Networks, Signals and Systems

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Lecture - 14

2- Element Synthesis

Good morning friends, we will be continuing with driving point impedance function or immittance function.

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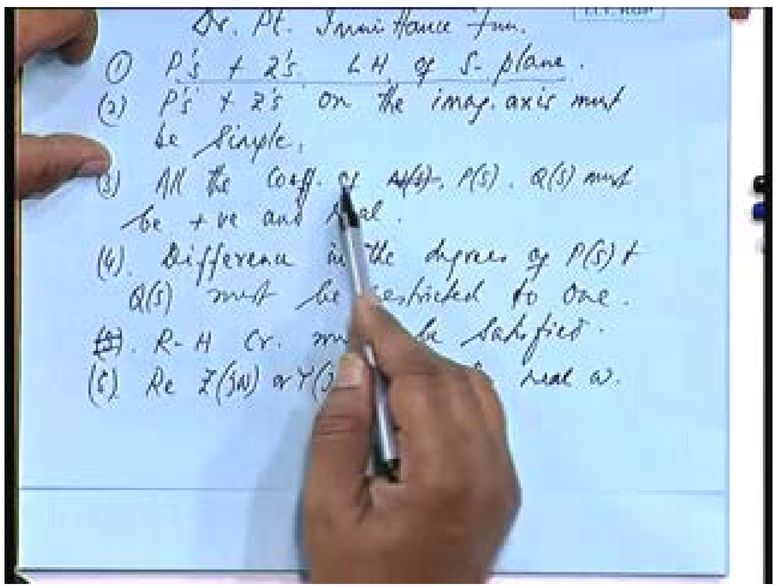

We have seen the properties to be satisfied are poles and 0s of the immittance function must lie in the left half plane, left half of s plane then poles and 0s on the imaginary axis must be simple on the imaginary axis must be simple. These are 2 very important properties and then to ensure that poles and 0s lie in the left half of s plane actually all the coefficients of the polynomials all the coefficients of numerator and denominator polynomials we were using p (s) and q (s) okay p (s) and q (s) must be positive all the coefficients of p (s) and q (s) must be positive okay and real then the difference in the degree difference in the degree of p (s) and q (s) the degrees of p (s) and q (s) must be restricted to 1 alright, difference in the degrees must be restricted to 1 and as a corollary to this that means I will not write as an extra point it is to ensure this Rowth Hurwitz criteria must be satisfied.

The criteria all of you know we discussed last time anyway we will work out 1 or 2 simple problems later on in the tutorial and lastly what was the last point we discussed, real part of Z or Y for all positive values omega must be greater than 0, for all real omega okay. We will see where are the exception is coming, where do you think some of these conditions may not be strictly satisfied, poles and 0s must lie in the left half plane alright and the image axis this must be simple all the coefficients of p (s) and q (s) must be positive and real, is it necessary that all of them should be positive that can be a situation when alternate terms are present that is you have an even polynomial or an or an odd polynomial. This situation can come when you are having say purely inductance capacitance circuits L C circuits where there is no dissipative element when there is no dissipation then there can be a sustained oscillation.

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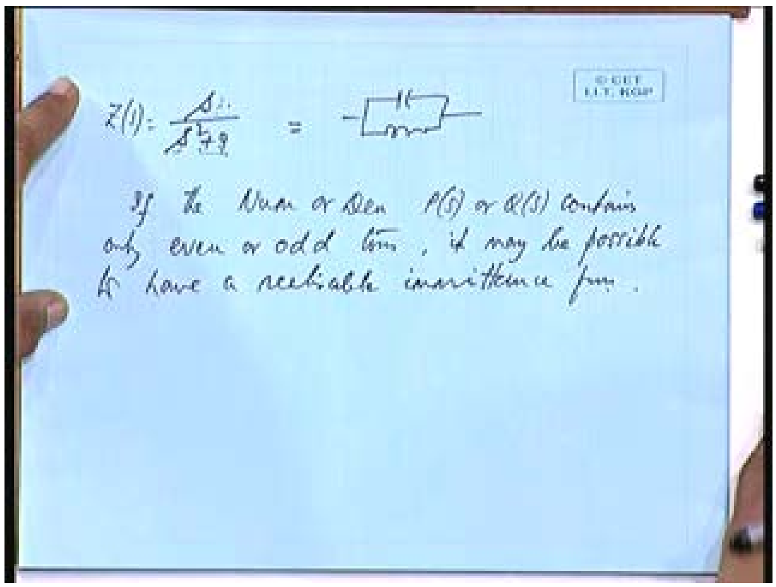

For example I can have a functions by S squared plus 9 suppose z (s) is this. So in the numerator polynomial you are having s the real term may or may not be present the S to the power 0 term here, s to the power 1 term is missing will it be a positive function yes, it will be this is the only exception that is if alternate terms are present, this is an even polynomial, this is an odd polynomial. So this you can see this is nothing but an l c parallel combination. We will see how to realize these very soon okay.

Now if the numerator if the numerator or denominator that is p (s) or q (s) contains only even or odd terms it may be possible to have a realizable immittance function okay other conditions are to be satisfied alright. Now let us see 1 or 2 simple function we will take and then we will see the properties of L C networks. We will take the typical structures of 2 element networks that is either L C or R C or R L okay so what would be what would be the impedance or admittance function lie for such networks, networks consisting of only 2 types of elements that is L and C or R and C or R and L, what would be the network function like. Let us take L C combination, let us have a simple series circuit L and C so what would be z (s) L S plus 1 by c s if you simplify this LCS squared plus 1 divided by c s okay.

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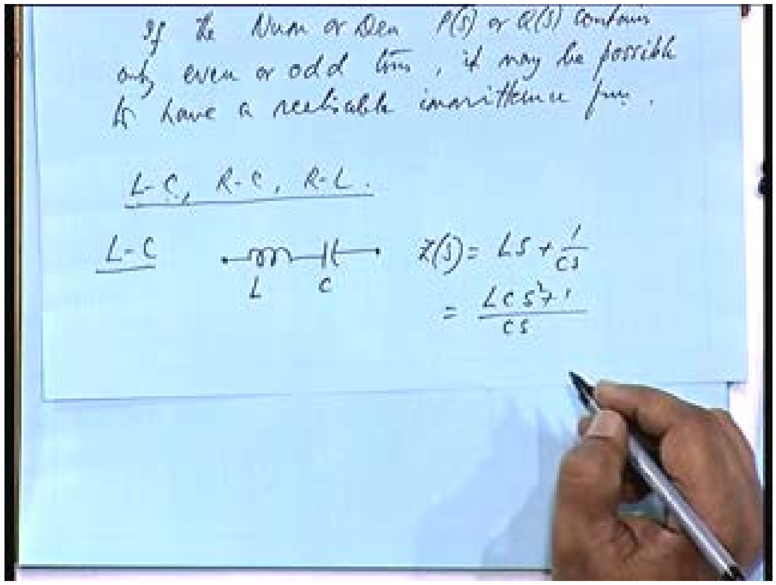

