Networks, Signals and Systems

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Lecture -13

Driving Point Immittance Functions – Realisability Conditions

Okay, Good afternoon friends we are discussing about poles and zeros location of poles and zeros and determination of residues. Suppose we have a function z (s), s plus a_1 in to s plus a_2 divided by s plus b_1 in to s plus b_2. So this type of function or may be s plus b_3 also when we make partial fraction of such functions it may be just the response function or when z (s) is there if you give an impulse input then this itself will give you the output function.

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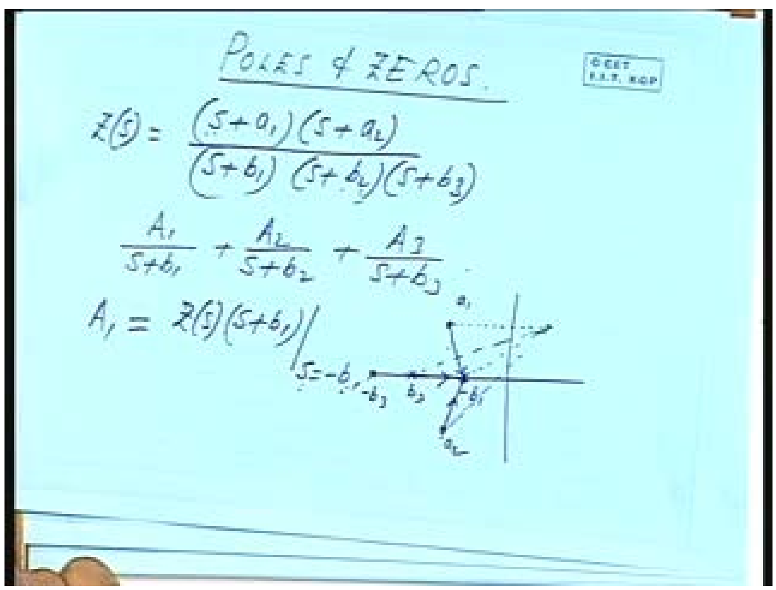

So any function of this kind when we want to measure then when we want to calculate the residues A_1, A_2 etcetera. We computed say A_1, we computed like this this function z s multiplied by s plus b 1and then evaluate this at s equal to minus b is it not now this b_1, b_2, b_3 they can be complex conjugate also if they are complex conjugate they should be in pair conjugate pairs okay. So z (s) in to s plus b_1 s evaluated minus b_1 I mean by putting s equal to minus b_1 evaluate a_1 what does it mean if I multiply by s plus b_1 this will go z (s) in to s plus b_1 means this we are evaluating at s equal to minus b_1.

So suppose you are having b_1 is here b_2 may be here, okay a_1 may be here, a_2 may be its complex conjugate a_1, a_2 both could have been real also similarly there can be a_3, a_4 and so on. So z (s) in to s plus b_1 when we are evaluating at this point that means I am placing s at this point is it not s is minus b_1. So from here last time we are talking about any location of s what was this vector representing at any s s plus a_1 if it is from the 0 it was representing one of these numerator factors s plus a_1 was this s plus a_2 was this so this is s plus a_2 similarly s plus b_1 is this s plus b_2 is this when I am taking s itself at minus b_1 and then measuring these distances so this will be s plus a_1 at s equal to minus b_1 similarly s plus a_2 and this is s plus b_2 okay had there been another point minus b_3 then from here to here that will be s plus b_3 so let us take a few concrete values of a_1 a_2 a_3 etcetera and then evaluate s

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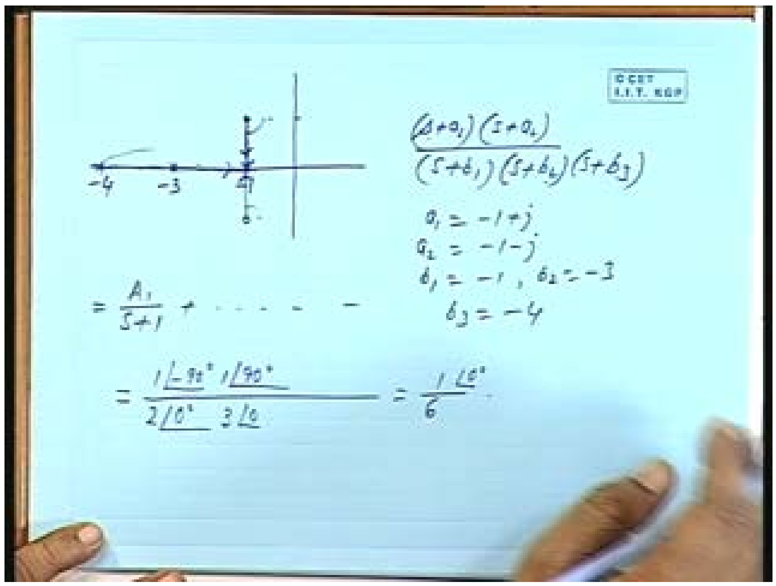

Therefore suppose you have sorry this is at minus 1 this is at minus 3 this is a_0 and this is a_0 I have got s plus a_1 in to s plus a_2 by s plus b_1 and say another 1 at minus 4 s plus b_2 in to s plus b $_3$ where a_1 is minus 1 plus j a_2 is minus 1 minus j b_1 is equal to minus 1 b_2 is minus 3 and b_3 is minus 4 so if I write this as equal to a_1 by s plus b_1 that is s plus 1, I am interested in calculating a 1 then this is s plus a_1 this is s plus a_2 this is s plus b_2 and this is from 4 to 1, s plus b_3 alright all evaluated after multiplying by b_1. So this all this one will not come okay and then we are evaluating at s equal to minus b_1 this is what we are interested in, so how much is this the numerator distances are how much is this this is one in magnitude and angle of minus 90 degree.

So 1 minus 90 degree, what about this 11 plus 90 okay divided by this is magnitude 2 and an angle of 0 is horizontal and this 1 is 4 to 13 angle 0. So how much is this 1 by 6 and an angle of 0 okay so vectorially also you can calculate this residues a_1, a_2, a_3, a_4 okay. Sir this is going to be better method, well geometrically you can always construct and see the residues okay if you can evaluate these vectors quickly from the position of the poles and zeros and then the calculations sometimes become very easy.

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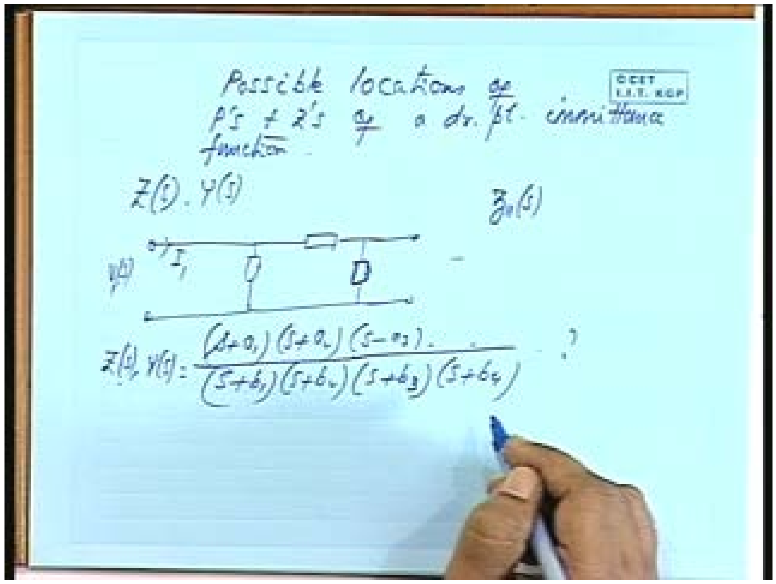

Now let us investigate, what are the possible location possible location of poles and 0s possible locations of poles and 0s of a driving point function, driving point immittance function, what you mean by immittance function? It is either admittance or impedance general g (s) or z (s) or y (s) function, there is some common properties both of them should have so what are those properties in terms of poles and zeros, locations of poles and 0s what could be the nature of poles and zeros now when we apply a voltage measure the current from the sending end then V_1 by I_1 it can be a_2 port network also when this is kept open this is called z_{11} okay.

