Networks and Systems
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Lecture - 05
Introductory Concepts (5)

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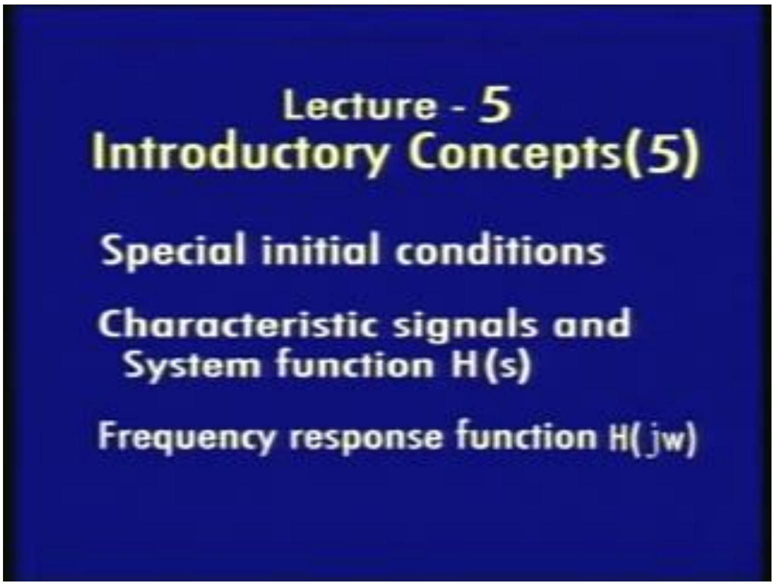

We had a look in the last class at the classical differential equation method of solution of a transient problem. Let us briefly recapitulate the features of solution by this particular method. The solution consists of 2 parts: 1 is the complementary function part of the solution; this is obtained after solving the characteristic equation of the system. And the roots of the characteristic equation gives us the natural frequencies or the force free part of the solution of the system. And these natural frequencies are characteristic of the particular system irrespective of the type of excitation and the complementary part of the solution consists is also referred to as the free response of the system.

This consists of various natural frequencies with coefficients whose values are a priori not known to start with. Then there is the particular integral solution which consists of frequencies which are present in the excitation or reforcing function. This is also referred to as a force response of the system. The force response of the system depends up on not only the parameters of the system, but also the excitation function or the forcing function.

Now, together the particular integral solution and the complementary solution together determine the total solution of the system. But, to evaluate this solution specifically we need to evaluate the arbitrary constants that are present in the complementary part of the solution.

To do this we need to know some initial conditions regarding the variables which we have to solve for. And normally this transient solution is calculated based after switching operation say t equals 0. Information about the reactive elements in a network capacitors and inductors are known to us before the switching operation. Let us say at t equals 0 minus using this information, we assume the continuity of the capacitor voltages and the continuity of inductor currents in the time from t equals 0 minus to t equals 0 plus.

Assume the same values to hold and therefore, the initial values or the inductor currents at t equals 0 plus and the capacitor voltages at t equals 0 plus are known to us. Using this information we will have to find out the initial values of the response quantity and its various derivatives depending up on the order of differential equation that is involved. And this particular process involves some manipulation as we have seen in the particular example.

Now, it often turns out sometimes turns out that the assumption that the capacitor voltage is continuous and the inductor current is continuous breaks down because, of the nature of the particular circuit. Today we will take up 2 examples where we cannot assume continuity of an inductor current or the capacitor voltage. So; that means, the inductor current may jump from t equals 0 minus to t equals 0 plus and so, can a capacitor voltage.

We will look at 2 specific examples of such situations and then move on. So, we will talk about special cases of discontinuous inductor currents. Let us take a circuit in which we have a 12 volts d c source is connected to a series combination of 2 inductors and 2 resistors. Let us call this l 1 call this l 2 1 henry and 4 ohms and let us have a switch, which is kept close for a long time and this switch is opened at t equals 0.

Now, if i call this i l 1 the current in this inductor as i l 1 and the current in this inductor as i l 2. Now the switch is opened at t equals 0 after it has been closed for a long time. So, let us see the nature of i l 1 and i l 2. This is the current in the first inductor this is the current in the second inductor i l 2. Now, when the switch is closed twelve volts drive a current to a 4 ohm resistor. Therefore, there is 3 ampere current because these are short circuit and therefore, at t equals 0 minus this current is 3 amperes.

So, whatever may be it is reached that 3 amperes here. As far as, i l 2 is concerned because this is shorted the current passes through shorted switch avoiding this l 2. Therefore it is 0 current is 0 here. Now, when the switch is opened out by kirchhoff's current law the same current must pass through them. So, there must be a common current which is certainly cannot be equal to 3 amperes and 0 amperes at the same time.

Continuity of current in this inductor will demand that the i l 1 continues to be 3 amperes. The continuity of the current in the inductor will demand that i l 2 continues to be 0 amperes, but both these conditions cannot be matched because at t equals 0 plus the same current must pass through both. So, we have the situation that i l 1 0 minus is 3 amperes i l 2 0 minus is 0 amperes and we further require that i l 1 0 plus must be equal to i l 2 0 plus whatever that is.

It certainly cannot be, if it is equal to 3 then the continuity of current in this is violated. If it is equal to 0 amperes then the continuity of the current in the first inductor is violated. Therefore, we must now find out i l 0 plus plus i l 2 0 plus. How do we do that? Now; obviously, there must be a jump in current because; obviously, this cannot continue at 3 amperes at 0 amperes.

So, there must be some kind of intermediate value therefore, if the current has jumped from 3 amperes to some intermediate value let us say i l 1 0 plus and this current had jumped from 0 to i l 2 0 plus both being equal to each other. And let us call this simply i 0 plus.

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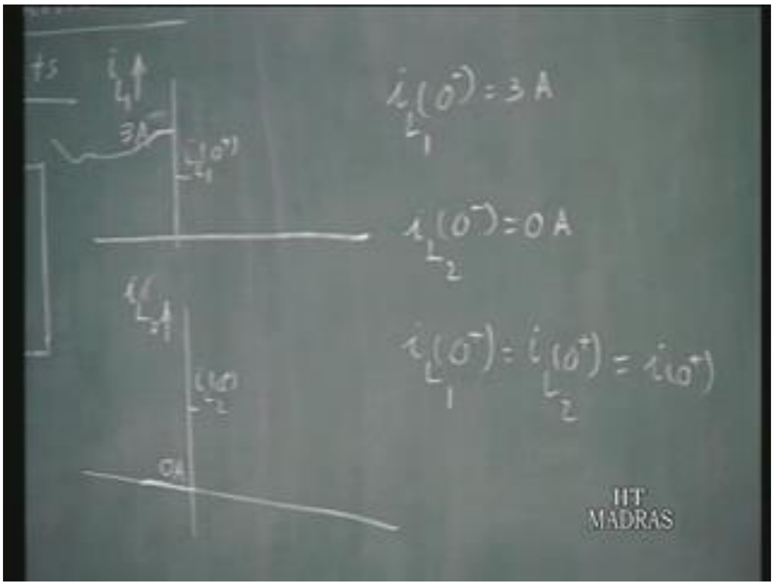

Then there must the voltage across this inductor v l 1 and the voltage across the inductor v l 2 let us say v l 2 like this. They must have some kind of some jumps in current therefore, there must a impulse present in this voltage as well as this voltage. So, the impulse in v l 1 from t equals 0 minus to t equals 0 plus. In this range, in this range elementary range in the jump from 0 minus to 0 plus the voltage across inductance l 1 must be described as, l 1 times current had jumped from 3 amperes to i l 1 0 plus.