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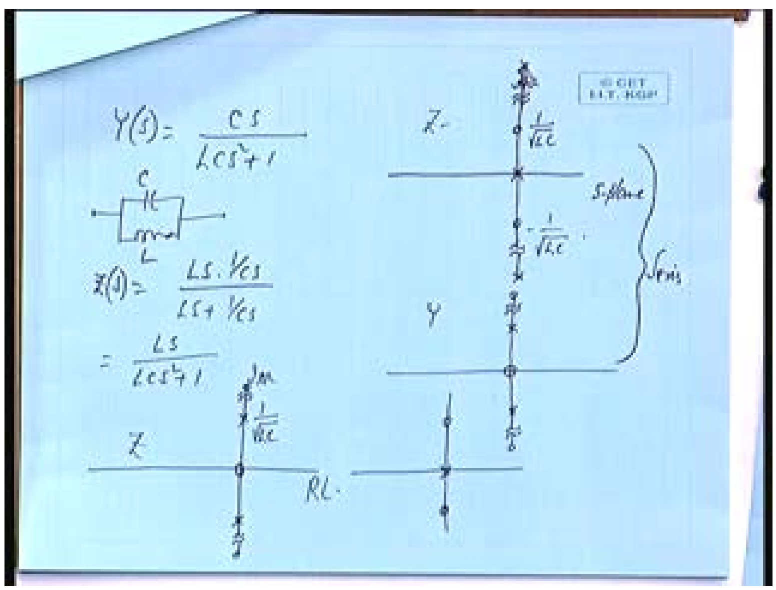

Let us take the admittance corresponding to this y (s) corresponding to this will be c s by LCS squared plus 1, where the poles and 0s located. For the impedance function there is a pole at the origin alright and there are 2 0s where 1 by L C, 1 by root L C and plus minus 1 by root L C j j. So here and here this is s plane, so roots are all imaginary okay this is 1 by root L C, this is imaginary, this is minus 1 by root L C okay, if you consider this is z, if you consider y the admittance function where the poles and 0s located it will be 0 now where ever we had the 0 earlier for Z will become poles. Let us take another example l and c in parallel what would be z_1

(s) into 1 by c s divided by l s plus 1 by c s okay if I multiply through out by c s it becomes LS by LCS squared plus 1 so for this l c parallel combination this is for series for the parallel combination what will be z (s) the 0 at the origin pole at 1 by root LC on the major axis okay. This is Z and what will be the corresponding y, what will be the corresponding Y, it will be just reverse.

So this will be a pole this will be 0s okay. Now can you draw any conclusion from this the structures of poles and 0s poles and 0s are all on the imaginary axis number 1, number 2 poles and 0s are coming alternately will have a little higher order functions and this then see and then the origin is always either a pole or a 0, is there any pole or 0 at infinity if I put s equal to infinity in the first case if I put s equal to infinity z (s) will tend to infinity this is higher order s square s square by s, so it will be LCS and s tending to infinity. So z (s) will be infinity and when a functions blows up to a very high value tending to infinity it is a pole corresponding s will be a pole so will show a break and at this is at infinity it is a pole here also at infinity there is a pole similarly here at infinity y (s) becomes 0. So at infinity this will be a_0 at infinity this will be a_0 similarly, here we can see for z s this will be a_0 okay similarly this 1 will be a pole at infinity.

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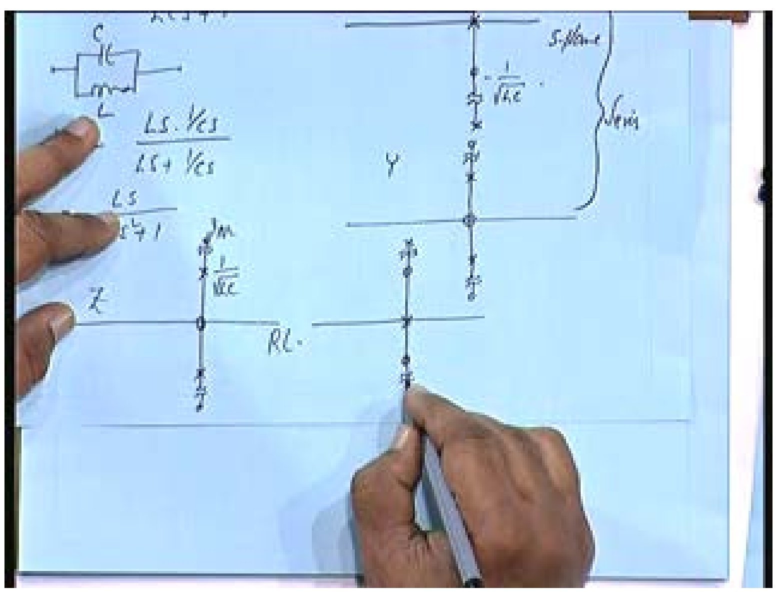

Let us take another example, say this is 1 Henry 1 farad, 1 Henry 1 farad what will be z (s) like LS plus 1 by c s plus LS into 1 by c s by LS plus 1 by c s and l is equal to LC is equal to 1. So this become s plus 1 on 1 by s plus s by s squared plus 1, is it alright? So that gives me s by s squared plus 1, this is s squared what will be the numerator like S square plus 1 whole squared plus S squared. So S to the power 4 plus 3 S squared plus 1 okay. Simplify this s square plus 1 whole squared plus s square, so is 4 plus 3 s square plus 1 okay. There are 2 real roots, what are the roots s to the power 4 okay S to the power 4 plus 3 S squared plus 1. I can write S square as x so it is basically a quadratic index. So what are the roots of x minus 3 plus minus root over 9 minus 4 by 2 so minus 3 root 4 so 2.24 divided by 2 alright. So 3 minus 2.24, 2.76 by 2.38

approximately and this is 5.24 divided by 2 is it alright 5.24 divided by 2, so 2.62 sorry S squared plus 2.62 divided by S into S squared plus 1.

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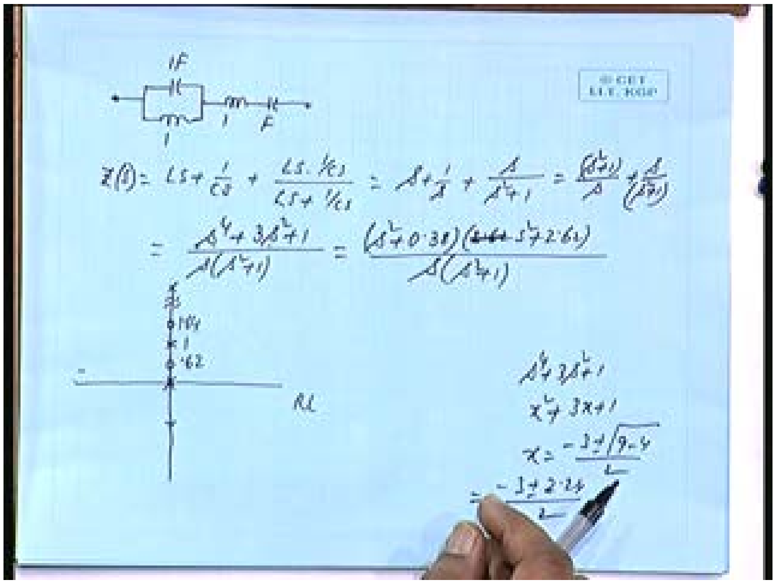

So lets us sketch the poles and 0s for this origin is a pole it is in the denominator, 1 is a pole then root over of .38 approximately .62 .63 so that is a 0 and root over of 2.62 that is 1.63 or so 1.64 approximately and this is say .62 you have got 0s and then at infinity I am not showing the negative values of omega it is identical okay.

