Circuit Theory

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Lecture 47

Properties and Synthesis of Transfer Parameters

forty seventh lecture and we are going to discuss properties and synthesis of transfer parameters in the last lecture we had discussed some of the properties of transfer functions and a summary is as follows we showed that all transfer functions

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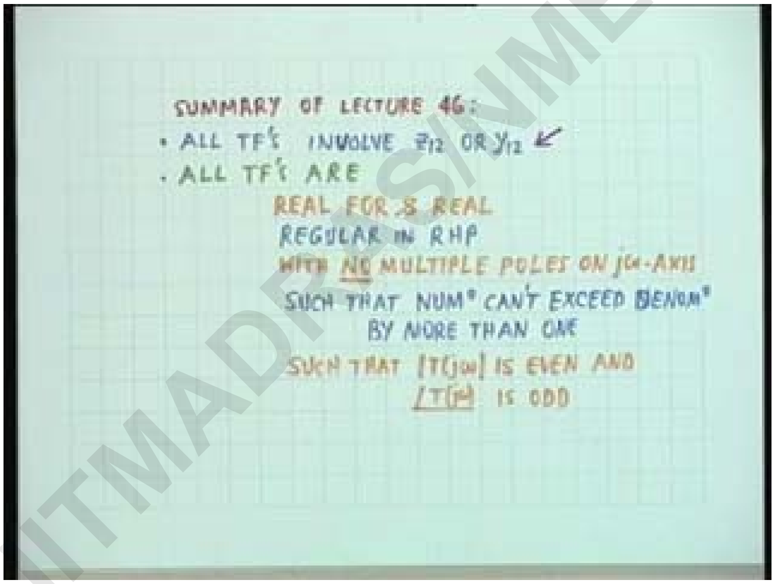

we take several examples of transfer function and we showed that all transfer functions involve besides the driving point parameters that is Zone one Z two two or Y one one Y two two the transfer parameters Z one two or Y one two

we have assumed the networks to be reciprocal therefore it is either Z two one or Z one two it doesn't matter they are equal they are identical we showed that all transfer functions are real for s real they are regular in right half plane does this mean something to you regular in right half plane means there are no poles in the right half plane regularity means absence of poles no poles in the right half plane all transfer functions are with no multiple poles on the j omega axis because multiple poles give raise to multiple poles on the j omega axis give rise to instability and we are talking of passive table reciprocal networks in all transfer functions the degree of the numerator cannot exceed the degree of the denominator by more than one

whereas the reverse is not true that is the denominator may exceed the degree of the numerator by any number okay all transfer functions such that that the magnitude is an even function and the angle is an odd function this where we ended the last lecture alright

today yes

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it cannot have a multiple pole even ay infinity no it cannot

it can have a simple pole at infinity [Noise] okay since all transfer functions

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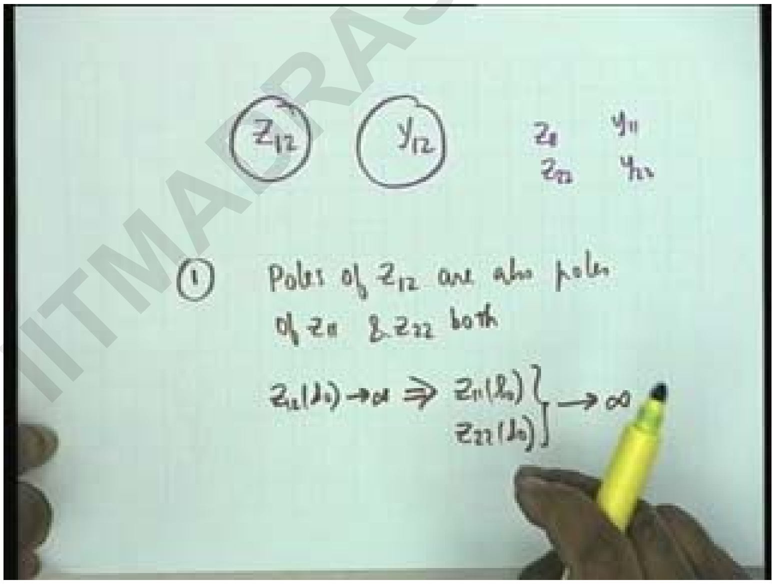

involve Z one two or Y one two and in addition to the driving point parameters that is Z one one Z two two or Y one one Y two two the properties of which you all ready know because they are DPIs it suffices to consider a properties of Z one two and Y one two and there are several properties which have of interest to us at the moment [Noise] we shall we shall discuss only those one of the properties is that poles of Z one two poles of Z one two are also poles of Z one one and Z two two both okay Z one one and Z two two both but the reverse is not necessarily true what we mean is that any poles of Z one two if Z one two s zero tends to infinity this implies that Z one one s zero Z two two s zero both of them will tend to infinity but the reverse is not necessarily true

that means if Z one one has a pole it is not necessarily shared by Z one two if [Noise] Z two two has a pole it is not necessarily shared by Z one two the question at this point is if Z one one has a pole does it have to be shared by Z two two [Noise] no alright it suffices to make a counter example

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whatever (( )) (00:04:16) if Z one one has a pole it does not necessarily have to be shared with Z one two that is the reverse is not necessarily true

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also Z two two Z one one and Z two two can have poles which are independent of each and independent of Z one two one example one counter example will suffice to prove this

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that is what i say that Z one one poles and Z two two poles can be independent of each other they can also be independent of Z one two but Z one two cannot have a pole which is not shared by both Z one one and Z two two agreed

what i said is to forward statement is correct the reverse statement is not necessarily true in other words it is possible for Z one one to to have pole which is not shared by either Z one two or Z two two

similarly Z two two can have a pole which is not shared by Z one one or Z one two and a simple counter example

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it is not necessary to have this belong to Z one two also

<a_side> ((not necessary)) (00:05:35) <a_side>

not necessary in addition Z one one and Z two two themselves can have independent poles they don't have to share at pole okay ah a simple example would be this suppose

