Networks, Signals and Systems

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Lecture - 22

Graph Theory (Contd….)

Image Impedance, Iterative Impedance and Characteristic Impedance

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Today, we shall be discussing about image impedance, iterative impedance and finally the characteristic impedance of a 2 port network, characteristic impedance of a 2 port network. Now let us consider a general network having impedances Z_A, Z_B and Z_C the ports are 1 and 2. Now image impedance we define, we define image image impedance as this if I load this side by an impedance Z_{i2} the impedance in from this side is Z_{i1} and if I load the same network, I show the network just by a block if on this side if I put Z_{i1} then impedance in from this side is Z_{i2} then Z_{i1} and Z_{i2} will be the image impedances for this network. So for a general network where Z_A, Z_B, Z_C are any certain values Z_{i1} and Z_{i2} will be different so there are2 image impedances you look into the circuit from this end if I load on that side Z_{i2} then the impedance in is Z_{i1}, if I look at the network from this end and if I load it with Z_{i1} the impedance in is Z_{i2} mind you you cannot have these unique values with any set, you cannot have any combination so they are dependent on these values are dependent on Z_A, Z_B and Z_C.

Let us what will be the relation between Z_{i1}, Z_{i2} and these element values Z_A, Z_B and Z_C. Now by definition you have got Z_{i1} the impedance in from this side is how much Z_A plus parallel combination of Z_C and Z_B plus Z_{i2}, Z_C in parallel with Z_B plus Z_{i2} agreed. So that gives me Z_A plus Z_C into Z_B plus Z_{i2} divided by Z_C plus Z_B plus Z_{i2} agreed. Similarly, Z_{i2} will be equal to Z_B plus Z_C into just replace a by b interchange a and b Z_C will be Z_A plus Z_{i1} divided by Z_C plus Z_A plus Z_{i1} agreed.

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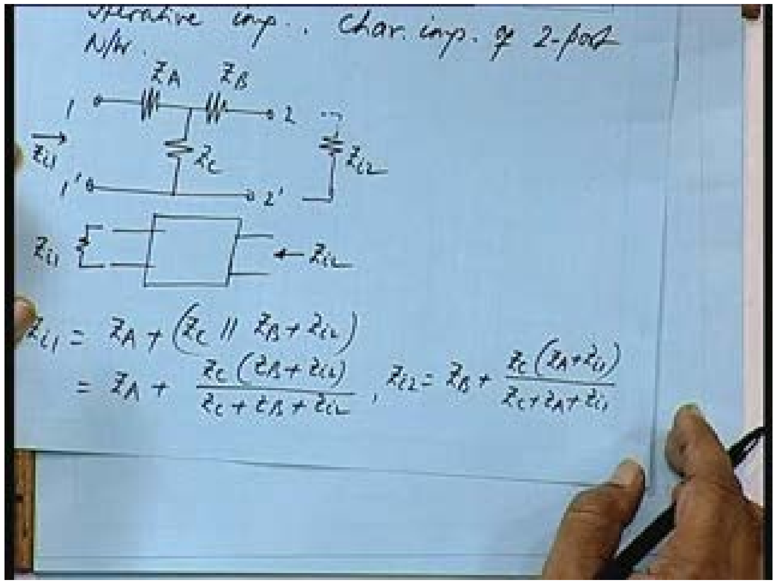

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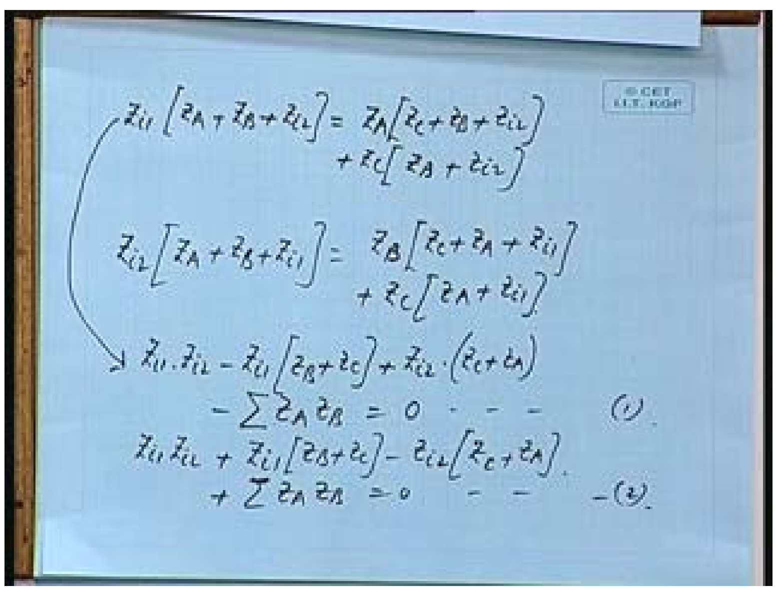

So if I cross multiply Z_C plus Z_B plus Z_{i2} if I bring to the left side what do I get Z_{i1} sorry Z_{i1} into Z_A plus Z_B plus Z_{i2}, Z_A plus Z_B if you add these it becomes Z_A plus Z_B plus Z_{i2} into Z_{i1} and this side you will get Z_A, Z_C plus Z_B plus Z_{i2} plus Z_C into Z_B plus Z_{i2}

correct me if I am wrong. See Z_{i1} into Z_C plus Z_B, Z_{i1} into sorry, Z_{i1}, Z_{i2}, Z_{i1}, Z_C, Z_{i1}, Z_B so actually this one has been written here first and similarly Z_{i2} into Z_A plus Z_B plus Z_{i1} equal to Z_B sorry Z_B into Z_C plus Z_A plus Z_{i1} plus Z_C into Z_A plus Z_{i1}. So from this you can write Z_{i1}, Z_{i2} minus Z_{i1} into Z_B plus Z_C plus Z_{i2} into Z_C plus Z_A minus I can write sigma Z_A, Z_B which means Z_A, Z_B, Z_B, Z_C plus Z_C, Z_A, so I am write writing in a compact form equal to 0.

Let me call it equation number1 similarly from the other1 we will get Z_{i1}, Z_{i2} plus Z_{i1} Z_{i1}, Z_{i2} plus Z_{i1} into Z_B plus Z_C minus Z_{i2} into Z_C plus Z_A plus sigma Z_A, Z_B equal to 0 it is so simple. So can you see you can manipulate these by adding and subtracting sorry this will be minus minus sigma Z_A, Z_B equal to 0. So if I add these 2 what do I get twice Z_{i1}, Z_{i2}, Z_{i1} into Z_B plus Z_C plus Z_{i1} into Z_B plus Z_C so this will get cancelled similarly this will get cancelled. So I will get twice z_{i1}, Z_{i2} equal to twice sigma Z_A, Z_B or Z_{i1}, Z_{i2} equal to sigma Z_A Z_B agreed. Similarly, subtracting 2 from1 we will eliminate these 2. So what do I get by subtracting I get Z_{i1} into Z_C plus Z_B equal to Z_{i2} into Z_C plus Z_A or Z_{i1} by Z_{i2} equal to Z_A plus Z_C divided by Z_C plus ZB so from3 and4 if I take the product I will get Z_{i1} squared as Z_A plus Z_C by Z_B plus Z_C into sigma Z_A, Z_B therefore Z_{i1} is square root of Z_A plus Z_C by Z_B plus Z_C into sigma Z_A, Z_B it is so simple so you can see from here Z_{i2}.