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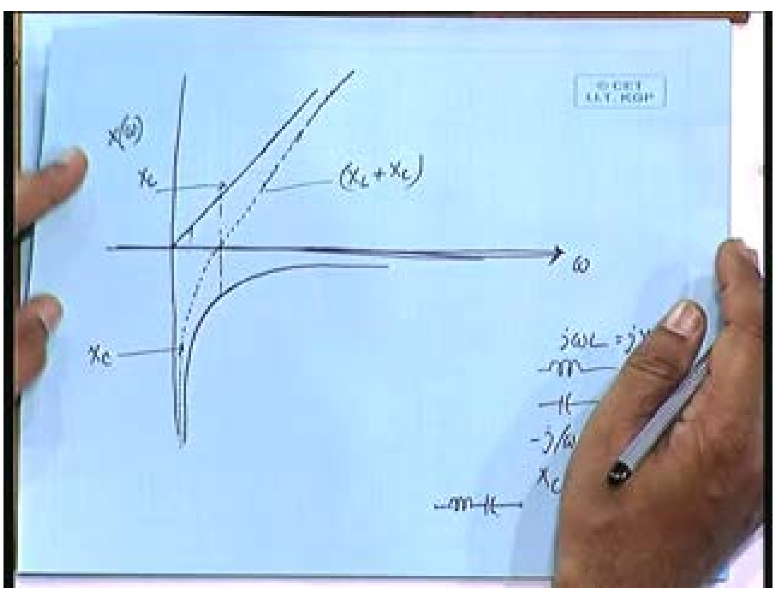

At infinity, this is infinity so this is a pole so you see pole, 0, pole, 0, pole again they are coming alternately okay. So LC network, LC network if we have similar to this if I take y(s) an admittance function the poles and 0s will be just replacing interchanging their positions this will be a 0, this will be a pole and so on so there also pole 0 poles and 0s will be appearing alternately. Hence forth, we will draw a diagram.

So this is omega because now we can take the frequency as the axis and corresponding value of x omega, x omega how will x omega vary with omega let us go back to the first problem suppose, we have just an inductance what will be its x j omega l. So if I write this as jX_L, jX_L then X_L will be varying linearly with frequency is that alright with the slope of l with the slope of l. So this is X_L what about x_c if I have a capacitor then x_c will be minus j by omega c is j x_c, so x_c is minus 1 by omega c is that alright x_c is all ways negative. So it is inversely proportional to frequency it will be a rectangular hyperbola varying like this. So this is x_c if I put this is tending to infinity if I put a series combination of l and c series combination of l and c then what will be the net effect it is x_L plus x_c which is minus 1 omega c so this magnitude minus this this magnitude that will be the net result so initially this is 0 this is minus infinity.

So it will the net value I will show by dotted line will go like this and when this magnitude is equal to this it will be 0 so the net value will pass through the origin at this point when omega l is equal to 1 by omega c and then final this is tending to 0 but this is increasing. So it will be asymptotically catching up with this okay. So this will be X_L plus X_c characteristics total x is that alright, if I take a series combination the reactance varies like this what about the admittance.

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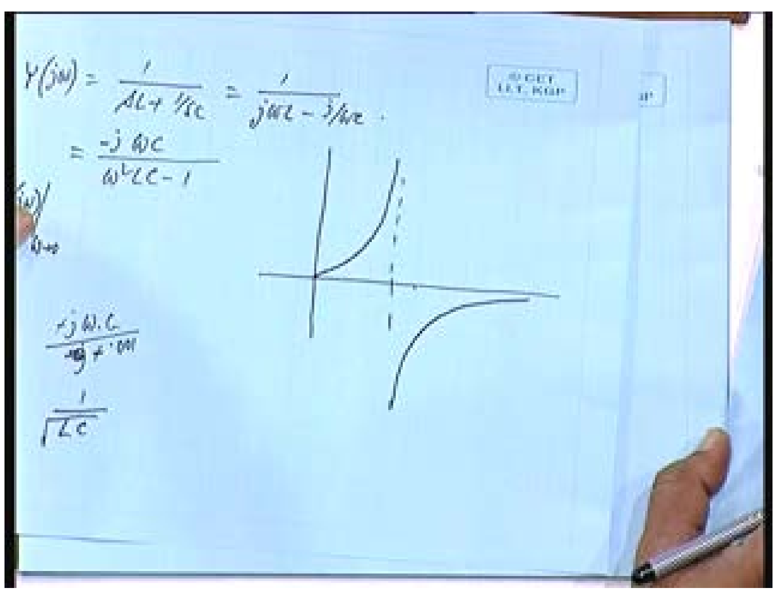

Let us see the admittance of this, it will be 1 over this quantity okay 1 by j omega l minus j by omega c. So how much is it if I multiply by omega c divided by omega square LC minus 1 j can be taken out so minus j by omega c by omega square LC minus 1 okay if you if you take small value of omega where will it tend to small value of omega, infinity this is minus minus will go this will tend to infinity, this will tend to infinity because omega is there omega will get cancelled and omega omega is tending to 0 it will that omega will be cancel each other that omega will be in denominator 1 omega will be in the numerator in the denominator is 1 denominator is 1 omega what will be the admittance function like? What will be the admittance function like? When omega tends to 0 that is y j omega omega tending to 0 infinity, omega tends to 0 means this this is negligible.

So this will be 1 and omega tending to 0, 0 this will be tending to 0. So it will be 0 and plus or minus will it be plus or minus plus j a small quantity plus j epsilon okay. So it will be starting from here and as omega gradually increases it will be having a slope very close to omega c neglect this compared to 1. So it will have a slope pretty close to omega c I mean slope of c it will be varying like omega c and at omega tending to LC omega square tending to 1 by LC a little less than that this will be a little less than 1 okay say .99 omega l square LC is .99 what happens to that this will be 10ding to 0 from the left hand side that is say minus .001.