So, i l 1 0 plus which is simply i 0 plus right i 0 plus minus original current plus 3 amperes. So, that is the strength of the impulse. So, there must be an impulse voltage which is equal to l 1 times i 0 plus minus 3 times delta t because, suddenly this current had jumped from this to this. So, it is negative impulse as a matter of fact if i 0 plus is smaller than this is a negative impulse. And v 2 l 2 is l 2 times i 0 plus minus the original current which is 0 times delta t.

So, the current in this inductor has jumped from 0 to i l 2 plus which is i 0 plus, which we will call i 0 plus. So, other voltages in this circuit are finite this is finite; the currents are finite. Therefore the resistance drops are also finite therefore; this impulse voltage must be matched by this impulse voltage. So, that kirchhoff's voltage law is satisfied. So to satisfy kirchhoff's voltage law we require therefore, that this these 2 impulses must be matched.

So, l 1 i 0 plus minus 3 plus l 2 times i 0 plus minus 0. This must be equal to 0 because the strength of the impulse plus the strength of this impulse v l 1 plus v l 2 must be equal to 0. The 2 impulses must add up to 0. So, solving this we get that l 1 plus l 2 times i 0 plus equals l 1 times 3 l 1 equals 2 henrys therefore, this is 6. Therefore, i 0 plus equals 6 divided by l 1 plus l 2 which is 3 that is 2 amperes. Therefore, this current had jumped from 3 amperes to 2 amperes and this current had jumped from 0 to 2 amperes. Now, this particular equation that we have here is the 1 that now fixes the new value of the current. And this is usually referred to and constant flux linkage theorem constant flux linkage principle.

What it means is l 1 plus l 2 times i 0 plus is the flux linkage associated with this circuit. So, total inductance times the current passing through that and this is initial flux linkage in the circuit because l 2 does not carry any current. This is the flux linkage associated with l 1. So, flux linkages in a circuit which do not have any net impulse e m f in the circuit cannot change suddenly. The result is that the old flux linkages must be equal to the new flux linkages and therefore, that fixes the new value of the current. This is another way of looking at it.

In any case, what we want to demonstrate through this example is that there may be cases where, inductor currents can be discontinuous. And such cases arise whenever as a result of a switching operation a new restriction of the inductor currents is brought into effect or brought into force where previously none existed. Therefore, whatever currents which they are having at t equals 0 minus will no longer satisfy kirchhoff's current law in the regime. Therefore, 1 or more of the currents have to jump and that can be dissolved using principle like this by trying to match the impulse voltages that arise are using the principle of constant flux linkages.

Remember that, the y we normally say inductor current is continuous in elementary treatment is because; we say, if the inductor current had jumped there must be an impulse voltage infinite voltage across the inductor. Since, all other voltages are finite this infinite voltage cannot exist therefore, inductor current must be continuous. But, in situation like this no doubt an impulse voltage arises across an inductor. But that is matched by another impulse voltage across the second inductor and third inductor as the case may be and the whole kirchhoff's current law can be satisfied only if such impulse voltages exist.

Therefore, this is a particular case which 1 has to keep in mind whenever as a result of a switching operation a new constraint on inductor currents is brought about.

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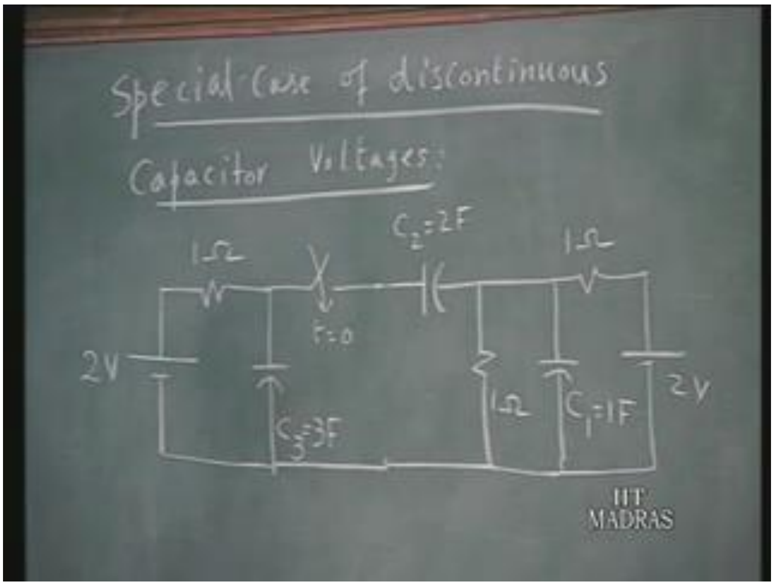

Just as inductor currents can be discontinuous in special cases and we have to calculate the t equals 0 plus values given the t equals 0 minus values using techniques, as we have seen in the last example. The similar situation arises in special cases where the capacitor voltages at t equals 0 minus need not be the same as the values at t equals 0 plus.

Let us consider this example, let us imagine that switch is kept open for a long time till all the voltages get stabilized and let us assume that this c 2 is also initially not charged. In which case the voltage across this capacitor becomes 1 volt because this 2 volts get divided across the 2 1 ohm resistors. Therefore, v c 1 will be 1 volt whereas, this becomes 2 volts this is 2 volts this is 1 volt and this is 0 volts. But once you close the switch these 3 capacitors form a loop.

Therefore, all the 3 voltages must add up to 0 and if this is 2 volts and this is 1 volt and this is 0 volts there is no way in which all the 3 voltages are going to add up to 0. Therefore something must give in and what happens is all the voltages of the capacitors change to satisfy kirchhoff's voltage law. And therefore, the voltages of the capacitors can be discontinuous.

Let us see how we go about it. At t equals 0 minus we are interested only in the capacitor voltages because all the other voltages all the other elements carry finite currents. And because of the jump in capacitor voltages infinite currents or impulse currents must flow through the capacitors. And therefore, we are taking stock of only the impulse currents in this transition. Therefore all other element currents are finite we can disregard them.

So, we have this c 3 i will call that v c 3 0 minus which is 2 volts and there is a switch of course, and this i will say v c 2 0 minus that is of course, 0. And then, you have this capacitor c 1 v c 1 0 minus that happens to be 1. So, that is the situation at t equal 0 minus and because this switch is open there is no necessity for all the voltages to lead up to 0 because, the balance residual voltage is absorbed by the switch.