When I am keeping it open it is the impedance seen from this side alright the impedance seen from this side what would be the property of this, we are talking about network elements which are passive in nature RLC okay. So what would be the nature of z_{11} is, suppose z_{11} s is s plus a_1 in to s plus a_2 divided by s plus b_1 in to s plus b_2, may be s plus b_3, may be s plus b_4 and so on can it be a driving point impedance or an admittance, is this possible? Any function of this type can it be driving point impedance or admittance function or is there any scope for a negative terms s minus a_3 you would like to examine that.

So before that would like to see the response suppose we excited by an impulse function of voltage, impulse function of voltage then V(s) equal to 1, suppose y (s) is given this function you say y (s) okay then what will be I (s) it will be y (s) itself y (s) in to 1, is it not? So if y (s) is written in a partial fraction form and so on then what should be the current i (t) what should be the current will be a_1 in to e to the power minus b_1 (t) and so on exponentially decaying terms had I had minus b_1 term or minus b_2 then it will be e to the power plus b_1 (t) or b_2 (t) that means the current will exponentially increase is it possible physically to get a current by applying just an impulse voltage.

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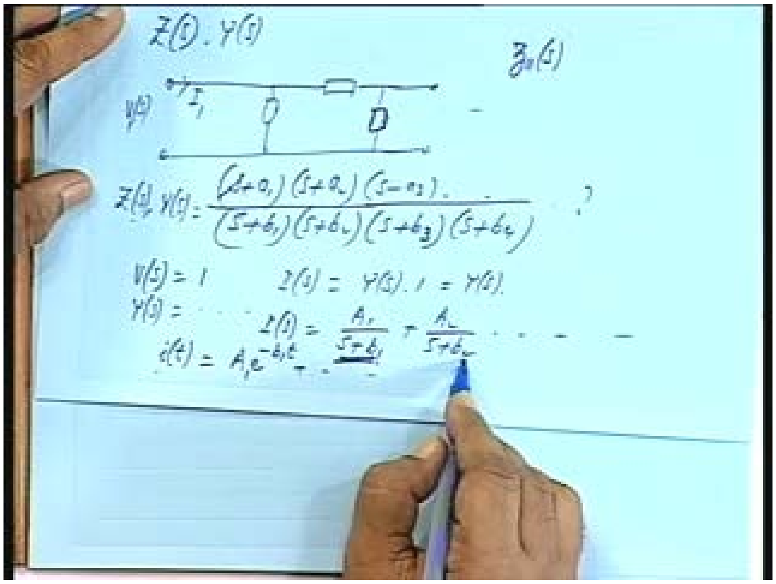

You just apply a voltage and withdraw it can you have a situation where the current will continuously flow through that and it will keep on increasing it goes against the principle of conservation of energy is it not so it cannot go up it can only die down alright so from the conservation of energy principle the factors will be of this type not s minus b_1 or s minus b_2 what does it mean s plus b_1 means the roots b_1 b_2 etcetera should be in the left half plane alright.

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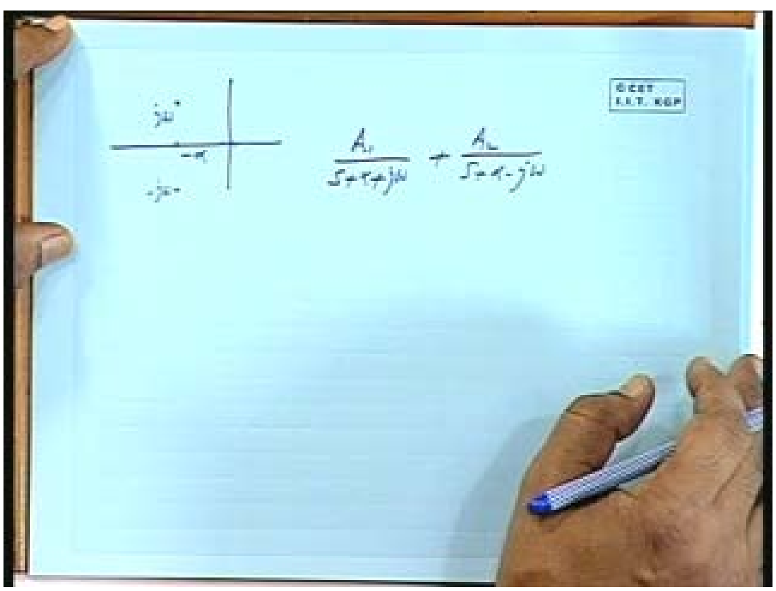

Suppose you have a complex root, suppose b_1 and b_2 are say minus alpha plus j omega minus alpha minus j omega that is also possible. So you will get A_1 by s plus alpha plus j omega plus a_2 by s plus alpha minus j omega where A_1 and A_2 will be complex and they will be it can be shown they will be complex conjugate okay, otherwise if you add together the numerator will not be all real coefficients okay so if you are having a network function which is a polynomial in the numerator, a polynomial in the denominator which have been written in the facted form and if the polynomial coefficients are all positive then they must appear if they are complex they must appear in conjugate pairs alright number 1, number 2 if you make partial fractions then A_1, A_2 will be complex conjugate it can be prove very easily.

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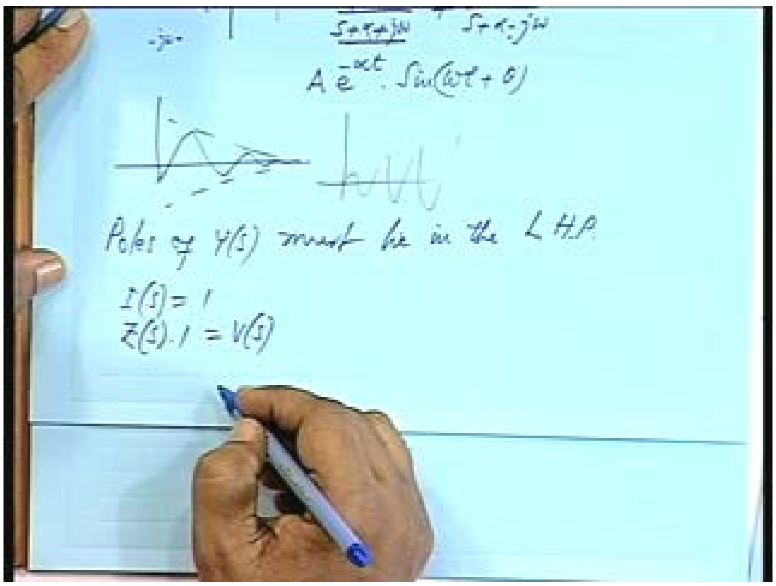

So if I combine them together they will be giving rise to some a e to the power minus alpha t sin omega t plus theta, so that will give me response like this which will be dying down if it is in this form had alpha been here that means if you have roots with real part on the right hand side then this will become plus alpha t and that will be causing a divergent oscillatory function alright. So it will keep on increasing can you have a situation when it will keep on increasing the current will keep on increasing and oscillatory when the voltage has been withdrawn again that is not possible it will be against the principle of conservation of energy.

So the poles of y (s) must lie in the left half plane, left half of s plane will talk about the roots in the s plane by the same augment if I give an impulse of current and measure the voltage across the terminals if I can give an impulse of current that is I (s) is 1 and what will be the output z (s) in to 1 that will be v (s) okay. So Z (s) is nothing but 1 by y (s) so s plus b_1, s plus b_2 will go in the numerator s plus a_1 a_2 etcetera will come in the denominator and by the same logic if I apply an impulse of current I cannot expect the voltage to build up indef indefinitely okay. So the roots a_1 a_2 these also should be in the left half plane so that means both poles and zeros of z (s) or y (s) should lie in the left half plane this is the first criteria for a driving point impedance or admittance function. So 1 by 1 will list out the properties of the driving point immittance function so 1 is poles and zeros must lie in the LHP in the s plane okay, is it possible, is it possible to get roots on the imaginary axis poles and zeros on the imaginary axis if you have say at some omega 1 a pole like this that means y (s) or z (s) has roots like this s squared plus omega one squared in to s plus b_1 and so on, one factor is say s square plus omega square omega 1 squared this will result in a term like some a (s) plus B by s squared plus omega 1 squared okay once again you apply an impulse.