So this will tend to and what about this this is minus j omega into c so minus j omega into c divided by a very small quantity negative say .001 when I am approaching this frequency 1 by LC under root from the lower side that means this quantity is less than 1 in magnitude say .9 or .99 then this is a negative very small quantity so this will be tending to plus infinity, is not it is a large quantity. So at that frequency it will tend to a very large quantity when I just cross over that frequency 1 by root LC what happens to this magnitude this becomes suddenly plus and over all quantity becomes minus infinity. So it will start from minus infinity and then when this quantity gradually increases from 1.001 to 2345, so this will be gaining higher and higher values so over all quantity will be reducing in magnitude and at a very large value of omega this will tend to 0 so it will 1tend to 0 like this okay.

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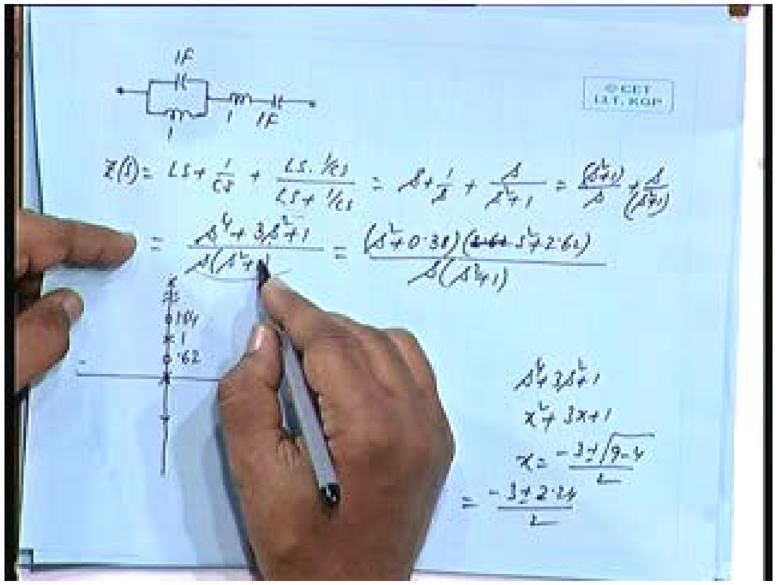

You can have 1 or 2 more combinations of this alright a series parallel combination you will find, for example if we take a combination of 1 inductance, 1 capacitance in parallel and then a series l c combination pardon 1 thank you. So if you take such a combination this will be the nature of function if you put s equal to j omega if you put s equal to j omega and then take out only the j you will get X, if you sketch X, if you sketch the x against omega you will get at those poles the function will try to blow up to infinity okay.

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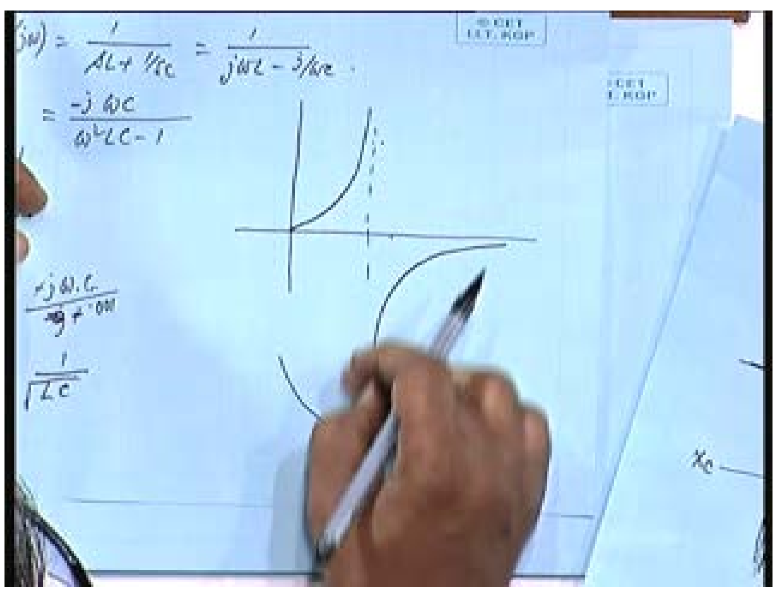

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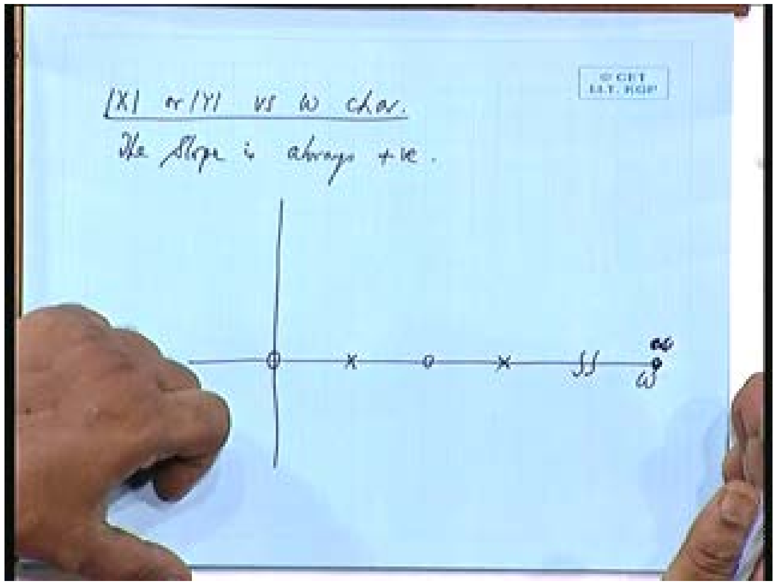

It will be like this it will be going up to infinity and when you just cross over that pole it will start from negative infinity. So this will be the nature of variation in both the cases I have taken a very simple order function this can be prove for any other function the slope is always positive whether it is y or z, the slope is always positive, this is nothing like going down like this the function is always increasing from a low value to high value if it is a minus in the minus region, negative region then from a very negative value it is gradually going to less negative value that means it is always increasing whether it is y or z okay alright.

So one conclusion we can draw the admittance, the reactance or admittance versus omega characteristic if we study the slope is always positive, poles and 0s are appearing alternately. So hence forth we shall be indicating on the x axis which is the frequency axis when we are making this x omega plot, this poles it was starting from a 0 value it was a pole here then again see if it is only for x_L then again a pole if you take the over all function over all function for this was a pole this was a 0, this is a pole. So poles and 0s will be coming alternately on the omega axis say if it is starting from 0 then a pole a 0 a pole and so on then at infinity this will be a pole then a 0 then this is infinity okay. This can be one configuration if I am giving the configuration for x, can you sketch the variation of x it is start from a 0 and go to infinity with a positive slope. So what can be the variation can it go this way, it cannot it has to go this way.