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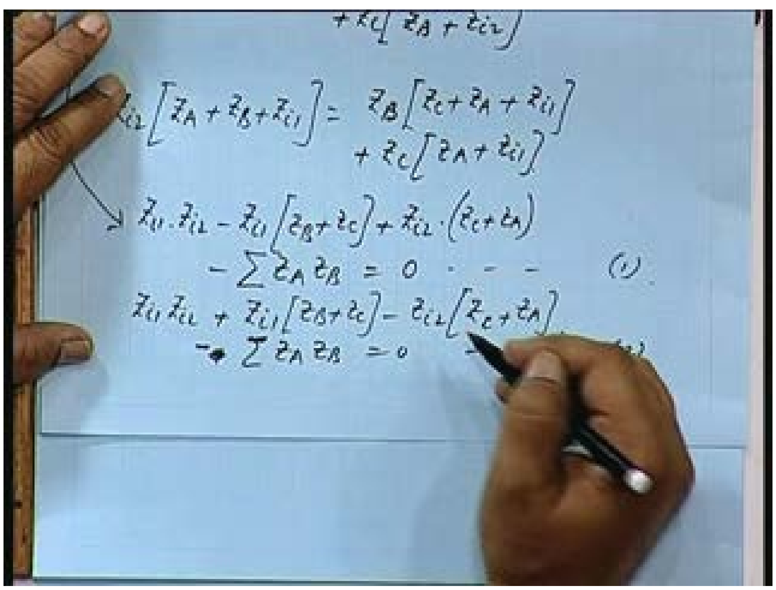

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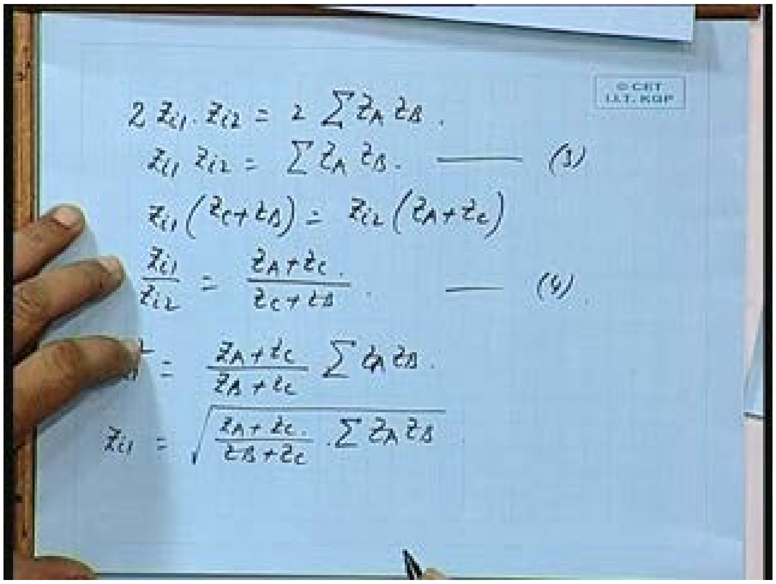

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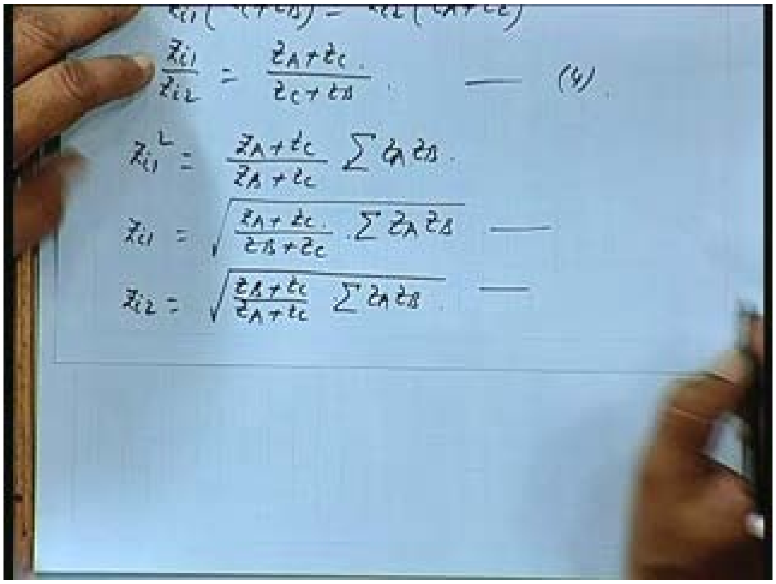

If you just look it look into the circuit from the other end its just replacing a by b, so it will be Z_B plus Z_C by Z_A plus Z_C into sigma Z_A, Z_B agreed, so these are the 2 impedances. Now if you are having say Z_A equal to Z_B, Z_A equal to Z_B then what do I get if Z_A is equal to Z_B if Z_A is equal to Z_B then it becomes a symmetric network so for a symmetric network here if I put Z_A equal to Z_B this will get cancel this will be 1 and sigma Z_A, Z_B will be therefore Z_{i1} is equal to Z_{i2} will be square root of sigma Z_A, Z_B

which is square root of Z_A, Z_C plus Z_A, Z_C plus Z_A squared that is Z_A squared plus twice Z_A, Z_C okay.

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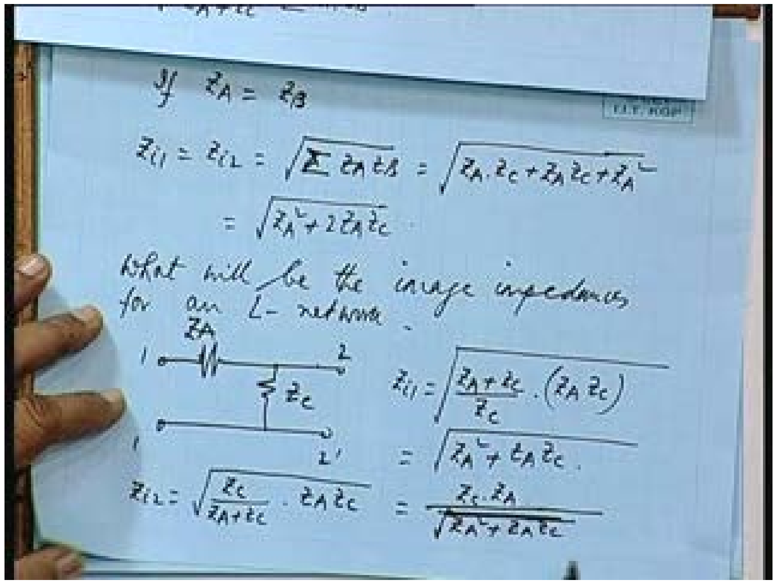

Now can you find out for an asymmetrical l network what will be the image impedances for an l network, l network means suppose you are having this network what will be for an l section what will be the image impedances you are given Z_B equal to 0, so put Z_B equal to 0 here what do I get Z_{i1} will be Z_A plus Z_C by Z_C and what will be Z_A, Z_B these terms only Z_A, Z_C because Z_C into 0 is 0 Z_A into 0 is 0 so multiplied by Z_A, Z_C which finally gives me Z_A squared plus Z_A, Z_C sorry, excuse me what will be Z_{i2}, Z_{i2}.