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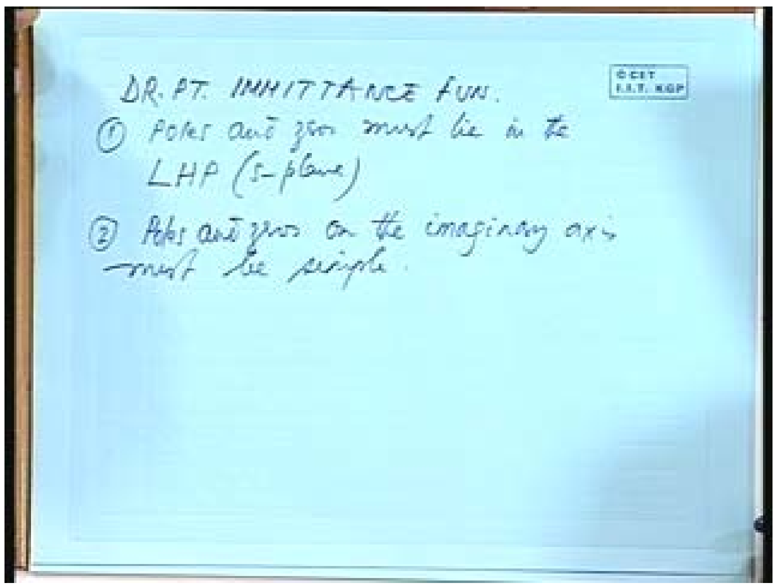

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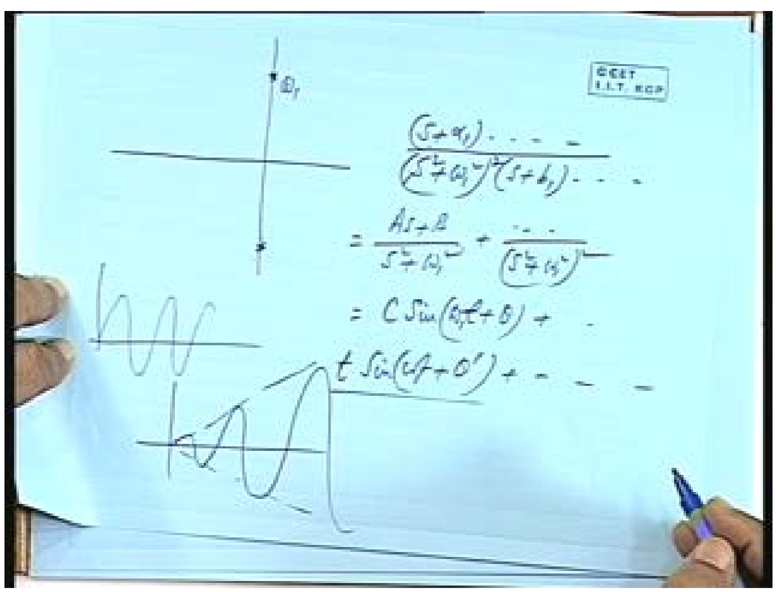

Okay if you apply an impulse of voltage and if this is the admittance function voltage in to admittance that will be giving you the current so one of the current terms will be this will give me some C sin cosine omega 1 t plus theta this kind of a term okay. So it will be giving you a current which may be oscillating it is not building up it remains a steady oscillation that is possible here theoretically if you have an LC network will have a sustained oscillation. So it can have a oscillation like this we call it a stable system state is it possible to have multiple roots on the imaginary axis if you have instead of s square plus omega 1 square if you have squared term then what happens? If you have a squared term then they will be a term like a s plus b s square plus omega 1 square plus something in the numerator by s squared plus omega 1 squared whole square whose inverse will give you t in to sin omega t plus a theta dash other terms are there okay.

So this term will give me t is function like this so it will go on increasing is that alright so such possibilities are ruled out by the same logic in the zeros also in the case of numerator also you cannot have multiple roots on the imaginary axis. So zeros and poles and zeros poles and zeros on the imaginary axis must be simple on the imaginary axis must be simple okay. Another thing when you talk about RLC elements, see both these admittance and driving point admittance and impedance functions they are after all obtained by some combinations of network elements like this. Suppose you want to measure z_{11} driving point admi impedance then keep it open and then measure the impedance is it not while measuring the impedance you take this plus this and parallel combination of this and so on.

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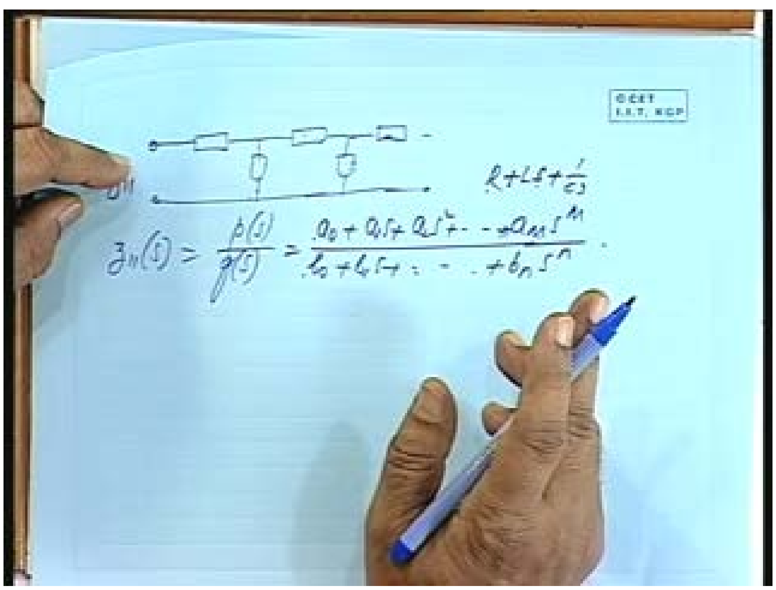

Now these elements are R plus some LS plus some 1 by CS this kind of additive elements or series parallel combinations of these, so when you make repeated conversions say from star to delta or making parallel combinations of such elements it is all positive terms, positive terms like this and their say parallel combination that is products and then again you divide by some sum in no case there is any scope for a negative sign, did you get my point? So after making all this combinations the numerator and the denominator will always have positive coefficients. So if I write z_{11} s as some p (s) by q (s) then this will be if I write in a polynomial form some a_0, a_1 (s) plus a_2 (s) squared and so on divided by b_0 plus b_1 (s) and so on say a_m s to the power M plus b_n s to the power n okay. So all the coefficients a_0, a_1, a_2 etcetera and b_0, b_1, b_2 etcetera must be positive is that alright.

