Basic Electrical Circuits
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Lecture - 19
Second Order (RLC Circuit) Natural Responses; Series and Parallel RLC Circuits; Different Equation-Characteristics Equation and Solutions
Forced Response of a Second Order Circuit

Hello everyone. Welcome to lecture 19 of basic electrical circuits in the previous lecture, we were looking at, how to calculate responses to step of a first order circuit, which would be an R C circuit or an R L circuit. In this lecture, what we will do is, we will look at, what to do for a second order circuit. That is second order R L C circuit, at the end of the previous lecture, we considered two seconds order circuits and then you wrote down the differential equations for them. In this lecture, we will start from that point and calculate the responses, and the different parts of the response, just like we did for the first order circuits.

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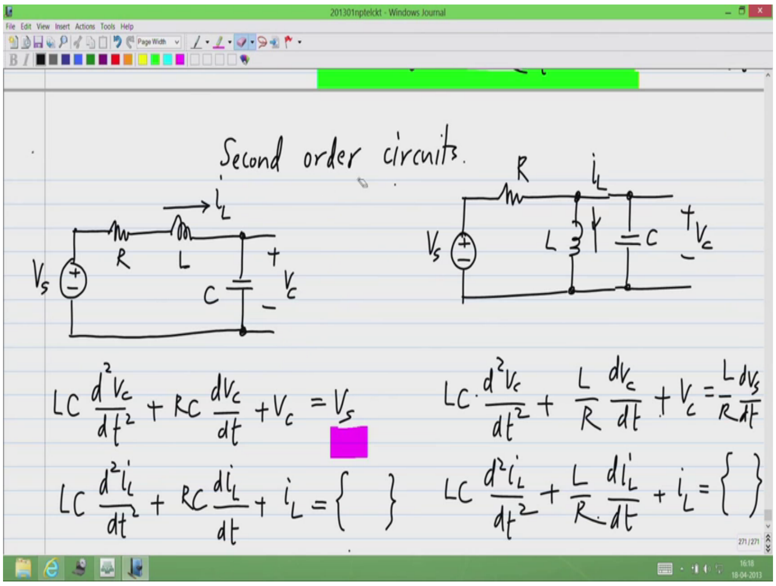

And as I said, we considered two circuits. I will assume that we are interested in the capacitor voltage V c. Now, this is not necessarily always the case it could be that I am interested in the current or the voltage across the resistance. I can write down the differential equation in terms of any variable. Now, I could write it in terms of V c. I could write it in terms of i L or V r or anything else. Now, if I write it in terms of V c, I will get L C times second derivative of V c plus R C first derivative of V c plus V c equals V s.

Now, the same thing could be written in terms of you some other variable. Let us say, we choose to write it in terms of the inductor current. Now, it turns out I will not show it here, but even if we write it in terms of the inductor current we would get the left hand side of the differential equation to be exactly the same. That is what I mean is here V c as variable, we will have L C second derivative plus R C, and first derivative plus V c equals something dependent on the input V s.

That is my convention; I always put the independent source on the right hand side, if I choose to write it in terms of i L. Then, I will get exactly the same L C, second derivative of i L plus R C first derivative of i L plus i L equals this will be some other function of V s. So, I am not going to find that here, but the point is, if you take a given circuit and then identify any variable and write the differential equation for it.

The left hand side will remain the same meaning, the differential equation, the left hand side part or the homogenous part of the differential equation will remain exactly the same. Is this any question about this? Now, let me write it in terms of write it for a different second order circuit which is ok. I have an input and V s, I have not looked at what kind of input, It is, so the differential equation written is quite general. Then, depending on the type of input, whether it is a step or sinusoid, we can go and do analysis further again. I identify this V c as variable; I believe that is, what I did last time as well. In that case, I will get L C second derivative of V c plus L by R first derivative of V c plus V c equals l by R first derivative of V snow.

Again, I can take some other quantity as variable instead of V c. I will take there obviously is some problem with this. Let me fix that, so I think we are back in action. So, if I choose some other you quantity as a variable. Let us say, the inductor current i L, again as before I will get the same equation on the left hand side and on right hand side. I will get some other function of V snow; you see also that for this particular circuit. And this particular circuit, the left hand side looks different. That is the middle term for instance R C times derivative in left side case, and L by R times first derivative in the right hand side case.

Now these are two sort of standard types of second order L C circuits. Now, we will do many things with the solution, we will see how to solve for these things for step response etcetera. Those will be general for any second order circuit. In fact they do not even have to be L C circuits now, in this particular case we have chosen two different L C circuits. And they will have slightly different types of responses now, what are the, what is the difference between these two? I like answers from the participants, what is the difference between these two circuits?

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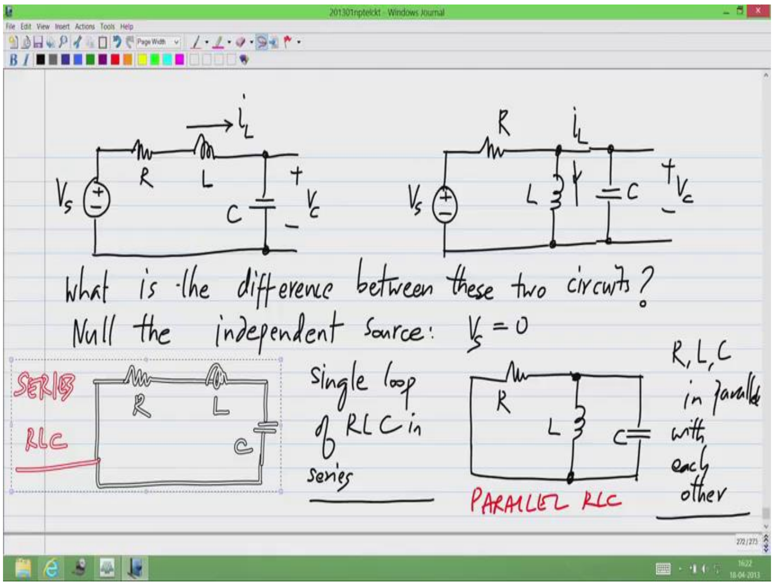

So, there was an answer from Vikas, that the first one is a series R L C. And the second one is series parallel, but it is actually parallel R L C, what I mean by this is the following with a nulled circuit. That is you null the independent source that means that, in this case, we have only a independent, we have only an independent source voltage source. So, we said V s equal to 0, if add a current sources. We would also said that to be equal to 0, once we this we get is R L and C. We get a single loop of R L C in series for the circuit on the left side and for the circuit on right side, if we null this R L C in parallel.

