Basic Electrical Circuits
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Lecture – 18
Step response of RC circuit with loops of voltage sources and capacitors; RL circuits; RLC circuits

In the previous classes, we have been looking at how do calculate the response of R C circuit to a unit step. Now, this method is applicable to any system described by first order differential equation and accelerated by a step input. So, I think we have a good handle on this. Today, we look at one particular case, which needs extra care, if we have to get the step response correctly.

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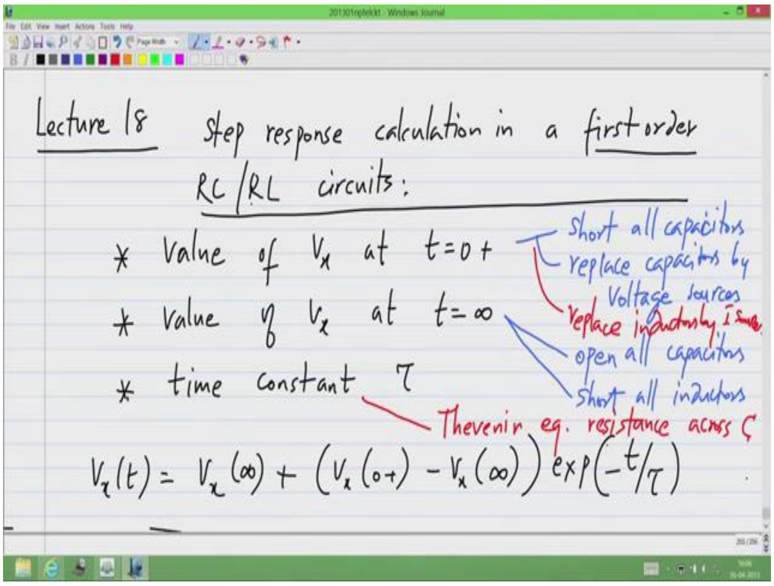

We said that the step response in an R C circuit and exactly the same thing will hold in an R L circuit as well. In a first order R C/R L circuit, what we need to know? Let us say, we are calculating a particular quantity v x, we could be calculating anything we could be calculating some voltage or some current, it does not matter. So, we need to know, value of v x at t equal 0 plus that is just after the step is applied value of v x at t equals infinity that is when the circuit reaches steady state, and the time constant tau once you have all of this the response is given by.

So, this is a general expression that is applicable to any quantity in a first order R C or R L circuits. In our examples we have been taking only an R C case that is with the capacitor, but the same thing applies to an inductor, if we have time we will work out an example today. Now, how do we find the value of v x at t equal to 0 plus, we do that by shorting all capacitors.

We can short circuit all capacitors or if the capacitors have initial conditions what we really do is replace capacitors by voltage sources, whose value equals the initial condition, and how do you find a t equal to infinity. You simply open circuit all capacitors, because if the voltage is reaches a steady state a constant value across all capacitors. Then, where currents will be 0 by the way we are talking only about first order systems. Here, but this is the case for all R C or R L circuits.

In case of inductors, we have to short circuit all inductors. Also it turns out just like you replace capacitors by voltage sources that represent the initial condition for t equal to 0 plus, you have to replace inductors by current sources. Finally, how do you find time constant tau, you find the Thevenin equivalent resistance across the capacitor. So, this is the algorithm. Now, are there any questions about this, any questions about these steps how to follow them, how they come about? So, if not let me go to slightly more complicated example, than what we looked at in the previous lecture.

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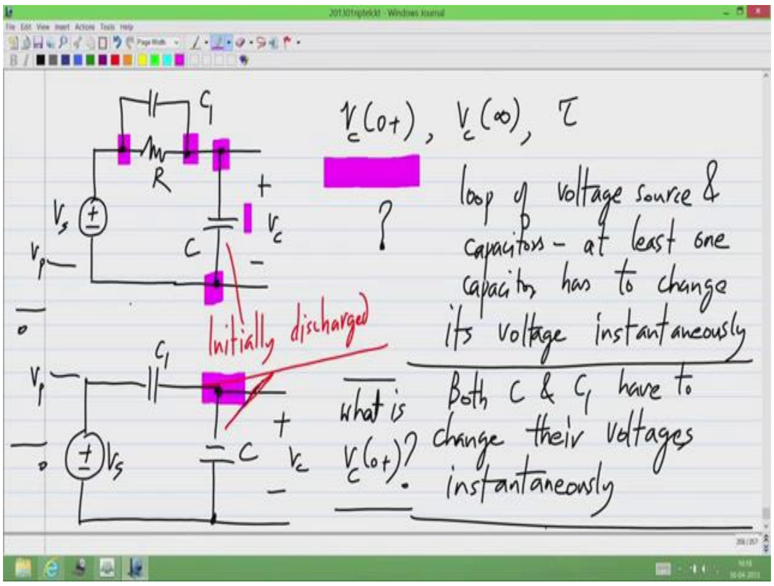

So, again this is v s and it goes from 0 to jumps from 0 to v p, and I will have R C, and let me call this c1. So, v s jumps from 0 to v p and let us say, I am interested in this voltage v c, the voltage across the capacitor R C. So, what I would like to know as to how to go about finding this as usual I need to find out v c of 0 plus. That is just after this step is applied v c of infinity that is after an infinitely long time, and the time constant tau. We have to find all these 3, but first let us start with v c of 0 plus.

So, I would like the participants to give me an answer, what is the value of v c just after the step is applied that is v c of 0 plus, what is the value the input v s jumps from 0 to v p, what do you think is the value? There is an answer that says it is v c or 0 the initial condition on the capacitor. Let us say, the initial condition on the capacitor is 0 volts, then what would be the answer. Let us say that this is initially discharged.

So, now clearly the contradiction is obvious, now the problem is that there is a loop of a voltage source and these 2 capacitors, so far we were considering that the voltage across the capacitor will not change instantaneously. We know that is the case, if the current through the capacitor is finite. Now, if you consider just at or just after the step is applied, so this voltage here which is the sum of voltages across c 1 and c that changes from 0 to v p.