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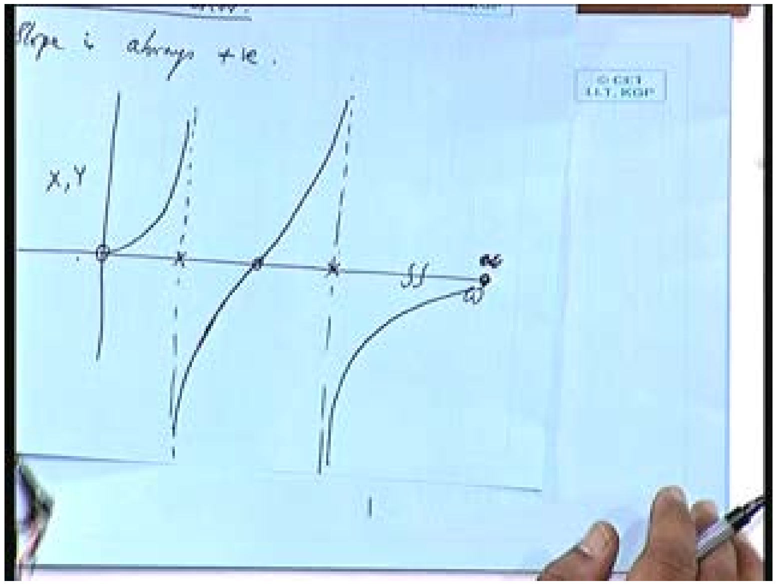

So this is for x or y either of them then from a pole, from a pole it has to go through 0 and approach again infinity from minus infinity it can go to plus infinity passing through a 0 it cannot go this way because then it will ensure a negative slope and we have seen the slope has to be positive. Similarly from this infinity to 0 it will asymptotically approach 0 this can be the possible x omega characteristics for a given set of pole 0 configuration is that alright.

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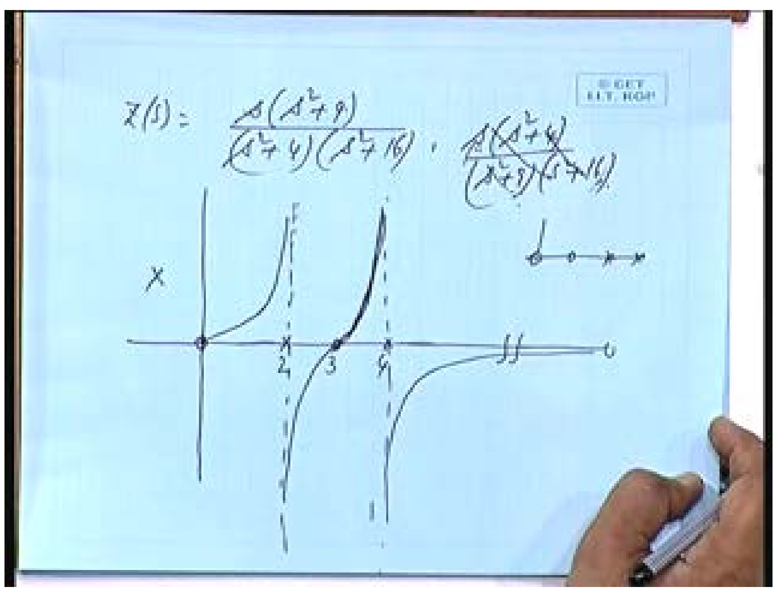

Let us take a function z (s) equal to s into s squared plus 9 by s squared plus 4 into s squared plus 16 what will be the pole 0 configuration for x and how will the impedance vary, sketch it free s is in the numerator. So this one will be 0 then 2 is a pole then 3 is a 0, 4 is a pole and then infinity has to be a 0 because last one was a pole.

So from 0 on the poles we draw dotted vertical lines and then it is very simple it will go to infinity like this from infinity, it will go through 0 to this, then from infinity it will go to 0 asymptotically. See this will be so this will be the impedance characteristic of this function. Now my question is is it possible to have a function like this s square plus 4 by s square plus 9 into s square plus 16, now you see 0, 0 then pole, then pole. So first 0, 2, 3, 4 is not the corresponding roots are 2 3 4 can you have 0 0 pole pole, 0 0 pole and pole they should come alternately alright.

So you cannot have this as a LC network function. Now suppose you are given a function z (s) equal to 10 into s into s square plus 9 by s square plus 4 into s square plus 16 okay. Now how many information are given to you one is this frequency 9, the other one is that is 3, 2, 4, 3 and one constant. So information given up 4 so I can realize this network with minimum number of elements 4 alright. This function can be realized by at least 4 elements if I have a network of say 1 Henry and 2 Henrys, this is not a canonic form a canonic form means which requires minimum number of elements to represent a function how much is this total is s plus 2s, 3s. So 3s I can realize by a simple 3 and inductive why should I have 2 inductances.

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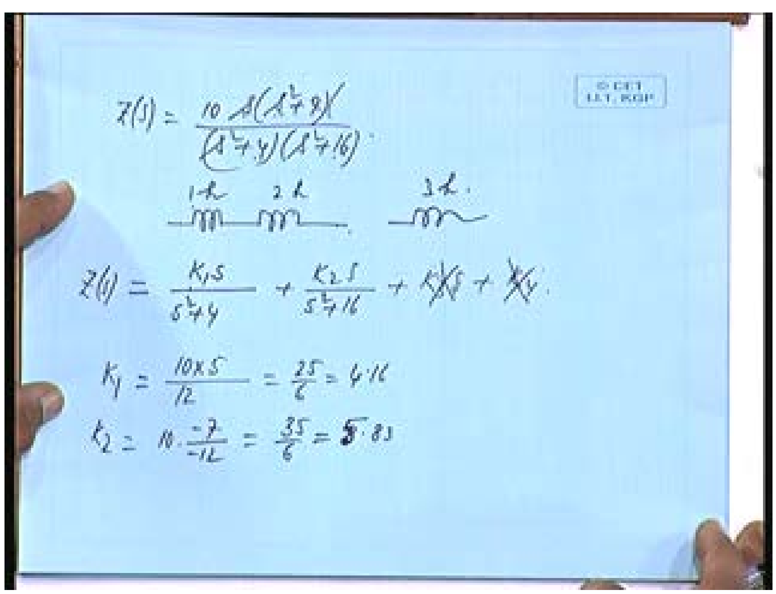

So this is not a canonic form this is a canonic form for that function 3s if I am given z (s) is equal to 3s realize it I will go for this this is a canonic form, canonic form means minimum number of elements required to realize that network function. So how many minimum number of elements will be required here the information that you are giving will be 4.

So if you are given 4 information is 4 minimum number of informations then I can have only 4 minimum number of elements alright. So this will be a network a canonic network with 4 minimum number of elements if I make partial fractions what will be the form k_1 s by s squared plus 4 plus k_2 s by s square plus 16 can I have anything like k_3 s plus k_4. Let us keep a general form like this. Since, the roots are all on the imaginary axis poles and 0s are all on the imaginary axis there is no scope for any resistive element. So z (s) with a k_4 a resistance so that is ruled out okay.

If I add these what will be the numerator s square plus 4 into s square plus 16 into k_3 (s) highest order will be s to the power 5, s to the power 5 is not given here. So this is also ruled out had I had a term like s square plus 25 then the numerator was s to the power 4 maximum power. So then k_3 (s) would have been possible but in this case you are having a maximum degree of s to the power 3 in the numerator. So here if I add up it will be s to the power 5, so this is not possible so k_3 (s) is also not possible.