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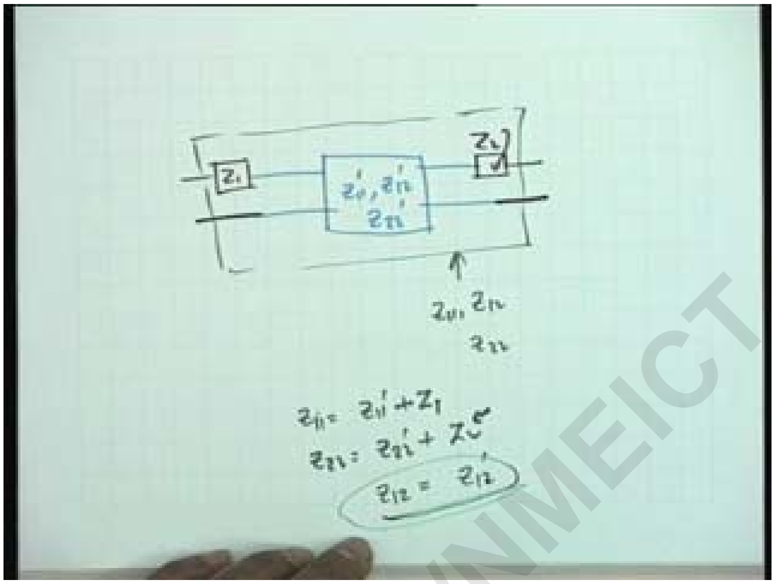

suppose we have a two port network which has the parameters let's say Z one one prime Z one two prime and Z two two prime okay suppose we have a network like this and then what we do is we supplement this with an impedance Z two here and an impedance Z one here okay

the supplement this with an impedance and call the total network call the network as the unprimed network that is we call this as Z one one Z one two and Z two two alright there is a network inside which is a prime network and then we supplement it with the help of two series impedances Z one and Z two

now you notice that Z one one is simply equal to Z one one prime plus Z one agreed similarly Z two two is Z two two prime plus Z two and what about Z one two

<a_side> ((same)) (00:07:00) <a_side>

same Z one two prime alright

therefore the the poles of Z one the poles of Z one are poles of Z one one not necessarily the poles of Z one do not affect Z one two is in that right the poles of Z one do not affect Z one two Z one two is the same as the previous Z one two prime similarly poles of Z two affects only Z two two not Z one one or Z one two and the simple example shows that Z one one can have a pole which does not belong to either the other two parameters

Z two two can have a pole which does not belong to either Z one one or Z one two but any pole of Z one two must belong to Z one one as well as Z two two

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how did i prove that this pole also belongs to this okay good question [Noise]

<a_side> excuse me sir <a_side>

yeah

<a_side> could you please write clearly sir (( )) (00:08:08) <a_side>

oh it's not clear the writing oh we will keep this up alright

how do i prove that any pole of Z one two also belongs to Z one one and Z two two alright let's recall

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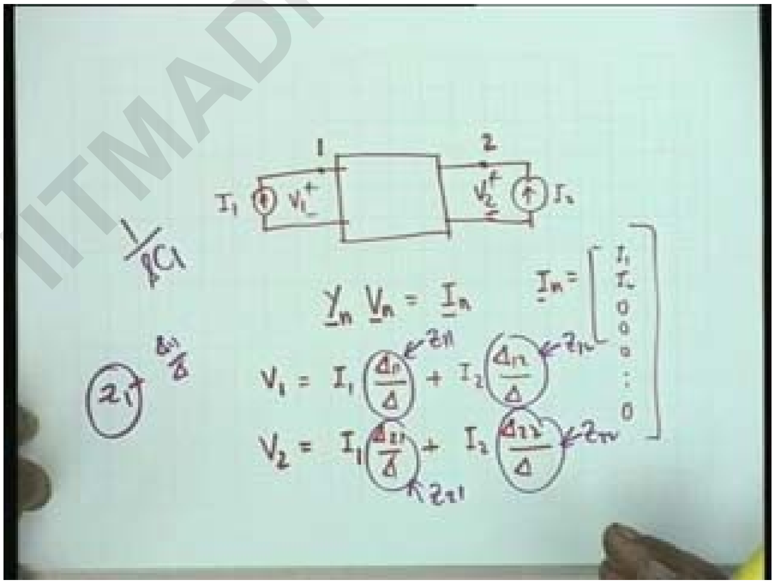

our node analysis we have two current generators is this clear can you see this okay we have two current generators at the two poles we call this as node one this as node two there is some reference inside some reference and the voltages are the V one and V two okay you recall that the node analysis gives you a nodal admittance matrix Yn multiplied by the nodal voltage vector Vn this is equal to In alright

this is the node node matrix equation the nodal equation nodal analysis equation it can be put in this matrix for you have self admittances and mutual admittances and so on and so forth alright is this okay

where i have just two generators I one and I two so In for example is equal to I one I two then zero zero zero etcetera zero alright and what we wanted to find out is V one and V two that is this two voltages i want to express in terms I one and I two and you recall that this was I one del one one by del plus I two del one two by del where del is the determinate of this matrix

similarly i have done this earlier V two is I one del two one by del plus I two del two two by del agreed so you can now identify what are the Z one one Z one two this is obviously Z one one and this is Z one two

which is the same as Z two one because the network is a reciprocal del one two is equal to del two one and this is equal to Z two two and you see that poles poles of all the functions should normally be the same because a poles are created by putting del equal to zero any value of s that which del equal to zero is a pole a pole this pole should be shared by all the four parameters any pole of Z one two must also belong to Z one one alright but the reverse is not necessarily true which we showed by this simple example that if there is an element in series at port one this affects only Z one one nothing else

<a_side> but sir for this case if we prove if del is zero (( )) (00:11:24) <a_side>

yeah if del is zero

<a_side> for the pole of uh for the pole for z one one del should be zero <a_side>

correct

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so what i do is i add an element another element Z one in series with this so all that it changes is that it becomes Z one plus

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del one one by del

so any pole of Z one also is now a pole of the augmented network it does not affects Z two two or Z one two alright

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del one one then the whole thing is not a pole or del one one can also have a pole at the same point

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that will be an independent pole

<a_side> (( )) (00:12:17) <a_side>

you see what i [Laughter] what your going to do ultimately ultimately is that del one one and del both in general will be rational functions and what you will do is you will break you make this into a polynomial divided by polynomial by clearing of inverse expressions like one by sC one and so on

so the denominators of all this rational function will be the same [Noise] correct and therefore the poles the zeros of the denominator shall occur at the same point poles must in general be shared on the other hand there are exceptions with regard to Z one one Z two two because we can add anything in series it does not affect Z one one alright let’s take a simple example