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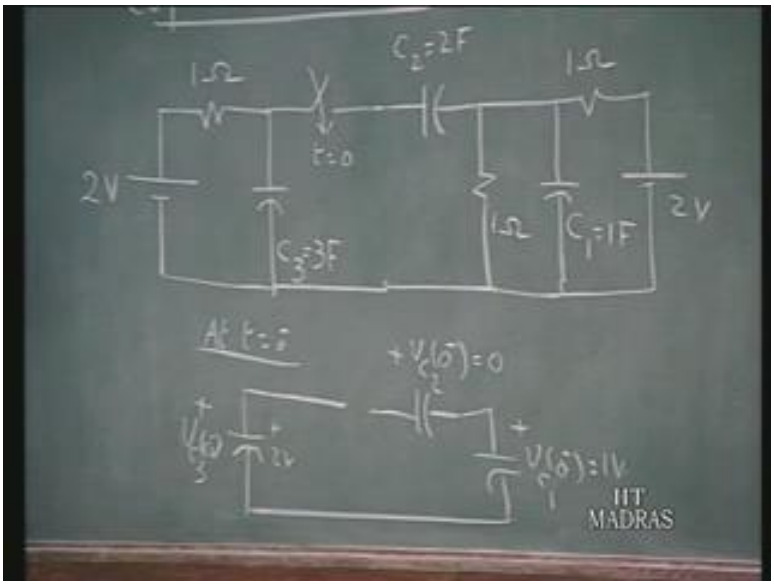

Now, at t equals 0 plus you have again the switch is closed therefore, these 3 capacitors form a loop v c 1 0 plus. And let us say this is v c 2, this is the reference sign we have taken v c 2 0 plus and this is v c 3 0 plus. So, we have a new regime at t equals 0 plus v c 3 0 plus v c 2 0 plus and v c 1 0 plus. Kirchhoff's voltage law tells us v c 3 0 plus equals v c 1 0 plus plus v c 2 0 plus right. But what is v c 3 0 minus 2 volts? V c 3 0 plus may be not be 2 volts.

So, there must be some initial instantaneous change of capacitor voltage. That means, in the process between t equals 0 minus to 0 plus and charge q must flow through these 3 capacitors. This q is the charge flow through the loop in the interval t equals 0 minus to t equals 0 plus. So, there must be a sudden increase or decrease in charge in the capacitors. That means impulse current must flow.

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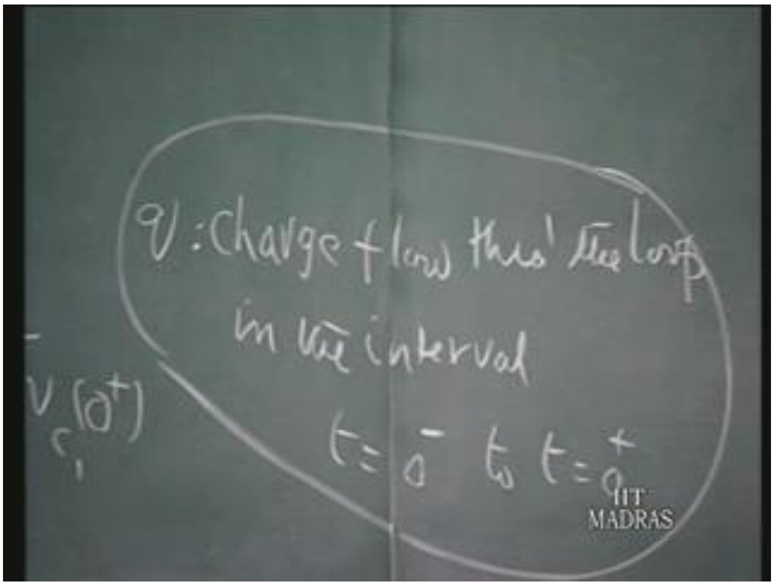

D q by d t will turn out to be impulse the current is impulse, but the area under the impulse is finite. Therefore, instantaneously an additional charge must flow and what is the value of this charge v c 3 0 plus equals v c 3 0 minus this is v c 3 0 minus, And there is a charge q coming out therefore, the resulting voltage drop is q by c three.

V c 3 0 minus minus q by c 3 because, there is some charge when q comes out some of it is getting discharged and the amount of charge presents a voltage drop of q minus c 3. So, v c 3 0 plus is v c 3 0 minus divided by minus q minus c 3 and v c 1 0 plus is equal to v c 1 0 minus plus q divided by c 1. Some initial charge is put on this capacitor and similarly v c 2 0 minus plus q by c 2 and this q is a common charge which flows through this loop.

That means, there is an impulse current; which integrated over the interval from 0 minus to 0 plus represent a non 0 amount of charge. And in this equation we know v c 3 0 minus v c 1 0 minus and v c 2 0 minus, we can calculate q due to the numerical values.

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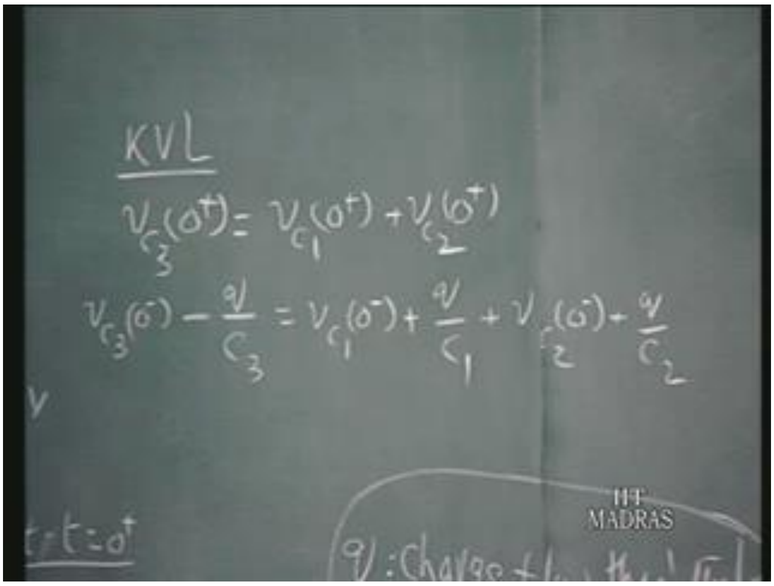

That turns out to be if you solve this you will have let me write this down here: q times 1 over c 1 plus 1 over c 2 plus 1 over c 3 solving this equation you will get this as 1. That is the balance the unbalanced voltages that we get here and from we get q equals 6 by eleven coulombs. And therefore, you have v c 3 0 plus we can calculate using this.

It becomes 20 up on 11 volts and v c 2 0 plus equals 3 up on 11 volts and v c 1 0 plus will be 17 up on 11 volts. So, the capacitor voltage is indeed had jumped and this represents an impulse current of 6 up on 11 delta t.