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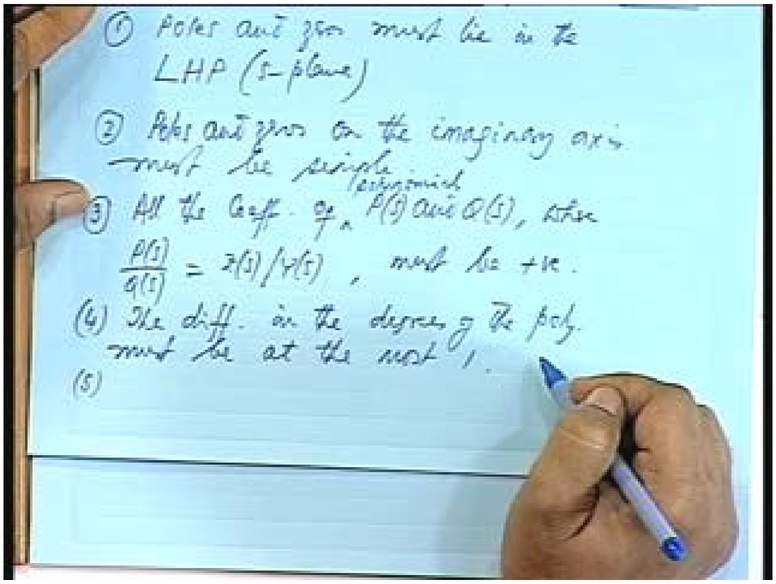

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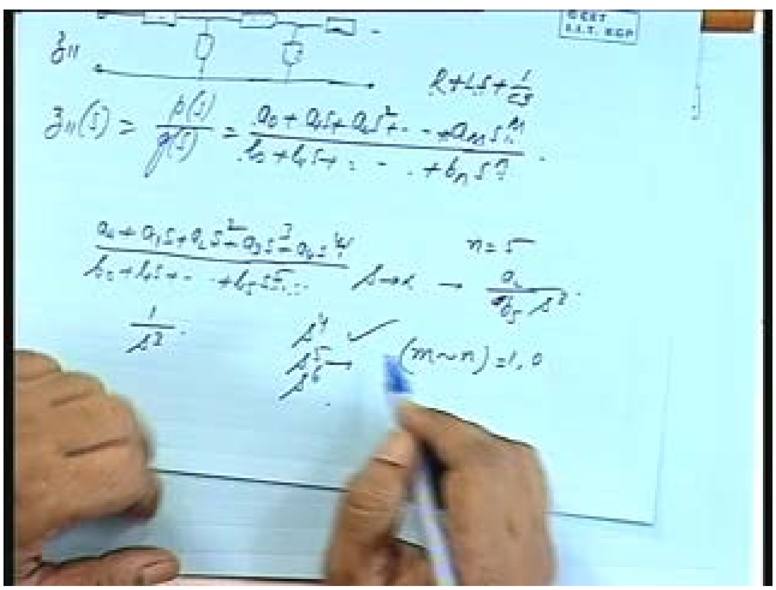

So all the coefficients of p (s) and q (s) where coefficients of polynomials polynomials p (s) and q (s) where p (s) by q (s) is the driving point admittance for impedance function must be positive okay. Can you have by any states of imagination by combining ls 1 by cs R etcetera can you have polynomial where you get a fractional part. So it has to be a rational polynomial s, s to the power 1, s to the power 2 you cannot have s to the power 2.5 alright. Similarly, for this okay, this also another point this polynomials must be in integral powers of s. Can you have an impedance say what can be the possible difference between m and n. Suppose n is 5, n is 5 then what could be the possible value of m. So suppose s to the power 2 is the last term, I get a_2, s_2, a_0 plus a_1 (s) plus a_2 (s) squared divided by b_0 plus b_1(s) plus up to b_5(s) to the power 5 is it possible to have this type of network function driving point impedance. Let us make s tending to infinity s tending to infinity means these will be negligible it will tend to a_2 s squared and this will tend to b_5 (s) to the power 5.

So when s tends to infinity this tends to a_2 by b_5 (s) to the power 3. Now can you have an impedance which is represented by one by s to the power 3 when you take a very large value of inductance a sorry large value of s then all the inductive elements will be offering highest impedance and all the capacity elements will be shorts. So by any states of imagination say short you take capacity values as shorts, so you do not ignore the capacity elements alright and you are left with only inductances. So what is the all these elements will be consisting of either a short circuit or an inductance alright. Now you will have suppose they are having all of them are having LC, LC, LRC etcetera. So this is an inductance this an inductance this an inductance this an inductance so overall combination will tend to be another inductance and that cannot be 1 by s cubed it can be only ls okay.

So the difference should be such that it cannot be, it cannot terminated in a square, can it be s cubed then also it will be ending in 1 by s square there is no element which can give you finally a value like 1 by s square, is it possible to get a_4 (s) to the power 4 then it will tend to 1 by s, s that means the entire network is tending towards the capacity parameter okay. So it can be s to the power 4 can it be s to the power 5. So s to the power 4 is possible can it be s to the power 5 it can be ratio constant that means it will tend to a resistive element, can it be s to the power 6 yes, then it will tend to an inductance alright. So s to the power 4 s to the power 5 s to the power 6 these are possible that means if I have the maximum power of this as s_5 this can be either 4 or 6 that means difference in the maximum maximum power of the polynomials the difference can be at the most one okay that is m minus n or n minus m that is m difference n can be 1 or 0 okay. So if this is s to the power 5 it can be one less or one more or equal the difference cannot be more than that is that alright.

So next property is the difference in the degrees of the polynomial polynomial must be restricted to one must be, at the most 1 poles and zeros must be simple on the imaginary axis the coefficients must be positive difference in the degrees in the polynomial must be restricted to one. Suppose we have one term missing that is, is it possible that a_1 is 0 can there be a missing term in the polynomial, so suppose p (s) is a_0 plus a_1 (s) plus a_2 (s) squared plus a_3 (s) cubed and so on if one of the terms is missing then what happens does it ensure all the roots lie in the left half plane, no so to check to check whether all the poles and zeros lie in the left half plane we have a criteria Routh Hurwitz criteria it states that all the coefficients must be pre present, all the coefficients of p(s) any of the polynomials because we want to ensure both p (s) and q (s) should have roots in the left half plane.

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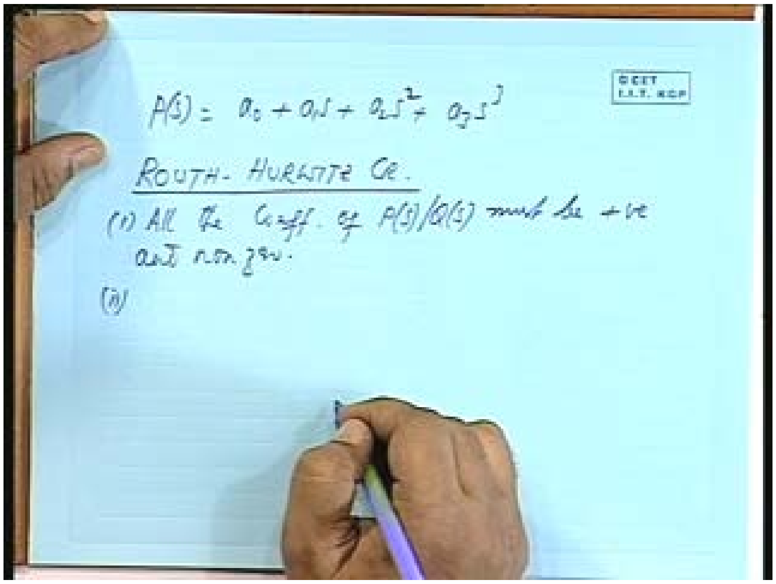

So all the coefficients of p (s) and q (s) must be positive and non-zero any question there can be an exception will come to that exception later on. Can you suggest where it will not be necessarily I mean it is not necessary to have all the coefficients present no suppose alternate terms are absent that means either it is a an even function or an odd function see s square plus omega square if it is a factor that means what it is an even function so for such cases it is possible and that will come to that will give you an oscillatory term that is for LC network for example.

You will have functions z (s) or y (s) where you will get s square plus omega one square s square plus omega 2 square and so on and one will be even, the other will be odd that is possible that is an exception that is alternate terms are absent. In that case you can have this will be evaluated. So for the general case all the coefficients must be positive and non-zero and the second criteria is you make a table, you make a Routh Hurwitz array and from the table of that from the column you can see the positiveness of those terms and decide whether you can decide whether it is a stable system or unstable system that is whether all the roots are in the left half plane or right half plane. So let us write the table suppose you are having a_0, a_1 (s) plus a_2 (s) squared etcetera as the polynomial n s to the power n you start with the coefficients a_0 alternate coefficients a_2, a_4 and so on. Then next make the next row with a_1, a_3, a_5 and so on next a_1, a_2 minus a_0, a_3 sorry a_1, a_2 minus a_0, a_3 divided by a_1 similarly a_1, a_4 minus a_0, a_5 divided by once again a_1 and so on you make another row.