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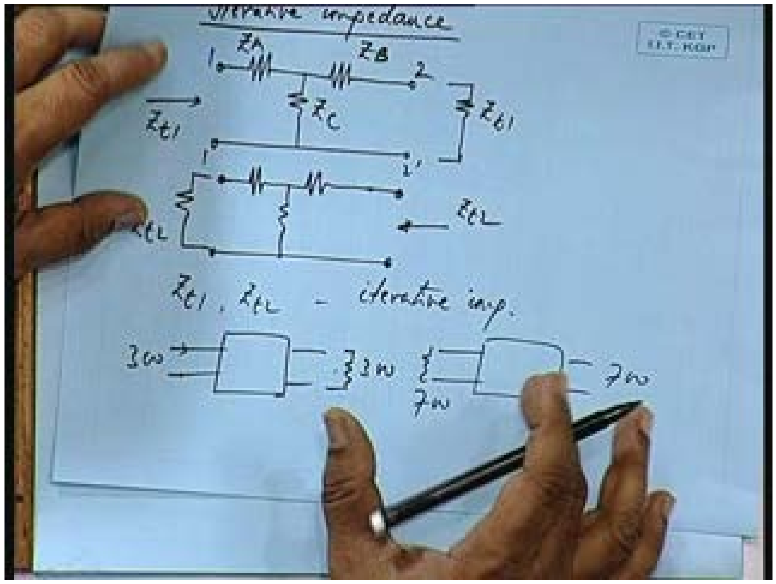

If I put Z_B equal to 0 is Z_C by Z_A plus Z_C so it will be Z_C by Z_A plus Z_C into Z_A, Z_C which means Z_C into Z_A I can multiply by Z_A and also multiply Z_A here in the denominator. So this will be Z_A square plus Z_A, Z_C under root is that alright. So this will be the expression for Z_{i2} this will be the expression for Z_{i2} and Z_{i1} is this much for an l section. Now let us define an iterative impedance, what do you mean by an iterative impedance for a network like this. Once again we will take a_t section Z_A, Z_B, Z_C by iterative impedance we mean if I terminate this side by say Z_{t1} then impedance in from this side is also Z_{t1} again if I terminate this side by Z_{t2} then impedance in from this side is Z_{t2} so Z_{t1} and Z_{t2} are the 2 iterative impedances mind you you cannot truncate you cannot terminate this by any impedance and see from this end the same impedance value, there is a particular impedance by which you can terminate and you can observe from this end the same impedance value.

So what is that particular impedance that you want similarly for Z_{t2} what are these 2 impedance values okay so now you will be taking say we may say if I replace if I trunc terminate this by 300 ohms impedance in from this side is also 300 ohms if I terminate this side by 700 ohms impedance in from this side is also 700 ohms then this 300 and 700 are the 2 iterative impedance values for a given network.

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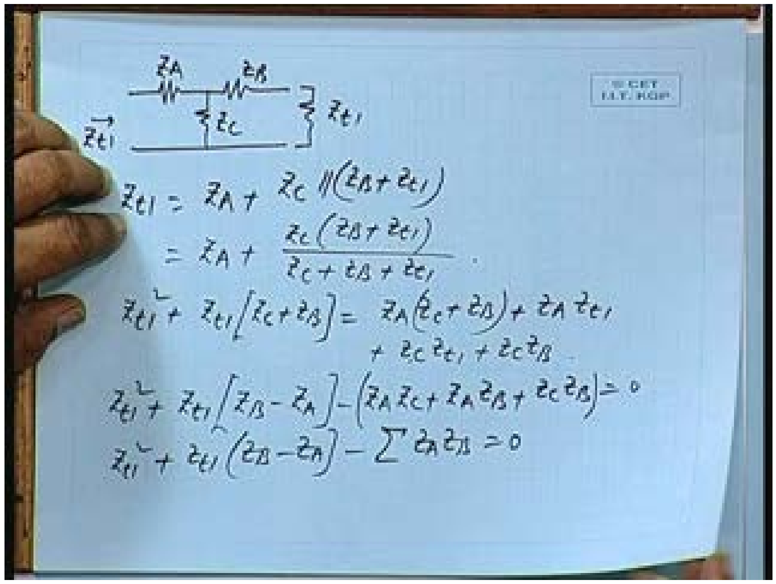

So let us take once again from definition Z_{t1} impedance in is Z_{t1} so Z_{t1} will be equal to Z_A plus parallel combination of Z_B plus Z_{t1} with Z_C okay. So Z_{t1} is equal to Z_A plus parallel combination of Z_C, Z_B plus Z_{t1} which means Z_A plus Z_C into Z_B plus Z_{t1} divided by Z_C plus Z_B plus Z_C if I multiply again cross multiplication will give me Z_{t1} squared plus Z_{t1} into Z_C plus Z_B on this side, on this side I have got Z_A, Z_C plus Z_B plus Z_A, Z_{t1} plus Z_C, Z_{t1} plus Z_C, Z_B if I transform everything if I transfer everything on this side then you will get Z_{t1} squared plus Z_{t1} into Z_C plus Z_B minus Z_C minus Z_A. So it becomes Z_B, Z_C will go so Z_B minus Z_A correct me if I am wrong okay minus Z_A, Z_C, Z_A, Z_C minus Z_A, Z_B minus Z_C, Z_B equal to 0 or I can put all of them as plus okay that is Z_{t1} squared plus Z_{t1} into Z_B minus Z_A minus sigma Z_A, Z_B equal to 0. So how much is Z_{t1} they can straight away solve these quadratic to get Z_{t1}, Z_{t1} will be minus of b.

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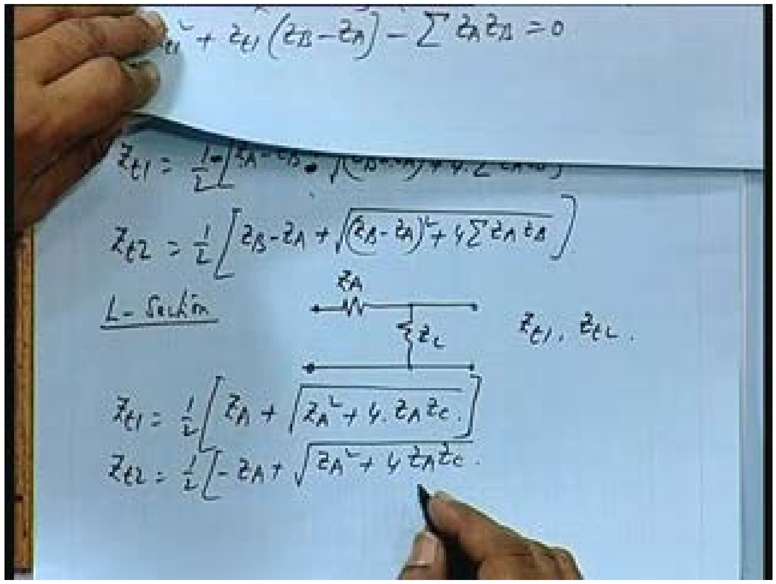

So Z_A minus Z_B plus minus root over of Z_B minus Z_A whole squared minus 4sc, so minus and minus make it will make it plus 4 sigma Z_A, Z_B divided by 2 okay. So this is the expression for Z_{t1}, now can you write in the in a similar manner the expression for Z_{t2} is very simple replace interchange Z_A and Z_B, so this will become Z_B minus Z_A. Now plus minus if I consider the minus value you can see obviously this is the quantity which is larger than Z_B minus Z_A alright. So you are extracting a quantity which is more than this. So it will be giving you negative values of Z_t, so that negative solution is ruled out, so we will consider only the plus value okay.