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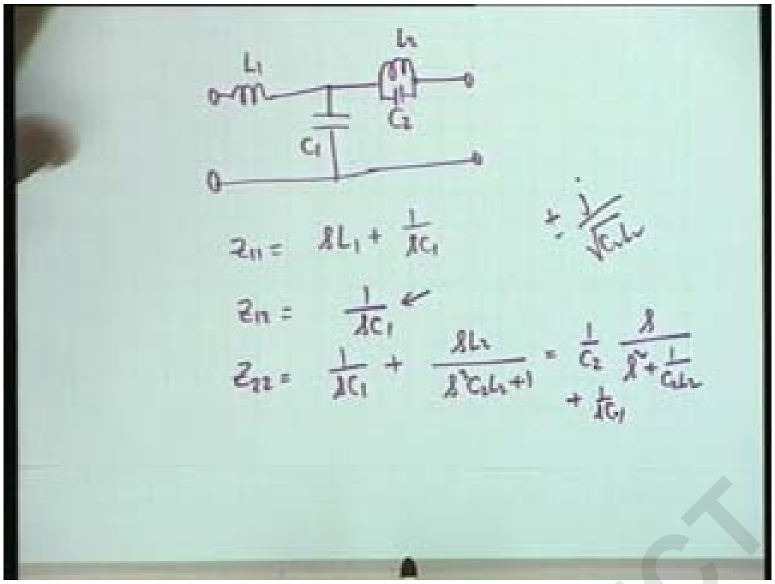

let’s have an inductor L one a capacitor C one and let’s say an L two and C two C two okay what are Z one one Z one two Z and Z two two of this structure sL one plus one over sC one Z one two what is it equal to

<a_side> ((one over sC)) (00:13:37) <a_side>

one over sC one and Z two two is one over sC one plus can someone tell me what this is

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sL two divided by s squared C two L two plus one agreed which is equal to one over C two s divided by s squared plus one over C two L two i am sorry plus one over sC one this we must ignore we must not ignore

and if you notice that the pole at s equal to zero which is the pole Z one two is also present in Z one one and Z two two that is this pole is shared by all the three parameters

on the other hand the pole at infinity of Z one one is not shared by either Z one two or Z two two there is no pole at infinity of either of them so this pole is as if a personal property of Z one one it is called the personal pole [Noise] you may call it a [Noise] personal pole

similarly the pair of poles at plus minus j by square root C two L two belongs only to Z two two it doesn’t belong to Z one one and Z one two alright so the property is that any pole of Z one two must also belong to Z two two and Z one one but Z one one and Z two two can have poles which are personal to themselves it doesn’t have to be shared

Z one two is not in that privileged position it transfer parameter poles must be shared by by the other two parameters also in a similar manner you can show

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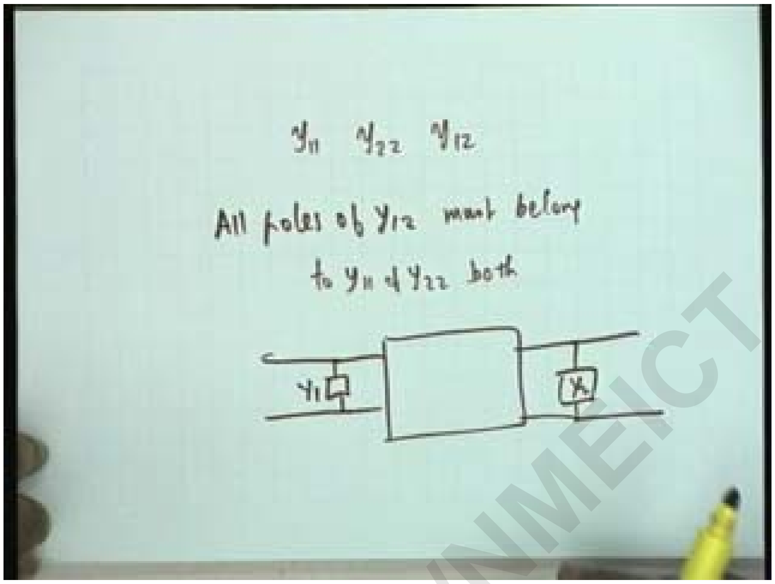

that if you take the Y one one Y two two and Y one two parameters you can show that all poles of Y one two must also belong to Y one one and Y two two all poles of Y one two must belong to Y one one and Y two two both but the reverse statement is not necessarily true

that is Y one one can have a pole which is not shared with Y two two or Y one two Y two two can have a pole which is not necessarily shared by Y one one as well as Y one two and the counter example here is that if you add and an admittance in parallel with port one if you add an admittance in parallel with port one Y one and an admittance Y two here

then Y one affects small y one one only Y two affects small y two two only it is a exactly the dual of the previous case in the previous case we are used to impedance in series now there are two admittance in ((parallel)) (00:16:58)

Y one does not affect Y two two why not because in measuring Y two two you have to short this so Y one goes out of the picture okay now [Noise] the third property that we shall be interested in is the special case of and LC two pole

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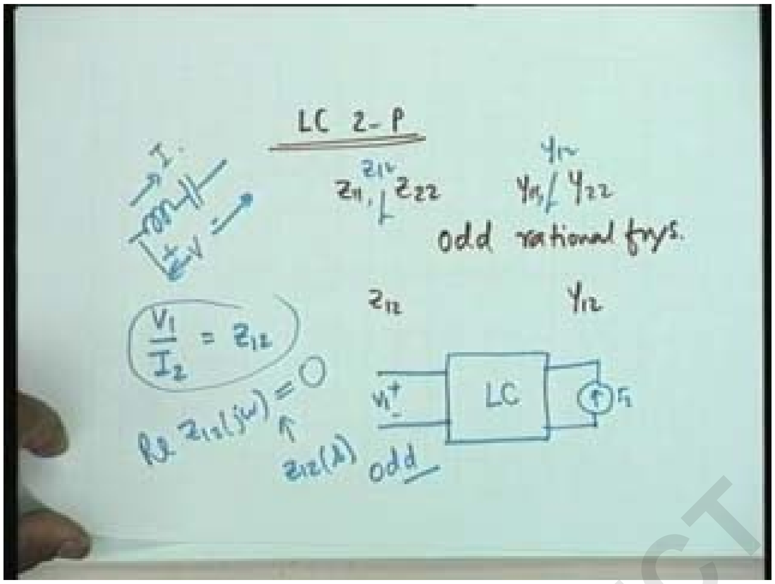

if a two port is LC okay then you no that Z one one Z two two [Noise] and Y one one and Y two two they had a particular character can you pinpoint this character the kind what kind of rational function

