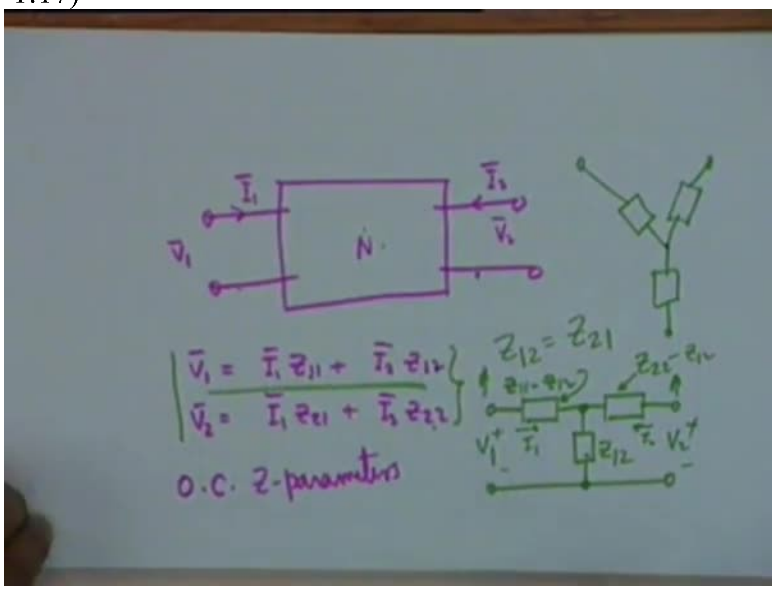
Professor S.C. Dutta Roy
Department of Electrical Engineering
Indian Institute of Technology Delhi

Module No 01

Lecture 24: Two-Port Networks

Electrical. 24th lecture on two port networks.

(Refer Slide Time: 1:17)



As I had discussed yesterday, a two port network is one which has 2 ports, as simple as that. And for sinusoidal excitation, we take the phaser quantities V1, I1, V2, I2 and as already mentioned, 2 of these variables can be dependent, the other 2 are dependent. And there are 6 ways of expressing these relationships. 2 of them which are most popularly used are the currents as the independent variables and the voltages of the dependent variables and we have I1Z11 plus I2Z12 and I1 Z21 plus I2Z22. In order not to write these bars again and again, we will omit the bars. It will be understood in the context that these are phasers.

I have already explained why there are 2 subscripts. 2 subscripts are needed to express the transfer impedances and therefore to be consistent we use two subscripts on the driving point impedances als0. Z11 is a driving point impedances with the port 2 open circuited. This Z11 is V1 divided by I1. So it is an impedance at the driving point at port number 1 with port 2 open circuited. In fact, all these 4 parameters, Z11. Z12. Z21, Z22, if you measure or define, these will be conditions under open circuit.

For example, Z12 is V1 divided by I2. That means you apply a current generator here and measure the voltage under what condition? Open circuit condition. That is, you have to make I1 equal to 0 and therefore these are called Z parameters and sometimes you use the adjective, OC open circuit Z parameters. And you also know that because of reciprocity, that is if capital N is a reciprocal network, then you know that the 2 transfer impedances are equal, Z12 is equal to Z21. There are many other interesting things that can be brought out from these relationships and one of them is that the blackbox, if you represent it by, if you characterise it by Z11, Z12 and Z22, only three out of four are needed if the network is reciprocal, then you can construct an equivalent model for the network like this.

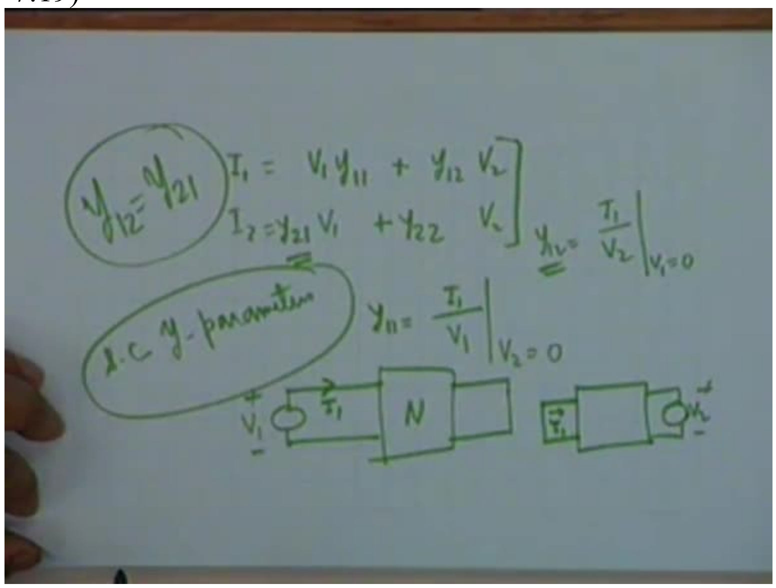
You can easily show that these 2 relationships can represented by 3 elements like this 3 elements like this where the shunt element is simply Z12 and the series elements are, this is Z22 minus Z12, this is Z11 minus Z12, this one. Then this simple network represents the 2 equations. I am not saying this network represents the original N because the original N is 4 terminal whereas the model is 3 terminal. So one, this cannot be equivalent to this. It is equivalent, it is equivalent to the 2 equations representing the network.

And therefore, if this network was 3 terminal, if these 2 terminals were common, then it would have been, this would have been a model of the network. It must be remembered all right? If it is a truly 4 terminal network, you cannot replace N by this. But as far as the mathematical relationship is concerned, yes, this network represents. This can be very easily shown. You you write V1, V2 here and the 2 currents are I1 and I2 and you can easily see that V1 is equal to I1 Z11 minus Z12 plus I1 plus I2. The current Z12 is I1 plus I2, Z12. And if you add them up, you get precisely the 1st relation.

Similarly, for the 2nd relation. So this is the shape of the network is that of a T and therefore, it is called T network model of the 2 equations. T network model, capital T. You can also if you if you pull this thing, this terminal up and this terminal up then you can also show it like this. If you pull it a little bit right, if you pull these 2 terminals up, then it becomes of the shape of a Y and it is sometimes called an Y equivalent model of the mathematical equations. So it is either called a

T network or a Y network. Now as I said, there is nothing sacred about the currents being the independent variables.