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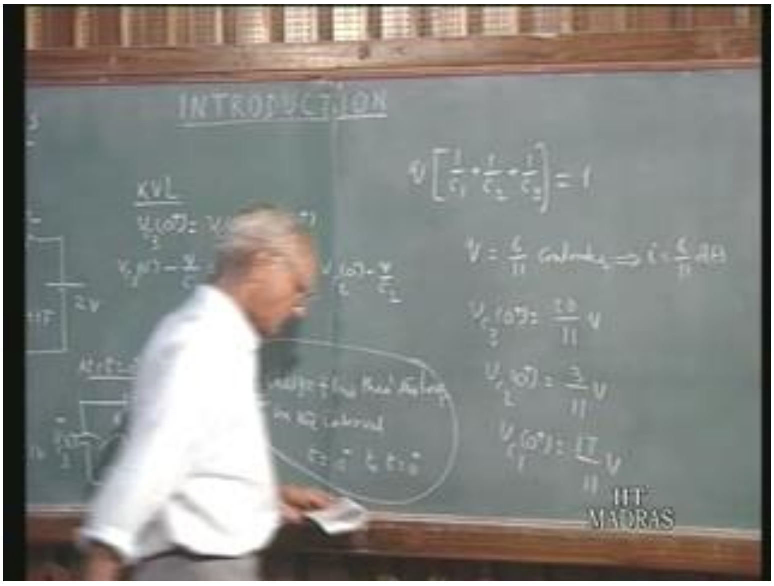

This is the description of the current in the interval t equals 0 minus to t equals 0 plus all the other the components which are finite we have ignored. So, this example illustrates the situation where the capacitor voltages have to change and therefore, when you want to solve this for the transient analysis of this problem. If you know the capacitor voltages at t equals 0 minus and for the solution of the differential equations we need to know the initial conditions at t equals 0 plus, we have to calculate these values.

This points of course, 1 of the difficulties in the classical method of solution of differential equations from t equals 0 minus; you have to calculate the t equals 0 plus conditions. Not only for various response quantities, but even for reactive elements sometimes you may have to calculate these values using principle of that like this. What we have really assumed here is that as far the capacitors are concerned the charge is concerned whatever is discharged here, it goes to charge these 2.

Therefore, this is just like the principle of conservation of flux linkages as applicable to inductors is what we discussed earlier, this is the principle of conservation of charge across the capacitors. So, we will leave this discussion at this stage all my intention is to point out that in the calculation of initial conditions, you have problems in the classical differential equation approach. Not only to calculate the initial have conditions and the various initial values liked the various derivatives of the response quantities. But even for reactive elements themselves it may or may not be continuous depending up on the special situation that we have on hand.

Let us now, introduce ourselves to the concept of characteristic signal of a linear system and the concept of system function. We will consider a linear time invariant constant parameter time invariant and constant parameter mean 1 and the same; continuous time system. So, linear, constant parameter, continuous time system we have an input quantity and an output quantity y of t. An electrical network consisting of r l c elements being a specific example of this in general, the output y t and the input x t are connected by a linear differential equation with constant coefficients.

Let us assume that the differential equation connecting these 2 is of this form. A n d n y d t n plus a n minus 1 d n minus 1 d t n minus 1 and so on and so forth plus a naught y equals d m x d t m plus b minus 1. You can put b m if you like b m minus 1 x d t m minus 1 so on and so forth plus b naught x. So, this is a n th order differential equation connecting the output quantity y with the input quantity x.

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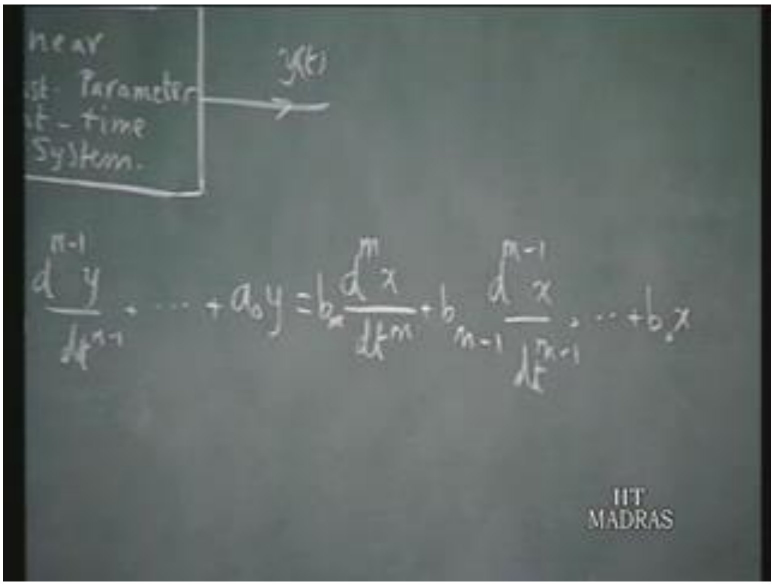

Now, the particular integral solution of this is given by the operator b m d m plus b m minus 1 d m minus 1 down the line to b naught, divided by a n d n plus a n minus 1 d n minus 1. So, on plus a naught this is a operator a function of d operating on x.

So, depending up on the input quantity you can calculate the particular integral solution for this this is what we do in the case of solution of the differential equation. And the electrical network which we considered in the last lecture is a specific example remember tha,t we ended up with the second order differential equation.

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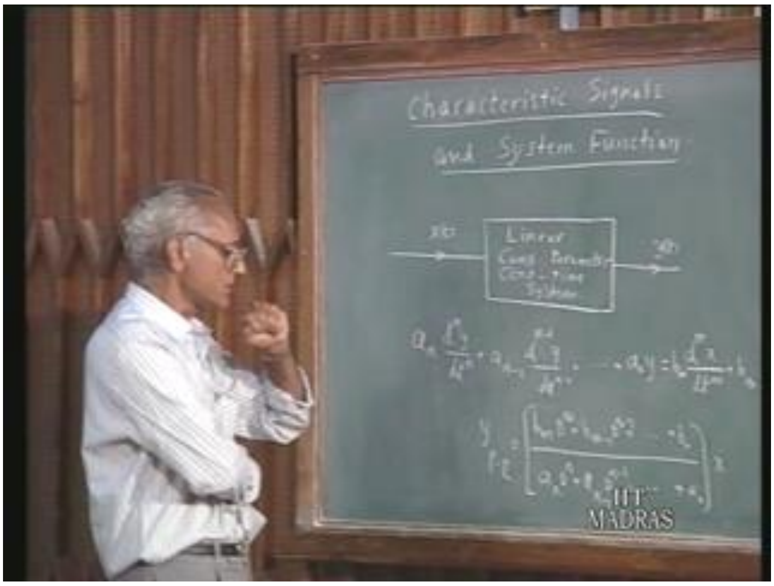

For which we can calculate the particular integral solution in the same manner as here. Now, it turns out that if the input function is of a particular type exponential function a e to the power of s t. Then the particular integral solution is this operator operating on a e to the power of s t. And from the theory of differential equations whenever you have an exponential function here, this operator function can be thought of as an algebraic function where d is replaced by particular value of s.

So, it turns out that the particular integral solution will be b m s to the power of m plus b m minus 1 s to the power of m minus 1 down the line to b naught divided by a n s to the power of n a n minus 1 s to the power of n minus 1 up to a naught times x of t which is a e to the power of s t.