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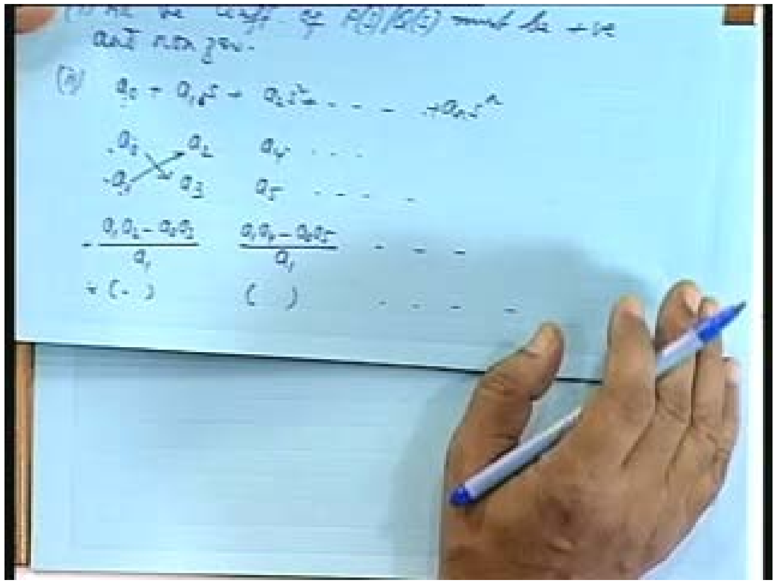

So these synthetic rows you generate again you take this and a_3 minus a_1 in to this quantity divided by this quantity itself that would be the new element in this row. Similarly, another element and so on after completing this you check the signs of the first column this is positive, this is positive, this is positive, this is positive, if all of them are positive then the roots are in the left half plane all the roots are in the left half plane if you find there is a sign change the number of times the sign is changing here will give you the number of roots lying in the right half plane.

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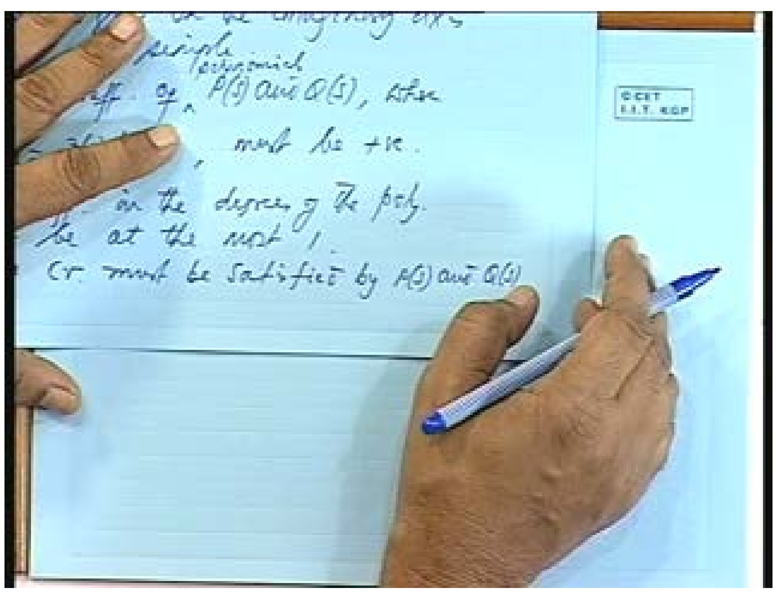

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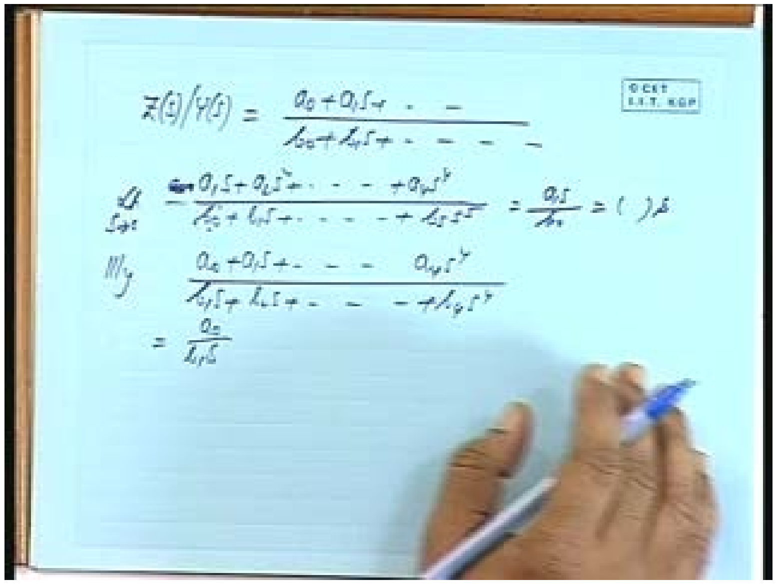

So RH criteria Routh Hurwitz criteria must be satisfied must be satisfied by p (s) and q (s), another point you I just forgot Z (s) or y (s) if it is written like this a_0 plus a_1 (s) and so on, b_0 plus b_1 (s), can the last term be absent say either a_0 or b_0, is it possible, can we have a situation like this a1 s plus a_2 (s) squared suppose, we have a_4 s_4 divide by b_0 plus b_1 s plus say b_5 s to the power 5 or may be b_4 (s) to the power 4, is it possible to have the first term absent? Is it possible? That means the first coefficients a_0 absent okay let us see when s tends to 0 s is very very small. So it will tend to the a lowest order term mean s and that will be equal to so a limit if s tends to 0 this will be a1 s by b_0 it will be something like a an inductor.

So it will tend to be an inductor it is possible similarly in the denominator can b_0 be absent a_0 is present say but then can b_0 be absent similarly, a_0 plus a_1 (s) a_4 (s) to the power 4 divided by b_1 (s) plus b_2 (s) square and say b_4 s_4 is it possible to have this term b_0 absent once again you put s tending to 0 it will be tending to a_0 by b_1 (s) it will be tending towards a capacitive element that is also possible so the last term either of the numerator or of the denominator may be present may be absent if both are absent a_0 and b_0 then you will be able you are you will be able to take 1 s common here 1 s common here, so those 2 common s will get cancelled.

So this is the next property that is the polynomials can have either the numerator or the denominator polynomial event, can have the last term or the here it is the first term absent given this what would be the next condition. Suppose we have all the poles and zeros in the left half plane is it a realizable function, can you realize it. So if I have a function s plus 1 in to s plus 10 divided by s plus 2 in to s plus 3, can you realize this, is it possible to realize both the poles and 0s are in the left half plane. Let us see what it will look like A by s plus 2 plus B by s plus 3 plus C by plus C may be okay a constant.

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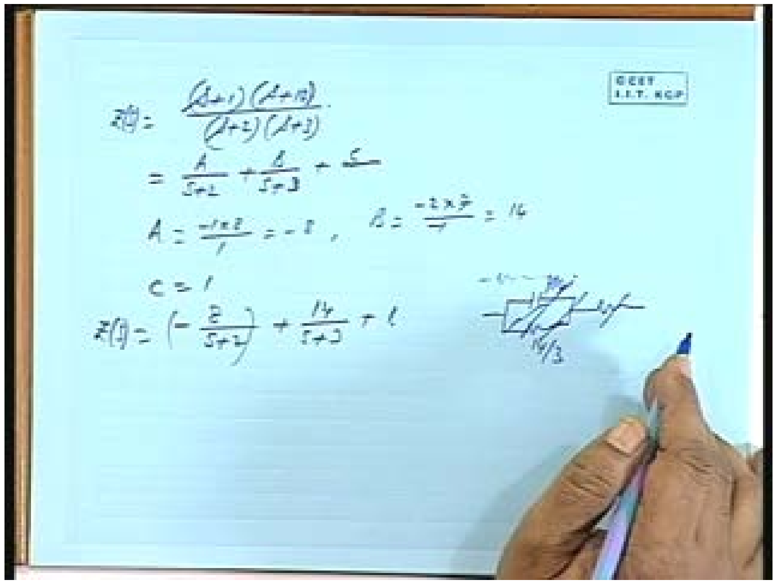

So how much is A if I make s plus 2 equal to 0 so this is minus 1 in to 8 divided by plus 1 so minus 8 okay B by s plus 3 if I multiply by s plus 3 this will be minus 2 minus 1. So it is 14 okay C if I make s 10 in to infinity this will be 0 this will be 0 so it will be s squared by s square 1. So this thing this thing can be written as minus 8 by suppose this is z (s) can I break it up in to form like this s plus 2 plus 14 by s plus 3 plus 1 this is z (s) is it realizable this is having a negative coefficient I have seen we have seen earlier all RC combinations will give me positive terms here it is minus 8 divided by s plus 2.