(Refer Slide Time: 7:19)

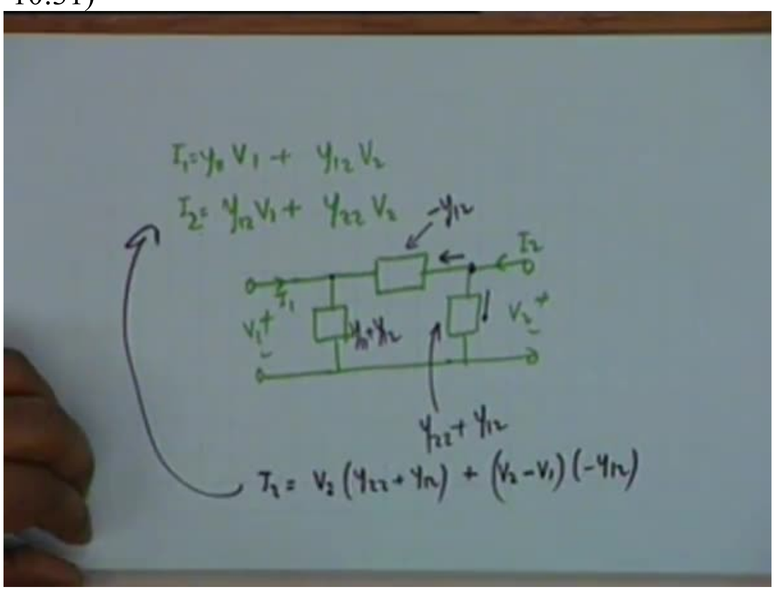


One could also have the voltages as independent variables and under that condition, the relationship shall be V1, V2. I2 shall also be expressed as a linear combination of V1 and V2. The coefficients now shall be of the dimensions of admittances and therefore, we call this as y11, small y, we call this as y12, we call this as y21 plus we call this as y22. The dimensions have to be admittances and you see that the coefficient of V1 is simply the driving point admittance at port number 1 all right? y11 for example you can see that this is I1 by V1 under the condition V2 equal to 0. In other words, what you do is, you apply a voltage generator V1 at terminal 1 okay?

Then you short-circuit terminal 2, V2 equal to 0 and measure current I1 all right? That is how it becomes a driving point admittance under the condition that the other port is short-circuited all right? Similarly, when you measure y12, what is y12? Y12 is I1 over V2 under the condition that V1 equal to 0. That means, you apply a voltage generator, let me represent it, you apply a voltage generator here, V2. Then you measure, you short-circuit port 1. V1 equal to 0 and measure this current I1. The ratio I1 to V2 shall be y12. y12 is a transfer admittance, similarly, y21 is also a transfer admittance.

And you can see that all these parameters are measured with one port short-circuited and therefore these are known as SC Y parameters, that is short-circuit admittance parameters all right? In similarity with the open circuit Z parameters, one can argue here that if the network N is reciprocal, then you do not require 4 coefficients to characterise the network. You require only 3. And the reason is that y12 shall be equal to y21 and under this condition, one can draw a very simple equivalent model for the 2 equations and that model by duality shall now look like a pi instead of a T, by duality.

(Refer Slide Time: 10:31)

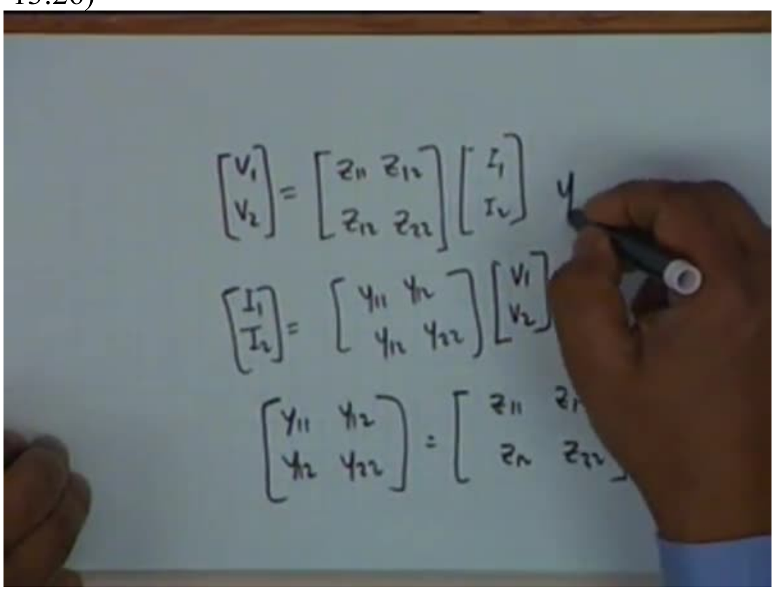


If I write these equations again, I1 equal to y11V1 plus y12 V2 and I2 is equal to y21 is equal to y12, so let me write y12 V1 plus y22V2. It is very easy to show that these 2 equations can be very easily represented by a network looking like a pi all right? V1, I1, V2, I2. I am omitting the bars because it is implied that in the context, they are all phasers. And these various parameters are, this is y11 plus y12, this admittance is minus y12 and this admittance is y22 plus y12. For example, to verify that this is indeed so, you notice that I2, if I write an expression for I2, I2 is V2 multiplied by this ad admittance. I2 is V2. V2 is the voltage across this.

So I2 is the current through this network, this element and the current through this element, the sum of the 2. I2 is V2y22 plus y12 plus V2 minus V1, this voltage is V2, this voltage is V1, multiplied by minus y12. And you see that this is precisely the 2nd relationship. And in a similar manner, you can show that the 1st relationship is also valid. So this is an equivalent model for the mathematical equations but not of the original network. The reason is that this is 3 terminal and the original network was 4 terminal. If the original network was also 3 terminal, then this would have been truly an equivalent model of the original circuit.

Is the distinction clear? I have repeated this. It must be understood carefully because otherwise you can make a mess of the whole thing. If the 2 lower terminals do not have the same potential and you substitute this, you might short-circuit something. The circuit might burn. So these are the 2 kinds of parameters which we are presenting at the present moment. We shall be concerned with other ways when we talk of transistor circuits and that is the other sets of parameters.

