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Circuit Theory
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Lecture - 23
Minor –I Exam Problems & Their Solutions and Hybrid and Transmission Parameters

This is the third lecture and in this we propose to solve the problems that I set in minor 1 examination and then, if time permits, we will look at 2 other parameters of the 2 port, namely hybrid and transmission parameters.

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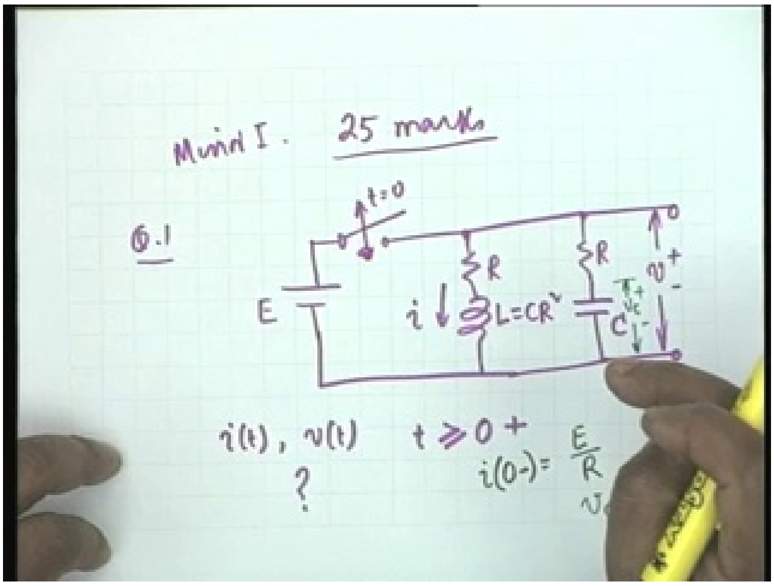

Minor 1 consisted of 3 questions, 25 was the total marks and the first question, question 1 related to this network, no, it is the other way round. t equal to 0, the switch is opened. There is a battery E and there are 2 parallel branches R and L. The value of L is C R squared, this is special value and this current is i. Then there is a resistance R, note that these 2 resistances are equal, and this capacitance is C. The voltage across this combination is V. The switch has been in the on position for a very long time and at t equal to 0, switch is thrown out.

What you are required to do is to find out the current, i of t and v of t, the voltage v of t, for t greater than or equal to 0 plus. This is the question. Now the question is, as you can see, it is a combination of initial conditions in inductor as well as a capacitor, but the element values have been very carefully chosen. Cleverly chosen, as usual see, this is a very interesting example and writing differential equations, well you would be able to solve it but since Laplace transform converts differential equations into algebraic equations, there was no point in writing differential equations. A few of you did try to write the differential equation.

Number 2, the first thing we do is to find out the 2 currents. Find out the initial conditions, i of 0 minus is obviously equal to E by R. If the battery is here for a very long time, the inductor acts as a short and therefore, the current through the inductor is I and the V c 0 minus, this voltage, V c 0 minus is obviously equal to capital E because there is no current in this arm, in the steady state and therefore, the voltage across the capacitor must be V c. Since we know the initial conditions, we can now draw the transformed equivalent circuit, transformed, Laplace transformed equivalent circuit.

There are 2 options, we can either draw Thevenin equivalent or the Norton equivalent. What we have to do is to find a current, i of t and the voltage across the combination. This suggests that at T equal to 0 plus, it is a single loop circuit. This suggests that you should use to Thevenin's equivalent not Norton's. Some of you have used Norton and then did not know how to manipulate. The simplest thing would be to use Thevenin's equivalent. Contain a loop as 1 loop only.

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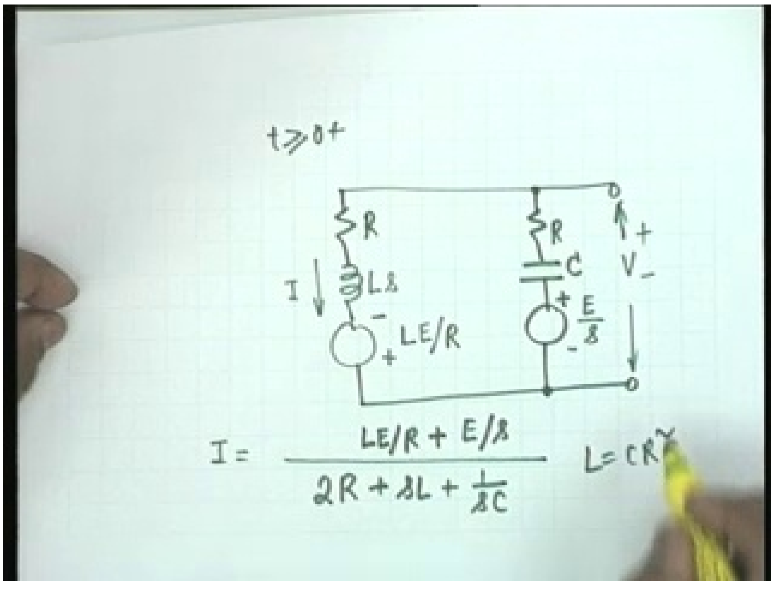

Do not make it more complicated than what the circuit given is, and if you draw the transformed equivalent circuit, for t greater than equal to 0 plus, obviously, what we have is R and then the inductance is, the inductance L while multiplied by s. Its impedance and then you have a voltage generator this is the Thevenin equivalent circuit. In the opposite direction, that is, minus plus L times i L 0 minus. i L 0 minus is E by R and therefore, L E by R this is the equivalent circuit for the inductor.