So this is not realizable I am bringing them to very small simple form okay, 14 by s plus 3 plus 1 this one I can realize as 1 ohm resistances 14 by s plus 3 I can realize by RC combination you put s tending to 0, so s tending to 0 will be blocking this capacitor so 14 by 3 is the resistance make s 10 in to infinity it is 14 by s that means 1 by 14 farad so this is an RC combination this is a 1 ohm resistance but I cannot realize minus 8 by s plus 2, it is not possible to realize by RC elements okay. So I would like to know whether it is possible to realize this okay so z (s) if it is given to you it can be y s also the general property we want to extract for z s and y s from a given function so that it is realizable I give a voltage an impulse voltage and then I withdraw it that means the source is returned here okay and impulse of currents say and then the current through this is allow to flow okay I have a an impulse of current and then it is shorted.

So that the current is maintained, how much will be the energy how much will be the energy of this if I apply if I apply any sinusoidal quanti sinusoidal input then what will be z j omega at any frequency I can put s equal to j omega z j omega will have a real part and an imaginary part okay. Now if I put s equal to j omega if there are s squared terms it will be j squared omega square that will be minus omega square it will be real. So all the s squared s_4 terms will be real and s s cube terms will be imaginary.

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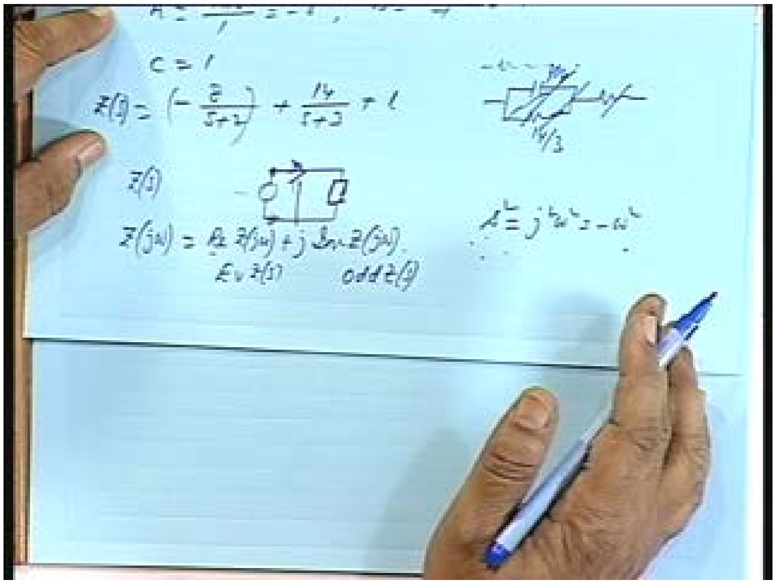

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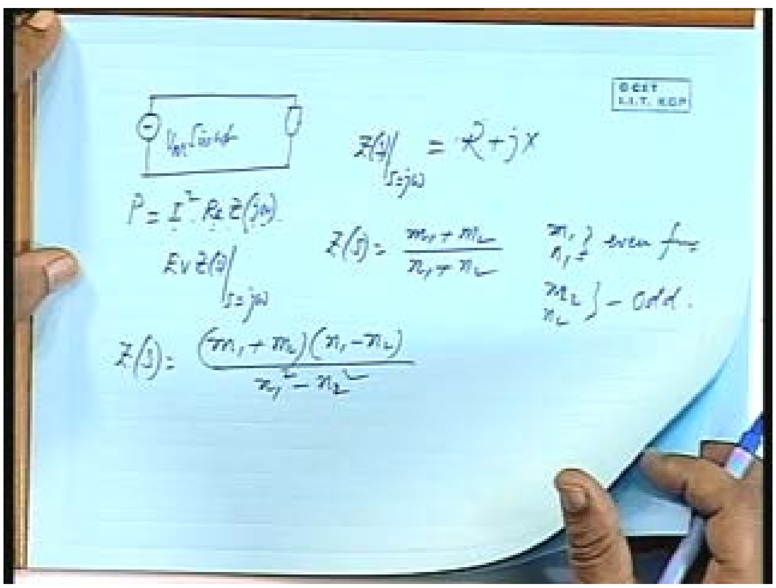

So real part will correspond to the even part even part of z (s) and the odd part will be if I put s equal to j omega in the odd part I will straight away get the imaginary part, is that alright is that okay. Now I excite z (s) by a sinusoidal source v m sin omega t any frequency then how much will be the power active power lost I squared in to real part of Z is it not that means z (s) at s equal to j omega I can write as some R plus jx okay, so it is I square in to this R which will be the power and that has to be always positive okay I square is a positive quantity that means the real part of this for any omega must be positive is that alright real part of z (s) z j omega is nothing but even part of z (s) evaluated at s equal to j omega is that okay.

So let us evaluate what is the even part so if you have z (s) equal to m_1 plus m_2 by n_1 plus n_2 where m_1 and n_1 are the even parts, even functions and n_1, n_2, m_2 and n_2 are the odd parts okay then z (s) can be written as m_1 plus m_2 I will multiply by n_1 minus n_2 both sides. So that denominator will become n_1 square minus n_2 square okay is that alright.

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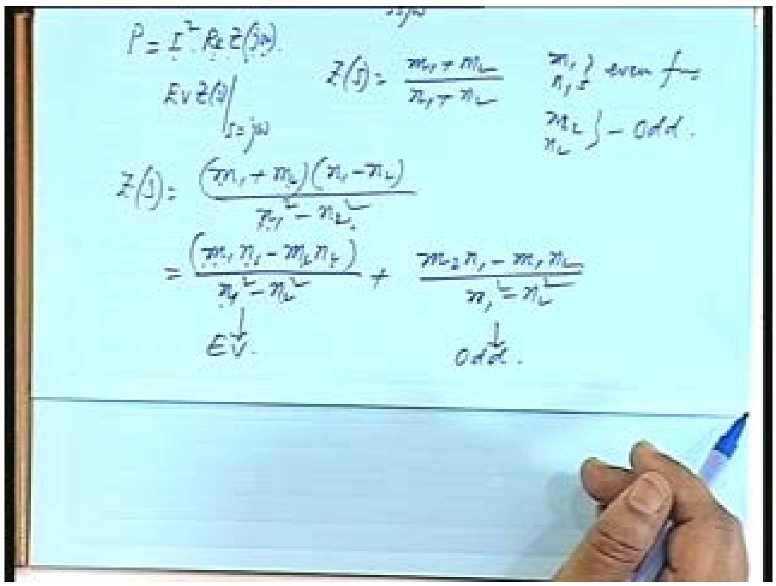

so the numerator is m_1 n_1 minus m_2 n_2 this is even in to even minus odd in to odd is even, even in to even is even this is an even function odd square even square minus odd square will also be an even function so even function divided by another even function plus m_2 n_1 minus m_1 n_2 divided by n_1 square minus m_2 square. So this is the odd part this is the even part okay and these has to be tested for s equal to j omega if I put here it must be always positive because that represents the resistive part that represents the power consume part is it not now n_1 squared minus n_2 square.