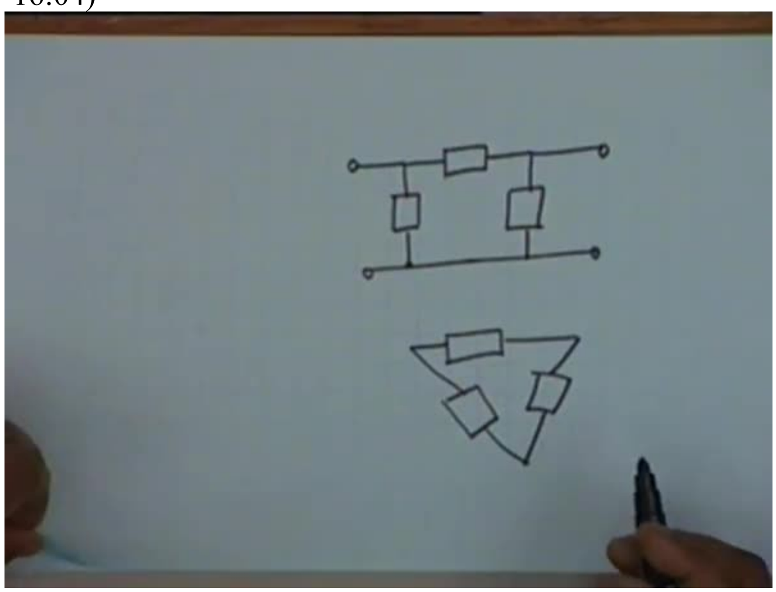
(Refer Slide Time: 13:26)



But if you notice, if you notice this carefully, the 2 sets of parameters, you see if I take V1V2, the open circuit impedance parameters and I write this as a matrix of single column, a single column matrix is also known as a vector. Then you notice that the coefficient matrix is simply this. Z12 Z22 all right? Whereas this is for the open circuit that parameters whereas for the short-circuit y parameters, it is the other way round. y11 y12, y12, y22. We are assuming that the networks are reciprocal. That is why we are writing y12 and y21 are equal. Multiplied by V1, V2. And if you are acquainted with a matrix operations, you notice that one coefficient matrix is simply the inverse of the other.

All right? For example, y11, y12, y12, y22 is simply the inverse of the other provided the Z the determinant of this matrix is not 0. That means this matrix is not singular. Inversion can be carried out only when the determinant Z11Z22 minus Z12 square is not equal to 0. All right? If this fact is recognised, then you can also find out, these parameters, y11 y12, y12, and y22 in terms of the Z parameters. Is not that right? You can find for example, y12 as you can see is simply minus Z12 divided by the determining of Z. Is that okay? This is obvious by inspection all right? And I had to do all this to convince you that the transfer admittance is not the reciprocal of the transfer impedance. They are quite different. One is not the reciprocal of the other. There is a negative sign and the denominator is the determinant of the matrix. Okay? Similarly you can find out Z12 in terms of y12. One is not the reciprocal of the other.

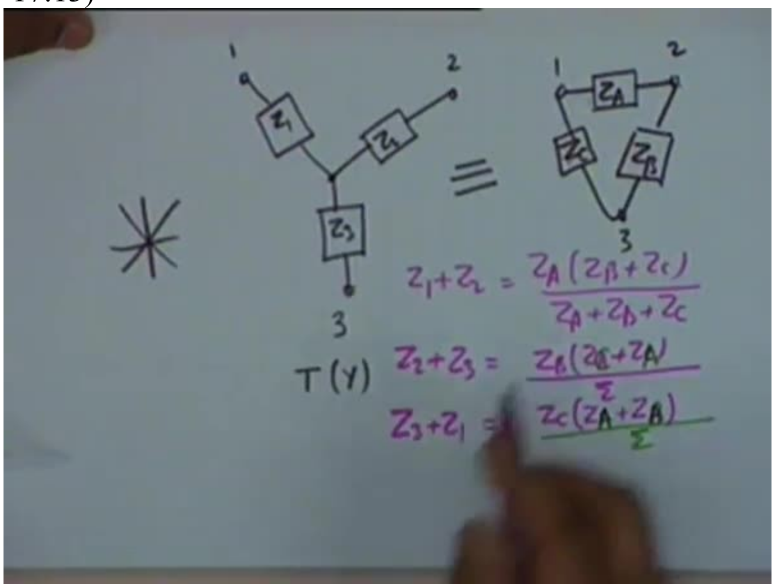
(Refer Slide Time: 16:04)



This pi network which we have just drawn which is the short-circuit y parameter equivalent model of the equations, well if you pull, if you pull these 2 terminals close together then another way of representing this network is a delta. This looks like a Delta and therefore this is also called the Delta network model. Instead of pi, it is also called Delta network model of the 2 equations, 2 simultaneous equations. In the context of network simplification, you have seen that if 2 elements are in series, you can find out the equivalent, if 2 elements are in parallel, you can find out the equivalent.

Now in general in a complicated network, series parallel reduction can proceed up to a certain extent but not beyond it and the two port theory than comes in to help.

(Refer Slide Time: 17:13)



For example, if I have a T network like this, T or a Y, all right, let us mark the terminals 1, 2, 3. A 3 terminal network which is of the shape of a T or a Y, T or Y and I wish to convert it to a delta. That is, I want to find out the equivalent, I wish to convert this into an equivalent 3 terminal network such that the parameters are 1, 2, ZA, ZB, ZC, yes, another name for this they start. This also looks like a star although star has many others, this is only 3. All right. I want to find out the conditions under which this network would be equivalent to this. This is a 3 terminal network, this also is a 3 terminal network.

To determine the equivalence of one network to the other, what we do is, we make either open circuit or short-circuit measurements for both the networks and equate the results all right? The algebra is quite simple once you understand what is it that we are doing. For example, let us let us leave 3 open and measure the impedance between 1 and 2. Obviously then Z1 plus Z2, this is what you will measure. On the other hand, if you leave this open and measure the impedance between 1 and 2, what you will measure ZA ZB plus ZC divided by ZA plus ZB plus ZC. Is that okay? So this gives you one condition. Since you have to find out 3 of the elements, 3 elements, you require 3 such measurements.

So the other measurement can be Z2 plus Z3, that is between 2 and 3, leaving 1 open. And this shall always be between 2 and 3. So ZB ZA plus ZC divided by the sum of the 3. Let us put it at Sigma. All right? The 3rd equation shall be, measure between 1 and 3. So Z3 plus Z1, you must notice that there is a certain kind of circular symmetry that I am following. 12, 23, 31, it always helps nature as symmetries, beauties of symmetry and it helps to preserve those symmetry. Z3 plus Z1 shall be between 1 and 3. So I write ZC, then ZB plus ZA, no, that does not retain the symmetry. I should have written pardon me?