For the capacitor, and the current transform is capital I, for the capacitor you have R then an uncharged capacitor C in series with a voltage with this polarity, whose value is V c 0 minus divided by s because you are taking the transform and therefore, this will be E by s. Very few students got this problem correctly. Once you have drawn this equivalent circuit, things are absolutely simple. This voltage is V, let us say, capital V, to transform voltage and obviously, if you look at the circuits, it is a single mesh circuit, simplicity itself. Capital I shall be equal to the total driving voltage divided by the total impedance.

Total driving voltage, you see, there is a question of sign now. L E by R, this source, voltage source, tends to send a current favoring I, right? In the same direction and therefore, L E by R, then this one, you see, minus plus then minus plus and therefore, this should be added. E by S divided by R, twice R, R and R, twice R plus s L plus 1 over s C and if you simplify this, you simplify this with L equal to C R squared. Normally, you see, this looks like a second order circuit and therefore, the denominator after clearing from 1 by s C, inverse power of s, the denominator should be a quadratic, agreed.

The numerator should all, should be a first order turn, but it turns out that one of the terms cancels out. The first order factor of the numerator cancels with one of the factors in the denominator and simplification with L equal to C R squared.

This algebra you can do, simply reveals that I is equal to E by R, 1 over s plus 1 by C R. I write it in this form to be able to transform this back into the time domain easily and therefore, I of T is equal to E by R, E to the minus t by R C u t.

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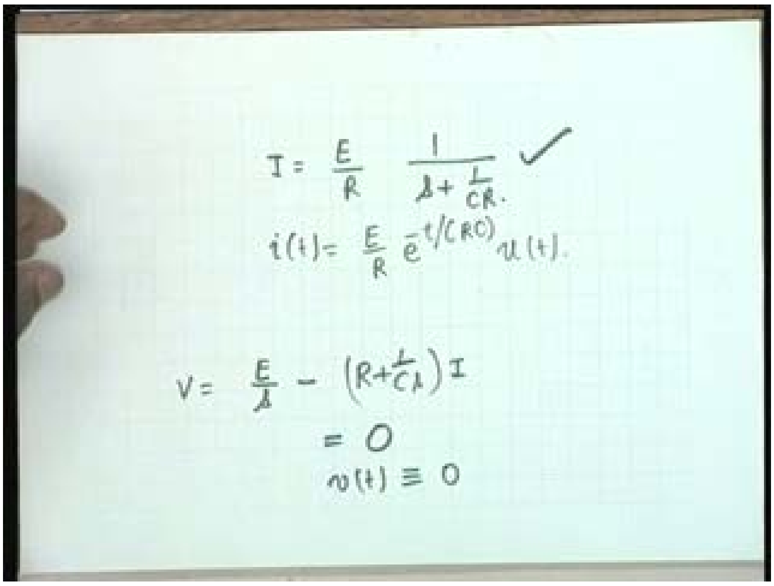

Student: Even if we do not cancel out and carry with the same procedure, then also it will give the same result.

Sir: Of course, but a little bit of more algebra. If you can substitute the value at the end, but if you did it right at the beginning, things become very clear, things sort out very easily.

Student: Sir, should not it be 1 over s plus 1 over c r squared because the denominator in term (..) so it will have one pole only.

Sir; That cancels with 1 of the zeroes. You see, this is what I say. This special value of L makes the numerator factor, the linear factor cancels with one of the linear factors in the denominator, so ultimately one factor in the denominator is left and it is a single pole circuit. This circuit is called a degenerate circuit because even with 2 elements, 2 dissimilar energy storage elements, it shows only 1 time constant and therefore, it is a degenerate circuit. The other part of the problem, that is, capital V, the voltage across the combination is, as you can see, is simply E by s minus this voltage, minus the drop in R and C.

Why minus, because the current flows in the opposite direction. So minus R plus 1 over CS multiplied by I and if you substitute this value of I, it is very easy to see that this is identically equal to 0, that is, V of t is identically equal to 0. This voltage is identically equal to 0. Now, as I said, this is one of most interesting circuits and I shall now, as an annexure to the solution of this problem, meanwhile is there a question?

Student: Sir, At t = 0 minus, the entire current flows through

Sir: The resistance?

Student: (..)

Sir: Correct.

Student: V t should be 0 at 0 minus because all the charge to the capacitor will discharge through the inductor.

Sir: At t equal to 0 minus the battery is there.

Student: Inductor is short

In that way short yes

Student: all the current flows through inductor and there is no current through capacitor.

Sir: Correct, capacitor is fully charged.

Student: the capacitor should discharge through.

Sir: No, capacitor is fully charged, fully charged at t equal to 0 minus. The voltage across the capacitors is equal to E and therefore, there cannot flow any current through the circuit and then as soon as the battery is disconnected, current has to flow, so it flows in the capacitor, in the opposite direction, to discharge the capacitor and ultimately, after infinite amount of time there is no current and the voltage, even though a current flows in the loop, the element values conspire to make this voltage drop across the combination equal to 0.

Now this is, as I said, one of the most interesting circuits of network theory and if I draw the circuit again.