Now, I will draw R like this, but it very clear that R and L and C are in parallel with each other. So, we get only two nodes with R L C and parallel with each other. So, basically by looking at the nulled circuit, we can tell whether its series R L C the circuit on the left side is known as s or try the circuit on the left side is known as a series R L C circuit. And the circuit on the right side is known as a parallel R L C circuit, now it depends on basically the nulled circuit. So, now it does not matter, where the sources for instance, what I mean is. So, let us say, a circuit like this or a circuit like this, if u null the source. Is these two look different from each other? But you null the source you simply get R L and C in series.

So, these are basically series R L C circuits. Similarly, even in this case, I could have sources in different places voltage sources in series with one of these branches or current sources in parallel with something else. In all these cases, I will get R L in parallel, if I do get hat it is a parallel R L C circuit. So, there is a question on you previous. Previously recorded videos I believe they should be online, but after this lecture I will go and check, if it is not there, I will ask them to put up online as soon as possible. The idea is to have every lecture online before the next lecture.

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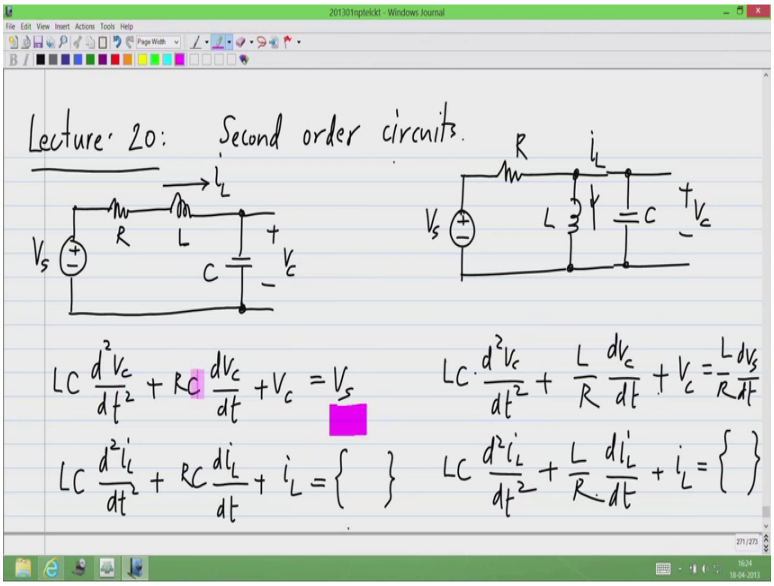

I will show that this is the differential equation governing this circuit. This is the differential circuit governing that circuit, but in general, if you have a series R L C circuit you will get. A differential equation of the form L C first derivative second derivative of V c, like I said this could be any other quantity. You will get the same thing the difference will be in the right hand side, now like I said you could have the input as a voltage source or a current source or something else as long as the nulled circuit reduces to this the left hand side of the equation will be of this form for any variable.

Similarly, if the nulled circuit reduces to parallel R L C circuit the left hand side of the differential equation will be of the form L C second derivative of the variable. I am taking V c as an example, but as I keep emphasizing, it could be any other variable L by R first derivative plus V c equals, this will be related to the independent source in some way. So, once you are able to set up the left hand side. The transient response or natural response can be determined, because for instance you can set the right hand side to 0. And that gives you a natural response with 0 input right, the 0 input response, which is also the natural response for 0 input, obviously with 0 input, there is no first response, first response is something. That is proportional to the input with 0 input.

The first response will be 0, any questions about this? I classified the second order R L C circuit into two types, but the method of solving the second order circuit will be the same even if it is not R L C, now R L C is an important practical case. So, I have classified them into two types where one has series R L C in a single loop. The other has R L and C in parallel with each other, if you have a series R L C in a single loop. The differential equation will be of this form, but the right hand side can be anything, if you have R L and C in parallel the differential equation will be of this form. And the right hand side could be anything any questions.

There is a question asking, is it possible to calculate the time constant, now we will do that a first order has a single time constant and a second order circuit will have two time constants, in general an n th order circuit will have n time constants. So, we can calculate that, now it turns out that for higher order circuits that is order higher than one. You can mention the time constants, you can specify the time constants or you can specify alternate every characteristic frequency. Frequently, that is what is done, so we will look into that.

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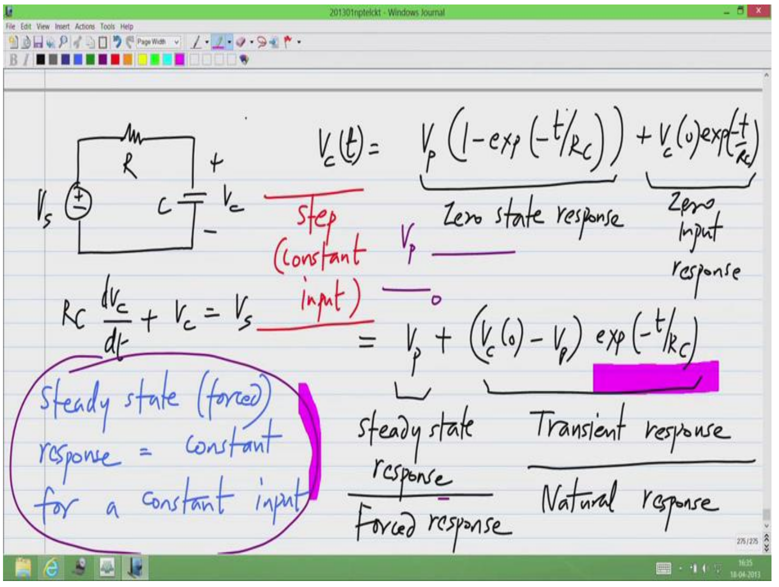

So, if you recall let us go back to the first order circuit this is again an example R C, but it could be any first order circuit the differential equation governing this with V c as variable was R C d V c d t plus V c equals V s. And we could write down V c for a step input, if V s is a step input that goes for 0 to V p, I could write V c as V p time's 1 minus exponential minus t by R C plus the initial condition exponential minus t by R C. This we have done before and recall this the 0 state response, and this is a 0 input response.