So, when it changes from 0 to v p, if we say that the voltage across capacitor c does not change the voltage across capacitor c 1, has to change alternatively if we say that the voltage across c 1 does not change. Then, the voltage across c has to change that is we have this loop of capacitor 2 capacitors and a voltage source, if the voltage source changes its volume. The voltage across at least one of the capacitors has to change instantaneously.

So, this is the problem, at least one capacitor has to change its voltage instantaneously. Now, it cannot be just one which changes because if the voltage across c 1 changes instantaneously that means that there is infinite current flowing through it. But then we assume that capacitor c did not change instantaneously. So, then K C L at this node will be violated because you have finite currents through c and r, but infinite current through c 1. So, it cannot be that only one changes, in fact both the old capacitors have to change the voltages instantaneously.

So, while logically at least one have to change it cannot be only be in fact the answer is that both c and c 1 have to change their voltages instantaneously. So, now that means that if their changing instantaneously infinite currents are flowing through both c 1 and c, now because infinite currents are flowing through them whereas, a finite current is flowing through r because the volt is across that is still finite. We can approximate this circuit without any loss of accuracy by removing the r altogether r, because the current through this is infinity this is some finite value, if you add that to the infinite current, it does not change anything.

So, we can approximately find them, we can find the answer by removing the resistor altogether, and having only c 1 and c because just as this step is applied the current through this slope is finite and this resistor contributes only a finite current. So, there is no loss of accuracy, if you just remove the resistor. Is this clear?

So, then assuming that both of them changes, we have to calculate the change in v c. So, let us assume again that it is c is initially it is discharged c, is initially discharged that is at t equal to 0 minus, we have 0 volts across this, which also means that there is 0 volts across c 1, because before t equal to 0 v s is 0. The voltage across c is 0 and voltage across c 1 is 0.

So, what I like, you to find out is the voltage v c that is the voltage across capacitor c 1 unit step v p is when a step v p is applied. There is an answer saying it is v p, but it cannot be v p because if this changes by v p it means that the voltage across c 1 does not change at all. That says that if there is no change in voltage across c 1. There will be no current here, but the voltage across c is has changed abruptly. So, there is infinite current there.

So, K C L will be violated at this node, so it cannot be that only one of them changes both of them have to change, and they have to change by an appropriate amount. So, that K C L here is also satisfied. So, now because the currents are infinite we cannot do useful calculation with currents, so we will work with chargers, which are integral of currents, time integral of currents.

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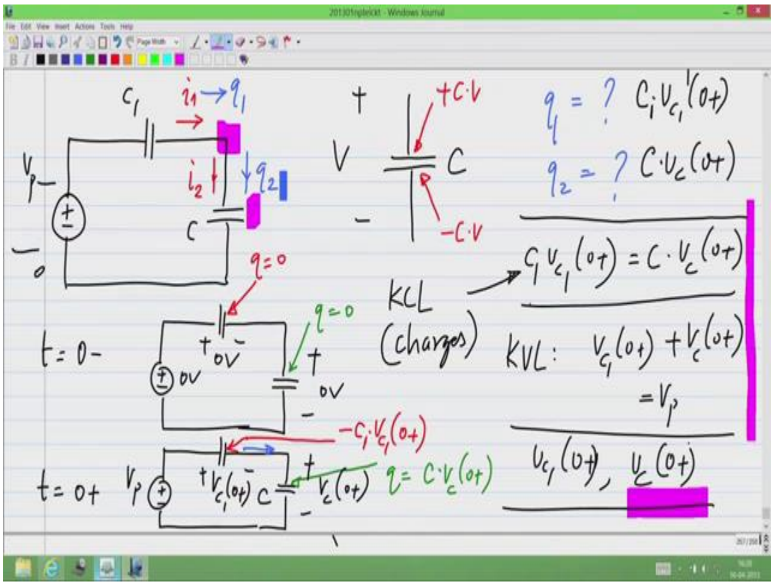

So, now if you consider this as a node what K C L says is this current i 1 has to be equal to the current i 2. Now, of course, when capacitor voltages change abruptly these currents will both be infinite and will not be able to do useful calculations with that. So, this is c 1, this is c 2 and this is v s, which changes from 0 to v p, and the same K C L can be rewritten by saying that instead of currents ill. Say, the amount of charge that flows that way q 1 has to be equal to amount of charge that flows this way q 2. Is this fine?

So, now let us consider the circuit for t equal 0 minus that is before the step appears, so we have 0 volts here and 0 volts there, and 0 volts over there. I also will write this circuit for t equal to 0 plus that is just after this step is applied. So, there will be some voltage across c, some other voltage across c 1 v c 1 of 0 plus, and this value will be equal to v p. Now, you see that in this case the charge on this plate is 0 and the charge on this plate in this second case is what is the charge on this particular plate in the second case at t equal to 0 plus. It will be equal to v c 1 is defined with this polarity, right?

So, let me just take a capacitor here, if I have a capacitor c with a certain voltage v across it what it also means is that on this plate there is plus c times v charge, and on this plate there is minus c times v. So, on this plate we have minus c times v c 1 of 0 plus that is by the definition of a capacitor when a capacitor c has a voltage v. There will be plus c times v 1 plate minus c times v on the other plate, it will be plus c times v on the plate with the positive sign of the voltage, and minus c times v on the plate with negative sign of the voltage.

So, the charge on this plate has changed from 0 to minus c v c 1 of 0 plus. Similarly, let me write down the charge on the other capacitor, the charge on this plate originally before the step will be 0, and just after this step will be c times v c of 0 plus. That is plus c times v c of 0 plus. So, now we can find these charges, the way I have written is charge coming out of c 1 has to be equal to charge going into c 2. We can also write it in a conventional formulation where the total charge leaving some node equals 0, either way it is the same in this case.

I will stick to the definitions. I have written, so what is the value of q 1 that is the amount of charge that is going from left to right in this wire just after the step, what will be the value of q 1, and what is the value of q 2? q 1 is what goes from here to there, when it transitions from t equal to 0 minus to t equal to 0 plus. So, now the charge here was 0, and it changed to minus c v c 1 of 0 plus, so obviously a charge of plus c v c 1 0 plus has gone from left to right, what has gone this way is the negative of this quantity. So, q 1 equals c v c 1 of 0 plus and q 2 this q 2 q, which is the current flow the charge flowing into the capacitor c. This is not c 2, it is c equals c times v c of 0 plus because originally there was no charge on this plate, later there is a charge of c times v c of 0 plus.