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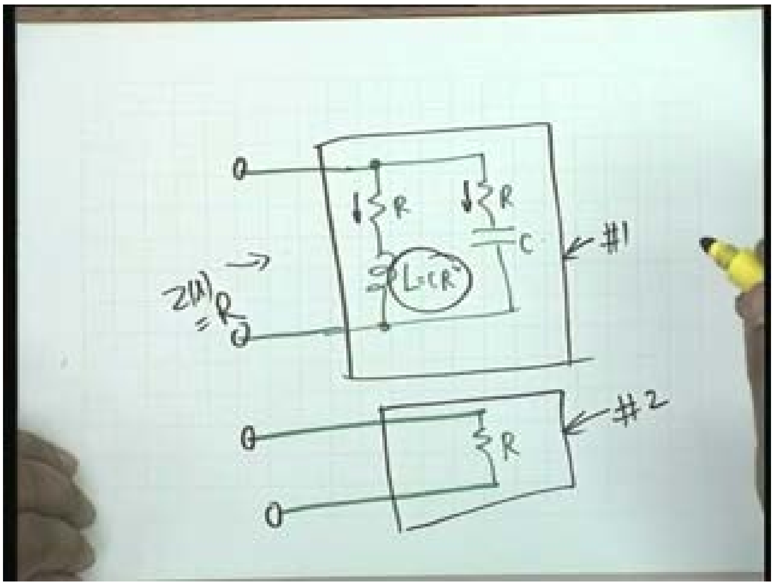

R L, R C as an annexure to the working out of the problem, let me point out that if this is enclosed within a black box, let me look at the black colour. If this is enclosed within the black box and you have you have a resistor R, also enclosed within a black box, call this box number 1 and box number 2. By measurements from the terminals, it is impossible to tell which box contains 1 pure resistance and which box contains the inductance and capacitor. There is no way it can be done. This is one of the ways that people try, to connect the battery and open it.

But as far as external manifestations are concerned, suppose you connect a battery here, suppose you connect a battery. The current at 0 minus would be E by R. At 0 plus, no current, right, no current. In other words, what happens in this is, whatever current flows in this branch, the negative of this must flow in this branch. Do you understand what I mean? So that total current here is 0 and obviously, if there was a battery and the battery is switched off, the resistance cannot store any energy and therefore, the voltage is identically equal to 0. This happens with this circuit also. People have tried many different ways to distinguish between the 2 circuits, they have failed.

Student: Is it because it the special value of the inductance?

Sir: That is correct it is because of this special current

Student: Makes the resonance frequency, I mean, it makes it resonant at all frequencies.

Sir: One of the poles cancels with 0. If you find out the input impedance, the input impedance is identically equal to R, identically equal to R. So the poles and zeroes cancels itself.

Student: Can it be short at the input terminal at 0 plus?

Sir: Try it out, if you can do it, that would be news.

Student: Sir is this regardless of the kind of the battery.

Sir: Regardless of kind of it, it could be a sinusoidal source, it could be a triangular voltage source, we do not care, it could be a current source. There is no way that it can be distinguished from.

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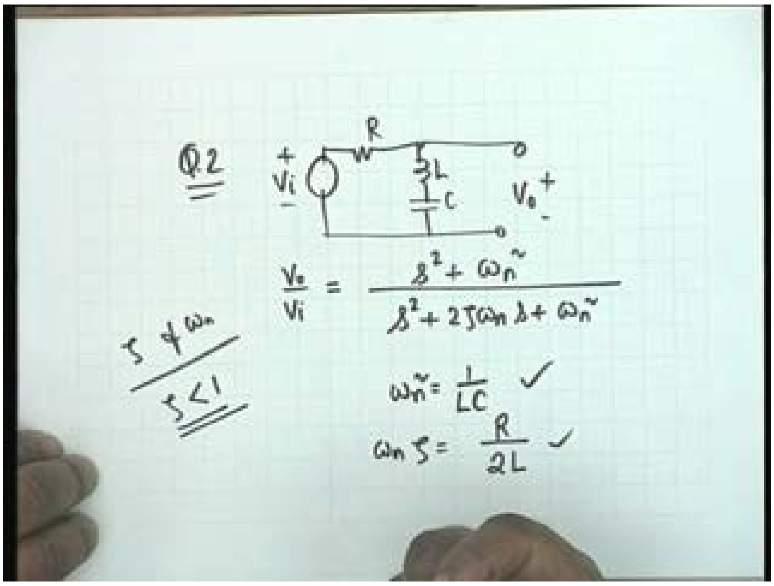

Question number 2 is, the first part was absolutely simple, there is no problem in this, L and C, there are no special values, this is V 0. The question was; in the network shown below write an expression for the transfer function, that is, v 0 by V i and I wanted in terms of zeta and omega n, zeta and omega n and I also stated that zeta is less than 1. There were questions in the exam hall why this is not needed? Why this redundant information? It is okay, life is full of redundant information. You can take it or leave it, it is given but it was not redundant here because if zeta is not less than 1, then you would not be able to say that the poles are complex.

So this is a useful information and by simple algebra, it is easy to show that the transfer function is s squared plus twice zeta omega n s plus omega n squared, where omega n squared is equal to 1 over L C and zeta is equal to R by 2 L, is that right? Zeta omega L is equal to R by 2 L, is that okay? So this is, this part is absolutely fine. The part which baffled you, should not have baffled you, but .t did, is the sketch of poles and zeroes. You see, if you look at the transfer function, obviously, the zeroes are 2 in number, twice zeta omega n s plus omega n squared.