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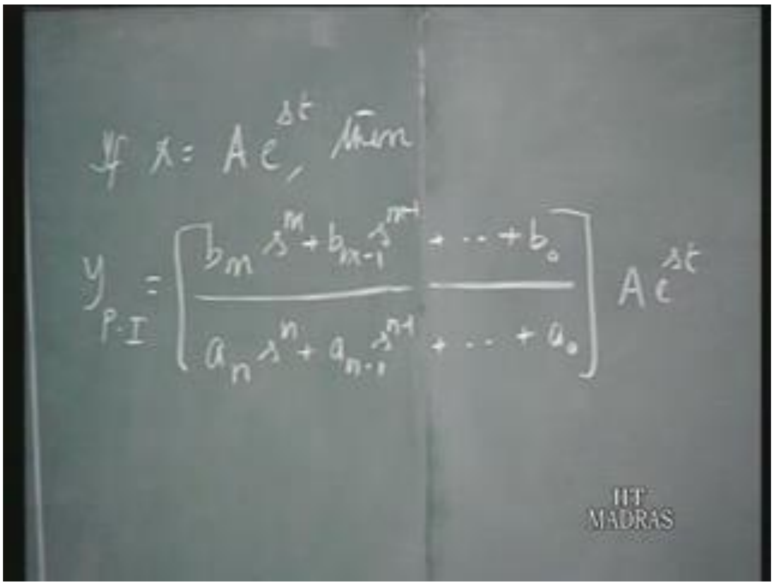

So, the solution for this differential equation in the particular integral solution all you have to do is substitute s for d. So, if x is a e to the power of s t y p i is some quantity times a e to the power of s t. We often call this h of s a e to the power of s t. So, the particular integral solution the function of time is h s times a e to the power of s t or h s times x t when, x t equals a e to the power of s t.

So, this is a very interesting property that, the time function describing the force part of the solution and the excitation have got the same function of time. Except that it is multiplied by h of s which is independent of time. So, we can think of this as proportionality factor this is a function of only s, but not a function of time. So, the input time function and the output time function as for the particular integral solutions are concerned they are exactly the same. Except that it is scaled down by a factor or scaled up by a factor h of s.

So, where the input excitation function and the output function have the same form of time function it is said to be a characteristic signal of a system. The characteristic signals are sometimes called eigen system eigen function. Characteristic function or characteristic signal are also called eigen signal.

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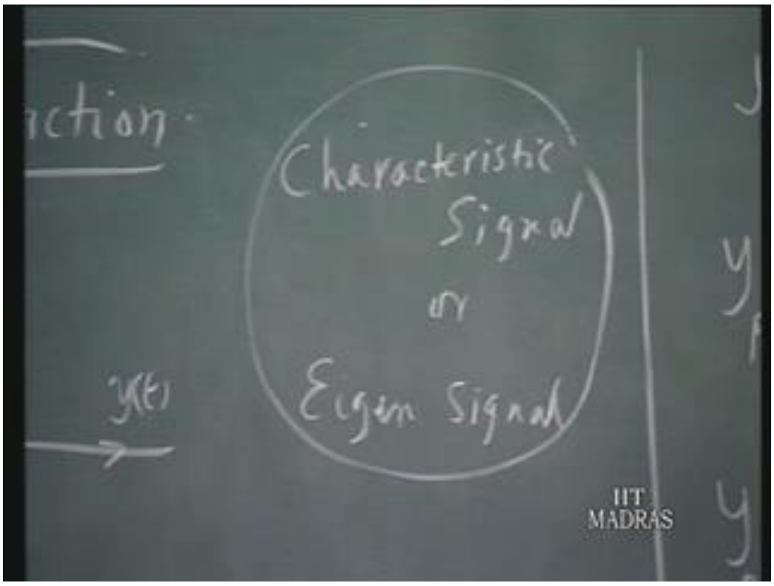

Again, the meaning of an eigen signal or a characteristic signal is it is that particular signal which if it is given as input. The output will also will have the same time variation except for a scale factor and that scale factor is h of s in this case. So, e to the power of s t is a characteristic signal e to the power of s t with a constant multiplier any constant is a characteristic signal of linear time invariant continuous time systems. This is a very important property.

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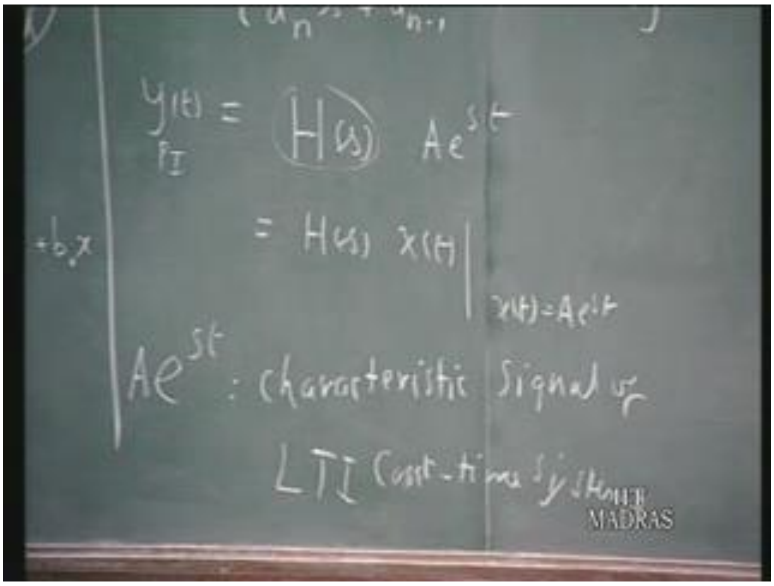

Any linear continuous time invariant system will have this as characteristic signal and therefore, if an input is in that form the output is obtained by merely multiplying this by h of s where, h of s is a kind of proportionality factor. And this h of s is called the system function and in describing the characteristic signal s can be complex s need not be real.

It can be need not be imaginary it can be complex in general. Therefore, the complex exponential signal of this type a e to the power of s t mathematically a can be complex as well. Therefore, a e to the power of s t is a characteristic signal and the complex frequency associated with this is s. And the system function which represents the proportionality constant between the output and the input is called the system function.

It is the function of the complex frequency of the characteristic signal e to the power of s t. This is called the system function and this will be of the form b m s to the power of m plus b naught divided by a n s to the power of n down the line to a naught. So, if you know the differential equation then the system function can easily be obtained. After all you have got b m s to the power of m b m minus 1 the same coefficients applied appear in the 2 polynomials constituting the rational function h of s. So, the system function is a rational function.

For lumped parameter systems which we are dealing with rational function is the ratio of 2 polynomials and for linear lumped parameter systems the system function turns out to be the rational function. It is the ration of 2 polynomials if i call this g of s over f of s g and s are 2 polynomials and these 2 polynomials are easily set up if you look at the differential equations being coefficients in the differential equation constitute the constants in these 2 polynomials.

So, and further it is since it is a rational function of a complex frequency variable s 2 polynomials. We also would find it useful to represent this in this manner some constant m times s minus z 1 s minus z 2 so on. Since, this is a n th order polynomial you have s minus z m divided by s minus p 1 s minus p 2 and so on, s minus p n. So, you can factorize the numerator and denominator in this form and the set of values are called the zeroes of h of s these are the values of s which make h of s 0 go to 0.