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odd all of them are odd rational functions if the two port is LC then all of them are odd rational functions what can you say about Z one two and Y one two what can you say about Z one two and Y one two can they be even or can they be neither odd nor even

this requires a bit of investigation now i cannot give you ah [Noise] strict proof of this this is beyond the scope of the class but let me sight a very simple simple logic suppose we consider Z one two by definition what is Z one two Z one two is what is the definition V two

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by I one with

<a_side> (( )) (00:18:45) <a_side>

V one by I two okay alright

i have a current generator I two here and V one this has to be kept open circuited and this elements are all LC alright so under this condition if i measure V one by I two if i measure V one by I two this would be Z one two we are asking the question we are asking question what is the is there is there any special character that you can assign to Z one two is it purely even is it purely odd or is it neither purely even not purely odd okay this is the question that i am asking

the logic that i am extending is the following that if this is an LC network any voltage in the LC network and any current in the LC network any voltage and any current they have to be ninety degrees out of phase in the steady state isn't that [Noise] right

in other words in other words if i take Z one two j omega if i take Z one two j omega this has to be purely imaginary which means that real part of Z one two j omega must be equal to zero which means now that Z one two of s if it is purely imaginary for s equal to j omega obviously Z one two of s must be purely odd

so the property that we have come to the conclusion know is that for an LC two port all parameters all Z parameters and all Y parameters must be purely odd

so you add to this Z one two and add to this Y one two all of them must be odd rational functions <a_side> (( )) (00:20:40) <a_side>

could i explain it again [Laughter]

the argument that i gave was all voltages shall have to be ninety degree out of phase because at a particular frequency at a sinusoidal frequency in this steady state all voltages must be ninety degree out of phase with all currents respective of every measuring and therefore this ratio if i take the real part that must be zero for s equal to j omega it must be purely imaginary either plus j times a constant or minus j times a constant that is either plus ninety or minus ninety

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we cannot have a real part

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what is what is what is obvious

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it is not a driving point function if it is a driving point function it is obvious it is a transfer parameter now which means that any point at any point you measure the voltage that any other point you measure the current

these two voltages and currents must be ninety degree out of phase it cannot be anything other word they cannot be in between because it is an LC network

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no not necessarily you can draw a phase of diagram with voltages and currents at different points no problem

<a_side> (( )) (00:22:02) <a_side>

they cannot be in phase no voltage and current can be in phase in a in an LC network

<a_side> (( )) (00:22:12) <a_side>

[Laughter] you construct your example you take you construct a counter example

<a_side> (( )) (00:22:20) <a_side>

not example

<a_side> (( )) (00:22:21) <a_side>

in the case of resonance well i was expecting this [Laughter] if you have [Noise] if you have a voltage and current this is a driving point function okay if this is ah V and this is I okay then the impedance is zero which means that the ratio of voltage to current is either zero or infinity

in other words at that point it has a pole we are not talking of a pole or a zero okay we are talking in general if the function has a pole well all LC parameters have to have poles on the j omega axis only oh is that obvious

that if the network is LC that's an interesting point let's pause for a moment if the network is LC then all poles have to be on the j omega axis poles of the all the parameters yes

<a_side> yes sir <a_side>

because Z one two cannot have a pole which is not shared by Z one one and Z two two also because Z one two poles must also be on the j omega axis okay we are not talking of poles or zeros we are talking of of the {ratio} (00:23:42) of frequency at which the ratio is neither pole nor a zero at that point the voltage and current measured anywhere in the network shall be ninety degree out of phase and if you if you consider this ah a challenge construct a counter example alright that i leave to go

the third point [Noise] the third point that i ah third or fourth

<a_side> (( )) (00:24:22) <a_side>

it shall be the fourth one okay the fourth point that i want to mention here is [Noise] the follows and this i have to state without proof because it proof is beyond this scope of this [Noise] of this class the fourth point is that

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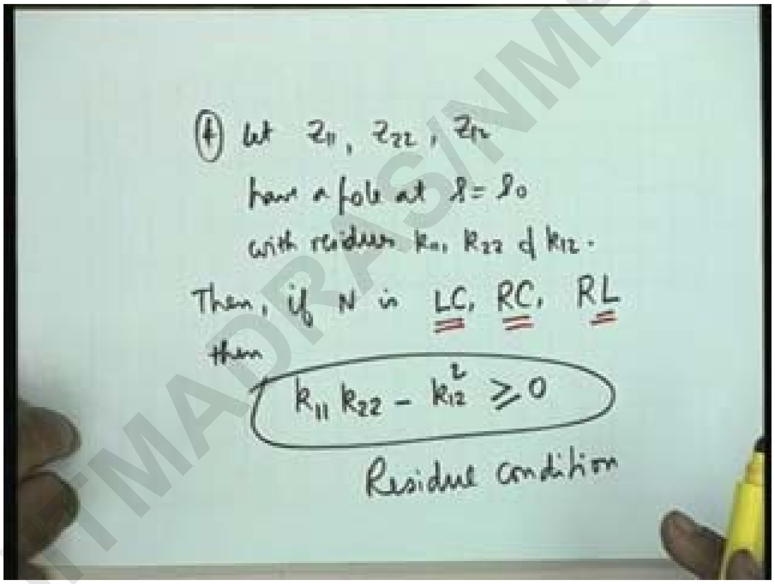

if you have a set of parameters let’s say Z one one Z two two Z one two [Noise] and suppose all of them have a pole at all of them have a pole at let’s say some point s equal to s naught with residues if there is a pole there should be a residual okay with residuals K one one K two two and K one two alright

then the statement of this propriety is that if the network is [Noise] two element kind that it is either LC or RC or RL

if the network is two element kind that it is either LC or RC or RL then the following property is true that is K one one K two two minus K one two squared [Noise] is greater then or equal to zero and this is called the residual condition as i said i cannot prove this in this class it is beyond the scope of this class but i can definitely illustrate by means of an example