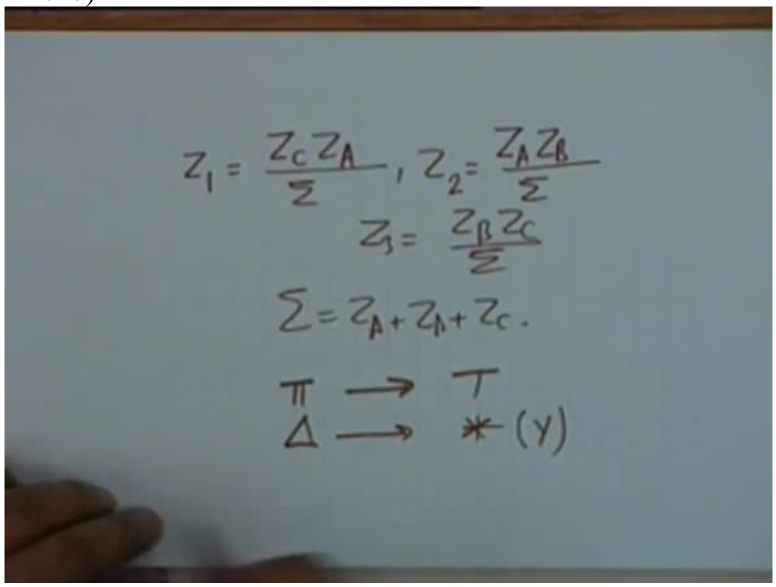
Student: 2nd equation.

Professor: 2nd equation. No, it is not wrong. I did not maintain the symmetry. I should have written like this. C plus A. And then this should have been written as A plus B divided by Sigma. These are 3 equations now which have to be manipulated to find either Z1, Z2, Z3 in terms of ZA, ZB, ZC or vice versa. All right? And I will simply point out how to do this. The algebra shall be left to you. You see if I look at these 2 relations, Z2 plus Z3 and Z3 plus Z1. Suppose I subtract this equation from this then I shall get Z2 minus Z1. The 1st equation gives me Z2 plus Z1 and therefore by adding and subtracting, I can find out Z1 and Z2. Similarly for the 3rd. And the results is this clear, the manipulation?

Student: (())(21:26)

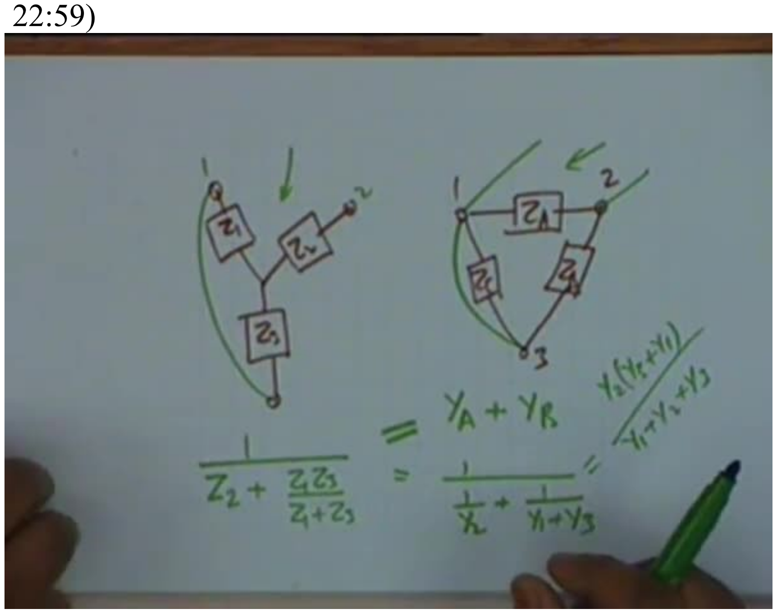
Professor: all right, we will do that also. Let us 1st find out Z1, Z2, Z3 in terms of ZA, ZB, and ZC all right? That is we are going from pi to T. pi to T or Delta to star. All right? The results are, I will I will come back to this.

(Refer Slide Time: 21:46)



The results are Z1 equal to ZC ZA divided by Sigma , then this is correct, Z2 is ZA ZB over Sigma and Z3 is ZB ZC over Sigma where Sigma is the sum of the 3, that is Sigma equal to ZA plus ZB plus ZC. This gives you conversion from pi to T or Delta to star. Delta to star is also Y. No, I beg your, yes, okay. Delta to star all right? If you want the other way, that is you want to go from T to pi. In other words, you want to find out ZA, ZB, ZC in terms of Z1, Z2 and Z3, let us see what should we do.

(Refer Slide Time: 22:59)

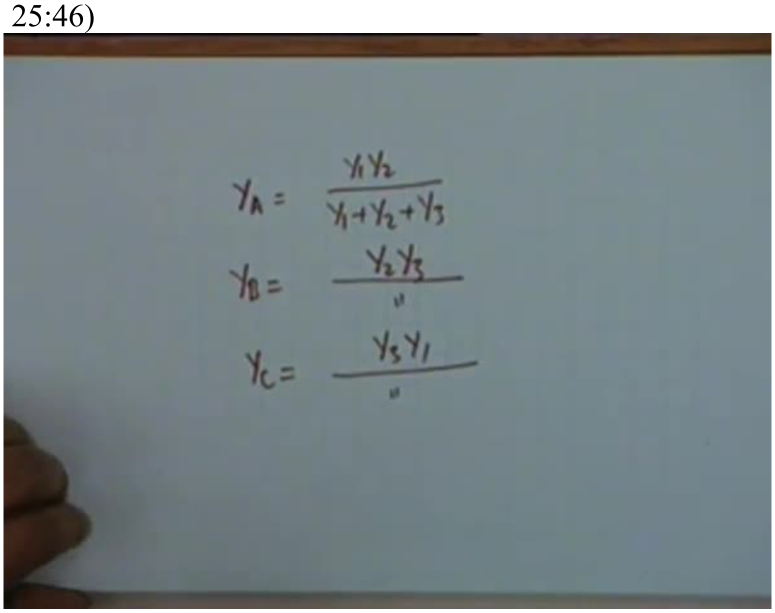


Let us draw the network again. You have Z1, Z2 and Z3 and then you have here ZA, again I will only indicate the steps, I will not carry out. 1, 2, 3. In the previous case, the duality of the situation suggests that we should measure admittances under short-circuit conditions. So what we do is, suppose we short-circuit 1 to 3 and measure the admittance between 2 and 1 all right? Suppose we short-circuit 1 to 3 and measure the admittance between these 2 points, what shall we get?