This can also be rewritten as V p plus V c of 0 minus V p exponential minus t by R C. This is specifically for a step input constant input, when I say step its really specifies constant input. And we call this the steady state response and this here transient response alternatively this is also called the forced response, and this is called the natural response, now for the second order circuit. Also we will calculate these things. That is the steady state response or the forced response, and the transient response or the natural response and at every step I will try to make an analogy with the first order case. So, that you can associate the results and understand the results clearly because I will not be deriving formally the solutions to the second order differential equation.

I will give you the solution, and say how it is similar to what we have in the first order case there is a question asking, what is the transient response and natural response? The transient response and the natural response are the same thing. They are just two different names for the same thing, now if you look at the total response there will be a part in the first order case containing exponential minus t by R C, now this exponential minus t by R C is the natural response of the first order circuit.

So, the part which contains this is the transient response or the natural response in a more complicated circuit, there will be, what are known as natural modes of the circuit, which will be of similar form exponential minus t by something related to the circuit. So, the parts of the response that contain those things are known as transient response or natural response. And this part which contain depends only on the input, which depends on the input is known as the steady state response, is this clear?

Basically for a first order case, whatever contains exponential of minus t by the time constant of the circuit is the natural response is this now first thing, we observe for a first order circuit. The steady state response or the forced response is a constant for a constant input, what I mean is the input changes from 0 to V p? That is input is basically V p after t equal to 0 that gives the steady state response, which is V p, which is also a constant. Now, it happens to be same as this, but in general, it will be some constant. And you would have seen earlier that this was true for any constant input case.

We discussed the step response of the first order case extensively; we calculated the steady state response by open circuiting all the capacitors. So, if we have a constant input the output will also be some constant. So, this is the first thing that we will use now, it turns out that exactly the same thing is true for second order circuits.

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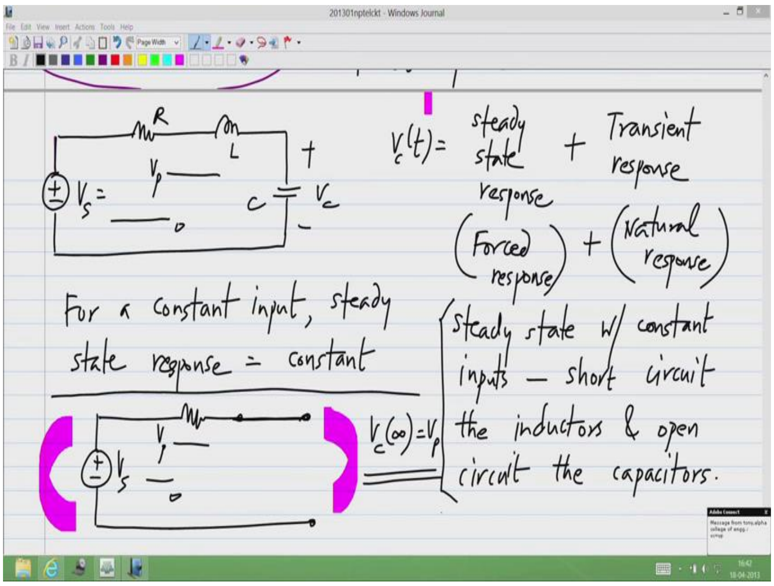

So, let me first take the series R L C case. Let me now consider these goings from 0 to V p. I have R L and C and I am looking at V c. So, V c of t will be of the form steady state response plus transient or forced response plus natural response. So, just like for first order circuit for a constant input here, you have to understand, what is meant by constant the input changes from 0 to another constant. So, I am looking at what happens after t equals to 0, and that is the constant input plus steady state response is also a constant.

Now, I would like answers from the participants, what is the steady state response of this circuit? Now, we have not evaluated the response in detail, but look at the circuit and thing about it the input is a constant at V p for t greater than 0 plus steady state response. I mean, what happens after a long time and all the quantities are constants, what will be the value for V c, what is the steady state value of V c, now like I said the steady state quantities will be constant that is the voltage across the capacitor will be constant current through inductor will be constant. Now, this is true even for the arbitrary complicated circuits.

So, if the current through the inductor is a constant then the voltage across the inductor is 0, if the voltage across the capacitor is a constant the current through the capacitor is 0. So, just like before for the just like the first order case, you evaluate the steady state with constant inputs .This is, what is imp constant inputs evaluate this you short circuit the capacitors and open circuit the sorry I started backwards sorry about that you short circuit the inductors, and open circuit the capacitors. So, if you do that for this particular circuit, what will we get? What is the value of the steady state V c? You please you the algorithm and find the steady state algorithm, what is it going to be?

So, clearly it will be the input source itself because here V s changes from 0 to V p. And I have short circuited the inductor. That is the inductor short circuited and the capacitors open circuited. So, if you have V p here exactly the same thing will appear there, so V c at infinity will be V p. This is fine, so part of the part of the response can be evaluated very easily, now let me give another example. So, that you clearly understand, what is going on. So, let me take another circuit. So, let me first take the series R L C case.

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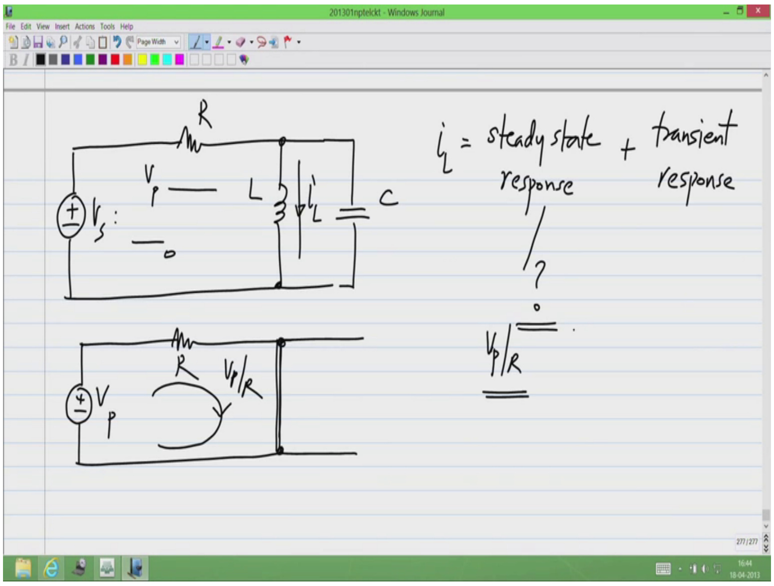

Let me say that V s changes from 0 to V p and I have R L C and in this case I am interested in the inductor current. That is my variable of interest I know that i L will also be of the form of steady state response plus transient response. So, what is the steady state response i of i L in this particular circuit. So, I got two different answers. Let us see, which is correct, R i will short circuit the inductor and open circuit the capacitor.