[Noise] the restriction is that the network has to be two element kinds either LC or RC or RL okay then at all poles [Noise] okay as i said if Z one two has a pole it must be shared by Z two two and Z one one also but it Z one one has a pole it does not have to be shared by either Z two two or Z one two does that violate the residue condition

Z one one has a pole so K one one is non zero Z two two if the does not have a pole then K two two would be zero Z one two does not have a pole then K one two will be zero so it will be zero equal to zero it does not violate a residual condition

now let's take an example let's take the same example that we took no let's take a different example

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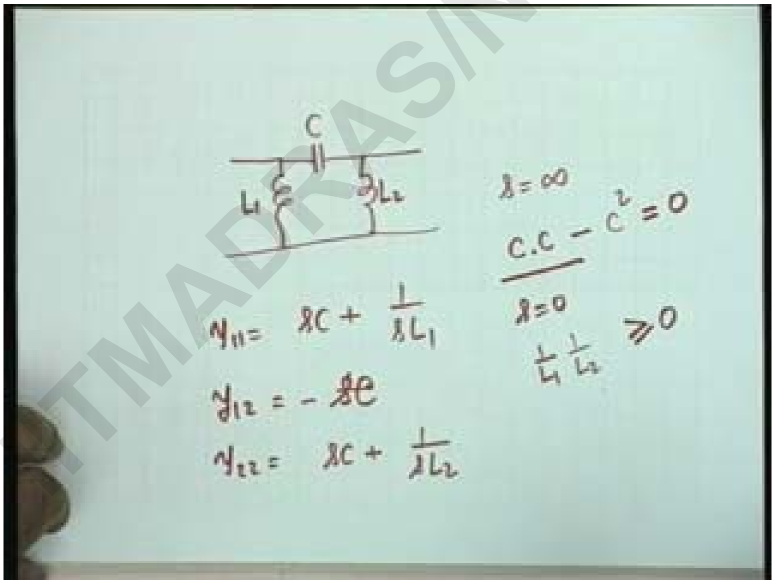

suppose we had we have L one two and C [Noise] which parameters tell me write down MY inspection

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Y parameters Y one one is equal to sC plus one over sL one is that okay is that okay

Y one two is equal to

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minus one over no minus sC minus sC don’t forget the negative sign and Y two two is equal to sC plus one over sL two

now you notice that the residue a pole at s equal to infinity a pole that s equal to infinity is common to all the three parameters and at this pole the residues are K one one is C K two two is C and K one two is

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yes

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K one two is minus C and therefore minus C whole squared is C squared and K one one multiplied by K two two minus K one two squared is exactly equal to zero residue condition is satisfied

on the other hand for the pole at the origin pole at the origin what is K one one is one over L one K two two is one over L two and K one two is zero and therefore this is obviously greater than or equal to zero okay is a demonstration of the residue condition i could do this with ah with RC or RL networks also any question alright [Noise] next we introduce a term

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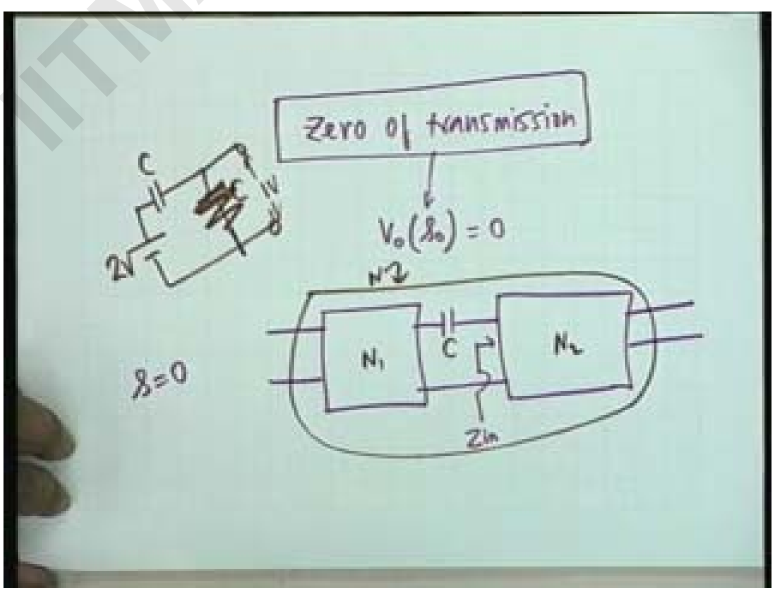

zero of transmission every obvious term nothing ah very special a zero of transmission of a two port network is the frequency at which there is no transmission as simple as that okay a zero of transmission is a frequency at which there is no transmission that is the output is equal to zero

if ah the output is a voltage let's say V zero then V zero at a zero of transmission s zero shall be equal to zero if the output is a current the current shall be zero okay

now [Noise] let's take some simple examples of zero of transmission simple examples on network to soak ah the idea of zero of transmission suppose we have a network which can be broken up into two sub networks connected by a capacitor

suppose this is my total network N which is broken up into two sub networks N one and N two and the capacitors C

obviously at DC at DC because of this capacitor there will be no transmission to N two so s equal to zero is a zero of transmission is that clear provided there is a hitch here provided if you measure this impedance Z in suppose Z in is that of a pure capacitor then what you have said is not true isn't it right no i have given this example earlier also yes

<a_side> ((sir if it was pure inductor)) (00:31:23) <a_side>

if it was pure inductor then also (( )) (00:31:29) zero of transmission that will be now two zeros at s equal to zero if the input impedance is that of an inductor then obviously at s equal to zero inductor axis is short so the output voltage would be zero agreed

now the point that i was mentioning is if Z in is that of a capacitor

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if the input impedance is a capacitor then obviously s equal to zero is not a zero of transmission this you can very easily see i have given this example earlier also that if you have two capacitors in series and the voltage let's say two volt let the capacitors be identical then you will get a one volt here [Noise] it is not a zero of transmission but on the other hand if it is anything but a capacitor if anything but (( )) (00:32:21) let's say resistance then obviously s equal to zero is a zero of transmission is that point clear okay similarly if we can break a network like this let's say ah [Noise]