We shall get ya plus yb, the admittance shall be ya plus yb. Now we short-circuit 1 to 3 and measure the admittance between 1 and 2, what shall we get? We shall get 1 over the impedance. Impedance will be Z2 plus Z1Z3 divided by Z1 plus Z3. Agreed? These 2 should be equal. This is okay? I am finding out by inspection. Z2 plus the parallel combination of these 2. Well, I can write this as 1 over y2 plus 1 over y1 plus y3 all right which I can simplify as y2y3 plus y1, I am writing in a circular fashion, circular symmetry, divided by y1 plus y2 plus y3.

Now similarly, you see what I have done is, I have expressed the sum of admittances in terms of the admittances of the T network and I can now write yb plus yc, another equation, yc plus ya, a 3rd equation and then eliminate one by one to find out the values of ya, yb and yc. From symmetry, the end results do I have to explain further? I have to obtain 3 equations. One I have shown how to obtain. You obtain the other 2, then you make systematic eliminations.

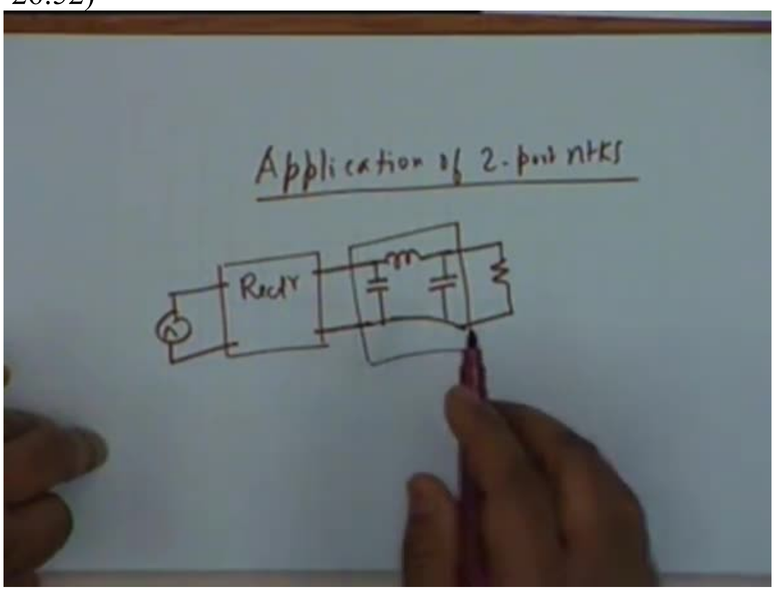
(Refer Slide Time: 25:46)



The final results are as follows. ya becomes equal to y1y2 divided by y1 plus y2 plus y3, yb now I can write this from symmetry yes y2y3 and yc shall be y3y1 divided by the same summation. These formulas do not have to be remembered if you recall the Z and y parameters but I leave it to you what you find most convenient. In any case, you have to find out. If you want to remember, then you have to find out some convenient way of remembering and that also, yes of course.

The question was barred. I do not know why you ask the question again and again. As soon as long as I sit here is teaching a course, there cannot be a closed book examination. All right?

(Refer Slide Time: 26:52)



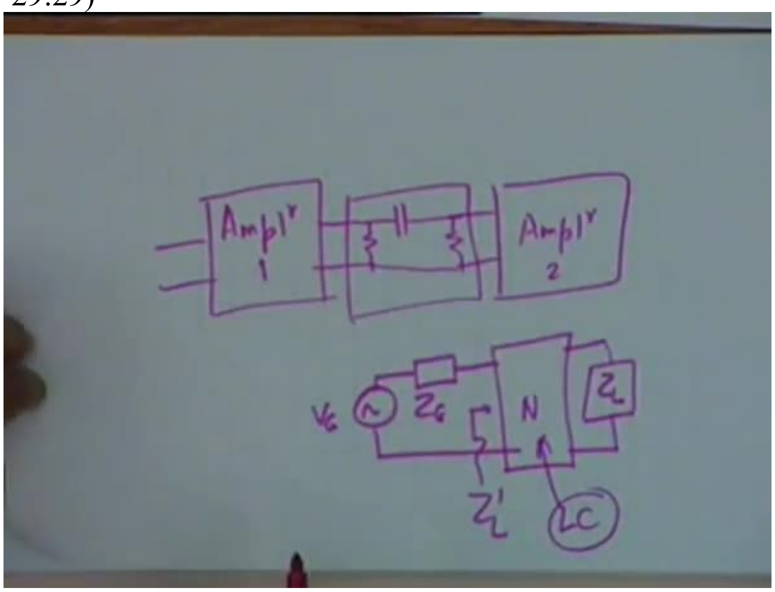
Application of 2 port networks. Where are 2 port networks used? Almost all networks that you see are 2 ports all right? For example, a communication receiver. Where is the input? Input comes from the antenna? And Where is the output? Output is the loudspeaker. A CRO, there is an input, input signal. Where is the output? Output is the visual output. It is a picture all right. Almost all networks are 2 ports. 2 ports of linear bilateral elements are also used to couple one system to another, to couple. So they are used as coupling network.

For example, you have the rectifier. You have let us say full wave rectifier containing a transformer and let us say a bridge rectifier, for diodes all right? You have to supply, what does a rectifier do? Rectifier is also a 2 port. Is not it right? It takes an AC at the input and produce a

DC. It does not. It produces a DC on which is superimposed a ripple or an AC. You wish to to drive a load with this VC and if you want to improve the DC content or reduce the AC content, or reduce the ripple content of the output, what do you do? You apply a filter in between.

And we have seen simple filters. For example, you could have a pi filter here okay? You could have a pi filter or you could have an L filter all right? Now the filter obviously, this is obviously a 2 port network. All right? So a 2 port is used to couple the system which is the rectifier system to the load. This is the load and this is the rectifier. So rectifier to load is being the filter or the 2 port acts as a coupling network all right? It couples one system to another. Similarly, when you want to amplify a given signal, and one stage of amplification does not suffice, then you have to couple one amplifier to another all right?

(Refer Slide Time: 29:29)



Let us take that example. I have two amplifiers, amplifier 1 and I want to present output of amplifier 1 to amplifier 2. Now the output invariably as we shall see later contains DC as well as the signal and one should get rid of the DC. So what one does is one uses a capacitor and this is the amplifier output and this is the amplifier input. So this CRC network or RCR network is being used as a coupling network. All right? There are also situations where Jack you use a matching network, an impedance matching network.