So, if I have V p which is the constant voltage V s after t equal to 0 the current that flows this way will be V p by R. So, the steady state value is clearly V p divided by R. So, this how we can find the steady state response quite easy open circuit the capacitors short circuit the inductors and find the corresponding values. So, next thing we have to do is calculate the rest of it, which is a little more complicated, but certainly possible.

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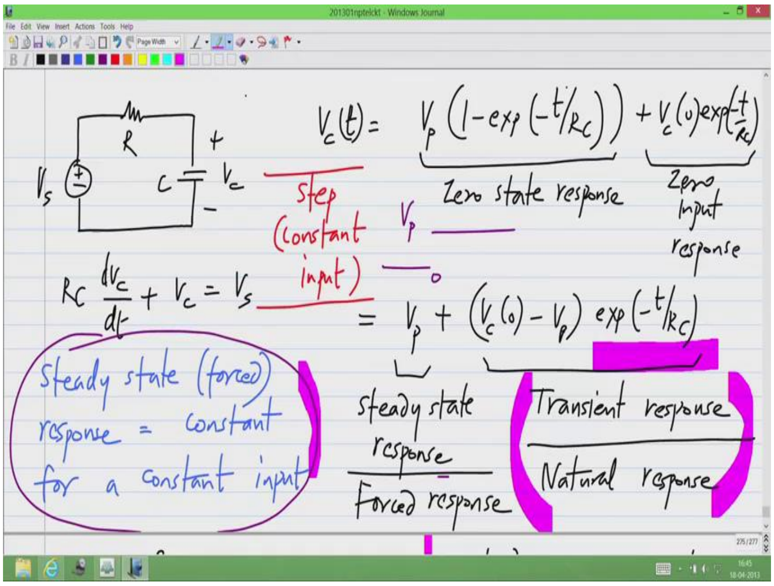

So, again I will make analogies to the first order circuits and go with it, now our goal is to find the transient response or the natural response. So, let me write it down for the first order case again.

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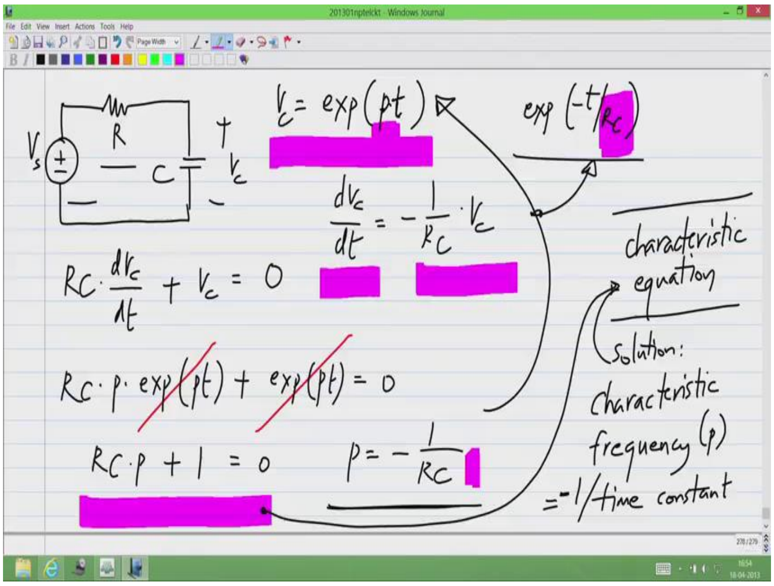

We know the exact solution for this, but let me do it in a slightly different way, now the differential equation governing this is R C d V c by d t plus V c equals something, now to evaluate the kind of natural response, I do not need the right hand side. So, I could also set this to 0 because even the 0 input, I will have some natural response, now for a particular input, you have to find a natural response that we will do by adjusting the initial condition. We will explain exactly, what I mean by that now, we know that the natural response for this differential equation will be of the form exponential some exponential and let me call it exponential p time t.

Let me call it exponential p times t remember. You know, exactly what the answer is, it is exponential minus t by C. I am trying to get the same answer in a slightly different way, now we know that like for instance, I could rewrite this and say that the time derivative is minus 1 by R C times V c. This we did earlier what it means is that the time derivative is a scaled version of the function itself. And we know that the property is true, if the function is exponential, if the function is exponential the time derivative is also an exponential, but it could have some scaling factor.

So, we know that exponential will satisfy this, we just have to find the constant inside the exponential, now how do we find the constant now for this we have already founded, but I will do it in a more general way which is also useful for second order circuits? So, what I will do is I will assume, that it is exponential of p times t so what will I get I have R C the time derivative will be p times exponential of p times t plus V c, which is exponential of p times t equals 0 and the exponential p t is common to the two parts. That will be that can cancel out. So, what I have will be R C time p plus 1 equal to 0 or p equals minus 1 by R C.

So, this is an alternative way off ending the argument of the exponential now, we did it earlier we already know the answer. Now, we know that this answer is correct, because if I substitute this into that one, what I get will be that thing now, we can use the same methods for second order equations it turns out. So, this equation how much we get the value of p is known as the characteristic equation now, remember we got this by substituting V c equals exponential P t, now we do not have to do it every time. We know that if you have a first derivative, you will have p. And if you have V c, you will not have anything and exponential P t will be common to every term. And that will cancel out and this become even more clear, when I do the second order case.

So, all we have to do is whenever I see a first derivative I put p and wherever I see the function put one. So, then I will get the characteristic equation is this clear any questions and solving this, what we get are characteristic frequency in this case frequency in higher order circuits. It will be frequencies and what is this is nothing but the reciprocal of time constant or rather negative reciprocal of the time constant, any questions about this? There is a question of how does this p come about see? I know that, if the differential equation of this type that is d V c by d t is proportional to V c.