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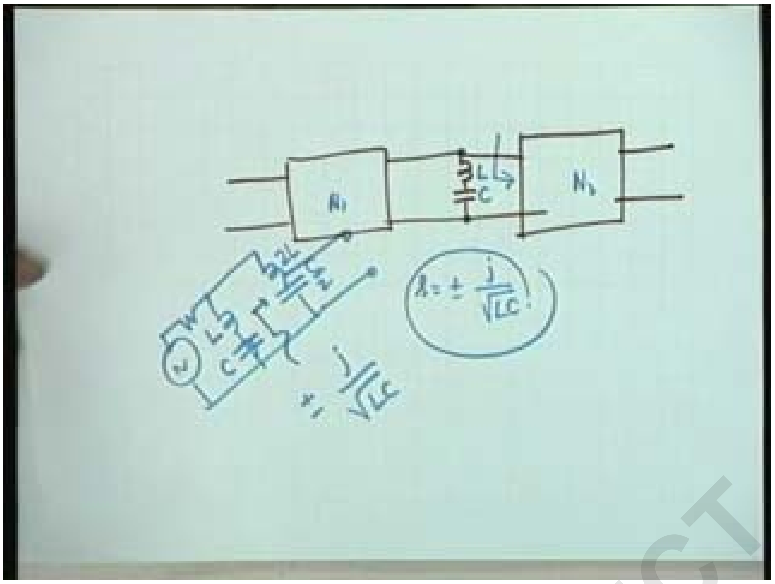

suppose a network N can be broken up into two sub networks N one N two and connected by a shunt series resonant network then obviously s equal to plus minus j by square root LC at this frequency at this two frequencies this axis a short circuit if it is a short circuit then obviously nothing will be transmitted to any two unless this exception must be remember unless the input impedance here is also a short circuit at this two frequencies

that is unless the network looking to the right has a an input impedance which is also zero at this frequency if it is zero then there will {shall shall}(00:33:36) occur current division between two short circuits okay current division between to so the zero of transmission shall not exists

<a_side> sir can you please explain <a_side>

can i please explain okay suppose i have a a network like this suppose this is L and C this is two L and C by two okay now obviously at the frequency plus minus j by square root LC this x is short and normally nothing should have been transmitted to the rest of the network but if by looking into the right by looking to the right if you have the pair of zeros is at the same frequency then obviously this is not a zero of transmission

that if if you measure the voltage across C by two example you will get a voltage why because there occurs a a division of current between two short circuits at the frequency s equal to plus minus j by root LC is it point clear okay there can be many other examples of zero of transmission

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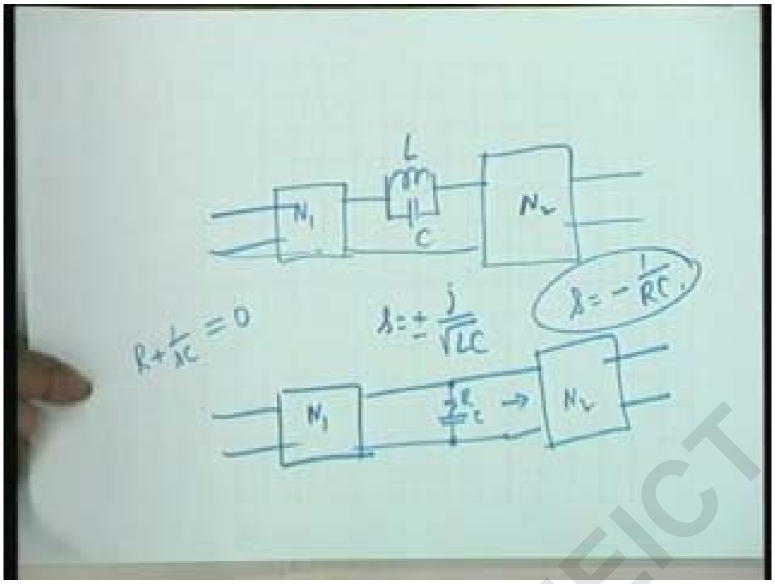

for example if we had a[Noise] a network like this L and C then at the frequency s equal to plus minus j by square root LC this parallel resonance circuit becomes infinite impedance and therefore it blocks transmission to N two

so you had a zero we have a pair of zeros of transmission at plus minus j by square root LC alright similarly i can take examples of let's say RC let's if there is a network N one which has an RC series network in parallel then there is a network N two then the overall network has how many zeros of transmission due to RNC in along that two

if it is LC then plus minus j by square root LC here one at s equal to minus one over

<a_side> ((RC)) (00:36:11) <a_side>

RC correct [Noise] at this frequency this is a short and therefore that is a zero of transmission once again that qualification should be there that the impedance looking to the right of this should not also had a zero at the same frequency

if it does then of course that is not correct

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pardon me

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no j here because this impedance this impedances is R plus one over sC and this will be zero when s equal to minus one by s no j alright okay now [Noise] Z of transmission

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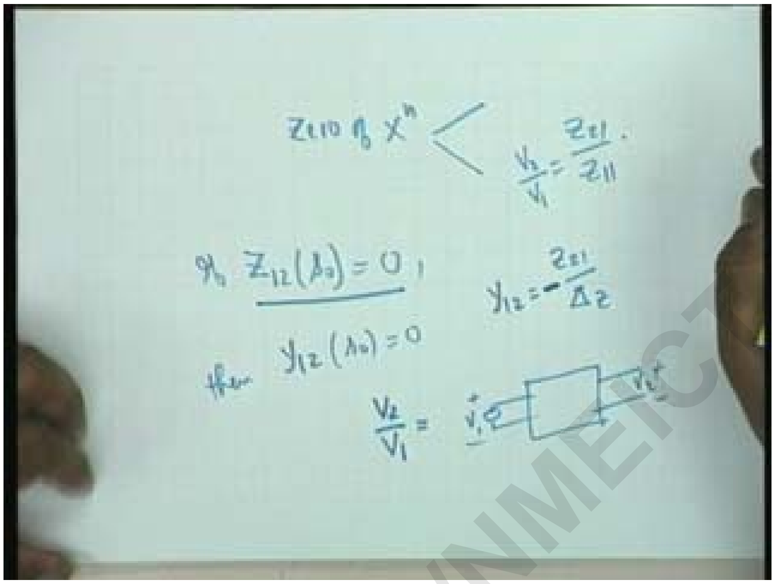

depending on zero of transmission two kinds of networks

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may ore may not be will come to this point a little later

zero of transmission for voltage and current may be different yes may be different but in general let let's since you raise the question let's answer this question in general if Z one two has a zero if Z one two has a zero then Y one two also has a zero at the same frequency can you prove this

if this is true then Y one two s zero is also equal to zero it {is} (00:37:50) it follows very simple because Y one two is equal to what is the relationship