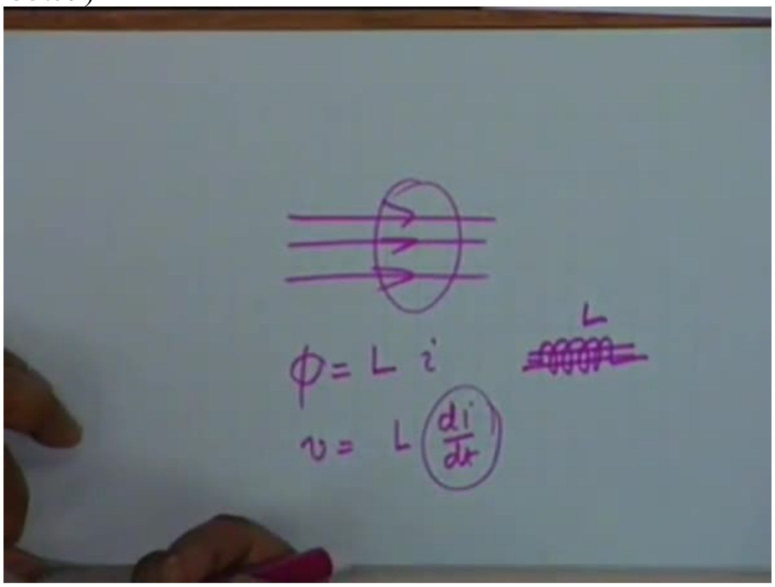
That is, you have a source VG in series with let us say an impedance ZG, this is a phaser. I am not using the bar because it is clear in the context. And then you have the load ZL. You wish to transfer the maximum amount of power to ZL, maximum available power from the source to ZL. So what you do is if Z sub G is not the complex conjugate of ZL, you know this is the condition for maximum power transfer. If this is not true, then what you do is, you insert a network N, a 2 port N to achieve this, to achieve the effective impedance ZL which you call ZL prime, you have to achieve prime equal to the complex conjugate of Z sub G.

Then you make sure that ZL shall receive the maximum available power. A question. Can N, what should be the components of N? What kind of components should it contain? Inductance and capacitance only, no resistance. Why not? Because then resistance itself will absorb power and the maximum available power will not be transferred to the load. So this N must be an LC network. These are the various applications of a 2 port network but in all these, 3 examples that we have cited, the coupling is through actual contact, that is actual wires leading current from one place to another.

The coupling can also occur through indirect means like magnetic field or electrostatic field also. If you bring a capacitor, if you bring a capacitor in an electrostatic field, a potential difference shall be developed between the 2. If you place two conductors in an electrostatic field, then the 2 conductors depending on the location of the 2 conductors, the potential shall be different and therefore, it has acquired, it has it acts like a capacitor with a charge. On the other hand, if there is a magnetic field, if there is a magnetic field, magnetic lines of force and you put a coil in this, and if the field changes with time, then you know the coil shall have an induced voltage.

This is not a coupling by conduction or by actual contact. This is a coupling through invisible means, that means the magnetic field. A coupling can occur through electrostatic field or magnetic field. In particular, the magnetic field coupling is of great interest to electrical engineers because it does not disturb the original circuit to the extent that it does if it was taken by direct conduction. Coupling can be magnetic coupling and magnetic coupling is of great interest.

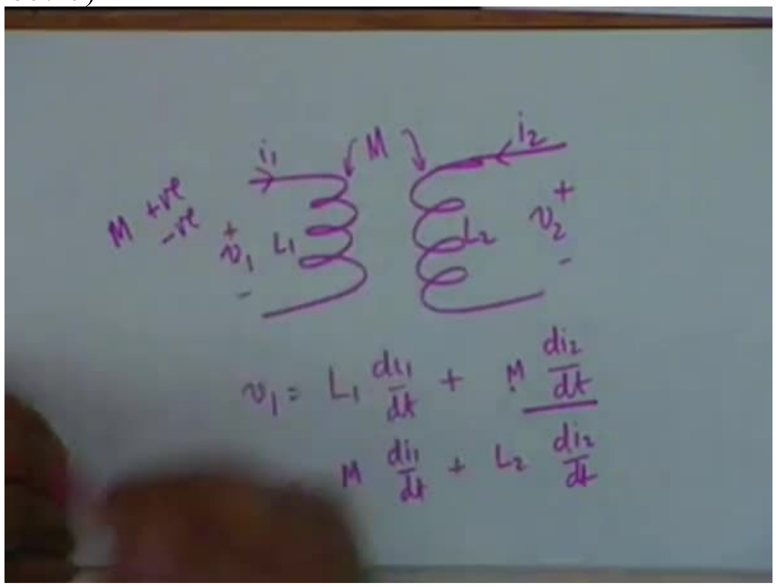
(Refer Slide Time: 33:59)



Now to understand magnetic coupling and to be able to characterise in terms of, in terms of mathematical equation, you recall that if I have a coil with an inductance L which carries a current I then the flux associated with the inductance shall be the product of L and I. L by definition is induct, the flux per unit current. So phi, the flux is equal to LI. And if I varies, if phi varies, the magnetic flux varies, then you know that the inductance develops a voltage across it which is L didt which is d phi dt and it is equal to L didt.

Now this is a case in which a coil of inductance L is in a magnetic field and links a current, the magnetic field is created by its own current all right? The magnetic field is created by its own current and if the field changes, that means the current changes, then the voltage across it is developed which is equal to didt. On the other hand, if the flux is a constant, then didt is 0 and the voltage across this is 0. This is why we said inductor acts as a short-circuit to direct current.

(Refer Slide Time: 35:15)



Now, if this magnetic flux is generated by another coil, another coil carrying a current let us say I2 and we have this magnetic flux also links the 2nd coil and if this flux phi changes with time, then obviously, the 2nd coil we shall have if the inductance is L2, well let us say this is I1, L2 di1dt, some constant multiplied by the rate of change of current all right? To distinguish between self induction and induction from another source, we use the symbol instead of L, we use the symbol M and M stands for mutual inductance, that is the inductance associated with 2 coils all right?

The symbol L is used for self inductance that is flux linkage due to its own current whereas the symbol capital M stands for mutual inductance and it characterises flux linkage due to current in another coil. All right? Now one should understand that if there are 2 coils interacting with each other, that is one generates an electric field and magnetic field which cuts across the 2nd coil, similarly the medical field emitted by the 2nd coil cuts across the 1st coil, and if these currents are changing, then obviously, the voltages across the 2 coils shall have 2 components.