Let us see n_1 plus n_2 in to n_1 minus n_2, so n_1 plus n_2 you say P plus JQ or some A plus JB capital A plus capital JB then n_1 minus n_2 will be A minus JB because it is the odd part which is becoming negative. So it will become minus JB, so it is only the imaginary part which will become minus is it not so A plus JB in to A minus JB is what s square plus b square that is always positive so the denominator is always positive, so I have to test the positiveness only of the numerator is it not the denominator is always positive is that alright. So let us take an example it will be clear the same example s plus 1 by s plus 10 divided by s plus 2 in to s plus 3 so this is z s I will write this as s squared plus 11 s plus 10 divided by s square plus 5 s plus 6.

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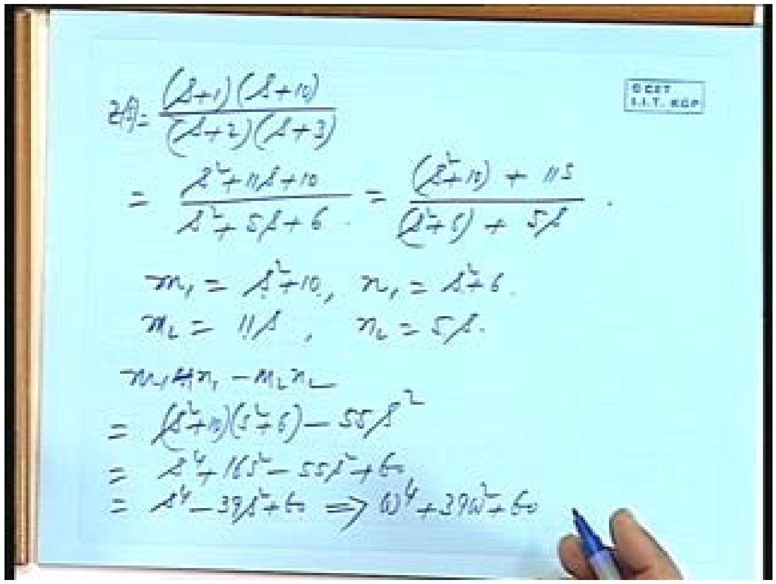

So what will be the even and odd part s square plus 10 is the even part plus 11 s this is the odd part similarly s square plus 6 plus 5 s okay so m_1 m n_1 m_1 n_1 minus m_2 n_2 is to be tested for positiveness because the denominator is always positive that is what to we have ensure this square minus this square is always positive so m_1 is s squared plus 10 n_1 is s square plus 6 m_2 is 11 s n_2 is 5 s. So m_1 m_2 sorry m_1 n_1 minus m_2 n_2 will become s squared plus 10 in to s square plus 6 minus 11 in to 5, 55 s squared okay. So that is s to the power 4 plus 10 plus 6, 16s squared minus 55 s squared plus 60.

So that is s to the power 4 is that alright minus 39 s square plus 60. Now if you evaluate at s equal to j omega what was this give you if I evaluate this at s equal to j omega omega to the power 4 plus 39 omega squared plus 60 is it always positive for all values of omega yes, so it is realizable because power dissipated if it is negative what is it physically mean if the real part is negative that means if I pass the current instead of getting heated up it will be cooling down, is it possible I square R is negative means what it is cooling down that is not physically possible so the real part of the impedance function z s the impedance function z (s) must be always positive so even though we have seen earlier for this example their residues are coming negative it may not be possible to realize by RC combinations. You may try with LC it may fail it may be possible with RLC alright.

So but it is a realizable function, so if you find that this test fails it is not positive throughout for all values of omega somewhere it is becoming negative then you can say it is not realizable by passive elements this is not a network function is that alright. So will stop here for today will continue with this and a few simple realizations will see with LC, RC and so on.

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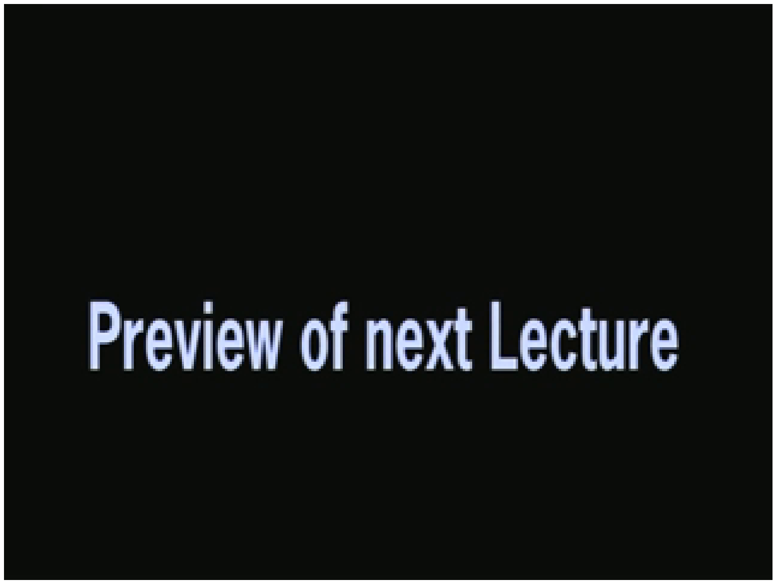

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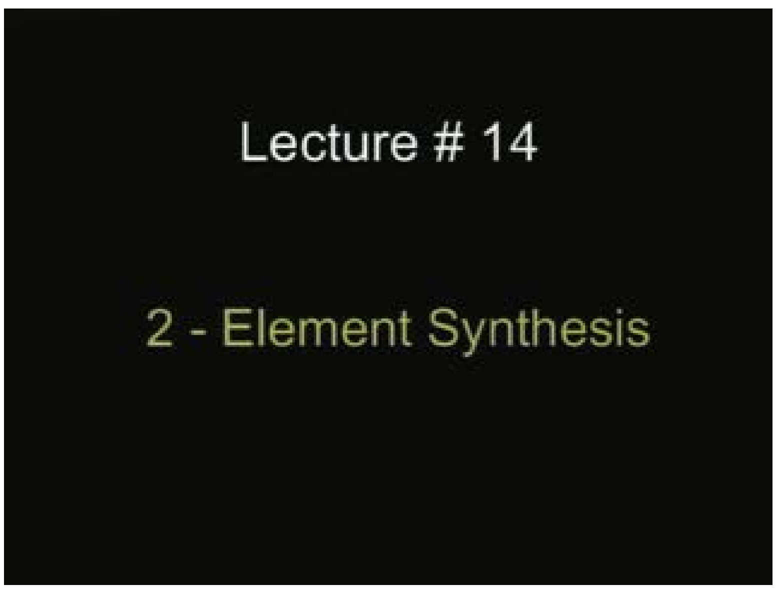

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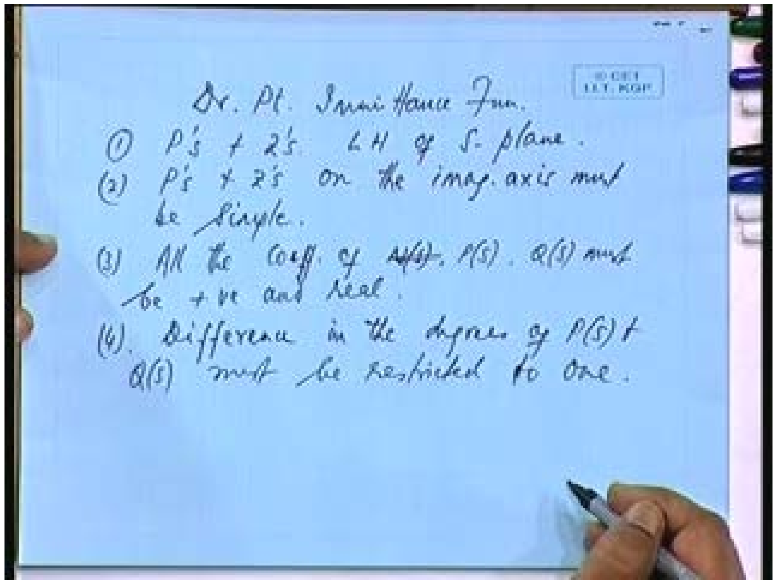

Good morning friends, we will be continue with driving point impedance function or immittance function. We have seen the properties to be satisfied are poles and zeros of the immittance function must lie in the left half plane, left half of s plane then poles and zeros on the imaginary axis must be simple on the imaginary axis must be simple.