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Z two one by del Z is there negative sign

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don't forget the negative sign so if Z two one is zero obviously Y one two is also zero in fact in fact if Z one two has a zero all transfer functions in general have a zero for example for example suppose i want the open circuit voltage transfer function of a network of a two port open circuit voltage transfer function it can be expressed in terms of Z one two and and what

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i have a network i connect a voltage here V one and i measure the voltage here V two what is the relations between V two and V one

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Z two one by Z one one that is it you write the voltage equations and put I two equal to zero so you get V one equal to I one Z one one and V two equal to I two Z two one I one Z two one the ratio is simply Z two one by Z one therefore if Z one two has a zero obviously voltage transfer function can also have a zero not always there is a qualification required it should be obvious

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that’s right Z one one should not have a zero then okay for example let’s take a simple example

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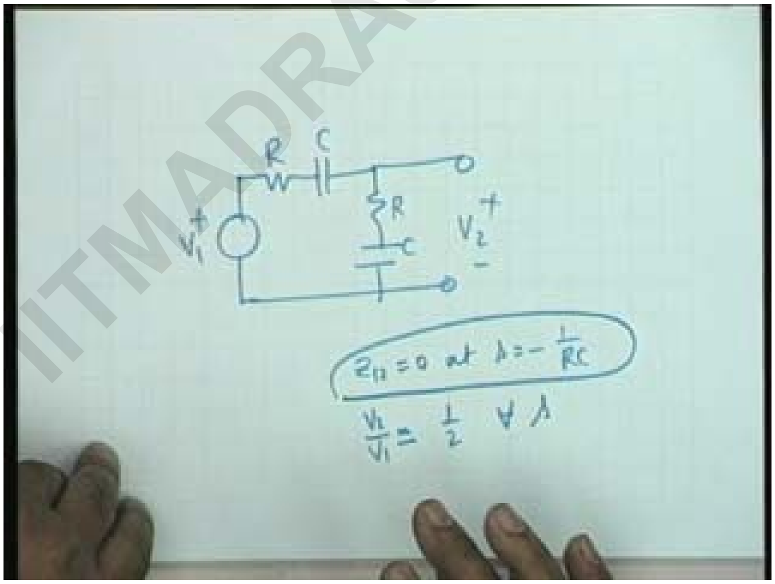

let’s say [Noise] an RNC in series and an RLC in shunt this is my V one and this is my V two obviously Z one two has a zero at s equal to

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minus one over RC but the transfer function V two by V one does not have a zero there

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it is equal to one or

<a_side> ((half half)) (00:40:08) <a_side>

half at all s therefore a zero of Z one two is not necessarily shared by all other transfer functions but generally it is so unless there is cancellation generally it is so

so it is suffices to consider in ordinary cases just Z one two or just Y one two alright is it point clear okay the other ah two terms that we have all ready introduced we would like recall at this point

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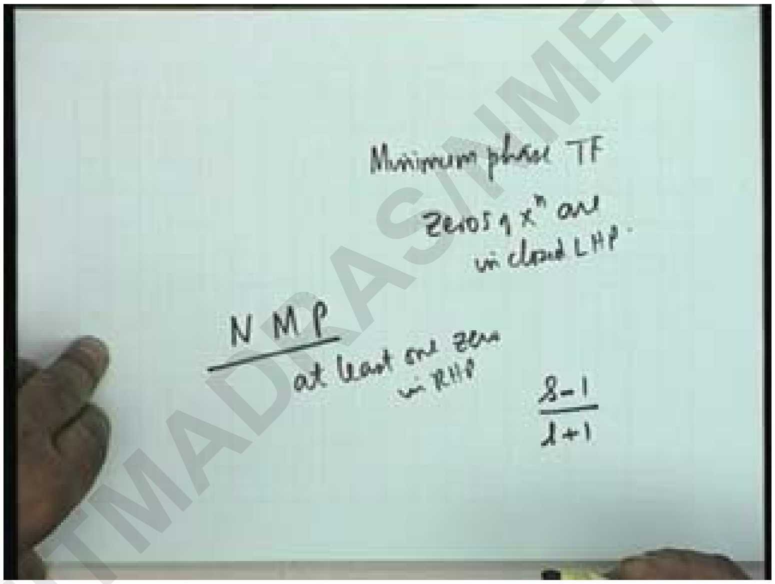

do you recall what is a minimum phase transfer function

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poles of any transfer function have to be in left half plane have to be they cannot be in the right half plane so it is the zeros minimum phase transfer function is one in which the zeros all transfer functions zeros are zeros of transmission isn't that right

so minimum phase transfer function is one in which the zeros of transmission are in the open or closed left half plane open or closed

<a_side> closed <a_side>

closed are in closed left half plane if the function has to be non minimum phase there must be at least one zero in the right half plane at least one zero at least one it can have more one zero in right half plane can you give me an example of a non minimum phase transfer function and all pass function first order all pass is of this form s minus one divided by s plus one the zero is in the right half plane the pole has to be in the left half planes

in addition if you recall all pass functions at the ((elegant)) (00:42:14) property that

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no

<a_side> (( )) (00:42:19) <a_side>

yes (( )) (00:42:19) of course but the property in term of poles and zeros they are