Basically this differential equation I know that an exponential will satisfy it because, what this is saying is the differential coefficient the derivative is the same as the function with some scaling factor. Now, you know from basic differentiation that, if u have an exponential its derivative will also be an exponential with some scaling factor. So, I know that the form of V c is exponential of time.

Of course there can be a constant here, so that constant I have assumed to be pi have to find out, what p is for the particular circuit? But I have assumed that the solution is of the form exponential p t and I have substituted it here. I get R C time's p times exponential p t plus exponential p t equal to 0. So, this is the standard way of solving differential equations because, I know exponential p t can be a solution, I do not know the value of p. I will substitute that and find then the value of p is this fine also know that the value of p we found is minus 1 by R C, if I substitute it there I will get exponential minus t by R C, which is consistent with what I had earlier these things.

We had already determined earlier is whatever appears in the exponential as t by something. That is the time constant by definition because, we have seen that, if we have an exponential t by tau the amount of time, it takes for it to settle is related to this tau. Now, I will do the same for a second order circuit.

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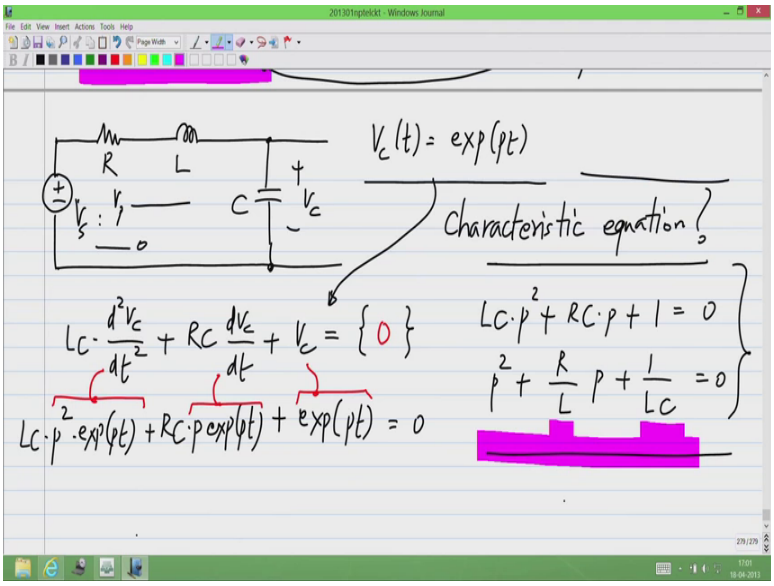

V s changes from 0 to V p. I am interested in V c, now the differential equation for this is L C d square V c by d t square plus R C d V c d t plus V c equals something to find the natural response, I will simply set the right hand side to 0. Then, I will get the form of the natural response the coefficient of the response. I will determine from the initial conditions. So, again in this case also exponential will satisfy it. So, I will assume that V c of t is exponential p t. So, please substitute this here and find the characteristic equation please find this out.

Please assume that, V c of t is exponential p t and find the characteristic equation locked. So, I have an answer here which is correct. So, all we have to do is substitute this, what I have would be exponential p t in place of V c plus R C times p exponential p t because, this will be that one this will be that one and if differentiate it once more. I will get p square now, I will see p square exponential p t this corresponds to this one and the right hand side is 0, and by cancelling this exponential p t. I will get L C p square plus R C times p plus 1 equal 0 alternatively, it could also be written as P square plus R by l times P plus 1 over L C equals 0.

This is the characteristic equation, I hope all of you are able to derive this yourselves all we have to do is to substitute V c is exponential p t in this equation any questions. Now, from this we can solve for the characteristic frequencies or equivalently characteristic time constants. But as I mentioned earlier for higher orders than one it is common to speak of characteristic frequencies p rather than characteristic time constants, but if you want to call them time constants. That is, that the reciprocal of p will be the time constant, now clearly there will be two possible solutions for p. And also the nature of solution will be different depending on the values of the coefficients.

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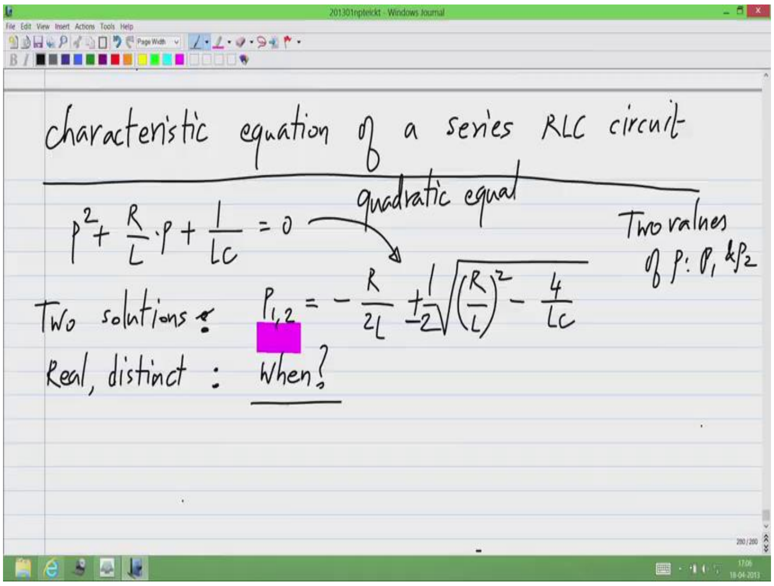

So, this is the characteristic equation of series R L C circuit. As, I have been emphasizing I have taken V c as an example of the quantity of interest, but you take a series R L C circuit by that I mean, if you null the independent sources you get series R L C. And then you pick any variable of the interest the inductor current the capacitor voltage whatever it is. Then you will get the same characteristic equation because the left hand side of the equation will remain the same.

So, for any series R L C circuit wherever you apply the source or whichever variable, you calculate the differential equation the characteristic equation will remain exactly the same and that is p square plus R by L times P plus 1 by L C equals 0. So, this has two solution snows, there are the two solution would be in general I think all of you know, the formula for solution of the quadratic equation it will be minus r by 2 l plus square root of. So, this is the solution in general. So, this can give you three different kinds of solutions the two characteristic frequencies P 1 and P 2 could be real and distinct, what is the condition for the characteristic frequencies to be real and distinct? Please give me the answer, when will P 1 and P 2 be real and distinct.