So, q 2 is c times v c of 0 plus, I think, I wrote this wrongly this is this capacitor c 1. So, this is minus c 1 v c 1 of 0 plus and the charge on this plate this capacitor is c times v c of 0 plus. So, this is also c 1, not c. Now, c 1 v c 1 of 0 plus equal c v c of 0 plus, so this comes from K C L, but reformulated in terms of charges. In addition to this we also have the k v l, which has to be always satisfied. Of course, which says that v c 1 of 0 plus v c of 0 plus that is the sum of these 2 voltages has to be equal to v p.

Now, from these 2 you should be able to calculate both v c 1 just after the step is applied and v c just after the step is applied, please do that and let me know the value of v c of 0 plus. So, as usual we use the K C L and k v l to determine everything, but in this case K C L is formulated in terms of charges because the capacitor voltages are changing instantaneously, and the currents are infinite that is all.

So, we have 2 equations 2 unknowns, so we should be able to solve them. So, please calculate v c of 0 plus and let me know, what it is? That is exactly right, so…

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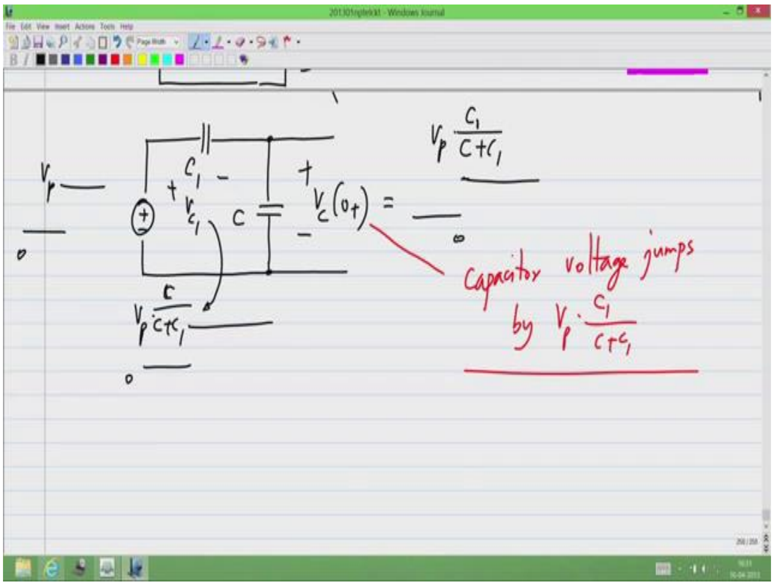

When a step of v p is applied to a capacitive divider, you see that this los like somewhat like a resistive divider, but with capacitors c 1 and c. The voltage here at t equal to 0 plus will change. Also instantaneously and it changes from 0 to v p times c by. Sorry, c 1 by c plus c 1, c 1 is this capacitor, and c is the capacitor, and you see that this formula is also reminiscent of the resistive diver formula except that the roles are interchanged. In the case of resistors you get r by r plus r 1. Here, you get c 1 by c plus c 1, and just to complete the picture, the voltage v c 1 will change from 0 to v p times c by c plus c 1.

So, when you have a loop of voltage source, and capacitors, and you apply a step the voltages of all capacitors in the loop will change abruptly, they have to, so that I explained, and it now you can also calculate how much they change by. And all you need to do is to write down K C L in terms of charges instead of currents that is all. Any questions about this, any questions on the circuits with loops of capacitors and voltage sources?

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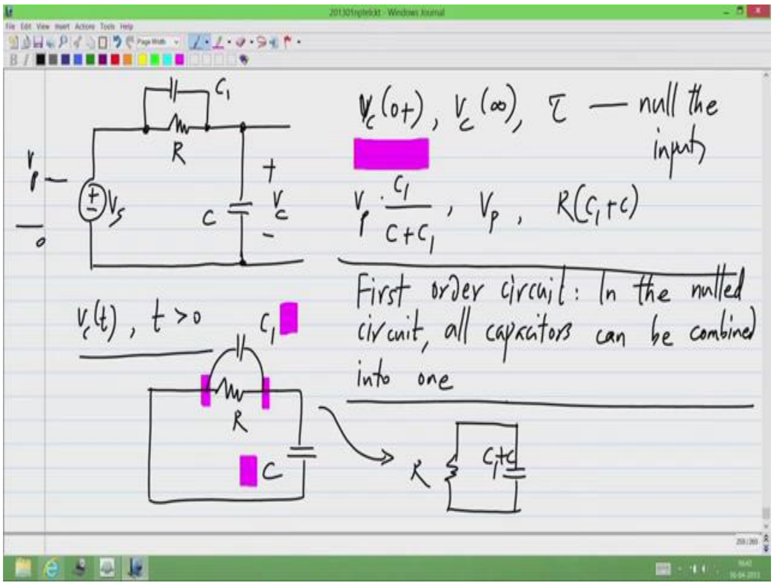

Now, of course we have not completely solved the problem yet what we were trying to solve was this and v s a step of a v p volts applied to circuit of this sort c 1 and c, and we want to determine v c of t for t greater than 0. And we have this standard formula based on the value of a value of v c at t equal to 0 plus and t equal to infinity. So, in order to sue the formula we had to find v c of 0 plus v c of infinity and the time constant tau. This part we have determined already and that is equal to V p times c 1 by c plus c 1. The net thing is v c of infinity, what is the value of v c of infinity that is we apply a step wait for a long time for things to reach steady state, what will be the value of v c of infinity? Please find out.

That is right clearly, it will be equal to v p, because if we open circuit both these capacitors we get a circuit, which is the same as what we have seen earlier and very simple this voltage is v p. And we have R and because no current is flowing through obviously the voltage here. Also will be v p, so v c of infinity is v p, and what is the value of tau the time constant, what is the value of tau, what is the value of tau? The algorithm I outlined earlier you null the input the time constant is a property has nothing to do with the input applied.