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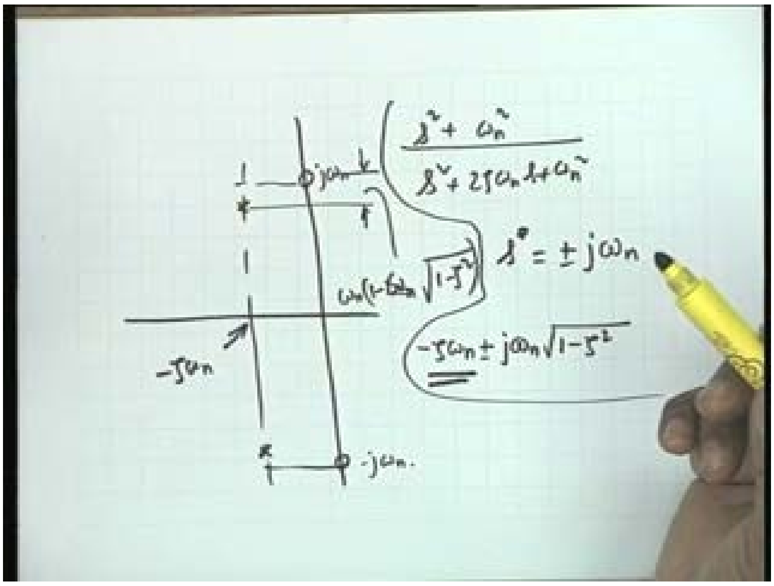

The zeroes are obviously, at s squared equal to minus omega n squared and therefore, this should be s equal to plus minus j omega n. There are a few who found the, who plotted the zeroes on the real axis, 1 at minus 1 by square root L C and 1 at plus 1 by square root L C. Obviously, that is unpardonable because s squared plus omega n squared equal to 0 has the solution s squared equal to minus omega n squared and if you want to take the square root of minus 1, it has to be j, plus minus j. These are the zeroes.

The second thing that baffled you was, the poles are, obviously, at minus zeta omega n plus minus j omega n square root of 1 minus zeta squared and therefore, they have the real part. I have the zeroes here, this is j omega n and minus j omega n. For the poles, the real part is minus zeta omega n. So I go a distance of minus zeta omega n, on the left hand side. Then note the imaginary part. The imaginary part is less than omega n, it is not greater. Many of you, about 30 percent of the class showed somewhere here, at the top. No, it shall be less. It is somewhere here, where this distance, this distance is omega and multiplied by square root 1 minus zeta squared. Some of you, over enthusiastic ones.

Student: (..)

Sir: Okay.

Student: (..)

Sir: That is right, so this is omega n 1 minus, 1 minus this, thank you. This is j omega n and this is j omega n 1 square root 1 minus zeta squared, so there is a difference between these 2. Some of you, over enthusiastic ones, thought that zeta much less than 1 may have been called for. No, unless that is called for, why should you assume that? I did not say that zeta is much less than 1 and they said that poles and zeroes are at the same point. Well, if poles and zeroes are like that, then it is a very different situation and we have to be a careful about this.

There is a slight difference because of zeta and even if zeta is point 2, zeta squared is much less than 1, that is correct. But it would not be correct to put the poles and zeroes in the same vertical level because that changes the situation completely. The other part was, give a rough sketch of the variation of the magnitude and phase of the transfer function with frequency, clearly indicating the frequencies of maxima and minima and transitions, if any, and the values there.

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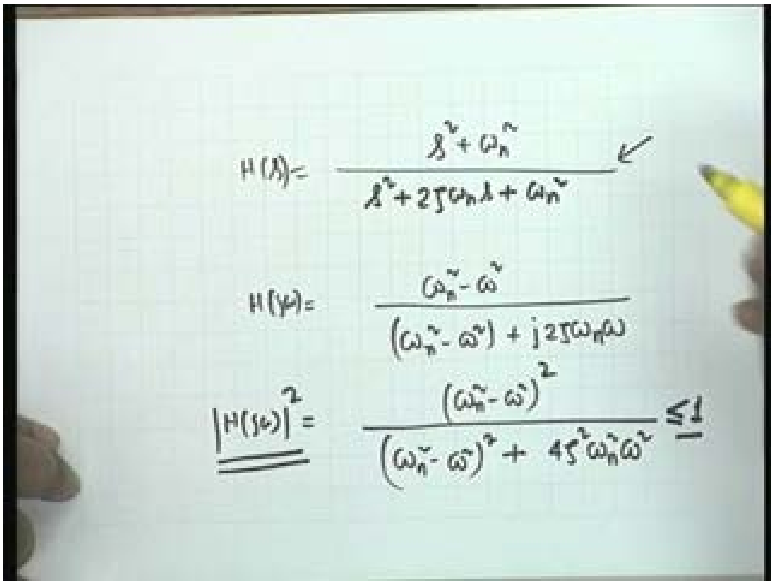

My transfer function is, now, this is sum, this is a part where I did not find a single satisfactory answer. What I have to do is to find, is to plot the magnitude and phase with frequency. Clearly indicating where this is maxima, minima or transition. Transition, obviously, can occur in phase, not in amplitude. One of the mistakes that many people did was to draw the peaking circle. The peaking circle is not applicable here. Why not, because the numerator is not a constant, it is only if the numerator is a constant. Even in the bank pass case or the high pass case, the peaking circle, as was done for the low pass case, was not applicable.