<a_side> (( )) (00:42:23) <a_side>

not symmetrical that's not the (( )) (00:42:27) mirror image mirror image symmetry [Laughter] the symmetry is that of mirror image considering the j omega axis as a plane mirror right j omega axis is a mirror it has a mirror image symmetry

so minimum phase and non minimum phase and now we are going to state a theorem

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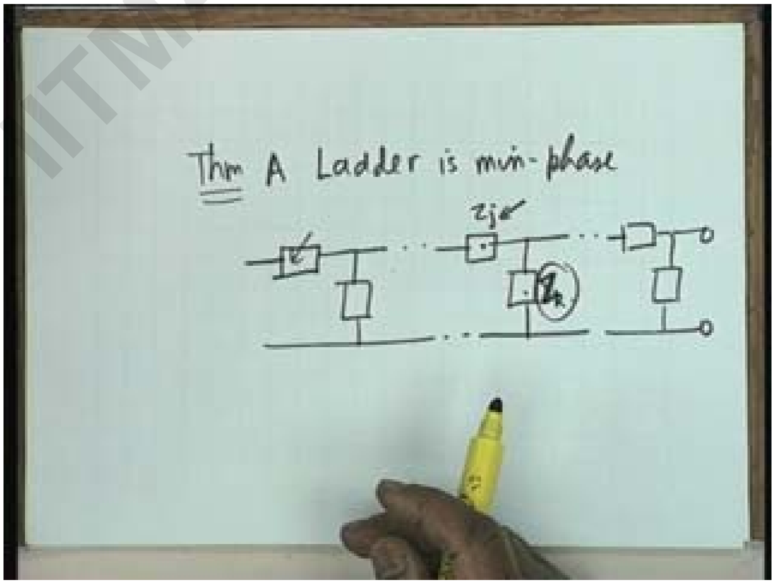

and the theorem is that if the network is a ladder if the network is a ladder alright you recall what is a ladder okay if the network is a ladder then it has necessarily to be minimum phase a ladder is minimum phase this is the theorem and the theorem can be proved very simply by common sense take a ladder take a ladder a ladder is like this [Noise] okay this is a typical ladder

a ladder is minimum phase all that you have to required to prove is that the zero of transmission of ladder is always in the left half plane poles no question poles have to be in the left half plane okay it's only the zero of transmission

now how can a ladder block transmission how can a ladder block transmission which is either two things can happen either a shunt element can be short circuit

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or a series a element can be an closed in circuit now a series element open circuit means what

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suppose an element Zj is an open circuit which means that it has pole at that frequency right how can it be an open circuit at that point that frequency must be a pole of this impedance

similarly if you have a let's say Yk [Noise] an admittance here let's put it a Zk an impedance Zk then

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zero can be created by zero of Zk right and a ladder has to be made up of only impedances right and if these impedances have passive and reciprocal and therefore the poles and zeros of these impedances are in the left half plane agreed

which means that the transmission zeros of a ladder must all be in the left half plane there is no other way that is zero of transmission can be created in a ladder right it is either a series impedance pole now we state it in the formal language

a ladder the transmission zeros of a ladder are constituted by two kinds two kinds of frequencies frequencies at which the series impedances have a pole or shunt impedance have a zero and since any driving point impedance any driving point impedance has poles and zeros [Noise] at the left half plane the transmission zeros of a ladder must be in the left half plane in other words a ladder must be a minimum phase are you convinced

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[Laughter] what what i saying is if it is to be minimum phase then it's zeros must be in a left half plane how can this zero be created either an impedance will be open series impedance where can it be open at it's poles and it's poles must be in the left half plane or a shunt impedance can be a short circuit

where can be it a short circuit at a zero where can it have zero in the left half plane and therefore all transmission zeros of a ladder must be in the left half plane

a question can a ladder have multiple transmission zeros

<a_side> ((yes sir)) (00:46:43) <a_side>

[Laughter] i am not finish the question anywhere anywhere in the in this plane can it have a multiple

<a_side> (( )) (00:46:53) <a_side>

pardon me

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why not

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anywhere because the zero of Zj any impedance can be anywhere in the left half plane suppose this zero is this a pole is shared by another series impedance then there will be two zeros of transmission at the same frequency

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no they are they are quite separate from each other let me let me take an example

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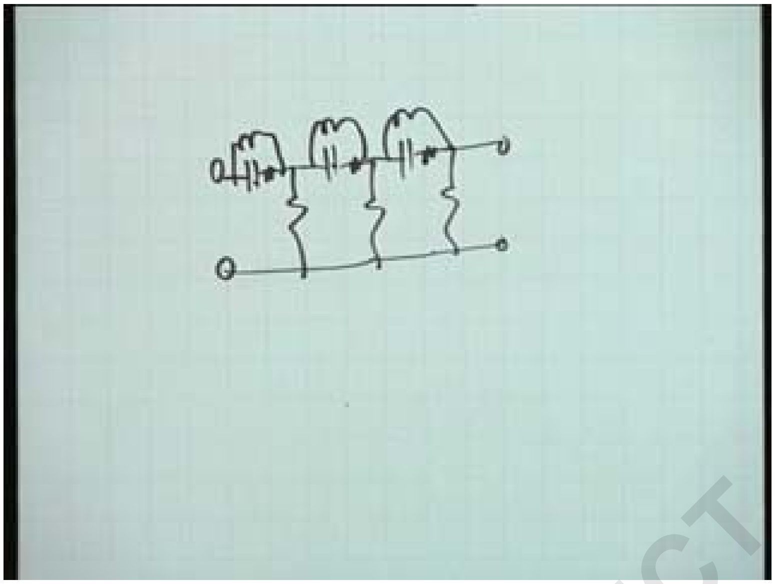

you know this phase shifting network where are the zeros of transmission obviously at s equal to zero at DC if you have a voltage source here nothing will appear here

how many zeros of transmissions

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obviously three one due to this one due to this one due to this say it can have multiple zeros of transmission at any point to this s planes suppose we had a resistance here then obviously this zeros would have shifted to be negative real axis

suppose we had an L here then identical [Noise] then this zeros of transmission would have been complex alright therefore it is possible for a ladder to have multiple zeros of transmission anywhere in the s plane no not anywhere in the s plane

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in the left half in the closed left half plane okay can it have multiple poles transfer function can it have multiple poles

<a_side> ((no sir)) (00:48:35) <a_side>

not on the j omega axis it may [Laughter] have elsewhere on the j omega axis no no transfer functions can have multiple poles on the j omega axis okay will start from here tomorrow [Noise]