So, you know that solutions to quadratic equation can be I mean you will always have two solutions, but the two solutions could be real and different from each other. Two solutions could be real and same as each other. And also the two solutions could be complex conjugates of each other, my question is when is the, when are the two roots, when are the two characteristic frequencies real and distinct that is real and different from each other.

I think, the question is not very clear or somehow you have not understood the question properly, we will have two values of p 1 2 values of p that is p 1 and p 2. The two values of p are given by p 1 and p 2 by these two solutions minus r by 2 l plus half of square root of this as r by 2 l minus half square root of this all, that this is just a solution to quadratic equation, that is all know, why I am calculating the solution to this …

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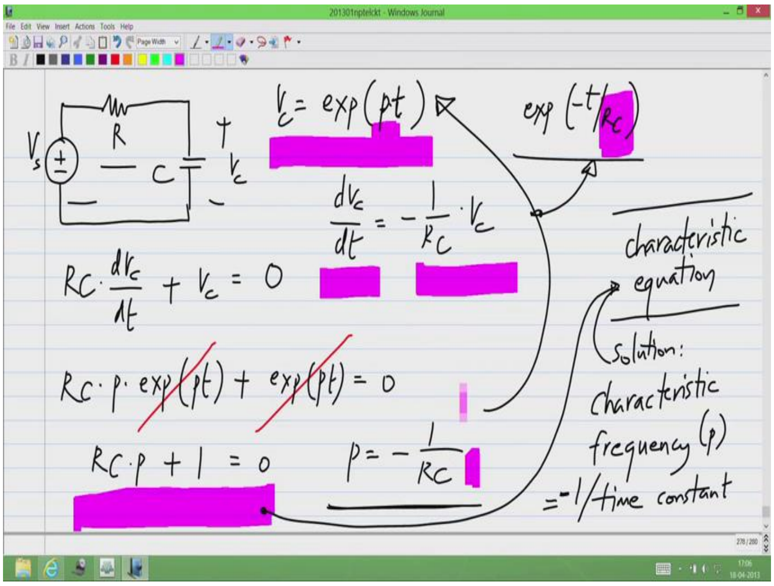

If you recall here. I have a first order equation in P. I solve that for p and I will get the characteristic frequency. I have to put this into exponential.

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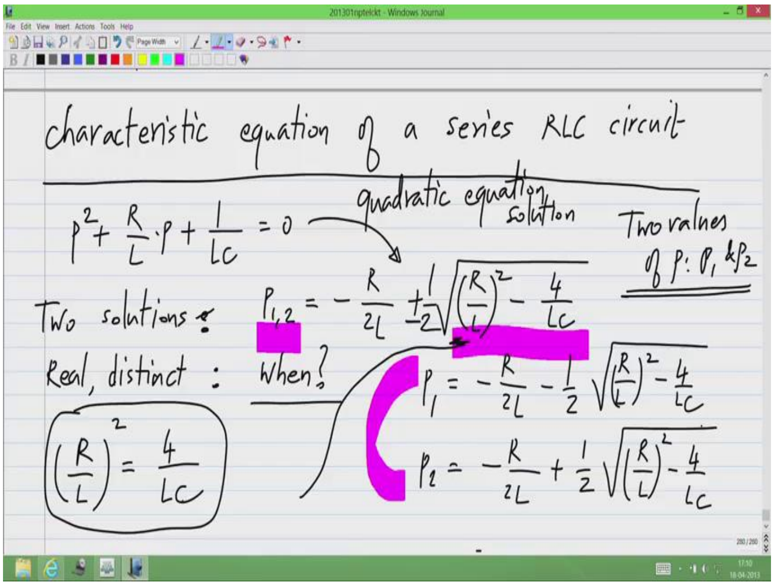

Here, I have a second order equation for p. So, I will get the characteristic frequencies two of them I have to put them into exponentials. Clearly, there will be two exponentials which will satisfy this. So, please tell me, when will the two values P 1 and P 2 be identical to each other. Clearly, the two values one, when this is plus 1 when this is minus, so my question is when is it that the values of P 1 and P 2 be identical to each other?

So, I have a couple of answers one of the answers is when there is no resistor now, that is not correct actually the correct answer is see, why do we get two diff solutions. Let me expand this, what this means is when I have this plus and minus 1 of the solutions P 1 is minus R by 2 L minus half square root of R by l square minus 4 by L C. The second solution is minus R by 2 l plus half square root of R by l whole square plus sorry minus 4 by L C. Now, when will this two be equal to each other?

Obviously, if this terms you have a minus sign here and a plus sign here. So, obvious they will be different from each other. Unless this entire thing happens to be 0, the term under the square root happens to be 0. So, if this part is 0 that is R by L square is 4 by L C, you can simplify this and that is the answer that was given by Sudhanya, but I will leave it like this under this condition.

You will have two identical roots now, if this quantity under the square root is positive. Then it will have a real square root right, if this is positive, it will have a real square root and the two solutions P 1 and P 2 will be real and different from each other, if the quantity inside the square root is negative. Then, the square root will consist of an imaginary number, then this P 1 and P 2 will be complex numbers and they will be complex a conjugate of each other is this part. Clear, please let me know.

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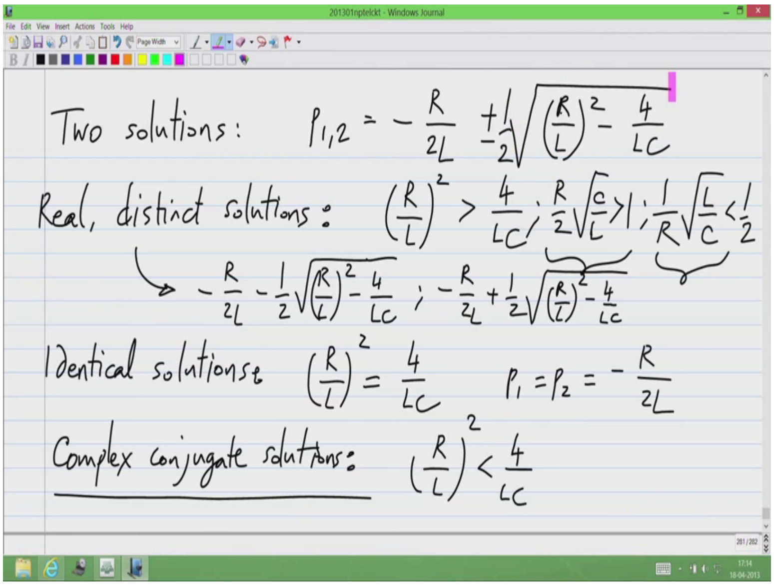

In summary there are two solutions to P 1 and 2 which have minus R by 2 L plus or minus, that is the meaning of this symbol one by 2 R by L square minus 4 by L C, now we will have real distinct solutions, if R by L square is more than 4 by L C. This also can be written as this can be re written in couple of ways, I could say one by R square root of L by C is less than half or I could also write it as R by 2 square root of c by L greater that one, these are some more quantities that we will define later.