So no question, no peaking circle, no. You have to look at the expression. If you look at the expression, you see that H of j omega is equal to omega n squared minus omega squared divided by omega n squared minus omega squared plus j twice zeta omega n omega. This is the expression and then look at the magnitude. H of j omega magnitudes square, let us say, let us take this square. Now, something will be obvious. Omega n squared minus omega square whole squared divided by omega n squared minus omega squared whole squared plus 4 zeta squared omega n squared, omega squared. And it does not take any special intelligence to observe that this magnitude cannot exceed unit, because the numerator is a whole squared, it cannot be negative. The decontaminator, that is, sum of 2 whole squared, cannot be negative either and this terminal identical to this, so the denominator is always greater than or equal to the numerator.

So this must be less than or equal to one. In other words, the maximum possible value is 1. Now how can 1 be reached, that is the question. Well, for that, either you look at this or you look at this. Let us find out at s equal to j 0, that is, at 0 frequency. 0 frequency omega n squared by omega n squared, so the magnitude is 1. At infinite frequency, it is this term which dominates, this term which dominates. So infinite frequency also, the value is 1. There is no other value in between where it can reach 1 and therefore, the plot must start the magnitude

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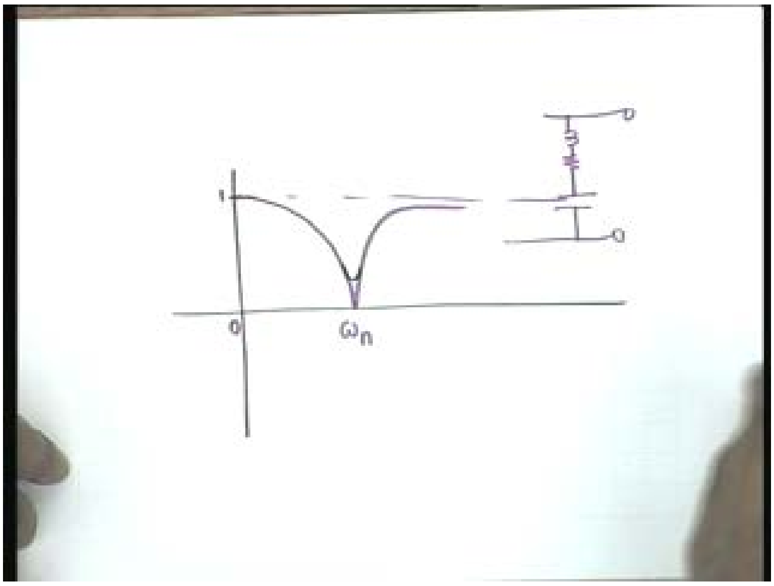

It must start at 1 and end at 1. Also, it is obvious that at omega equal to omega n, the value is 0. So the minimum value is 0, at omega equal to omega n and the maximum value is 1 occurring at 0, as well as at infinity. This is the magnitude for it. Yes, any question?

Student: Sir is not it differentiable at omega n?

Sir: is it differentiable at omega equal to omega n?

Student: No.

Sir: No, there is a sign change, there is a discontinuity. You can see it from here that omega is, there is a phase discontinuity at this point. So it just comes like this and it goes like this. it is not a smooth curve. However, let me point out. If your output was taken across a real inductor, which has a small resistance in series and a real capacitor, if the output was taken across this, then what would have happened is, this sharp dip to 0, would have rounded off like this. Then it is differentiable and there would not be a discontinuity in the phase. Phase would also be smooth.

Now let us look at the phase. Is there any question on the magnitude? A magnitude cannot have, well, these are not strictly maxima or minima, is that point clear? Mathematically, highest value, these 2 are the highest values and this is the lowest value, lowest value is not a minimum, but in electrical engineering, we use loosely. We do not care whether the slope exists or not, maxima and minima. It is in that sense that I used these terms.

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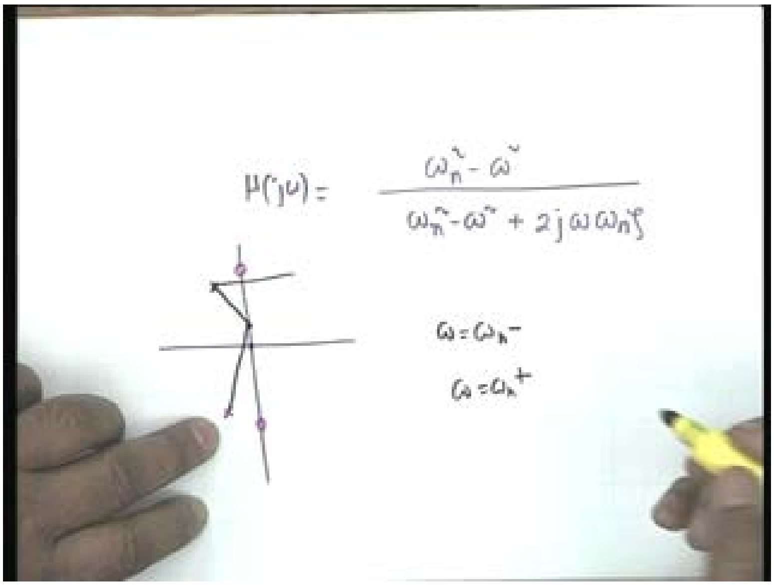

Now let us look at the phase. I have omega n square minus omega squared divided by omega n squared minus omega square plus 2 j omega, omega n zeta. 2 or 3 of the students ignored this term, say zeta is, or let me not, let me not tell you that the mistake. Above, as far as phase is concerned, you notice that the numerator term is positive, if omega is less than omega n and is negative if omega is greater than omega n. Obviously, there is a phase change at omega equal. There is a phase transition through 180 degrees and if you have looked at the pole 0 diagram, the poles are here and you notice that if you draw the vectors, this is one way, let us say, at 0 frequency, obviously, the phase due to this 0 and this 0, they cancel each other. So the phase becomes 0 and then due to this vector and due to this vector, the 2 phases also cancel each other.