So similarly this one will be Z_B minus Z_A whole squared plus 4 sigma Z_A, Z_B if we have if we have an l section that means a section like this what will be this is Z_A this is Z_C what will be Z_{t1} and Z_{t2} then put Z_B equal to 0. So that will give me Z_{t1} equal to half of Z_A plus root over of z s squared plus4 into Z_A, Z_C, Z_{B0} so Z_A, Z_B, Z_B, Z_C, Z_C, Z_A that will give you just Z_C, Z_A and Z_{t2} will be half of Z_B minus Z_A so minus Z_A plus root over of Z_A squared plus 4 Z_A, Z_C okay.

Now if you have a symmetric network, for a symmetric network Z_A equal to Z_B. So what you get if Z_A is equal to Z_B then this will be 0 and this will be 0, this will be 0. So it is square root of 4 sigma this and half 4 and half will get cancel. So it will be sigma Z_{t1} equal to Z_{t2} equal to sigma Z_A, Z_C plus 2 times Z_A, Z_C plus Z_A squared sigma Z_A, Z_B becomes Z_A square Z_A into Z_A plus Z_A into Z_C plus Z_A into Z_C, so that gives me this which is nothing but Z_{i1} or Z_{i2}, we call this that is for a symmetrical network the image impedance and the iterative impedance will be identical and that will call as characteristic impedance some people write Z_o some people write Z_C.

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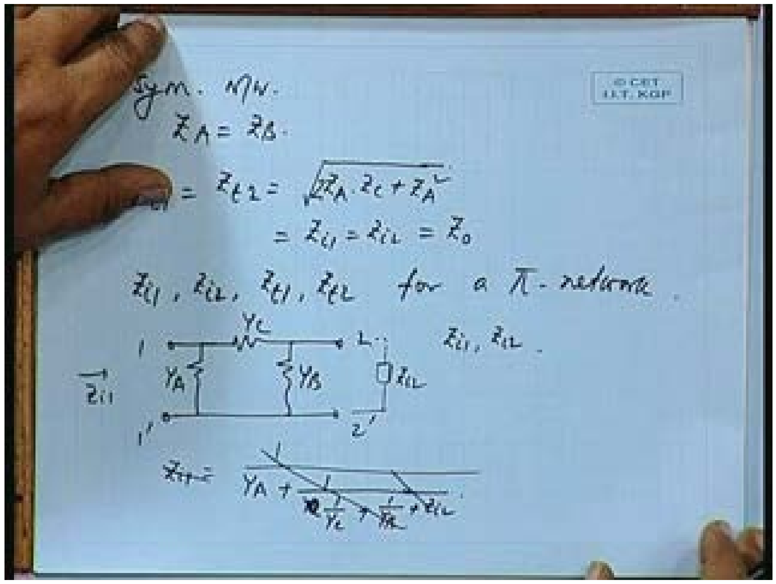

So the characteristic impedance refers to a symmetric network and that is equal to Z_s squared plus twice Z_A, Z_C under root. You can also find out the image and iterative impedances for a phi network that is all so now it is interesting derivation for a phi network. If we consider Y_A, Y_B and Y_C then what would be Z_{i1} and Z_{i2}, you can see for yourself any phi network can be converted to an equivalent t network and you can divide it or straight away from definition suppose this is terminated by Z_{i2} and impedance in is Z_{i1} so go from the definition Z_{i1} is equal to this admittance plus this total admittance if you invert that will be giving you Z_{i1} so Z_{i1} can be written as1 by Y_A plus admittance of this which is 1 by impedance Y_C how much is it 1 by1 by Y_C plus1 by Y_B plus Z_{i2}.

So this impedance is Z_{i2} plus so sorry 1 by Z_{i2} admittances are to be added sorry, I write here separately Z_{i1} is 1 over the admittance Y_A, admittance you add Y_A plus this admittance and what is this admittance it is 1 by this impedance what is this impedance1 by Y_C, is it not. This whole thing I am considering as an impedance and what is this impedance this admittance plus this admittance that is Y_B plus 1 over Z_{i2} is this this admittance so inverse of that is the impedance this is to be added with this impedance which is 1 by Y_C.

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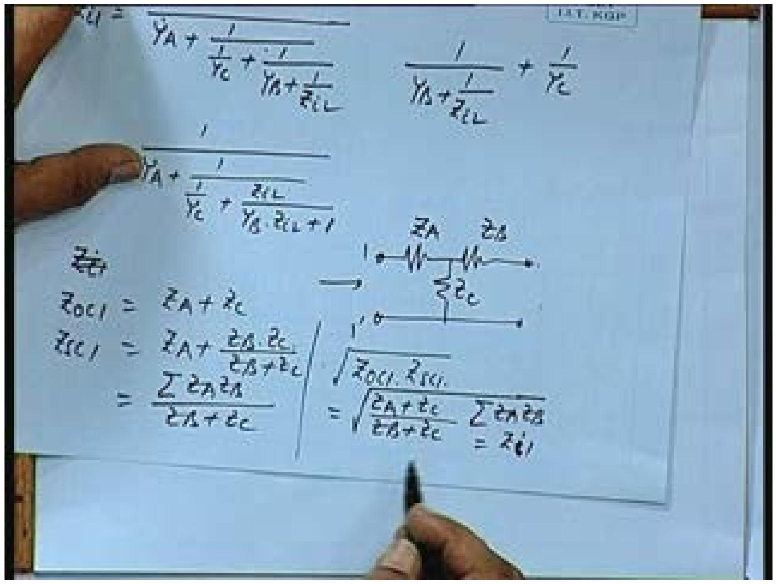

So this total impedance if I take the inverse of that that becomes the admittance, so it will be1 by Y_C plus1 by Y_B plus 1 by Z_{i2}. Now you can simplify this Z_{i2} divided by Y_B, Z_{i2} plus 1 and so on you can simplify and then finally you get a relationship between Z_{i1} and Z_{i2} for the impedance seen from this side similarly, impedance seen from this side you establish a relation between Z_{i1} and Z_{i2} and in the same manner you can evaluate Z_{i1} and Z_{i2}.

One interesting relation is you can verify for yourself Z_{i1}, let us go back to once again to t network if I perform from this end and open circuit and short circuit test that is keep this open Z_A, Z_C and Z_B. So Z open circuit seen from this side how much is it Z_A plus Z_C okay short circuit this, seen from this side11 dash if I short circuit it how much is it Z_A plus Z_B, Z_C by Z_B plus Z_C agreed which means Z_A, Z_B plus Z_A, Z_C, Z_B, Z_C so sigma Z_A, Z_B divided by Z_B plus Z_C. If I take the product z open circuit 1 into Z short circuit 1 okay how much is it? How much is it? If I multiply by this it is and then take the square root Z_A plus ZC divided by Z_B plus Z_C into sigma Z_A, Z_B is it not Z open circuit and Z short circuit seen from the same terminal pair gives me this product and then if I take the square root what is this you can identify this as Z_{t1} sorry Z_{i1}. Similarly, seen from this side it will be Z_B plus Z_C by Z_A plus Z_C so that will give me Z_{i2}.