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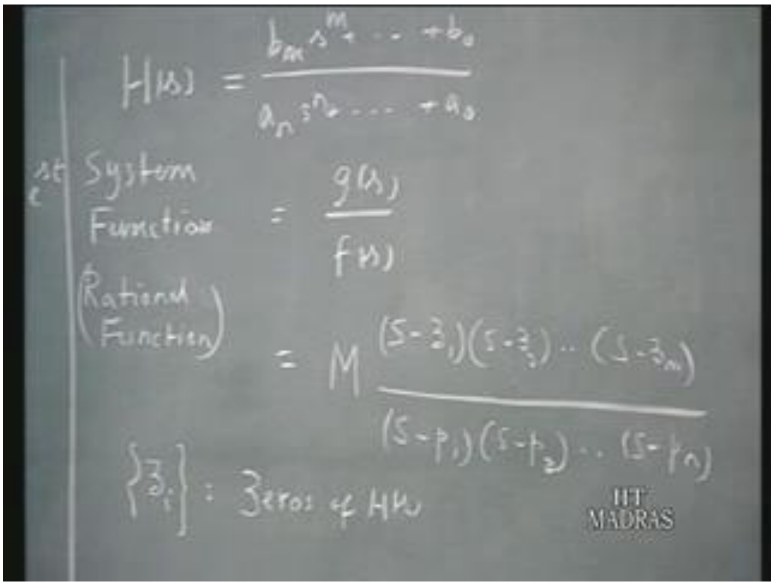

If s is equal to z 1 or z 2 or whatever it is the h of s becomes 0 that is why, they are called the zeroes of h of s. The set of values of p which make the denominator vanish are called poles of h of s. These are terms which some of you may be familiar with from your study of complex variable theory. So, in any case at the frequencies of s at s values of s which correspond to a pole of h of s; h of s becomes infinitely large. It blows up that means, the denominator is made equal to 0 on the other hand s equal to z i any 1 i equals 1 to m.

Then the system function becomes 0. These are usually represented in the complex plane by the 0 locations are given like this and the pole locations are given by crosses. So, these represent poles and the zeroes are represented by small. Since, these are values are in general complex then they can be represented in the complex plane this is called the s plane or complex plane and the values of the zeroes and poles are represented in this fashion.

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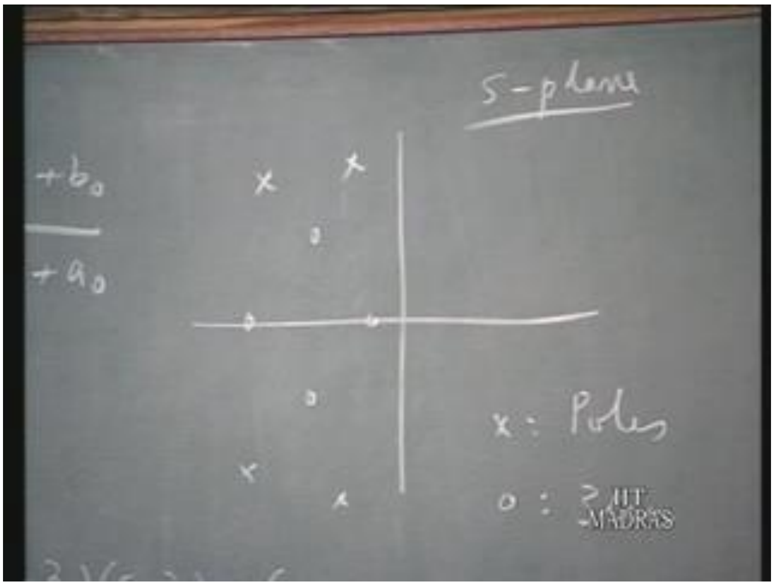

You recall that, whenever these coefficients are all real whenever there's a complex pole it is accompanies by its conjugate whenever there's a complex 0; it is accompanied by its conjugate So, they appear in pairs. So, as far as real zeroes and real poles are concerned they can appear of unit order singly without second pole or 0 appearing as a conjugate because, 0 or pole by itself is real there's no necessity for a conjugate pole or 0 to appear since they are real.

Now, system function plays a very important role in linear system studies as we will see later and particularly when you take up laplace's transform techniques. This system function is very important tool in our analysis of linear systems. But, this has nothing to do with laplace transforms really.

It is a, we can regard this as the ratio of the force response to the excitation when the excitation is of the form a e to the power of s t; that is all we need to know about it. So, what we have seen now is that if w are talking about a linear time invariant continuous time system represented by this black box now put in an input x t and y t Then the force response of the system instead of particular integral system i am calling y of s that is force response is h of s times x t if x t is a characteristic signal.

This is the summary of what we have discussed just now this proportionality is valid only when s t is of the form a e to the power of s t not for other signals. And secondly, we saw that h of s is the ratio of 2 polynomials in s g of s over f of s. And if you look at the way in which we calculated g of s and f of s we took the operator function giving the particular integral solution and form the f of s and g of s.

F of s equals a n s to power of n a n minus 1 s to the power of n minus 1 and so on and so forth. So, f of s equal to 0 is a characteristic equation; that is the characteristic equation from the differential equation that is what is called the auxiliary equation.

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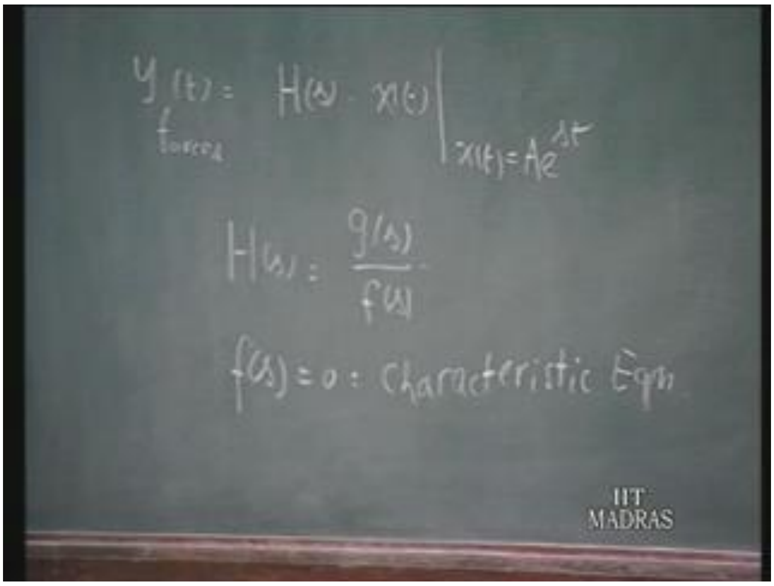

So, the zeroes of roots of this equation which are the same as poles of h of s, we said poles of h of s are the zeroes of f of s or the roots of the equation f of s equals 0. So, the roots of f of s equals 0 that equation which can be called also as zeroes of f of s. The roots of the equation f s equals 0 can be termed as zeroes of f of s, values of s which makes f of s 0, which are also the poles of h of s. These are gives the natural frequencies of the system. What is meant by natural frequencies?

These are the frequencies present in the complementary solutions or the homogeneous differential equation solutions. So, this h of s builds in itself a lot of properties. Not only it gives the force response for this type of excitation, but it also gives you the form of the complementary solution straight away. So, whatever information is available in the differential equation is built in this system function.