So the phase starts from 0 at dc. At infinite frequency, well all of them tend to infinity, all vectors tend to infinity, so again the phase is 0. In between, suppose, omega is slightly greater than 0, then this angle, this angle has decreased, whereas, this angle has increased and therefore, the angle due to the 2 poles is positive and the total angle would now be negative. Therefore, between omega and omega n, the phase is negative. What happens at omega equal to omega n?

Student: 180 degree.

Sir: If omega equal to omega n minus, not exactly at omega n, the phase becomes?

Student: Minus pi by 2.

Sir: minus pi by 2 and if you go to omega equal to omega n plus, the phase becomes?

Student: Plus pi by 2.

Sir: Plus pi by 2 and therefore, that is all that is required for a phase plot.

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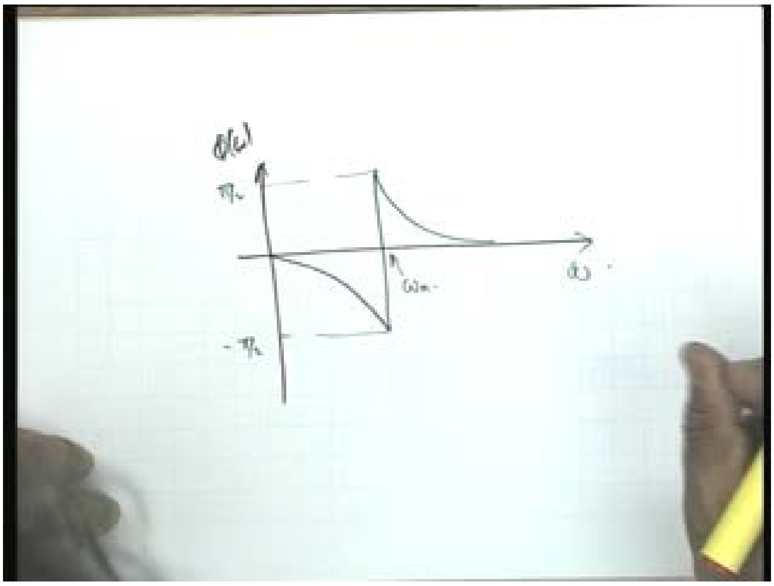

Therefore, the phase plot phi omega would be like this. It goes like this, now there is a problem here, there is a problem here about the curvature. Is it like this or like this, tan inverse, it is a plot of tan inverse and tan inverse plot is always like this. There is a curvature problem, be clear about this. So it goes to minus pi by 2, at omega equal to omega n, it goes through a phase change of 180 degrees, so it goes to plus pi by 2 and then again it goes to 0. This is the phase plot. This frequency is omega n.

Next, third part very few people have attempted and I thought that would be very simple, this concerns the half power frequencies. Now obviously, the maximum power, if you look at the magnitude plot, obviously maximum power, is a dc or at infinite frequency. Maximum value of the magnitude function and half power would therefore, mean the frequencies at which the magnitude becomes 1 by root 2. It has nothing to do with omega n, it is not a selective response. It is not a high queue, accepter type of response, it is a rejection response. It has nothing to do the value at this point. Value at this point is 0 and 1 by root 2 of 0 is also 0.

So the half power frequencies always refer to the maximum and the maximum is 1 and therefore, you have to find out where the value is 1 by root 2 and in order to do that, we look at the magnitude again.

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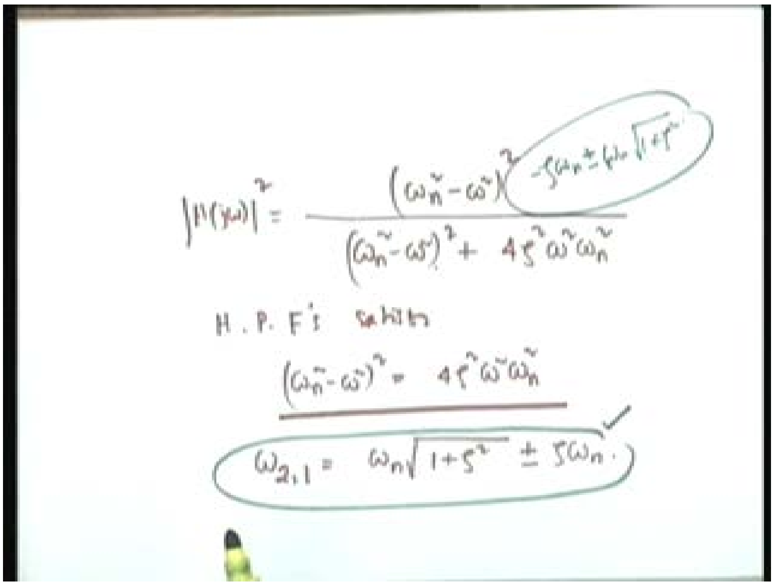

If you recall H of j mega magnitude squared, I am taking this square so that I do not have to work with the square roots. It is omega n square minus omega squared whole squared divided by omega n squared minus omega squared whole squared plus 4 zeta squared omega squared omega n square, is that okay?