Now let us find out k_1 (s) and k_2 (s) what will be the residue k_1 multiply by s square plus 4 okay and divide by s. So this s will go then make s square plus 4 equal to 0, so it will be 10 into 5s square plus 4 is 0 means 4 divided by 12 is that alright. So 50 by 12, so 25 by 6, 4.16, k_2 similarly multiply by s square plus 6 divide by s make s square plus 6 equal to 16 equal to 0. So this will become minus 7 this will become minus 12, so 10 into minus 7 by minus 12 so that gives me 70 by 12, 35 by 6, 5.83, 5.83 okay.

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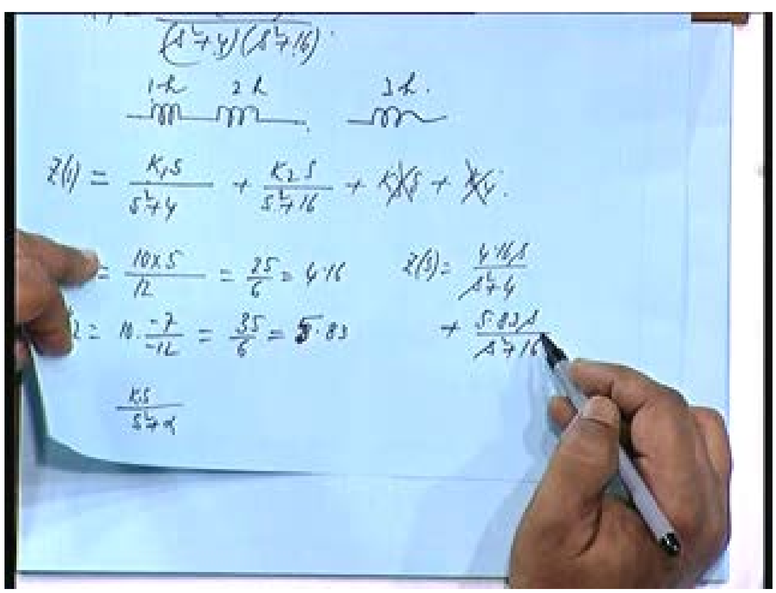

So I have got z (s) equal to 4.16 s by s squared plus 4 plus 5.83 s by s squared plus 16, what is this combination it mean an impedance function you get some thing like k (s) by s squared plus alpha what does it mean if I make s_{10} into very very small value 10 into 0, this will be absent. So it will be k (s) by alpha k (s) by alpha means k by alpha Henry alright. Similarly, if I make s_{10} into infinity alpha will be knocked off.

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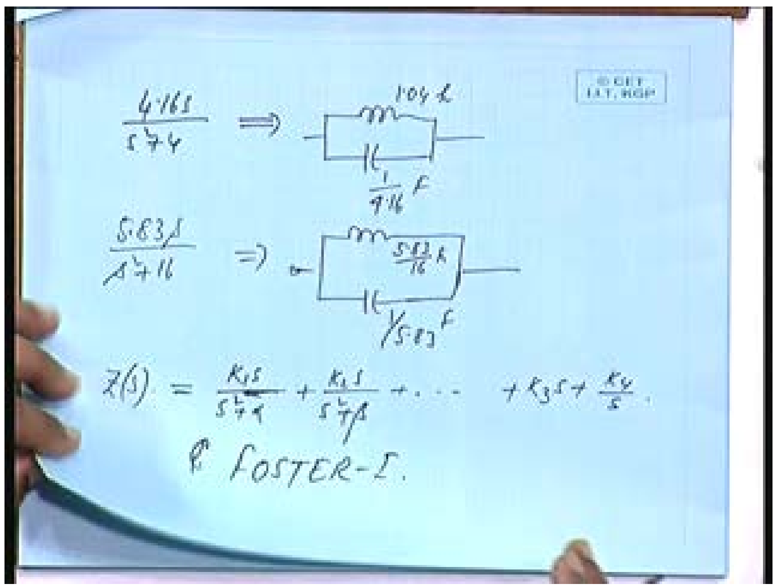

So it will be k (s) by s square s will go so k by s, so 1 by k farads. So here I will get 4.16 s by s square plus 4 will give me an inductance of how much when s tending to small value 4.16 by 4. So that is 1.04 Henry is that alright that means at a low frequency capacitor blocks the current the entire current flows through the inductance. So it becomes an inductive circuit at a very high value of capacitor frequency, capacitance is a bypass. So the entire current flows through this it becomes capacitive. So it will be 4.6 by s, so s will so 1 by 4.16 farads is that alright. Similarly 5.83 s by s squared plus 16 could you please tell me the values 1.04 by 16 when s is small it is 5.83 by 16 Henry and this one will be 1 by 5.83 farads okay. So if I put these 2 in series I get the total impedance function this plus this.

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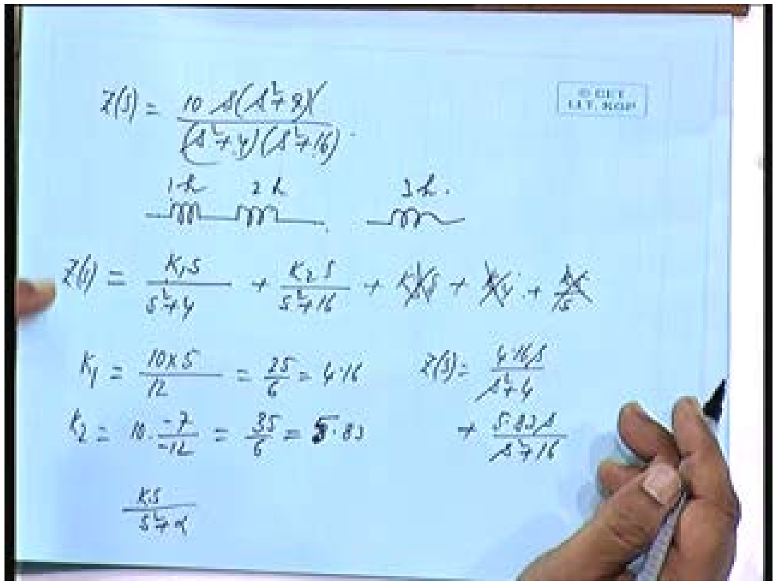

Okay, so whenever you start realizing the function from z (s) that is take the impedance function break it up into forms like this k_1 s by s square plus alpha plus k_2 (s) by s square plus beta and so on plus a free term k_3 (s) plus a term k_4 by s. In the previous case I forget to include another term k_5 by s is there any possibility of k_5 by s coming because s is in the numerator not in the denominator. So in this case that was also ruled out but suppose in the general function s is in the denominator it is possible then you will have a function like k_4 by s also. So you have to see all possible elements of this type either an inductor a capacitor or LC combinations if I can break it up in this form and realize each element of this partial fraction separately put them together in a string that is called coir sorry foster 1 synthesis, foster 1 synthesis.