Once, you have the system you do not have to look at the differential equation again because, all the information that is available in the differential equation is given here.

Because from this you can set up the differential equation if you wish, but you do not even have to do it because; the complementary solution if you want all you have to do is solve for f of s equal to 0 that equation. It gives you all the terms that are present in the natural part of the solution or the complementary solution. The special cases it often turns out that we would like to have x t of the form e to the power of j omega t.

This is the special case of x t being e to the power of s t if x t is e to the power of j omega t; that means, you are taking s equals j omega t. In which case, the forced response will be h instead of s j omega times x t where x t is 0.

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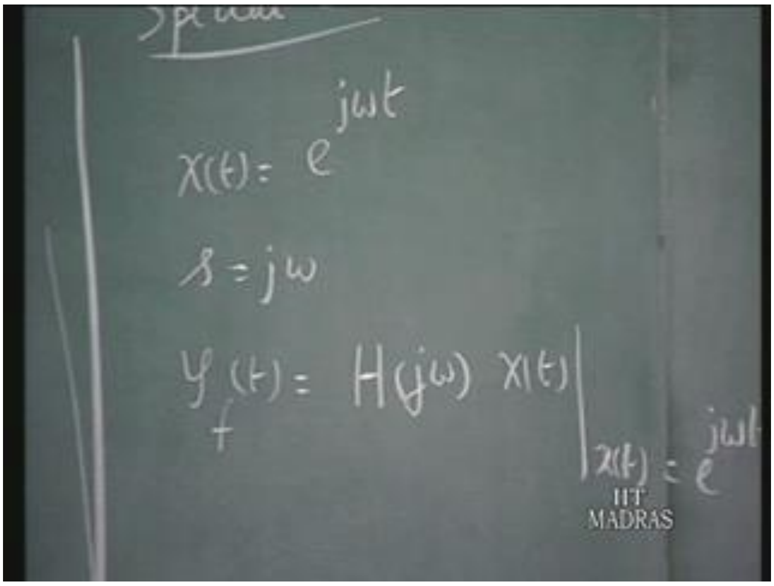

Now, this is important because whenever we are talking about sinusoidal quantities as the excitations or inputs sine omega t cos omega t; they can be related to e to the power of j omega t. For example, cos omega t can be thought of as the real part of e to the power of j omega t, alternately, you can think of this as the sum of 2 exponential functions as i already mentioned earlier. Similarly, sine omega t can be regarded as the imaginary part of e to the power of j omega t or the combination of 2 characteristic signals.

So, e to the power of j omega t is closely related to the sinusoidal functions which are very important in system studies. And therefore, the response of a system to a signal of e to the power of j omega t can be regarded as a special case of the response to an exponential signal e to the power of s t. After all, e to the power of s t and e to the power of j omega t are closely related.

So, this is also important and when we study later on in Fourier transform methods and Fourier series methods h of j omega becomes very important. And this h of j omega it is in itself sometimes called system function, but more commonly we can call it the frequency response function frequency response. Also sometimes, when there is no scope for confusion this is also called system function. So, this is very important that is h of j omega is also regarded as a system function or a frequency response function.

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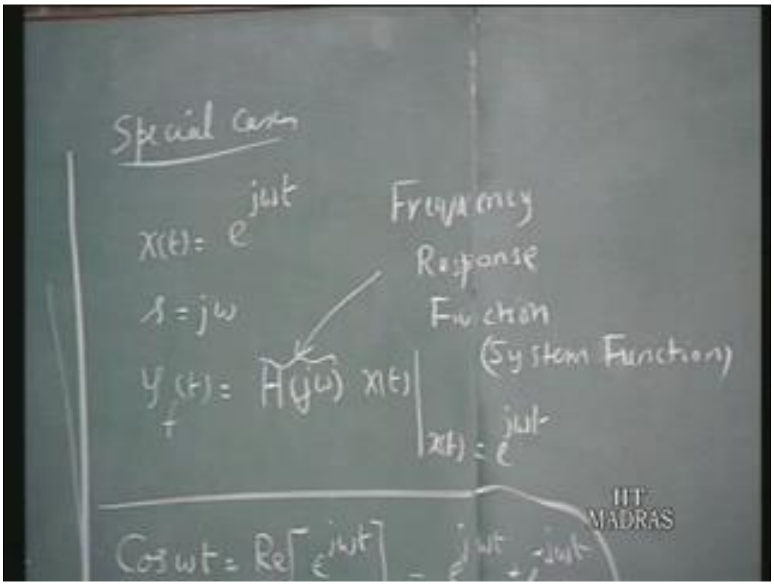

This is the special case of h of s when h is equal to j omega and this becomes very important when we analyze any system on the basis of sinusoidal inputs. Because e to the power of j omega is as good as cos omega t sine omega t as far as analyses are concerned. We then before we move on to other topics let us see what kind of system function you have when we have discrete time systems. As an example let us take a second order discrete time system.

Now, this is a second order discrete time linear constant parameter discrete time system. What we have studied earlier is a continuous time system this is a discrete time system. It can be shown that x n equals some constant times z n is a characteristic signal. So, just like e to the power of s t being a characteristic signal for continuous time domain in the case of discrete time system a times z to the power of n is a characteristic signal. A is a multiplying constant we disregard that z to the power of n is a characteristic signal. And the force response y n the particular integral solution for y n can be written as b 2 z square plus b 1 z plus b naught divided by a 2 z square plus a 1 z plus a naught multiplied by x of n when x of n is a characteristic signal.

So, if x of n is a characteristic signal the force response of the second order discrete time system will be b 2 z square plus b 1 z plus b naught by a 2 z square plus z 1 z plus a naught just in the same way, as we had in the continuous case. From these coefficients you form these 2 polynomials and this move we will write this h of z where h of z is; once again x n is a characteristic signal is a z power n and h of z is called a system function. So, this is a discrete time system function which is a function of z h of z just like h of s, you have got h of z here and the working is quite analogous to the continuous time case.

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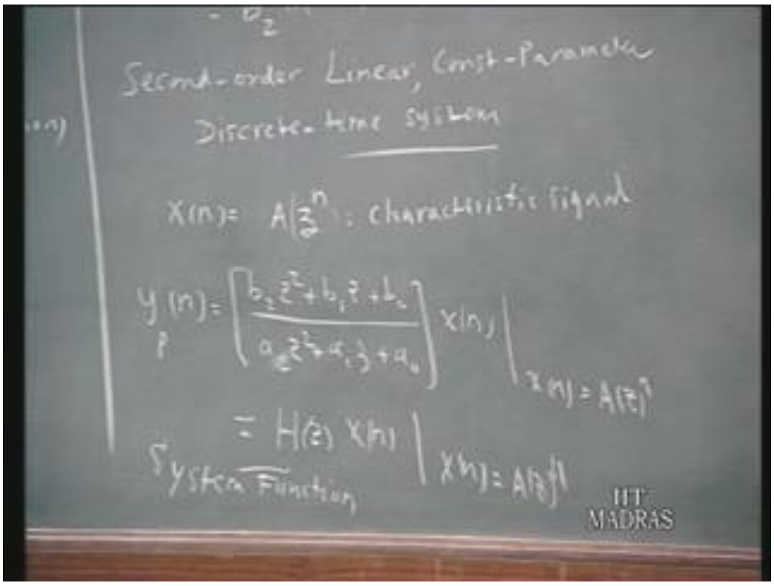

The characteristic signal is z to the power instead of e to the power of s t and the system function is h of z instead of h of s, but z is the variable that you get in this. We will deal with this later at the end of the course when you deal with discrete time systems. So, this is a parallel development as applicable to discrete time systems it completely follows the same lines that, we have for the continuous time systems. So, so far we have talked about 3 different ways of characterizing a linear system.