One would be due to its own current variation and the other components would be due to the current variation in the 2nd coil. And to denote, to characterise the 2nd component, we require a constant called mutual inductance and we denote this as capital M. For example, V1 shall be, if this current is I1 and if this current is I2, then V1 shall be L1, let the self inductances be L1 and

L2. L1 didt, this is due to its own current and the 2nd component shall be due to di2dt and the coefficient is capital M, the mutual inductance.

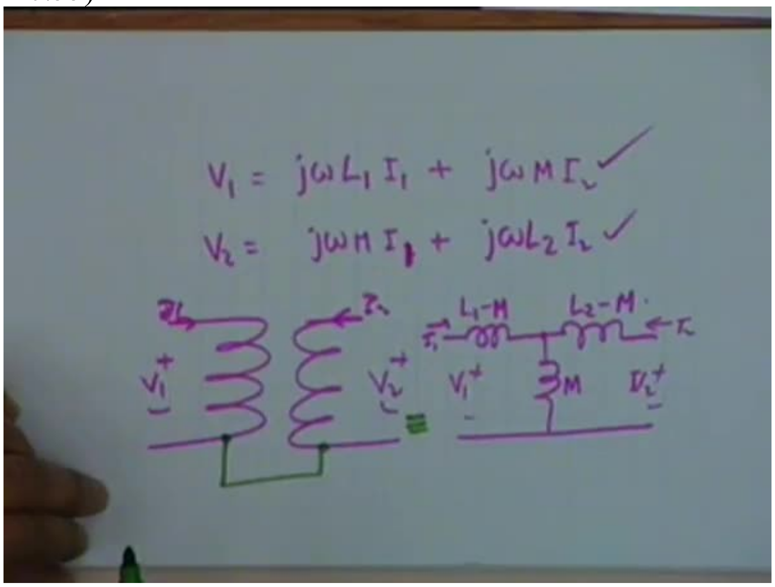
What you should do actually is to have M12 and M21, that is the voltage induced in the 1st coil due to current in the secondary, if you call this M12, then the other one, you should call M21 and you should write M di1dt plus L2 di2dt, this would be the voltage in the 2nd coil. However due to reciprocity theorem, the 2 constants are equal, that is M12 and M21. Does it require further explanation to convince you that they are indeed equal? Because the cause and response, the excitation and the response are interchanged. Therefore the coefficient or the ratio of the 2 must be the same.

That is why we have used 2, the same usual inductance. Now the voltages do not necessarily add. It depends on the orientation of the coil. For example, a flux in one coil might try to cancel the flux in the other coil. Under that condition, this voltage shall subtract from the self induced voltage. Is the point clear? Depending on the orientation of the currents, for example, you can have let us say clockwise turns, like this. One current can be clockwise, the other can be anticlockwise.

And then one of the coils produces a flux which tends to cancel the flux produced by the other coil. And therefore , this voltage may try to destroy the self induced voltage. Under that condition, this sign shall be negative and we say that under that condition, not the voltage, we say the mutual inductance is negative. So M, mutual inductance can be either positive or negative. Do you understand this situation when they are positive and when it is negative?

It is positive if the mutual induction produces a voltage which is of the same polarity as due to self induction, then M is positive. On the other hand, if mutual induction produces a voltage which tries to annul the voltage due to self induction, we say capital M is negative. We will have more to do with this later but at the present moment, you look at these 2 relationships and tell me if the excitation was sinusoidal, then how would these relationships exchange?

(Refer Slide Time: 40:55)

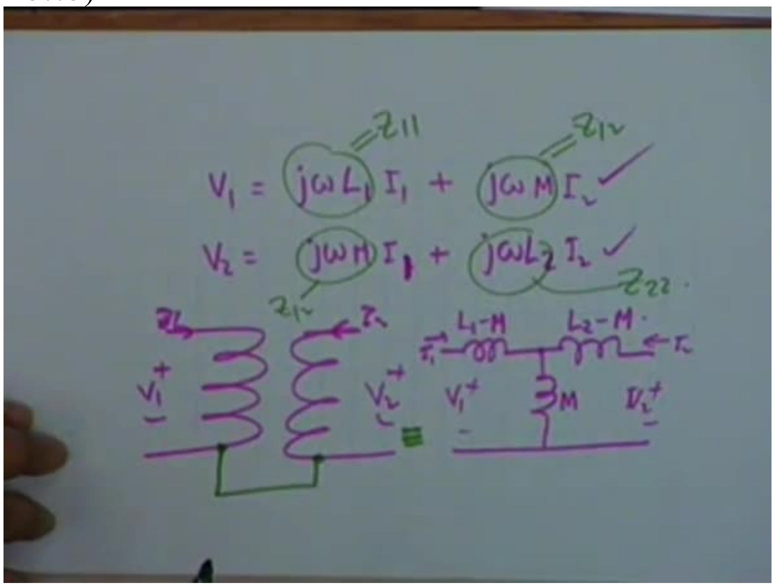


If the excitation would be sinusoidal, then we could express in terms of phasers. That is we would have simply return, V1 equal to J omega L1, this is impedance of the inductor, self inductance multiplied by I1 plus J omega MI2 and V2 would be written as J omega MI2 plus J omega L2, I beg your pardon, this would be I1, L2I2. All right? And it takes very little thinking to show that this is equivalent to, this circuit which has no physical contact, the coupling is through magnetic field, that this is equivalent to simply a T network like this where this inductance is M, this inductance is L1 minus M and this inductance is L2 minus M.

Can we say, is this okay? This is V1, I1, I2, V2. Similarly here, V1, V2, I2, I1. You can easily show by writing the loop equation that this 1st equation is satisfied, the 2nd equation is also satisfied. Now can we say that this transformer is equivalent to this? No. I am going to test this again and again so that you never make such a mistake. This is not equivalent to this. It is only equivalent to the 2 mathematical equations. On the other hand if we had this, then they would have been exactly equivalent.