So Z_{i1} is Z open circuit 1 into Z short circuit1 Z_{i2} is Z open circuit 2 and Z short circuit 2 these are very interesting result and for a symmetric network, Z characteristic equation characteristic impedance Z naught which is Z_i that will be equal to Z open circuit into Z short circuit because Z_{oc1} and Z_{oc2} they become same for a symmetric network okay.

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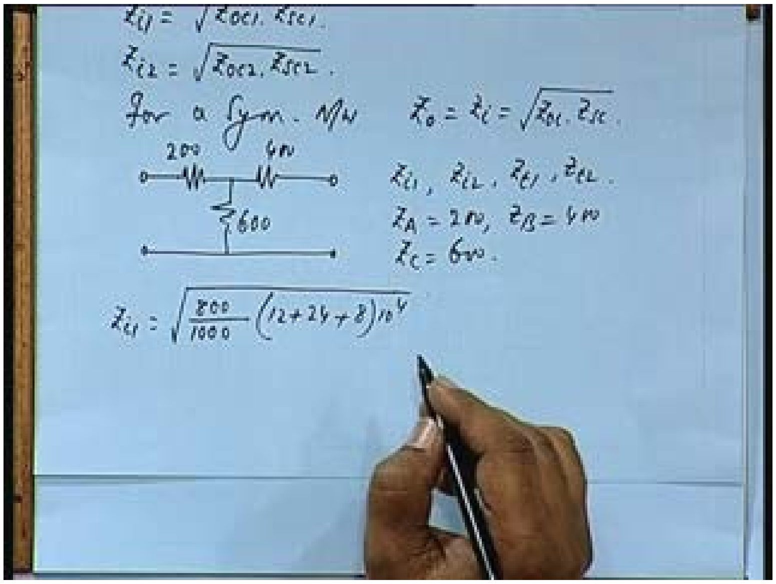

Let us consider some simple values say this is 200, this is 400 and this is 600 what will be Z_{i1}, Z_{i2}, Z_{t1} and Z_{t2} okay. So we have got Z_A equal to 200 Z_B equal to 400 and Z_C is equal to 600, so Z_{i1} will be equal to root over of Z_A plus Z_C 600 plus 200, 800 divided by 600 plus 400, 1000 into sigma Z_A, Z_B be 200 into 600, 6 2's are 12, 6 4s are 24 plus4 2s are 8 into10 to the power 4 do you agree.

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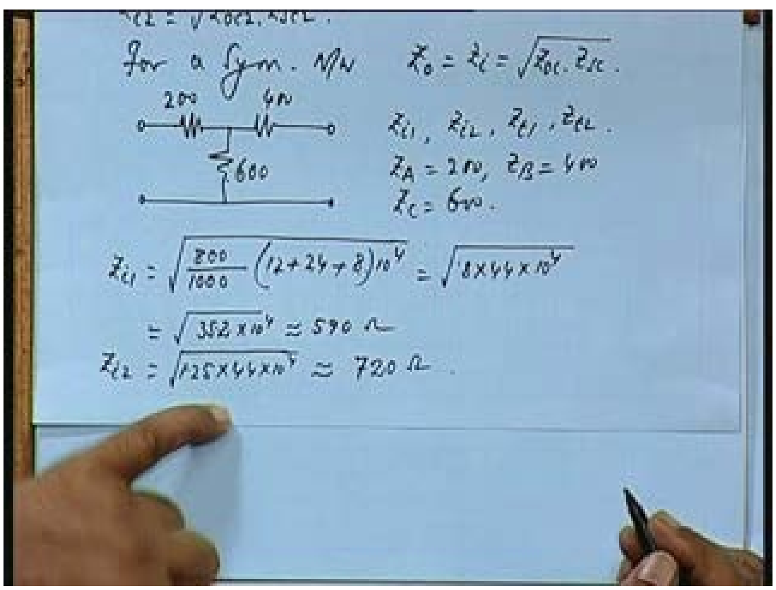

So that gives me .8 into12 plus 24, so12 plus 8, 20 plus 20 into 44 into10 to the power 4 do you agree, so that is approximately 35.2, 44 into .8 into 10 to the power 4. So 35.2 is approximately say 595.9 into10 to the power 2 so 590 ohms approximately. Similarly Z_{i2}

will be just these 2 figures you will interchange so 10 by 8 which means1.25 into 44 into 10 to the power 4 which means approximately 44, if I assume this to be 11.

So it will be 2 20 sorry, 11, 44 into1.25, so that gives me 5 by 4 so 55 square root of 55 is so 7.3 or 7.2, so 720 ohms. So these are the 2 values of Z_{i1} and Z_{i2} if you ask me what will be the iterative impedances Z_{t1} and Z_{t2}, so Z_{t1} if you just substitute these values in Z_{t1} and Z_{t2} how much did you get Z_{t1} was half of Z_A minus Z_B plus root over Z_B difference Z_A whole squared sorry plus 4 sigma Z_A, Z_B. So how much will it come to half Z_A that was 200 minus 400 plus root over of 200 minus 400, so 200 squared plus 4 into Z_A, Z_B, Z_B, Z_C plus Z_C, Z_A that was 44 into 10 to the power 4.

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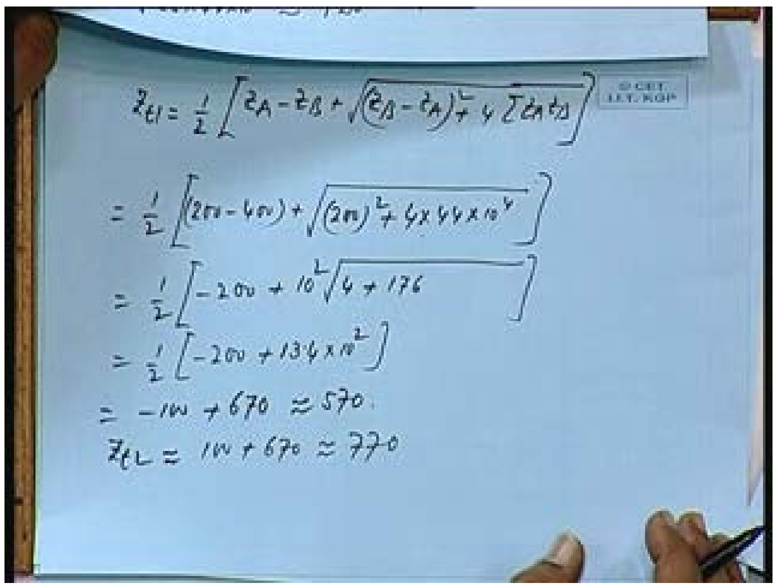

So half of minus 200 plus I can always take 10 to the power 2 outside, inside I am left with 2 2s are 4 plus 4 into 44, 176, correct me if I am wrong. So that is half minus 200 plus176 plus 4, 180 is that alright, 200 squared 10 to the power 4, so 176, 180 square root of 180 is 13.5, say 13.4 into 10 to the power 2. So that is this is an approximate figure minus 100 plus 680, so 13, 670, so that is 570 and Z_{t2} is everything is same except that Z_A and Z_B will be just interchanging their positions.