Let us take another example z (s) equal to s squared plus 1 into s squared plus 3 divided by s into s square plus 2 into s squared plus 4 and s squared plus 5 okay. So numerator is s to the power 6 denominator is s to the power 4 so what will be the form like K_1 (s) by s square plus 2 plus K_2 (s) by s square plus 4 will there be any K_3 (s) term, will there be any K_4 (s) term yes, K_4 by s will be present because s is in the denominator K_3 into s will be present because here it is s squared, s squared, s into s to the power 6s to the power 6 is present here.

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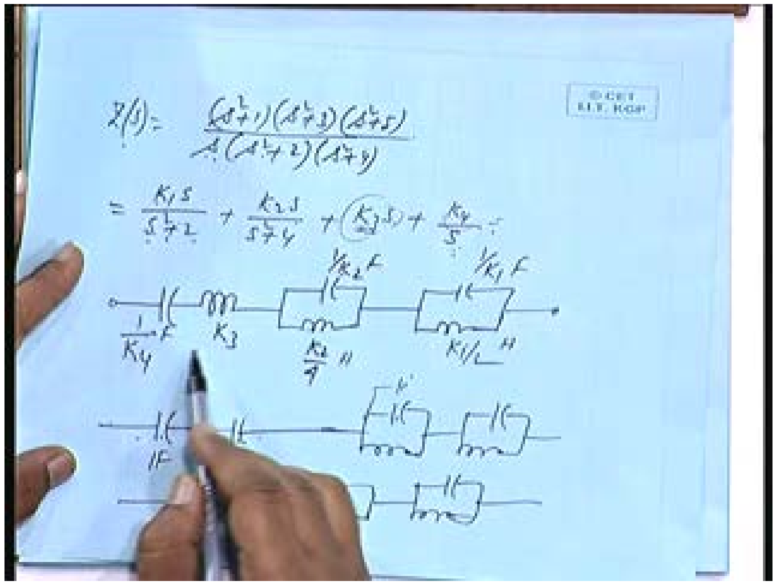

So for this type of function all the 4 elements will be present realize after getting the value of K_1, K_2, K_3, K_4, what will be the network like a capacitor of value 1 by K_4 farad. Okay an inductor of K_3 Henry and then terms like this K_2 (s) by s squared plus 4 will give me a tank circuit a parallel LC combination, how much is this when s tends to 0, K_2 by 4 Henry is that alright and when s tends to infinity it will be 1 by k_2 farads okay. Similarly, this one k_1 by 2 and 1 by k_1 farad. This will be the network is that okay any question if I have z (s) like this all the possible terms are there can I have another inductance or another capacitance in series that will not be a canonic form because in series you cannot have more than one capacitor in the canonic form, another capacitor put up and add it together. I could have got an equivalent value another inductor could have been added but these cannot be added.

So each one of them will give rise to 1 pole corresponding to each pole like s square plus 2, s square plus 4 you will have one LC parallel combination. Since they are distinctly different, so you will have distinctly different combinations but series combinations there can be only one K_3 and K_4 I cannot have another k_4 by s then I could have put them together k_4 by s and k_4 by s k_4 by s together alright. So 0s can be different in the network no I did not mean that whatever be the given network function in the canonic form you can have 1 series element of inductance at the most 1 capacitance at the most and parallel combinations of LC okay, each 1 giving rise to 1 pole and depending on the order of the numerator polynomial how heavy it is compared to the denominator, if the denominator is 4, s to the power 4, numerator is s to the power 6 and if you divide you will always get a free s term that means there is a series inductance, if s is in the denominator there is a series capacitance also alright. So either this will be absent or this will be absent or both may be absent or both may be present, so what will be the number of elements of l and c how much can be the difference, see how many inductance is at there 1, 2, 3 how many capacitances are there 1, 2, 3. Suppose this is not there this is also going to give me another function z (s) this is one possibility.

So how many inductance is at there 1, 2, 3 capacitances 2, difference is 3 minus 2, 1. I can have the inductance absent then how many capacitances are there 3, how many inductances is at there 2, can you have 2 inductance and 4 capacitances, 2 inductances and 4 capacitances, no sir pole will be increasing, no let us see the structure can be always like this I can be all get for any z (s) function a structure like this now suppose 4 capacitances 1 I can put here 4 induct 2 inductances so one inductance I can put like this another inductance I can put like this. Now 3 capacitances are already gone where can I put the forth capacitance still it will be a canonic form it is not possible if I put a capacitance here I could have added them together I cannot put a capacitance here then I could have added this together.

So I cannot have more than 3 capacitances if there are 2 inductances to get a canonic form that will not be a unique function if I put a capacitance here I find the overall z (s) and that z (s) I can realize suppose you find out, suppose this is 1 farad this is 2 farads and so on you find out z (s) and again from there if you try to realize you will be able to get a function like this that means I can realize the same network function that you are giving me by less number of elements. So that was not a canonic form so the difference in the number of elements l and c cannot be more than 1 they can be equal, l can be greater than c or c can be greater than l but then the difference can be only one, is that alright. This is foster 1 synthesis if instead of that we would have started with an admittance function.

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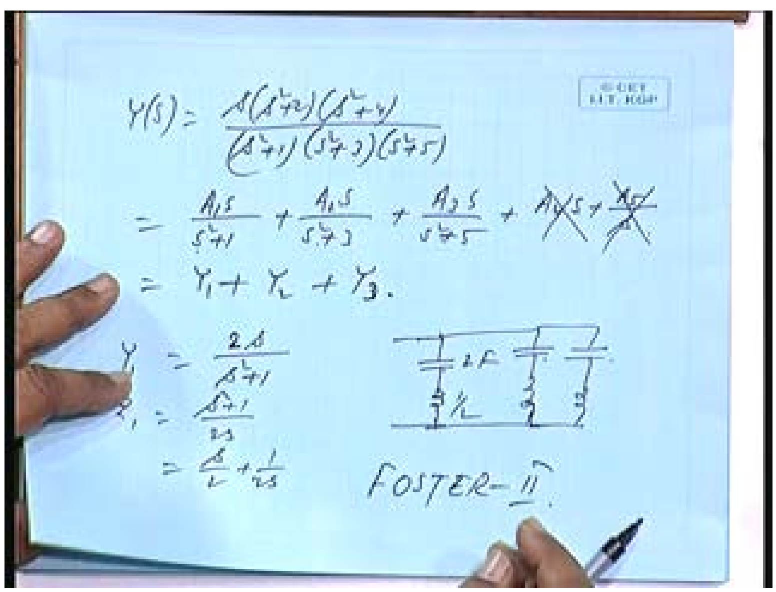