So, then we will be there two real and distinct solutions which are minus R by 2 L minus half square root R by L square minus 4 by L C. And the other one will be minus R by 2 R plus half square root R by l square minus 4 by L C, now there will be two identical solutions, when I say two identical solutions, we will calculate P 1 from this plus sign P 2 from this minus sign. Those two values will be same as each other, if R by l square equals 4 by L C. In that case, P 1 and P 2 will be equal to minus R by 2 l. There will be complex conjugate solutions, if R by l square is less than 4 by L C remember.

In that case, the number inside the square root will be negative and the square root of a negative number is an imaginary number, now there is a comment here, I guess it is not a question that says second order non-linear equation can solve by Laplace transformation. First of all, this is not a non-linear equation this is a linear differential equation, and its only a linear differential equation that can be solved by Laplace transform, now we have not even come to Laplace transforms, and we will not do that in this course.

So, we will you solve the transient response using p Doman techniques. And it is, it has two roots there are many possibilities. But it quite simple to do that in the time given also in fact understanding this, is a pre requisite to a good understanding of Laplace transforms? Now, under these conditions what happens is that I already calculate square root of R by L square minus 4 by L C is less than 0, what is that what is square root of minus 1, please answer this question, what is the square root of minus 1? its denoted by the letter i or j, which by definition is square root of minus 1, now in electrical engineering because we use I for current, we always use j for square root of minus 1. So, what is this is basically square root of minus 1 times 4 by L C minus R by L square, this is basically j square root of 4 by L C minus R by l square. So, in this last case when R by L square is less than 4 by L C.

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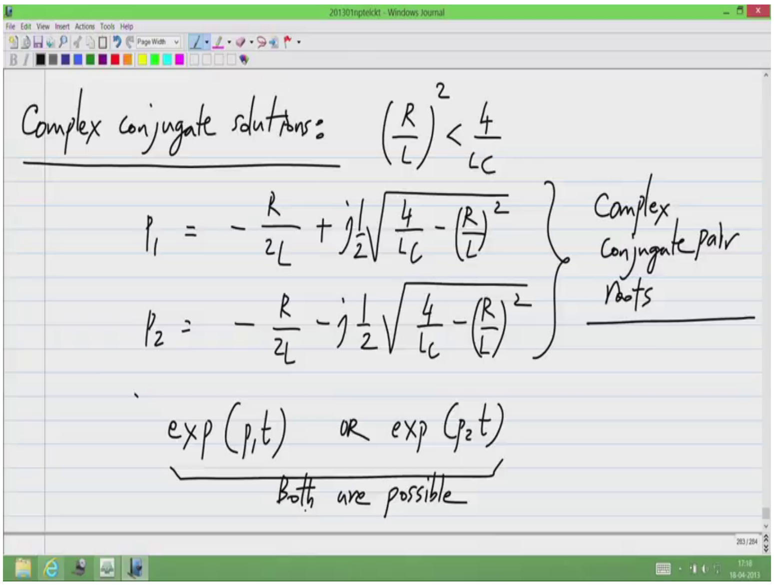

The two roots will be P 1 is going to be minus R by 2 L plus j square root of 4 by L C minus R by L square times one by 2. And P 2 will be minus R by 2 L minus j square root of 4 by L C minus R by L square. So, we will have two roots which are complex and not only are they complex, they are the same real parts minus R by 2 L, and imaginary parts with the opposite signs plus half times this minus half times that. So, these are complex conjugates complex conjugate pair roots.

So, in general a second order system will have three possibilities, it will always have two characteristic frequencies. The two characteristic frequencies will be identical, if R by L whole square will be equals 4 by L C, this is for a series R L C circuit and if R by L whole square is more than 4 than L C. It will have two real roots, which are different from each other and if R by L whole square is less than 4 by L C.

It will have a complex conjugate pair of roots is this part clear. So, we have to calculate P 1 and P 2 which are characteristic frequencies from the characteristic equations. Then, what do we do with it? The solution can be exponential P 1 t or exponential of P 2 t both these are possible, now it turns out that in a linear system, when we have a linear differential equation, when there are two possible equations. The general solution is a linear combination of two linear solutions. So, finally let me write down the natural response.

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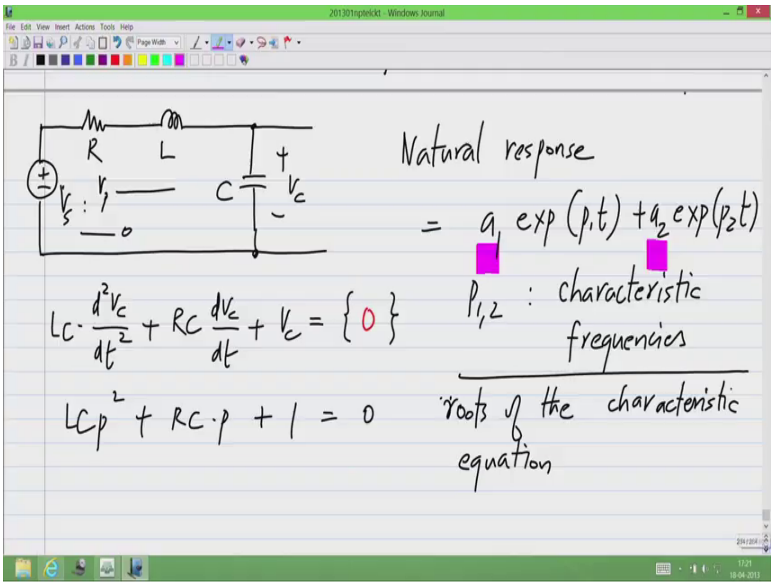

The natural response will be of the form a 1 exponential P 1 t plus a 2 exponential P 2 t, where P 1 and two are characteristic frequencies or basically the roots of the characteristic equation. And what is the characteristic equation? All I have to is to substitute the square, where as second derivative and p. I have first derivative and one where I have only V c equals 0. This is exactly, what you will get, if you substitute V c by p time's t. And now we have to find a 1 and a 2. From initial conditions, just to show what I mean, I will go back to the first order circuits and do it.