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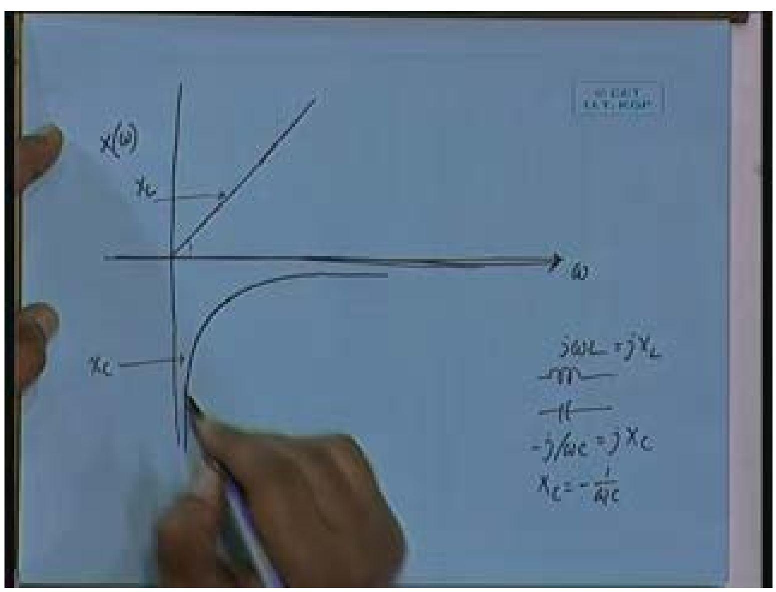

These are 2 very important properties and then to ensure that poles and zeros lie in the left half of s plane actually all the coefficients of the polynomials all the coefficients of numerator and denominator polynomials we were using p (s) and q (s) okay p (s) and q (s) must be positive all the coefficients 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 one alright difference in the degrees must be restricted to one 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 would be its x j omega L.

So if I write this as j x_l j x_l then x_l will be varying linearly with frequency is that alright with a slope of L, with a 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 one by omega C is that alright x_c is always negative so it is inversely proportional to frequency it will be a rectangular hyperbola varying like this. So this is x_c s square plus 1 suppose it is 2 s by s square plus 1 what does this mean if I make s tending to 0 it will be going to 2 s so when is the admittance becoming 2 s admittance is c s in case of admittances is c s is the admittance.

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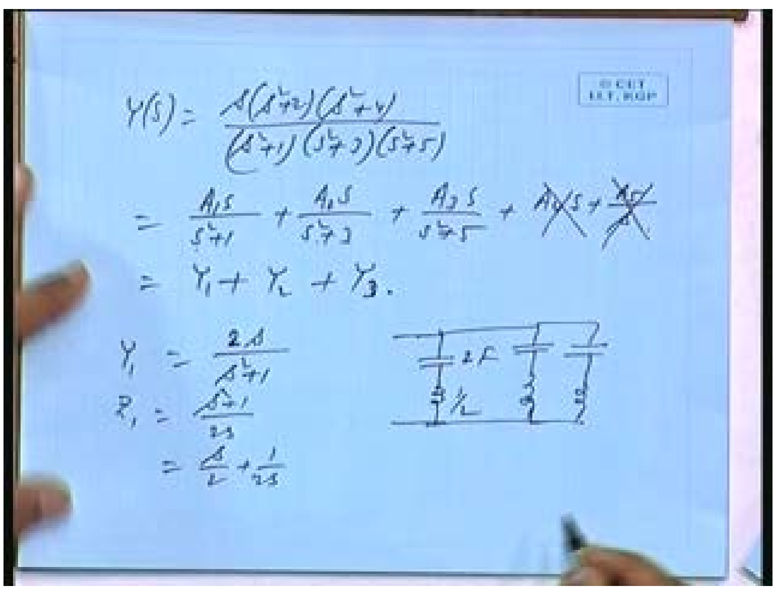

So it is two farads so it will be a two farad capacitance at that time at a very low frequency inductance is 0 it is a series combination you see you if Y_1 is this corresponding Z_1 is how much s squared plus 1 by 2 s that means s by 2 plus 1 by 2 s. So half Henry inductor and 2 farads capacitor will give 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.

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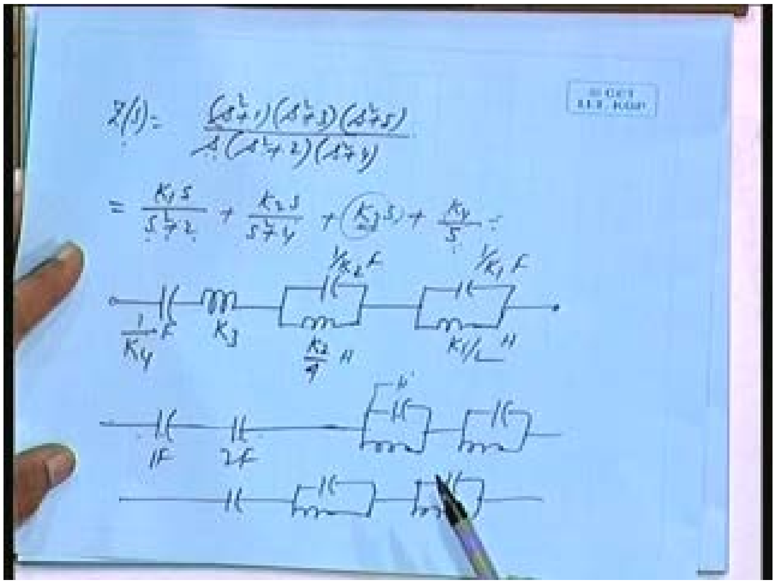

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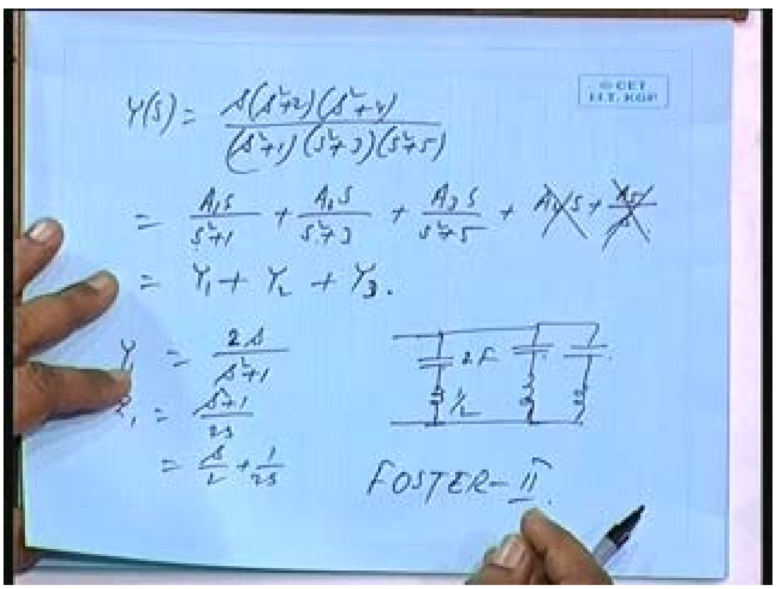

So similarly you get another LC combination another LC combination okay interesting it these values will be different from the foster realization, foster one realization but how many inductances were there 1, 2, 3 and 3 capacitances you go for this realization you will get the same number of elements type of elements will be of the same number 3 inductance is

3capacitances so if you go from impedance it is foster 1 if we start from admittance function this is foster 2 realization okay, we will stop here now we will continue with this in the next class.