Then, what happens is, I had earlier said that you find the resistance across the capacitor in this case there are 2 capacitors, but please hold on for a second there is some problem here, I have to restart the journal. Sorry, about the interruption, so we have to null the circuit and when I have the null circuit. I have 2 capacitors c 1 and c, but as you can observe this c 1 and this c appear in parallel. They are connected between the same 2 terminals, they will be in parallel. In fact this will always be the case first order circuit, which is what we are considering means that there will be only one capacitor.

Now, there are apparently 2 capacitors, what I mean by there is only one capacitor is that when you null the circuit all the capacitors can be combined into a single capacitor. That is the meaning of first order circuit, in fact if we cannot do this, it is not a first order circuit. Now, we have R C 1 and c or in other words R times t and c 1 plus c, now please tell me, what the time constant will be? I have already given you the null circuit, so you should be able to find out the time constant.

So, clearly it is the product of the resistance you see here, and the capacitor that is equal to R times c 1 plus c. So, now we have determined all the quantities, let us take a numerical example and please try to solve that because it is only when you solve it independently. That you get a hang of, what is going on and give me the expression for the voltage, we see as a function of time.

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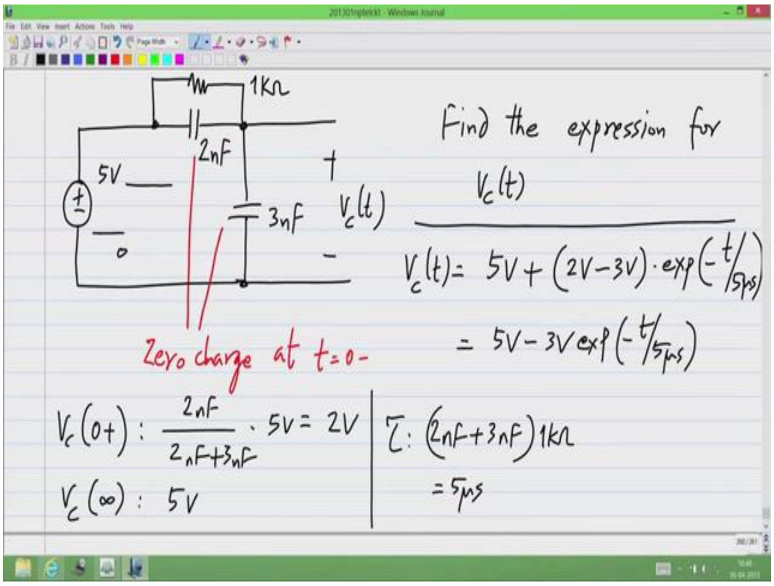

Before that if you have any questions regarding this Please ask. So, let us say, the input jumps from 0 to 5 volts and it is the same circuit I had earlier. I will say, this is 2 nano farads and this is 3 nano farads this is 1 kilo ohm, and both are initially discharged both of these capacitors that is 0 charge just before the step is applied at t equal to 0 minus.

Now, what I want is expression for v c of t, so please find this. As usual you have to find the voltage, we see at t equal to 0 plus just after the jump at t equal to infinity that is at that is the final value, and finally the time constant.

So, the value at t equal to 0 plus this is 2 nano farad by 2 nano farad plus 3 nano farad times 5 volts, which is equal 2 volts and v c of infinity is found by open circuit in these capacitors. So, all of this 5 volts appear here, so that is 5 volts itself and finally, the time constant tau we saw that it is r times c plus c 1, when I have null this we have these 2 capacitors in parallel that makes for 5 nano farads and 1 kilo ohm in parallel with that.

So, 5 nano farad times 1 kilo ohm gives the time constant of 5 microseconds and from this from what we know earlier. We can write out the expression for v c of t, which is the final volume plus initial minus final volume times exponential minus t by tau, which is 5 microseconds, which is to say it is 5 volts minus 3 volts exponential minus t by 5 microseconds. So, it is interesting to, I hope the technique is clear, if it is not please ask me and I will explain again. Now, let me copy this circuit and here in the second case what I will do is I will remove this capacitor and I have a single capacitor of volume 5 nano farad.

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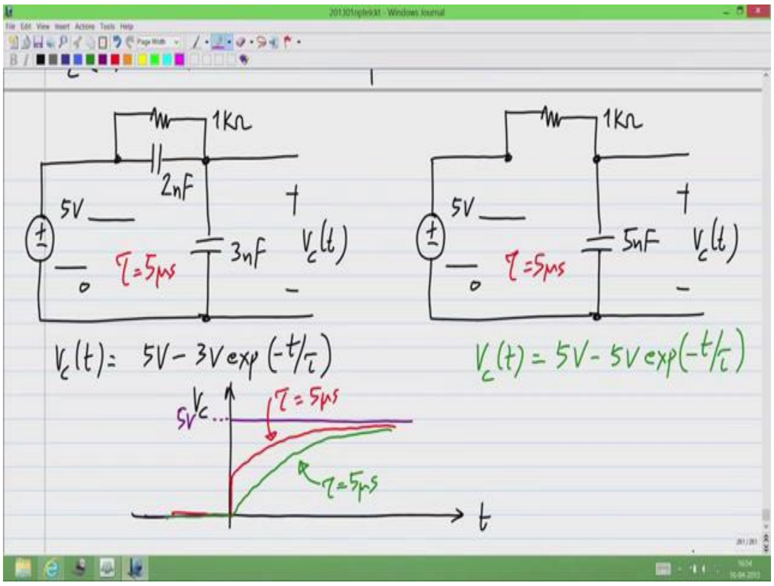

I both cases I will assume that all capacitors are discharged for t equal to 0 minus. So there is a question how to find the initial value, I will repeat that. Now, what is the time constant of this circuit, the circuit on the right side. So, clearly this is 5 microseconds because when I null this circuit, I have 1 kilo ohm in parallel with 5 nano farad. In fact it los similar to this when it is nulled that is the reason I chose the value tau is 5 microsecond for both of these.

Now, in this case v c of t we determined to be 5 volts minus 3 volts exponential minus 3 by tau and in this case I will write out the expression, if you have forgotten. Please go back to the previous lecture notes and you should be able to find it, and anyway you should know how to solve this one. It will be 5 volts minus 5 volts exponential minus t by tau. Let me put that in green, now what I will do is, I will plot everything on the same graph versus t. This is v c in both circuits and let us say, the import plot here it jumps from 0 to 5 volts in the circuit on the left side what happens is that at t equal to 0.