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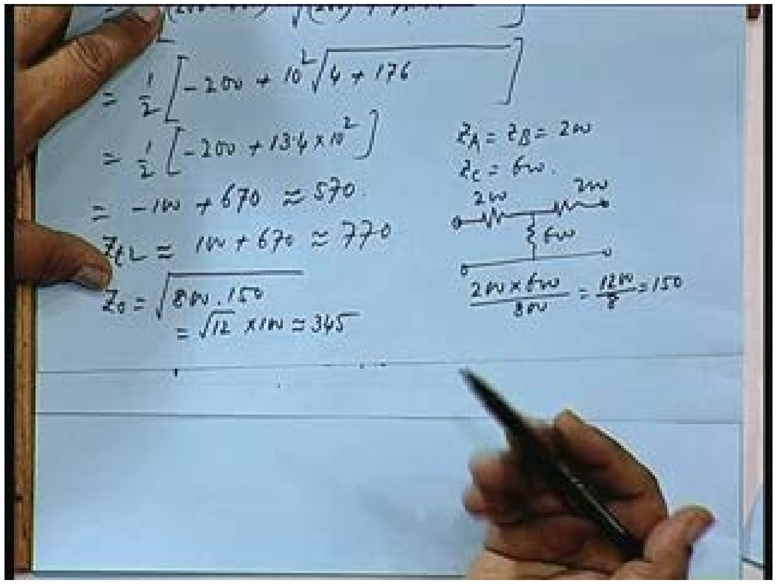

So it will be of minus 200 it will be plus 200, so it will be 100 plus 670 so that is 770. So these are the 2 values for Z_{t1} and Z_{t2} if I have Z_A equal to Z_B say 200, 200 and 600, if Z_A equal to Z_B equal to say 200 and Z_C equal to 600 then you have got a network like this what will be the characteristic impedance, this is 200, this is 200, this is 600. You can either put those values here in the expressions or you can apply short circuit and open circuit test directly.

So root over of if I have an open circuit test it is 600 plus 200, 800 and if I apply a short circuit test 200 plus parallel combination of 200 and 600. So it will be how much is 200 into 600 by this plus this is 800, so 0s will go 6 2s are1200 by 800, 1200 by 8 so 150 so 800 into 150 square root of that okay 1, 2, 3, 4.

So 8 into 1.5 is root over of 12 into 100 that is approximately 34.5, so 345, so in that case the characteristic impedance is calculated directly from the short circuit and open circuit test, you can also substitute the values in the general expression okay. Thank you very much, we shall continue with this in the next class and then we will got into the calculation of propagation constant thank you very much. Sorry, we forgot to include this 200 ohms resistance here actually this was 600 this was 200 and this was 200, so the short circuit impedance as in from this side would be 200 plus 150.

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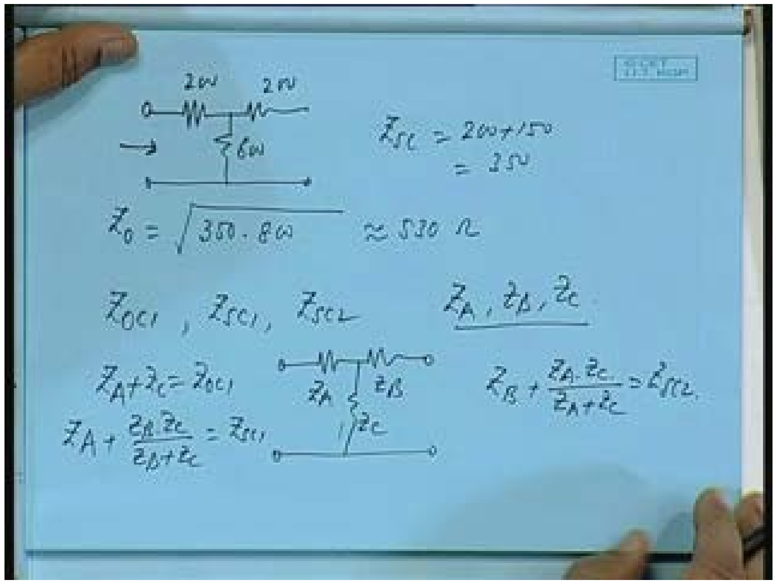

So it should be 350, so z characteristic equation, characteristic impedance will be 350 into 800 and that is approximately 530 ohms and not 345, I am extremely sorry please make this correction now suppose we have a question. Suppose you are given z open circuit1 z short circuit 1 and z short circuit 2 these 3 values are given can you determine, can you determine Z_A, Z_B and Z_C is very simple. Here you can see the network is like this Z_A, Z_B and Z_C, so if you are measuring the short circuit impedance say open circuit impedance then Z_A plus Z_C is equal to Z_{oc1}.

Similarly, Z_A plus Z_B, Z_C parallel combination Z_B into Z_C by Z_B plus Z_C that is equal to z short circuit 1 similarly, seen from this side Z_B plus Z_A, Z_C parallel combination Z_A, Z_C by Z_A plus Z_C these are parallel combination of Z_A and Z_C so that is equal to z short circuit 2. So from these 3 given conditions you have to determine Z_A, Z_B and Z_C, so one can solve like this Z_B plus Z_C equal to you can verify for yourself Z short circuit 2 by z short circuit 1 okay, z short circuit 2 by Z short circuit 1 that will be see the numerator is Z_A, Z_B, Z_B, Z_C, Z_C, Z_A so that will get cancelled so Z_A plus Z_C and Z_B plus Z_C these2 will be involved here and then1 Z_A plus Z_C will get cancelled here.

So this product will give me this say z dashed and then Z_A plus Z_C is known that is Z_{oc1} so you can evaluate from here Z_C if you can little bit of manipulation will give you Z_C equal to Z_{oc1} squared into Z_{sc2} by Z_{sc1} minus Z_{oc1} into Z_{sc2}. Now I leave it to you to compute and verify this relation it is very simple, it is a question of only elimination of the terms Z, I can take common Z_{oc1}, Z_{sc2}. So I am left with Z_{sc1} by Z, Z_{oc1} by Z_{sc1} minus 1 under root of this into under root of this. So therefore Z_A can be evaluated Z_{oc1} minus Z_C which is computed from here similarly, Z_B is z dash which you have already computed minus Z_C, so this is how you can compute Z_A, Z_B and Z_C.

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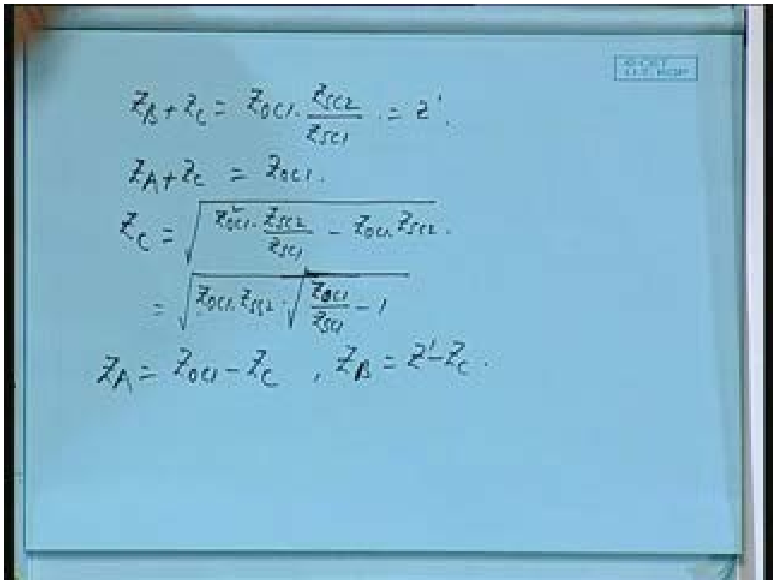