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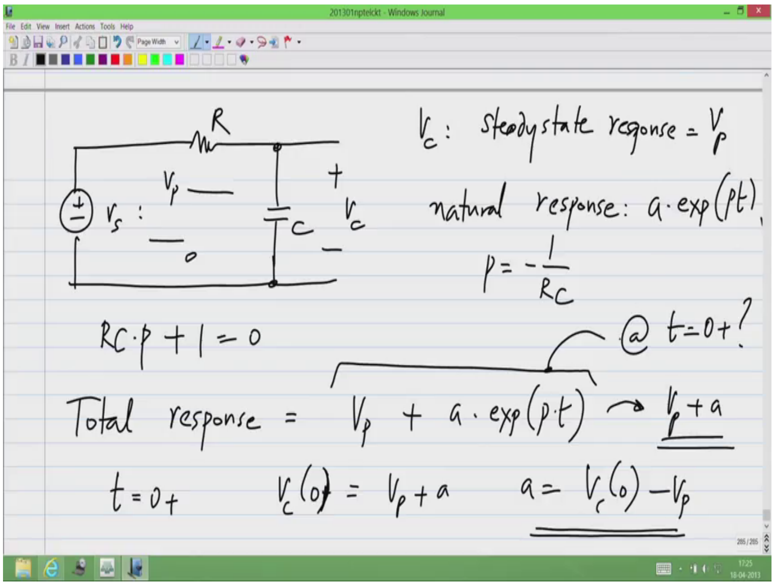

That way V s goes from 0 to V p, we have R C. And I know that the steady state solution to V c is steady state response equals V p, and the natural response is some constant a times exponential p t, where p equals minus 1 by R C. How did I get this? I get this from the characteristic equation C dash P plus 1 equals 0. So, the total response is the steady state response V p plus transient or natural response a exponential p times t.

There is a question, which asks characteristic frequency says something about the damping of the signal, now we will talk about that later, we did not even introduce the term damping factor, now it turns out that if the characteristic frequencies are both real and negative. You will have over damp system the identical is critically damped system and otherwise it is under damp system, but we will come to that, in the next lecture coming back to the first order system .The total response is the steady state response plus transient response, but we have this constant that has to be determined.

What do we do with that ? We do, but looking at the initial condition, now if you look at the total response and substitute t equal to 0 or 0 plus, what do we get? What is the value of this at t equal to 0 plus? All you have to do is some mathematical substitution. So, the question is the total responses of the form V p plus a times exponential p times t, what is the value of this at t equal to 0? All you have to do is to substitute t equal to 0, in this and if you do that you will get V p plus a.

So, if you have V p plus a at t equal to 0. So, V c of 0 happens to be V p plus a. So, obviously then a has to be equal to V a has to be equal to V c of 0 minus V p. And I can go back and substitute this into the equation. So, I will get the total response to be V p plus V c of 0 minus V p exponential p times C which minus t by R C. This is exactly, what we had obtained later using completely different technique by completely solving the differential equation, but the advantage of this method is that, it can be extended to second order circuits as well. So, in general the way to solve, it is as follows.

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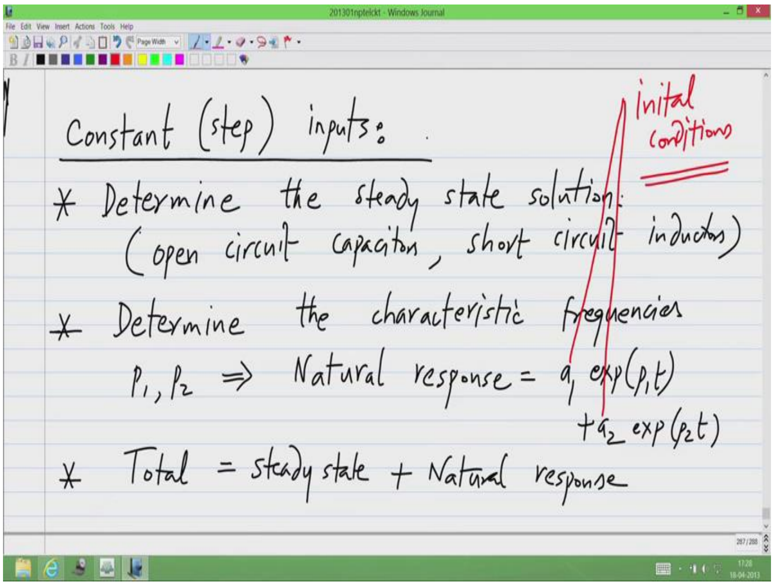

We have constant or step inputs, you first determine the steady state solution. And this you do by open circuit capacitors and short circuit the inductors. Then, you determine the natural or the characteristic frequencies for a second order system. You have two of them P 1 and P 2. So, then this means that the natural response will be of the form a 1 exponential P 1 t plus a 2 exponential P 2 t. Finally, the total response will be steady state plus natural response and you will have to determine these two constants a 1 and a 2, which you do based on initial conditions. So, this is showed for a first order system exactly the same thing is true for a second order system.

Is it clear, any questions any questions about this in a second order circuit, we will have second order differential equation and two characteristic frequencies I see some questions, but it seems to half typed, I am not being able to understand what the question is in case of first order there is, only one characteristic frequency and it does not matter, what the values are the characteristic frequency is always going to be negative. It is minus 1 by R C for a passive first order R C circuit and in a R L C circuit, it will be minus R by L.

So, there are in case of second order, there are three distinct classes of solutions because there are three possibilities for the characteristic frequencies, in case of first order there is no such thing, there is one case and it will always be exponential. So, in the next lecture, we will start from this point and see what these solutions look like and that will also take us to different kinds of responses under damped critically damped over damped. I will not go t through every detail of this, but what I want to point is for a second order system also, you should be able to write the natural response and even a complete response in case of a constant input. That is a stepped input by evaluating the initial conditions correctly, now no more questions. We will stop here and continue next week.