There will be a jump because of this voltage and this capacitor loop the output will jump and it will jump up by 2 volts. So, let me put this is in red, it will be 0, it will jump up to 2 volts. This we have to determined, earlier we saw that v c of 0 plus is 2 volts and then after that it will go towards 5 volts with the time constant of 5 microseconds. In the circuit on the right side there will not be any jump in the output voltage, because here the currents will be finite, because we have a resistor and no capacitor here. So, the output does no jump at t equal to 0. So, the output starts from 0 and it remains at 0 immediately after the input step and it will go towards 5 volts, also with a time constant of 5 microseconds.

So, that is the difference between these 2 circuits. They are related in that they have a same time constant, but because of this capacitor, here the output will jump whereas; in that case there will be no jump. So, we have a studied extensively the algorithm for writing down the solution to a first order R C circuit in case of a step input. Of course it is not good to simply mug up the algorithm, we should understand where the algorithm came from that we discussed earlier, when we have a first order R C circuit for t equal to infinity, when all the voltages are constant you can open circuit the capacitors.

That is how you find the final voltage for initial voltage just after step you can short circuit the capacitors, and find it, and in those cases where you have loops of voltage source and capacitors. You cannot use this algorithm because you cannot short circuit both of these, if you short circuit both these capacitors, then you have a short across a voltage source. So, that is not possible. In that case you have to find the output voltage by applying K C L and k v land.

This K C L and k v l instead of using charges instead of using currents, you have to use charges because the currents are infinite and charges are finite. So, that is how you find the initial voltage that is at t equal to 0 plus and finally, the time constant is found by mulling the circuit and finding the resistance across the capacitor, when you null a first order circuit, you will always end up with a single resistor and a single capacitor effectively. Now, regarding a finding the initial voltage.

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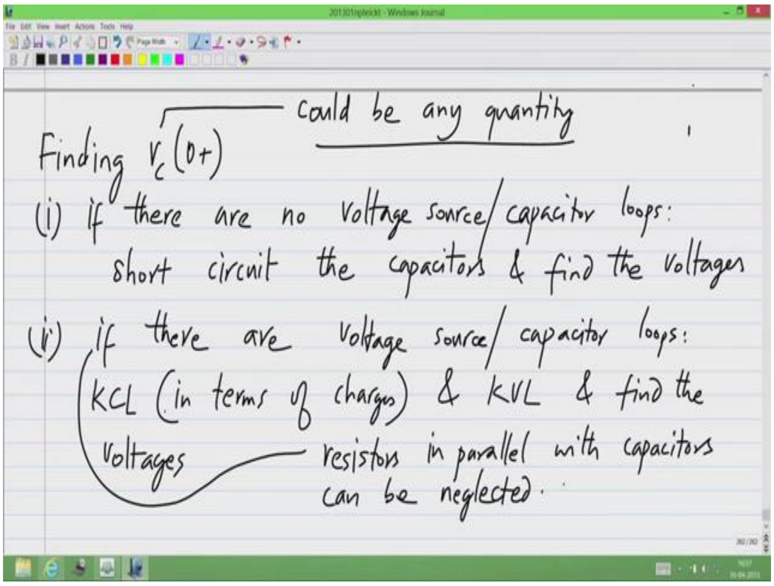

In this case I will say, finding v c of 0 plus, but it applies to any quantity just after the jump. It does not have to be a capacitor voltage. Now, if there are no voltage source capacitor loops, then it is very simple short circuit the capacitors and find the voltages, and if there are voltage source and capacitor loops, what you have to do, is apply K C L. In terms of charges, and k v l, and find the voltages. In this case the resistance in the loop can be neglected. That is if you have a capacitor in parallel with a resistor. Let me not say resistors in the loop, but resistors in parallel with capacitors can be neglected.

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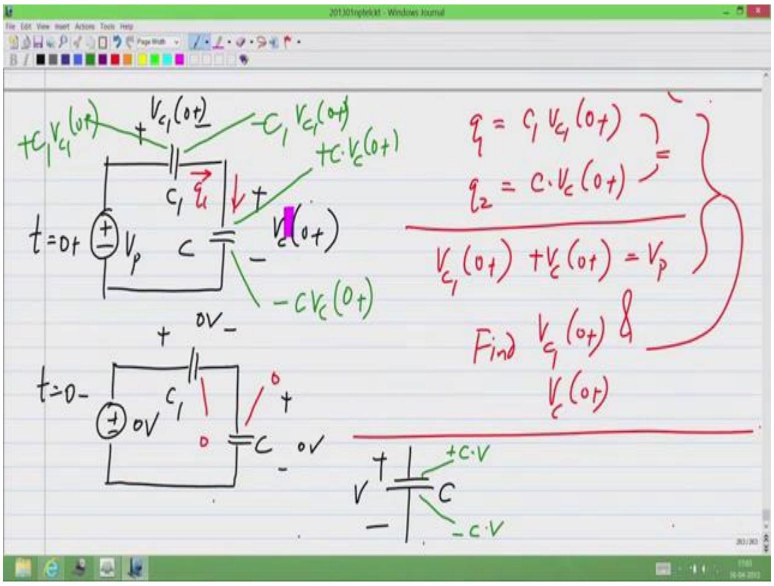

So, I showed the example earlier, the input jumps by v p. So, if I write the circuits at t equal to 0 plus c 1, and c and t equal to 0 minus that is just before applying the voltage. So, this is 0 volts and I assume 0 initial conditions. So, this is 0 volts and that is 0 volts, and here it is v p voltage across. This is v c of 0 plus and v c 1 of 0 plus.

Then, we have to find the charge that is flowing this way and the charge that is flowing that way, and equate the 2 to do that we have to find the initial charges, here it is 0. There also it is 0, and here it is plus c v c of 0 plus, and here it is minus c 1 v c 1 of 0 plus. That is the charge, so that means that this q 1 is basically the difference between the initial and final charge, right. If, this is 0 and this is minus c 1 v c 1 of 0 plus q 1 has to be c 1 v c 1 of 0 plus and q 2 is c times v c of 0 plus.