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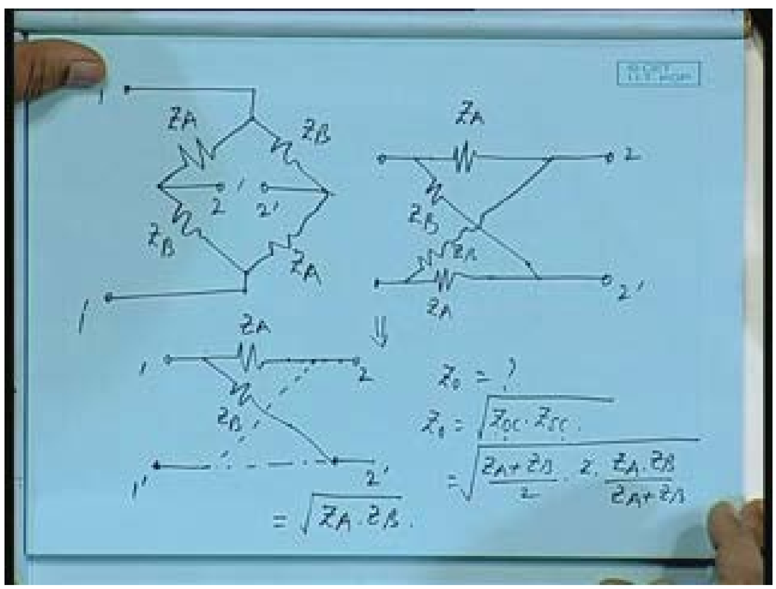

Now suppose you are given a lattice network what is a lattice network, it is like this you are having an bridge network like this this is Z_A, Z_B, Z_B, Z_A and you are having the output terminals here 2, 2 dashed, 1, 1 dashed okay. So this can be also shown as Z_A, Z_B, Z_A and Z_B these are the output terminals, this is Z_B quite often we show this as Z_A, Z_B and rest of it is shown by dotted line that means this is Z_A and this is Z_B, it is repeated. So this is also a standard notation for a lattice network what will be z not for this kind of a network now Z naught as you know is equal to Z open circuit into Z short circuit it is a symmetric network. So whether you look from this side or that side Z_{oc1} and Z_{sc1} they will be equal to Z_{ooc2} and Z_{sc2}.

So how much is z open circuit if I keep it open it is Z_A plus Z_B and again Z_A plus Z_B in parallel so it will be Z_A plus Z_B by 2, is it not 2 ideal, 2 identical impedances in parallel. So that will be effective impedance will be half of that and what will be the short circuit impedance if I short it is Z_A and Z_B in parallel once again Z_A and Z_B in parallel, so it will be 2 times parallel combination of Z_A, ZB which will be Z_A, Z_B by Z_A plus Z_B. So under root of this.

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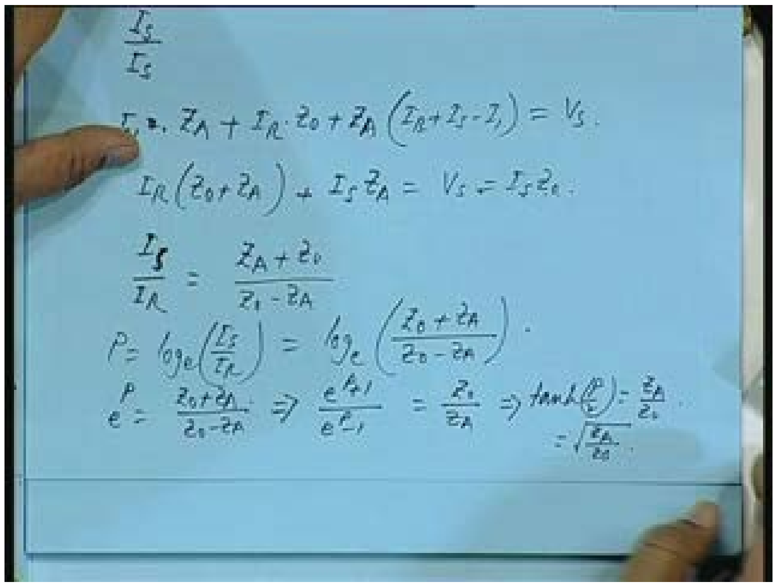

So 2 will get cancel Z_A plus Z_B will get cancelled so this will be Z_A into Z_B is that okay. So this will be the characteristic impedance now if you look back what will be the propagation constant what will be the ratio of the currents I_s and I_r. Now once again I will take this diagram suppose this is I_s and when I put an impedance z not here this impedance the current through this impedance is I_r okay let this current be I_1 then the current through this is I_s minus I_1 is it not and this current is I_r this gets added with this, so this final current will be I_r plus I_s minus I_1 okay. Now what will be the voltage drop if you look at the voltage here v_s is equal to this total drop. Now let us compute the drops it will be I_1 into Z_A, so I can write I_1 into z I_1 into Z_A plus I_r into Z naught I_r into Z naught plus Z_A into Z_A into this current plus this current I_r plus I_s minus I_1 so I_r plus Is minus I_1 this entire drop will be equal to v_s okay.

So we can write I_r into Z naught plus Z_A Z naught plus Z_A plus Is into Z_A and I_1 Z_A will get cancelled with this I_1, Z_A equal to v_s and what is v_s? V_s is again I_s into Z naught the impedance in from this side, so I_s into Z naught do you all agree therefore if I transfer this to this side I_r into Z naught plus Z_A is equal to I_s into Z naught minus Z_A. So that gives me I_r, I_s by I_r as equal to Z_A plus Z naught divided by Z naught minus Z_A okay.

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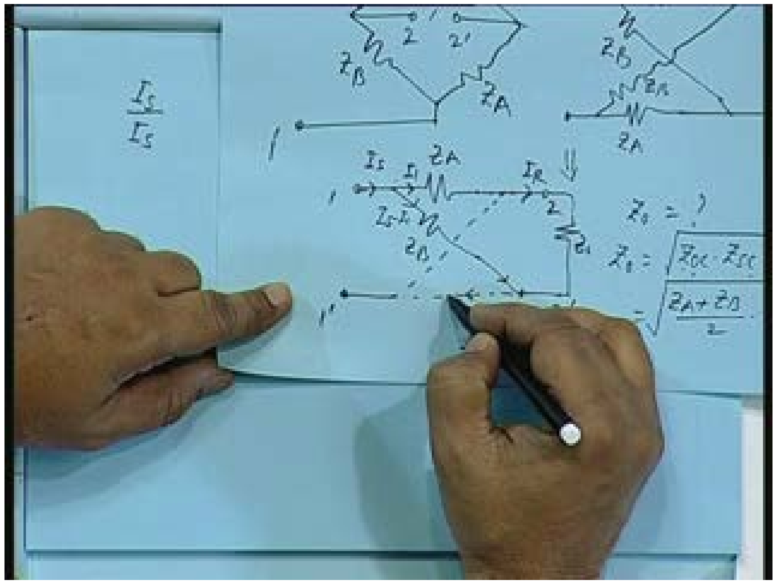