Now obviously, half power frequencies would be reached when this term is equal to this term. You do not have to write this is half and then simplify. It should be obvious, when in the denominator both the terms are equal, obviously, the magnitude square would be equal to half and therefore, half power frequencies satisfy omega n squared minus omega squared whole squared equal to 4 zeta squared omega squared omega n squared and how many half power frequencies shall be there?

Student: 2.

Sir: We want 2, is not it? Unfortunately, this is a quadratic equation and you shall have 4 solutions. 2 of them will be negative and 2 of them will be positive. It is the positive ones which you have to take and the algebra simply shows that omega 2 1 shall be equal to omega n 1 plus zeta squared plus minus zeta omega n. This is the solution. Now let me tell you where you made a mistake.

Those of you who attempted, but did not get it correctly, made a mistake that they wrote 1 of the solutions is, well some of you wrote minus zeta omega n plus minus omega n square root 1 plus zeta square, in which, one of the frequency is positive, the other is negative. Is not that right? The correct solution should be this, in which, both of them are positive. You see obviously, this term is greater than zeta omega n, so both of them are positive and this is the correct solution.

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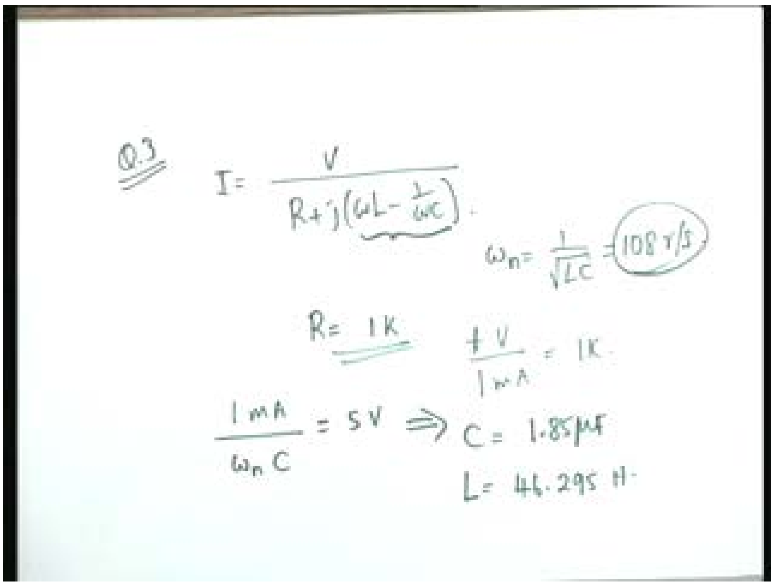

The third problem concerns a double tuned circuit, but only in a very small part. Most of the problem concerns a single tuned circuit and I do not know why it did not occur to you that it is a problem concerning a single tune circuit. Majority of the questions asked, relate to a single tune circuit. It is given that the current in a single tune circuit, attains a maximum value of 1 milli ampere at 108 radiance per second. What does that mean? It means that at the frequency, well, current in a single tune circuit is R plus j omega L minus 1 by omega c.

It is not proper to be conditioned by the circuit that we examine in the class, that is, we took the output across the capacitance, voltage across capacitance is current multiplied by 1 by omega c. So there is an additional factor, additional frequency term there, whereas, this is simplicity itself. It is only the current in the circuit. Obviously, the current shall attain a maximum value when the reactive part is 0 and therefore, what is given is omega n 1 by square root L C is equal to 108 radiance per second.

Those of you who multiplied this by 2 pi, made an unpardonable offence. It is given in radiance per second why should you multiply by 2 pi? So omega n is given. It is also given that the maximum current, maximum current obviously is reached. At this frequency, the maximum current has to be V by R and the source is, source is 1 volt, sinusoidal and therefore, R is equal to 1 k. The maximum current, i max is given as 1 milli ampere, so 1 volt divided by 1 milli ampere is obviously 1 k. So the resistance is known.

The other thing that is known is, under this condition, that is, under current resonance, the voltage across the capacitor is 5 volt, which means that 1 milli ampere multiplied by the impedance of the capacitor at that frequency. So divided by omega n and times C. Omega n is given as 108 radiance per second. This is equal to 5 volt, from which you can find out C and if you find out C, then you know what is L. The correct values, my calculation, gives C as 1 point 8 5 micro Farad and L as 46 point 2 9 5 Henry. I hope I am correct. So we found at all the parameters of the single tune circuit.

Then it says, the second parts says, that the single tune circuit is inductibly coupled, loosely to another identical single tune circuit. Now we come to the case that was discussed in the class. A double tune circuit and the output is taken across the resistance in the secondary. This is precisely the case that we dealt with in the class. Output is taken across the secondary, the magnitude response shows 2 peaks, one of which occurs at 110 radiance per second. Well, one of which means, it must be the upper peak.