So, we have to equate these two q 1 equals q 2, and also we know that v c 1 of 0 plus voltage across this plus v c of 0 plus. The voltage across that equals v p, from these two you can find v c 1 of 0 plus and v c of 0 plus. So, if there are any questions about this please let me know. I very quickly outline how to find the initial voltage in a case where there are loops of voltage sources and capacitors. Clearly you cannot short capacitors because if you short both capacitors you will end up with a short circuit across the voltage source v p.

A charge across c 1 is not negative; it just goes from the definition of voltages. So, there is no meaning to saying charge across c 1 is negative, if you have a capacitor c with a voltage v, with this polarity the charge on this plate is c times v plus c times v the charge on this other plate is minus c times v. So, that is what happens in any capacitor here. I have a capacitor c 1 or the voltage v c 1 defined in this polarity. So, the charge on this plate will be plus c 1 times v c 1 of 0 plus, and charge on this right side plate will be minus c 1 times v c 1 of 0 plus. Similarly, here the charge on this plate will be minus c v c of 0 plus, any other questions?

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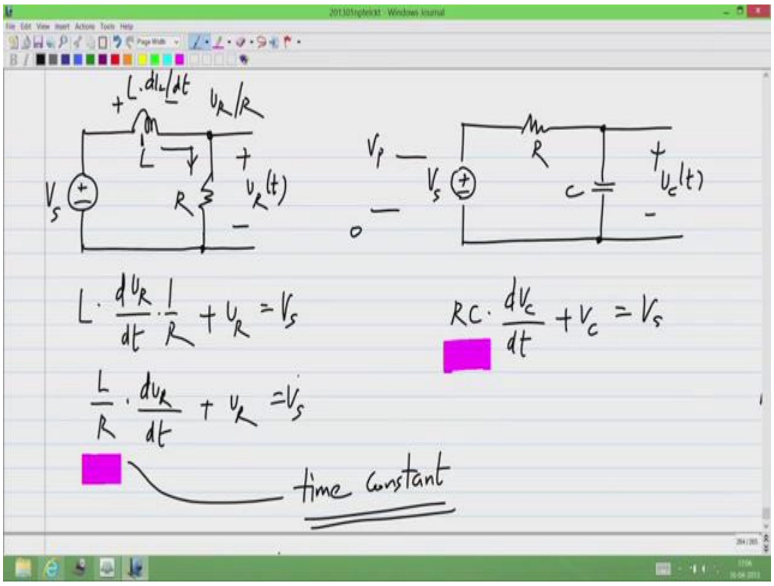

Now, I will not discuss circuits with inductors in great details, but let me outline briefly what happens and you can compare that to this R C circuit and in both cases I will take v as jumping from 0 to v p. Now, a current through this clearly is v r divided by r and the same current flows through the inductor, the voltage across the inductor is L times d i L by d t or i L s the inductor current and v s. The applied voltage is a sum of v L and v R. So, L times d i L by d t, which is L times d v R by d t times 1 by R. This is equal to L d i L by d t plus v r equals v s. So, L by R times d v R by d t plus v R equal v s, in this case I will not derive it again, but we had done it earlier R C d v c by d t plus v c equals v s. So, now in the R C case this was the time constant, in the L R case this turns out to be the time constant.

I said earlier that a first order R C circuit, if you null the sources will always be reduced to single capacitor and a single resistor across each other, single capacitor and resistor are parallel. Similarly, first order R L circuit will always reduce to single inductor and a single resistor in parallel. This always happens and once you do that the time constant will be equal to L by R, where L is that single inductor and R is that single resistor in the circuit.

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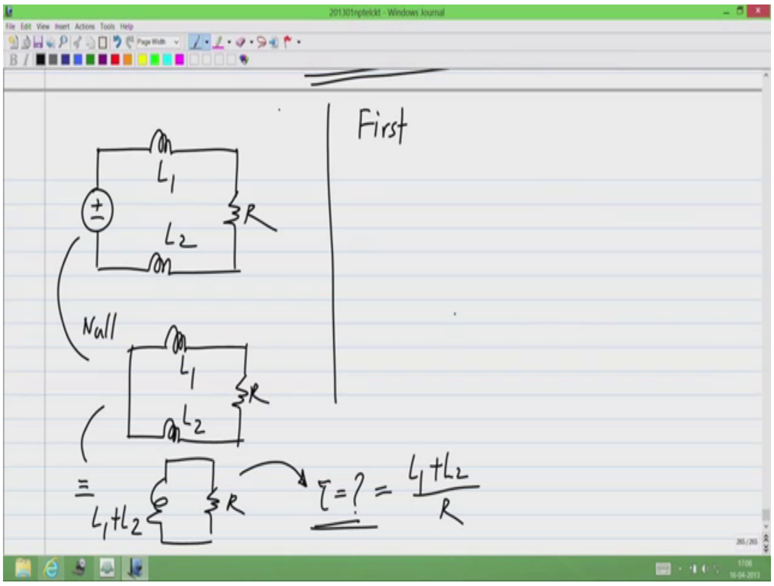

I could have something like this, but when I null the source, what I have is that, and you can see that this L 1 and L 2 are peer, and series. This is equivalent to L 1 plus L 2 and R in parallel, so what will be the time constant of this circuit. The time constant is the inductance by resistance and it is equal to L 1 plus L 2 divided by R. I think somebody answered saying L 1 plus L 2 times R, it should be divided by R. And because the differential equation los the same for R C and R L circuits, the solution also looks the same.