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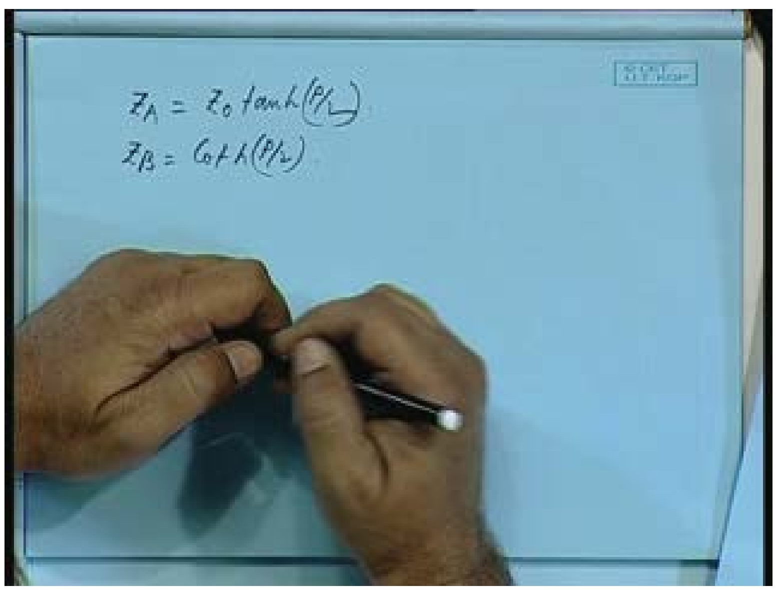

So the propagation constant which was log of I_s by I_r will be equal to log of Z naught plus Z_A by z naught minus Z_A which means e to the power p is equal to Z naught plus Z_A by Z naught minus Z_A and that is equal to that give me if I take component or dividend though e to the power p plus1 by e to the power p minus 1 is equal to Z naught by Z_A and what is this? This is nothing but cot hyperbolic, cot hyperbolic p by 2 if I invert it so that will be giving me tan hyperbolic p by 2 is equal to Z_A by Z naught or tan hyperbolic p by 2 is Z_A by Z naught Z naught is equal to root over of Z_A into Z_B. So that gives me root over of Z_A by Z_B okay so we get Z_A is equal to Z naught tan hyperbolic p by 21 may write like this and Z_B equal to cot hyperbolic p by 2 either way you can write alright okay. We will stop here for today; we will take up some problems in the next class, thank you very much.

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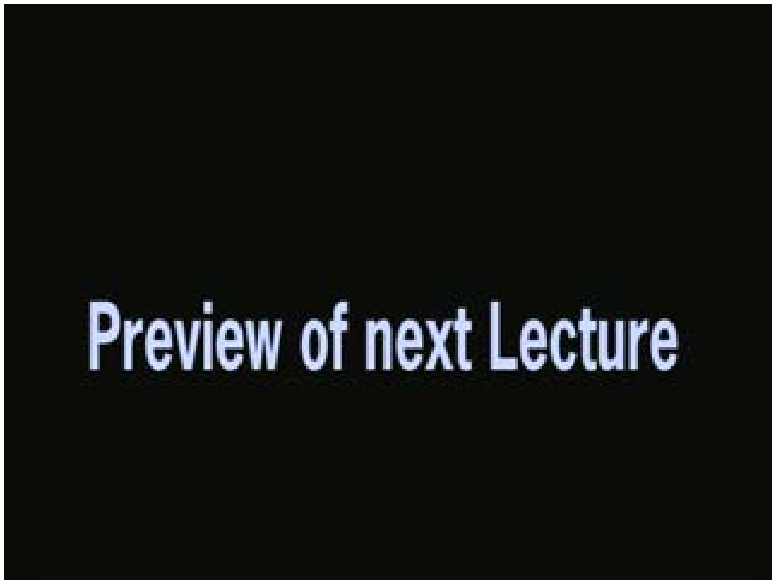

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Last time we are discussing about the image impedances and iterative impedances and we derive these relations for a t network that was Z_A plus Z_C by Z_B plus Z_C into sigma Z_A, Z_B this means combination of 2 impedances at a time. So it was a structure like this Z_A, Z_C and this was Z_B similarly, Z_{i2} we derived as Z_B plus Z_C divided by Z_A plus Z_C into sigma Z_A, Z_B this we derived last time.

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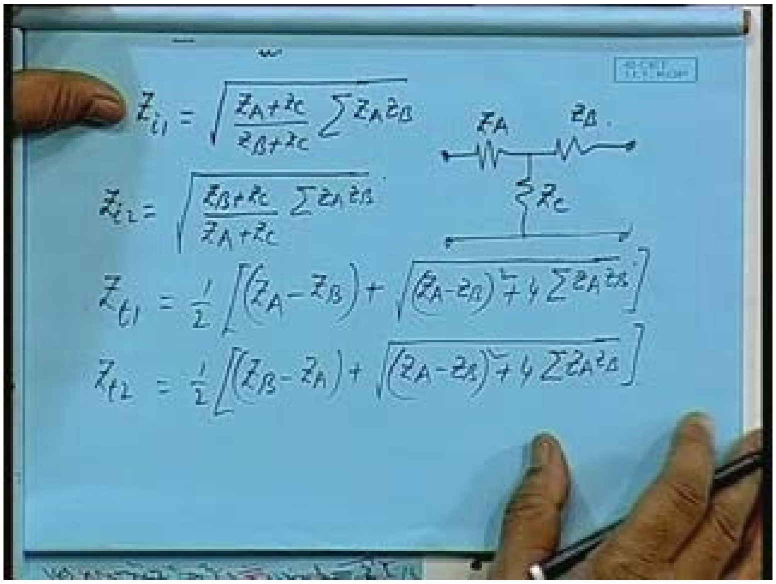

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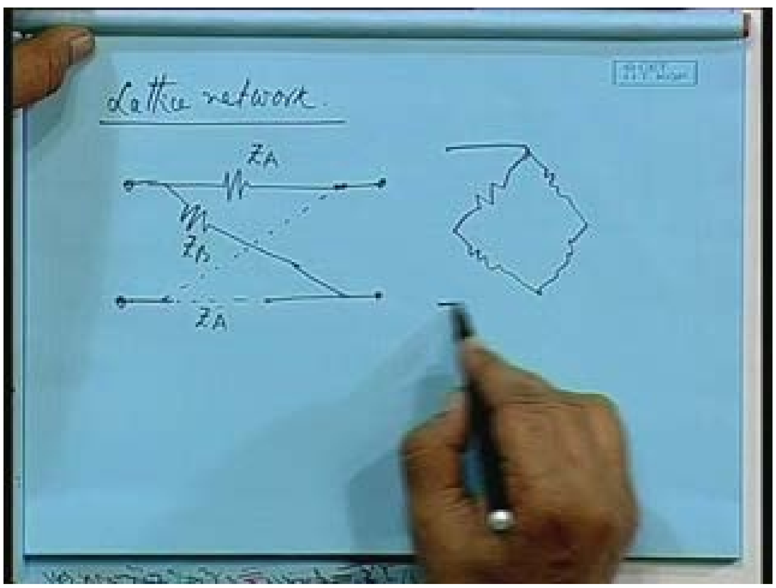

We also derived for the iterative impedances Z_{t1} as half of Z_A minus Z_B plus under root Z_A minus Z_B whole squared plus 4 times that sigma term Z_A, Z_B. Similarly, Z_2 was Z_{t2} was half Z_B minus Z_A plus Z_A minus Z_B whole squared the same expression okay. Then we discussed about a network that is a lattice network where we considered Z_A, Z_B, Z_A this was the notation for the counter parts, this is Z_B and this is Z_A, this can also be seen as a bridge network okay like this this was see.