So if the same function z (s) is given I can realize it in terms of admittances then what happens so I will just invert it y (s) will be s into s square plus 2 into s square plus 4 divided by s square plus 1 into s square plus 3 into s square plus 5 again I make parallel okay I make a partial fractions so it will be a 1 s by s square plus 1 plus a_2 s by s square plus 3 plus a_3 s by s square plus 4 okay will there be a_4 s and a_4 by s. Since, s is not in the denominator this is ruled out since it is already s to the power 6 and numerator is s to the power 4. So if I put this then it will be s to the power 7, so this is also ruled out okay so I will get a_1 s by s squared plus 1. Let us call these as Y_1 plus Y_2 plus Y_3 okay so what will be Y_1, Y_1 is say 2 s by s square plus 1, suppose it is 2 s by s square plus 1 what does this mean if I make s_{10} into 0 it will be going to 2 s so when is the admittance becoming 2 s admittance is c s. In case of admittances c s is the admittance, so it is 2 farads, so it will be a 2 farad capacitance at that time at a very low frequency inductance is 0 it is a series combination, you see if Y_1 is this corresponding z_1 is how much s square plus 1 by 2 s that means s by 2 plus 1 by 2 s. So half Henry inductor and 2 farads capacitor will given me this impedance whose admittance is this. So each admittance you just invert and then separate you will get the corresponding LC values is that alright. So similarly, you get another LC combination another LC combination okay interestingly this values will be different from the foster realization foster 1 realization but how many inductances were there 1, 2, 3 and 3 capacitances you go for this realization you will get the same number of elements type of elements will be of the same number 3 inductances, 3 capacitances. So if we go from impedance it is foster 1 if you start from admittance function this is foster 2 realization okay we will stop here now, we will continue with this in the next class.

Preview

Lecture-15

2- Element Synthesis (Contd…)

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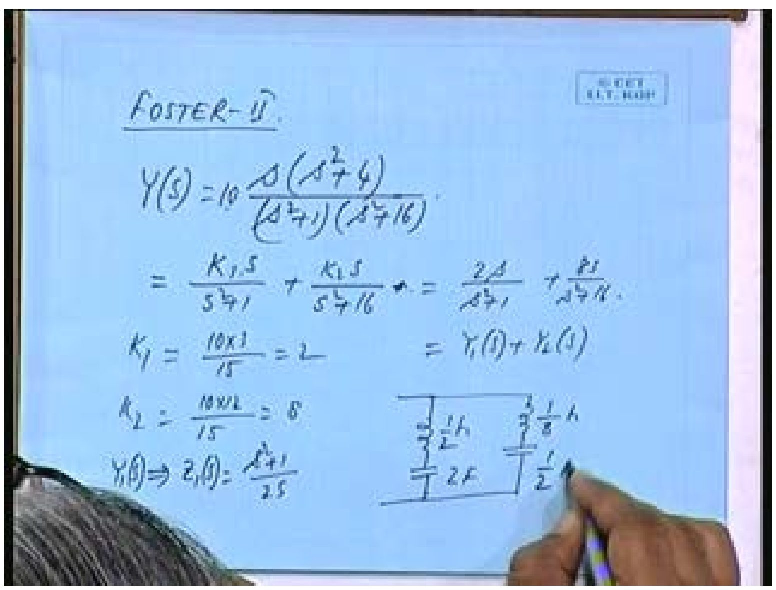

Okay good morning, last time we are discussing about foster 2 realization of network functions. Suppose you are given z (s) and you have obtained y (s), y (s) you say s into s squared plus 4 divided by s squared plus 1 into s squared plus 16 okay. Then I can write this as k_1 by k_1 (s) by s square plus 1 plus k_2 (s) by s square plus 16 how many elements will be there, can you guess how many elements will be there, how many informations are given to you I could have add a constant here 10 or so.

So this is one information 1, 2, 3, 4 so you can have only a 4 elements synthesis, now each of these factors will take away 2 elements. So 2 plus 2, 4 elements are already gone alright. So blindly you can write there is no other term k_4 s or k_5 by s okay. So how much is K_1 multiply by s square plus 1 divided by s make s square plus 1 equal to 0. So 10 into 3 by 15 so that is equal to 2 K_2 so 10 into 12 by 15 make a square plus 16 equal to 0, so this will be 12 into 10 by 15, 8. So I can write this as 2s by s squared plus 1 plus 8 s by s squared plus 16 okay. So this is Y_1 (s) plus Y_2 (s) so how much is Y_1 (s) what are the values of l and c corresponding Z_1 (s) Y_1(s) gives me Z_1 (s) which is just inversion of this s squared plus 1 by 2s.

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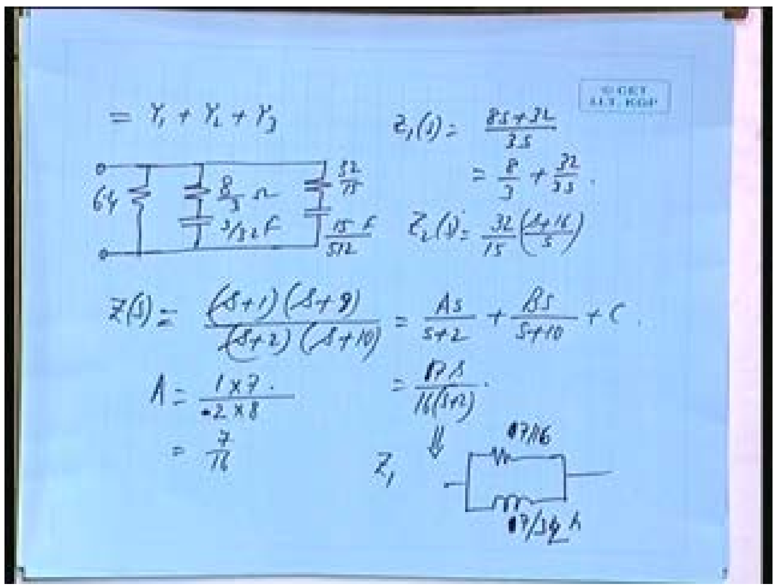

So that is s by 2 half Henry 1 by 2s, so 2 farads is that okay another combination Y2 (s) how much will be the element values of y2 (s) invert it s square by 8, s that is s by 8, 1 by 8 Henry and 16 by 8s, so 2 by s that will give me half a farad parallel combination of r l elements, is that alright 17,16, 17, 7 by 32, 16 into 232, a 7 by 16, 7 not 17 sorry, not 17, thank you very much, it is 7, 7 by 16 ohms resistances and 7 by 32 Henry inductance. So if you are having in the impedance function the first one, first factor as 0 then it will be an r l network that means admittance function of rc network and impedance function of rl networks are identical, conversely impedance of rc network and admittance of rl network are identical, poles and 0s thank you poles and 0s will be alternately coming.

If in the impedance function it starts with a pole it is an rc network if it is in the, if it starts with the 0 it will be an rl network and then the method of partial fraction is identical alright. The partial fraction that you have made for admittance of rc network will be similar to impedance of rl network, is it not. So in the next class we will be taking up a some tutorial exercise on synthesis by different techniques of different rl, rc and rc, lc networks. Thank you.