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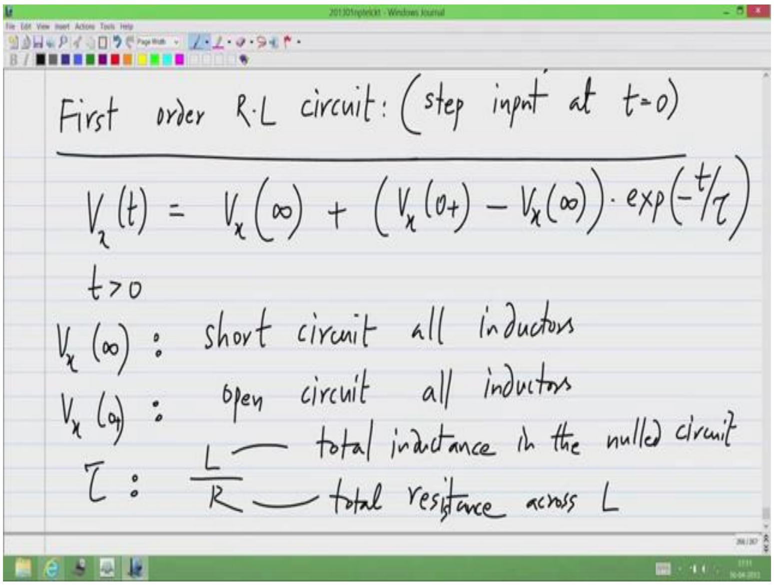

Let me rewrite it here. First order R L circuit. In this case we, if we want to find the voltage v x as a fraction of time for t greater than 0 and I am assuming that there is a step input at t equal to 0, V x of t will be v x of 0 plus. Sorry, v x of infinity plus v x of 0 plus minus v x of infinity times exponential minus t by tau. So, you have to find v x of infinity. For this short circuit all inductors this is analogous to open circuiting all capacitors. This is because one all the quantities have reached steady state, which is a constant.

We know that the voltage across an inductor is a time derivative of the current through the inductor times the inductance. Y L is a constant, v L has to be 0, and that means that you replace the inductor by a short circuit at t equal to infinity, v x of 0 plus, what did we do, we short circuited all the capacitors to find the quantity just after the jump. So, in this case we open circuit. All inductors and finally, the time constant tau is given by L by R, where L is the total inductance. You see, it could be a combination of more than one in the null circuit, and R is the total resistance again it could be the equivalent resistance of some complicated circuit across L.

So, the algorithm is exactly the same except the time constant is of the form L by R. Hopefully with this information you will be able to solve for step response in any R L circuit as well any questions about this, any questions about way to find step responses in R C or R L circuit? Now, just like when we had loops of voltage sources and capacitors, we have current sources, and inductors in parallel current sources, and inductors connected to the Same 2 nodes. Then, you have to have a special case you can think about the special case yourself. I am not going to discuss it here, but it will be analogous to having loops of voltage sources and capacitors. There is a question, what does the total inductance in null circuit? I am not clear of what this question means, but for instance in this case there are 2 inductors, but they appear in series in the null circuit. So, obviously the total inductance is the sum of inductance.

Now, if we are talking about a first order circuit when you null the source, you should have a single inductor. There may be separate inductors in this, but when you null it you should be able to combine many of them into a single wall, so that is always the case in a first order circuit if this is not possible, it is not a first order circuit. Everything we discussed so far applies only to first order circuits.

Then, we can go to so far; we have considered circuits that have a resistor, and a capacitor or a resistor, and an inductor. We have not considered cases where we have both resistor and capacitor and inductor that is we have capacitors and inductors in the same circuit. So, now we will consider that and they will be known as second order circuits because they will lead to second order differential equations.

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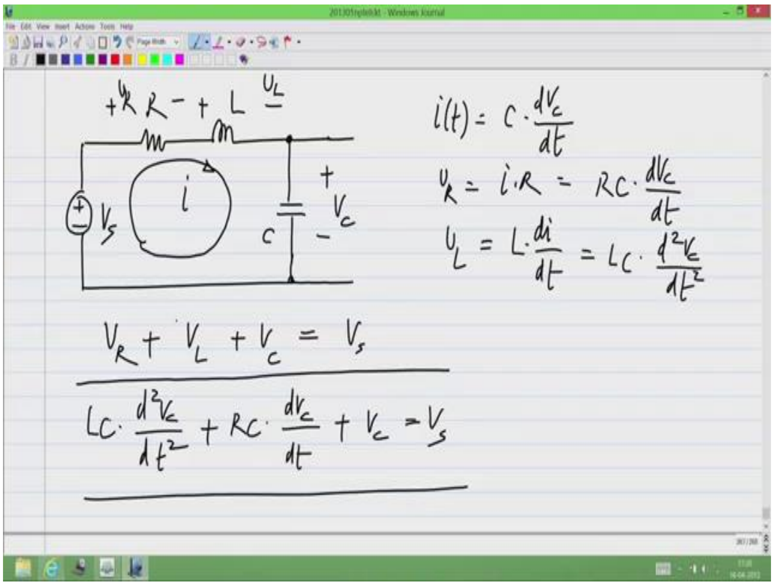

So, first let me take a case where I have a voltage source v s, and this will apply to a series combination of R L and c and let me write everything with this capacitor voltage v c as the variable. So, if the capacitor voltage v c is the variable. We know that all these 3 components are series. So, there is a certain current that is flowing through the loop what will be i of t in terms of the capacitor voltage v c. Please give me the answer what is i of t in terms of the capacitor voltage v c, i of t would be c d v c by d t, because this i is nothing but the current flowing through the capacitor as well. So, it is c times d v c by d t the voltage across the resistor v R is i times R. That is R C d v c by d t and the voltage across the inductor v L is L times d i by d t, which is L c times the second derivative of v c.

So, we can form this differential equation v s. Let me put v s on the right hand side, we know that the voltage across the resistor plus voltage across the inductor plus voltage across the capacitor equals v s. So, L c second derivative of v c plus R C first derivative of v c plus v c equals v s. So, this circuit with the series R L c obeys second order differential equation. That is given by this in general if you arrange the R L c in a slightly different way; it will also obey a second order differential equation. Now, we can of course, solve this and find what the solution is we do not have time to go through a detailed derivations of the solutions of this. So, I am just going to give you the solutions in a certain particular cases. So, before we go there, let me do it for a slightly different circuit.