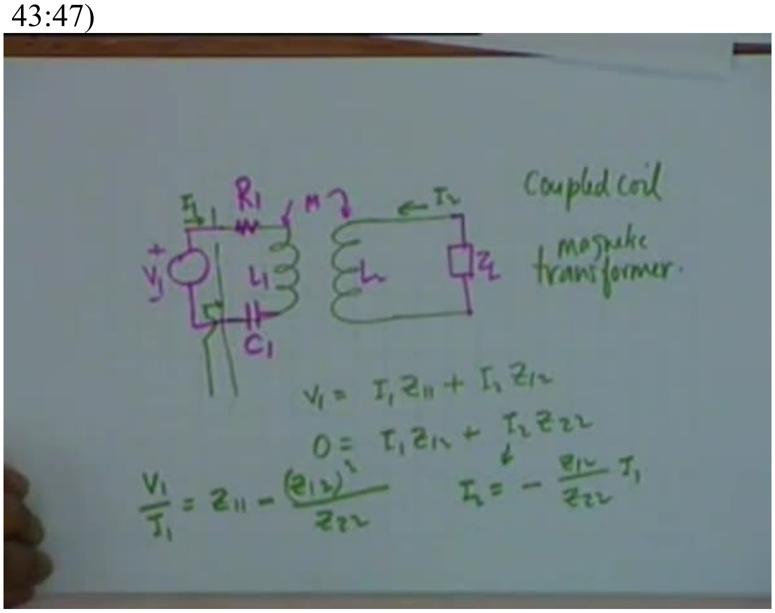
That is why, I have shown this in green and equivalence is also in green. Only when this line is there, the Green line, there shall be a green to this equivalence. Is that okay? All right.

(Refer Slide Time: 43:03)



Now suppose I write J omega L1 as Z11, J omega M as Z12, is as Z12 and this as Z22, then do not you see that this is simply the same T model, that is Z11 minus Z12, Z22 minus Z12 and this is simply Z12. Is that okay? So instead of looking at it from the impedance parameters, OC impedance parameters, we look at it directly in terms of the components. Well, there are 2 things that one should notice.

(Refer Slide Time: 43:47)

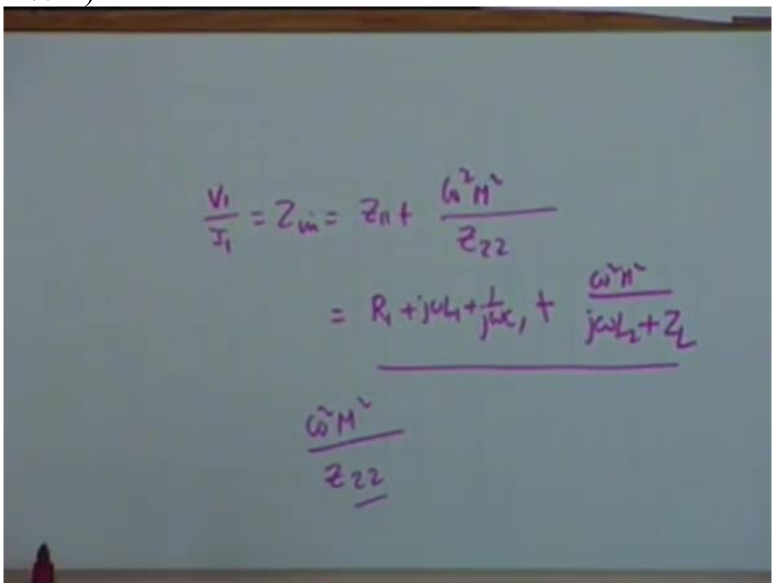


One of them is that if you have let us say incidentally this is called, this circuit, this two port where the flux is generated in 2 coils interact with each other, is called a coupled coil system. At least 2 are needed. They are coupled to each other. Or it is also called simply a transformer and to indicate that the coupling is magnetic, sometimes one says, this is a magnetic transformer. All right? Suppose that we connect a transformer like this. All right? And we have a voltage source here, V1. The mutual inductance is M, this is L1, this is L2. This could be capacitance, resistance or whatever it is, let us call it ZL all right?

There may be other elements here. For example, one could have a resistance R1. Let us also introduce a capacitor C1. What we want to find out is, what impedance does this voltage generator see? What impedance does this voltage or in other words, we want to find out what current V1 drives into this system of coupled coils. What current? Well, all we do is we write the 2 equations. If this is the V1 and this is, this current is I2, if this current is I1, then you know you can write V1 equal to I1 Z11 plus I2 Z12 all right? And the 2nd loop, there is no driving voltage. So 0 shall be equal to I1 Z12 plus I2 Z22 all right?

Now from the 2nd equation, you can write I2 as equal to minus Z12 by Z22 I1. Okay? You substitute this here, then what do you get? V1 by I1. If you substitute this relation in the 1st equation, what do you get? You get Z11 minus Z12 Square divided by Z22. So what does this do? What does the couple coil do? Not only the 1st coil interacts with the 2nd because the 1st coil induces a current to flow in the 2nd circuit. But the 2nd coil also has an effect on the 1st coil. How? If the 2nd coil was not there, if there was no current here, if this was kept open, then my input impedance should have been simply Z11. By definition, V1 by I1 under the condition that the output, the 2nd port is open. Now because of a current flow in the 2nd coil, the impedance is modified by this.

(Refer Slide Time: 47:21)



Can you tell me about this relationship shall be in this particular case? We call this Zin. Z11 minus what is Z12? What is Z12 in this case? J omega M and therefore minus J square Omega squared M squared will be simply omega square M Square divided by Z22. Whatever is included here, for example I had included R1 plus J omega L1 plus 1 over J omega C1, you recall we had a resistance, inductance and a capacitance. So this is Z11 minus omega square M squared divided by J omega L2 plus ZL. Pardon me? It is plus, thank you so much.

Well, it is plus but this is not resistive. Jack It has the resistive component, a reactive component also. And one can work wonders with this reflection of impedance. You can see what is happening is the secondary impedance, the secondary, the 2nd coil impedance is being reflected onto the 1st as an addition of term omega square M squared by Z22. And this allows us to use the transformer as a matching device. What is a matching device? A matching device is one which allows maximum power from the source to be transferred to the load. For example, in a stereo amplifier, the output impedance of the amplifier can be as large as the order of let us say K, 1K, 1000 ohms whereas a speaker, what is the impedance?

8 ohms and 8 ohms has to be matched with 1000 ohms. If you connect directly the speaker, you will not be able to hear. The the whole voltage, the power shall be killed because 8 ohms cannot take maximum power from 1000 ohms. So what you do is, before you connect the speaker, you have an output transformer. What does the output transformer do? It converts that 8 ohms into

1000 ohms. So what the amplifier sees is 1000 ohms and what the speaker sees, what does the speaker see? 8 ohms. And therefore maximum power is delivered. Well we shall work out problems on this and other aspects of a transformer after the minor.

Student: (())(50:03)

Professor: I have told you, till what is done today.

Student: (())(50:10)

Professor: Work it out. I have given you the problems in the tutorial set.