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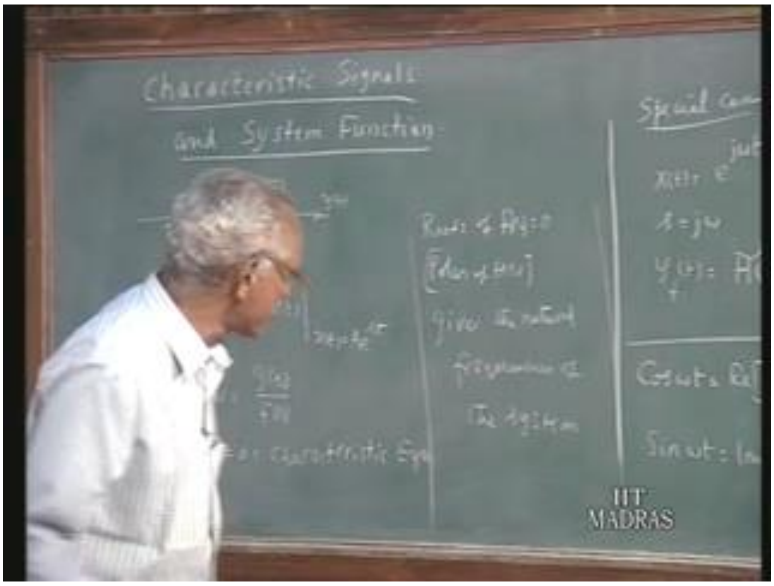

What are the different ways? Let us see what they are. So, far we have discussed different ways of dealing with linear systems, let us see what they are recapitulate what they are: 1 is the differential equation; solution of differential equations will give us the constant solution. We saw the difficulties associated with this. Second method is system functions h of s. You can use the system function it gives the same information as the differential equation h of s then we also saw an equivalent is a frequency response function h of j omega.

It turns out that when we later study Laplace transformation methods the system function some into its own we will try to exploit the properties of the system function to deal with the transient. And when we study later the Fourier transform methods we will use the frequency response function h of j omega. There is also a fourth way of describing a system response this is called the impulse response.

So, if you give an impulse to a system the input is the impulse the output we will call it impulse response unit impulse this h of t. This is an independent way of characterizing a system all are equivalent. That’s if you know the system function h of s we will be able to analyze the find out the response for any given excitation. Similarly, if you know the frequency response function h of j omega we should be able to find out the response to any excitation. And likewise, an impulse response h of t is also an independent way of characterizing a linear system. If you know the response to an impulse you should be able to find out the response to any given input x of t.

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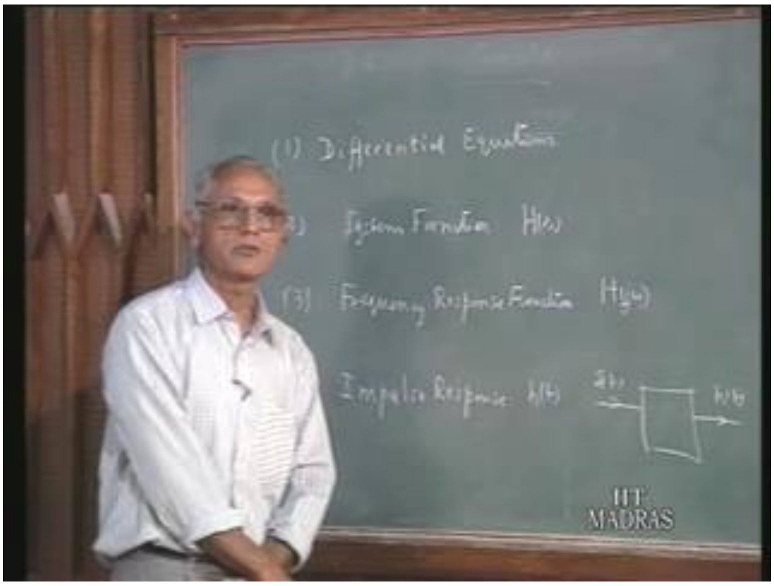

That is also an independent way of doing this there is yet another way, what is called the step response. So, here you are giving u of t unit step as the input and what you get is the output a t. That's the step response these are all different ways of characterizing a linear system and all are equivalent. Each will give complete information about the system which you need to solve for the response under any given excitation.

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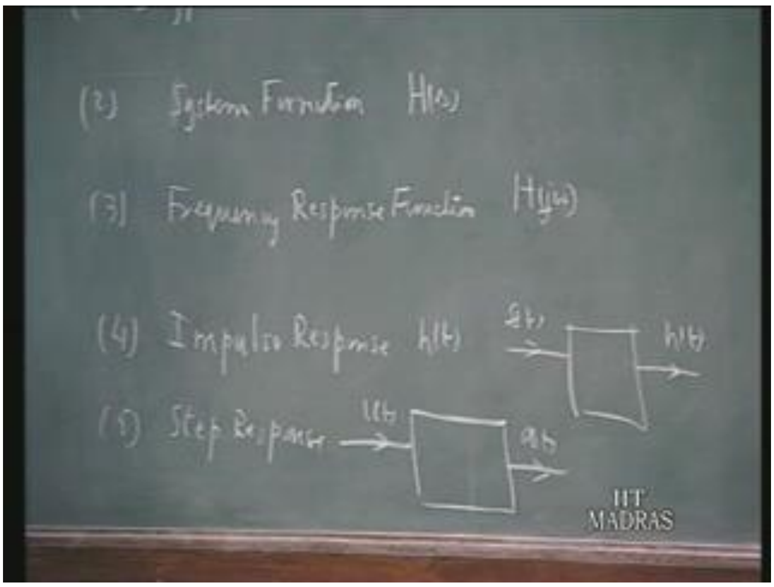

We have studied the differential equation to some extent and we will leave it at that; we have noted the methodologies that is involved and we also noted some of the difficulties.

The difficulties will be overcome when you use the system function approach using the laplace transformation methods which we will take up at some point later point in this course. And we will also study how to exploit the information that is available h of j omega the frequency response function when we study Fourier series and Fourier integral methods. But, we do not have to go to this complex frequency or the frequency omega.

We can carry out the work in time domain using the impulse response or the step response. They are independent ways of characterizing the input output relations of a linear system and this is something which we will look up we will examine in some detail in the next lecture. But, we will use this information again further when we go to Laplace transformation methods; we will see how, the h of s system functions and the impulse response h of t.

How they are closely related to each other that will be taken up at a later point of time. But in the next lecture, we would have a closer look at the impulse response method of characterizing a linear system.