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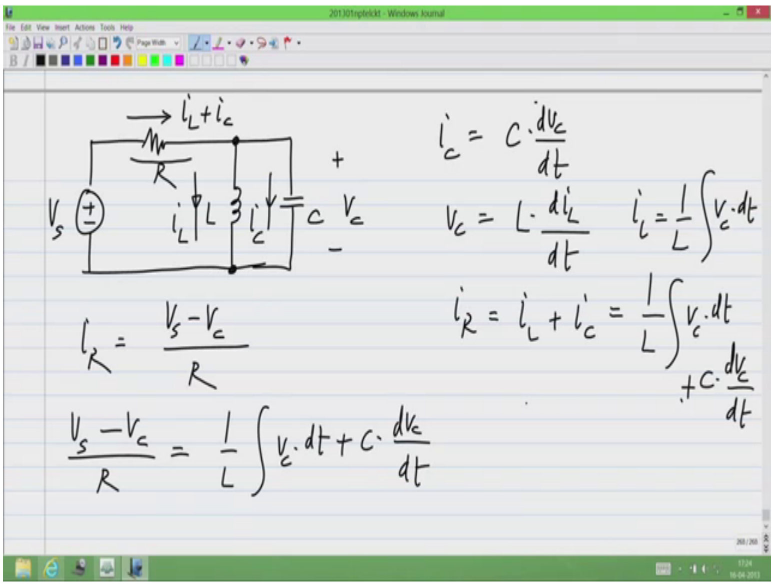

Or let me, Let me have R L and c arranged slightly differently. And let me take the inductor current as the variable or rather may be just like before I will take v c as the variable. So, in this circuit I know that a certain i L and certain i c, and this current equals i L plus i c, L c is nothing but c times d v c by d t. Also you see that the voltage v c here is across the inductor v s minus v as well. So, the voltage v c is related to the inductor current by L times d i L by d t or i L would be one over L integral v c d t. That is because the capacitor and inductor are in parallel.

Finally, this current i R equal i L plus i c, which is equal to one over L integral v c d t plus c d v c by d t. Also we know that the current through the resistor is the voltage across the resistor divided by R. So, v r equals v s minus v c divided by R. Sorry, not v R i R equals v s minus v c divided by R or v s minus v c divided by R equals this whole thing one over L integral v c d t plus c times d v c by d t. Now, this has integral and differentials in the same equation, we would like to have only a differential equation where everything is expressed as time derivatives. So, what I will do is I will differentiate the entire expression once more.

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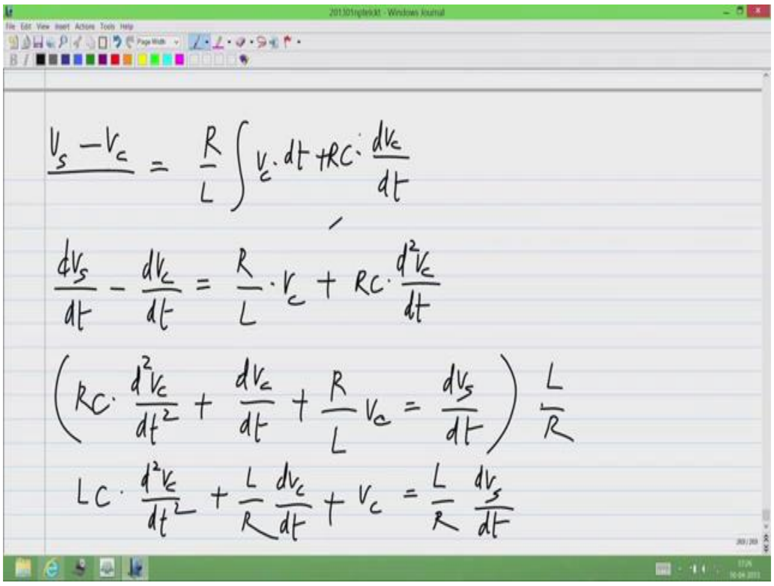

So, I will end up getting I will also move R to the other side that is this R can be moved here. So, if I differentiate everything I will get R by L times v c, because the derivative on the integral cancel plus this R C second derivative of v c. So, if I rearrange this, I will get R C, R by L v c equals d v s d t. The reason I did this is to put the source on the right hand side and the unknown v c on the left hand side, and I will re arrange this further. I will multiply the whole thing by L by R. I will get L c this plus L by R that one plus v c equals L by R, d v s by d t. So, I am going to just derive the equations the whole idea was to show that they will be in the same similar form for both the circuits.

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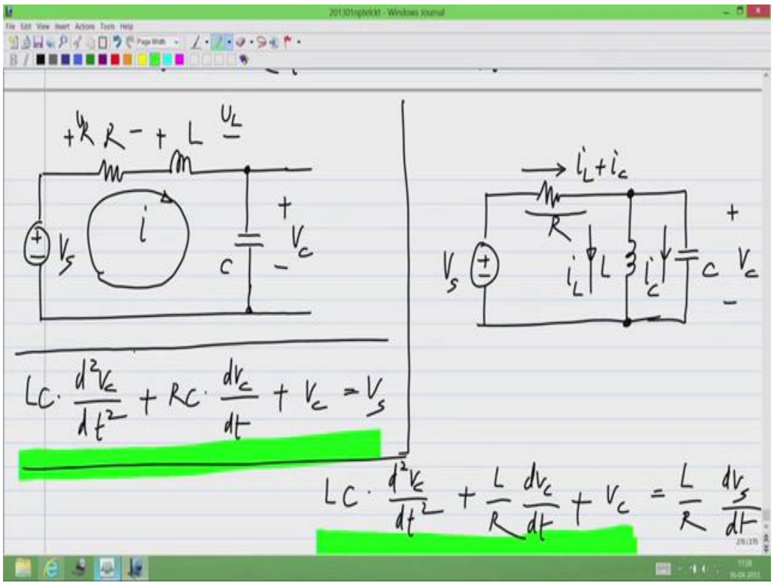

So, let me put these side by side. So, this is the differential equation governing the circuit, and if I take the other circuit. I will have this other differential equation, the main point I wanted to make here is that the two are similar to each other, mainly especially the left hand side. It is of the same form you get a second order differential equation. The coefficients are different, so that means that the exact properties will be different, but both of them will give you second order differential equation. It turns out that this is also true, if you find some other arrangement of R L and c, and also you have current sources in the circuit and so on, so what we will do in the next lecture, is to get an idea of what the response of this circuit look like. So, we will stop here today, in the next lecture we will take up this second order circuits. If, you have any questions, I will be answer them now. If there are no questions we will close here. I will see you on Thursday.