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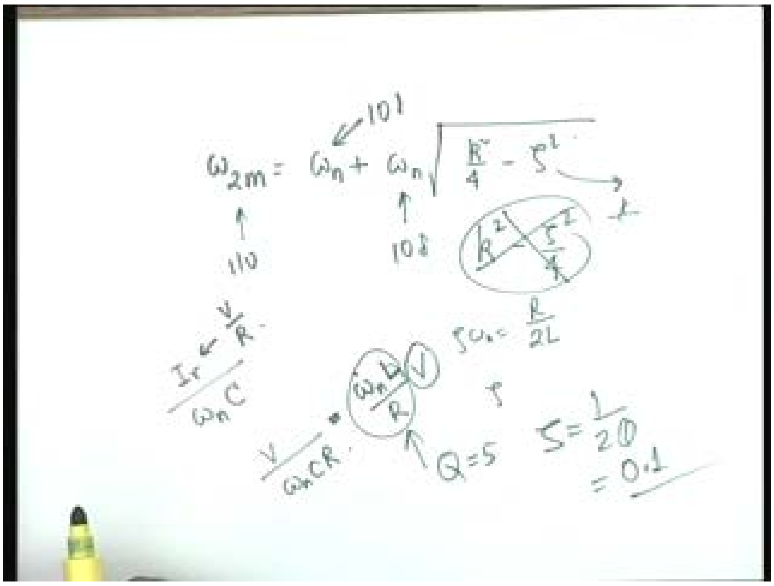

One greater than omega n is the upper peak, one less than omega n is the lower peak. So, and by simple manipulation, we had shown that this maximum, omega 2 m is given by omega n plus omega n multiplied by square root of k squared by 4 minus zeta squared. this is a formula derived in the class, given in the book, figures in your notes, despite all this, I was shocked to see this as k squared minus zeta squared by 4.

Those who had made this mistake know that this was a Himalayan mistake. And in open book, open notes examination, no, sorry, it cannot be done. It should not be done. It is an offence and all that we are given now is, this is 110 this is 108 this is 108, k is not known but zeta, how do you find zeta? Zeta is 1 over?

Student: R by 2 L

Sir: Okay, zeta is R by 2 L.

Student: Zeta omega n equal to R by 2L.

Sir: Zeta omega n equal to R by 2 L from which you find out zeta. Well, the other way is, if you remember, in a single tune circuit, at current resonance, that is, when the current is maximum, a voltage across either the inductor or the capacitor is Q times the applied voltage. Did you know this?

Student: No sir.

Sir: 110, it does not matter, if you did not know it, but now, at least now you should know it and it is very simple to prove. You see, at current resonance, the voltage across the capacitor would be I resonance divided by omega n times C and I resonance is V by R and therefore, this is V by omega n C R, which is equal to omega n times L, no, there is no R. Have I made a mistake?

Student: No sir, there will be an R.

Sir: Which is equal to omega n L by R, multiplied by V and you know this is the Q of the coil. So the voltage across the capacitor is Q times V. I am not complicating the situation. If you remember this, similarly, you can show that the voltage across the inductor is also Q times.

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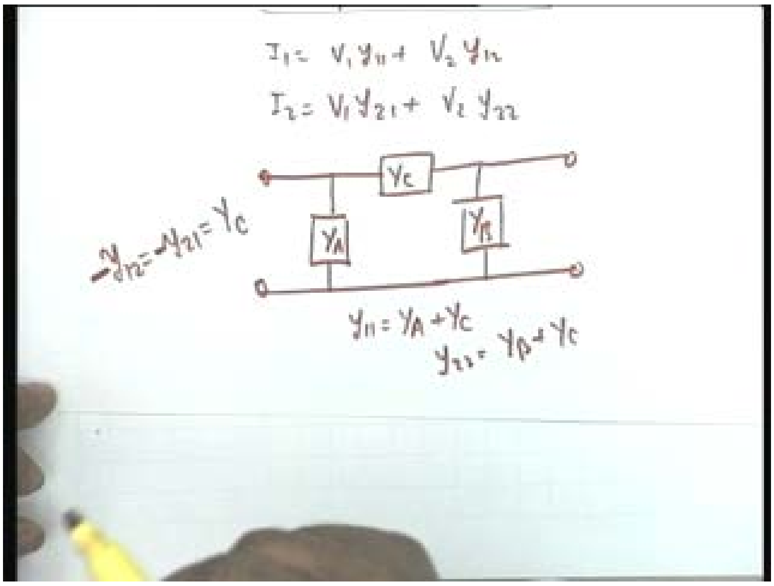

Student: V is the micro voltage of the applied?

Sir: V is either the peak value or the RMS value, it does not matter. Whenever you make a measurement, you measure the RMS value. Even if you take the peak value, it does not matter because you are taking ratios. So Q here is 5 and zeta, as you know, the definition of Q is, Q is equal to 1 by 2 zeta, so zeta is 1 by 2 Q. This is simply point 1, because Q is given as 5. This was another alternative to finding the question. Yes? Any other, any other question? We will do a little bit of recapitulation first, if you recall the y parameters, y parameters of the 2 port.

Well, the defining equations are I 1 equal to v 1, y 1 1 plus v 2 y 1 2, I 2 equal to v 1 y 2 1 plus v 2 y 2 2 and I think, last time, in the last lecture, we had taken an example of the pi network, Y A then Y C then Y B and we said that by inspection, you can see that y 1 1 is equal to Y A plus Y C. y 1 1 is the input admittance, with the output short circuited. So Y B goes out of consideration Y A comes in parallel to Y C. y 2 2 is equal to Y B plus Y C and either by applying the definition or by remembering the equivalent circuit, you can see that y 1 2 is equal to minus y 2 1 equal to Y C.

Student: Sir is equal to y 21 is equal to minus?

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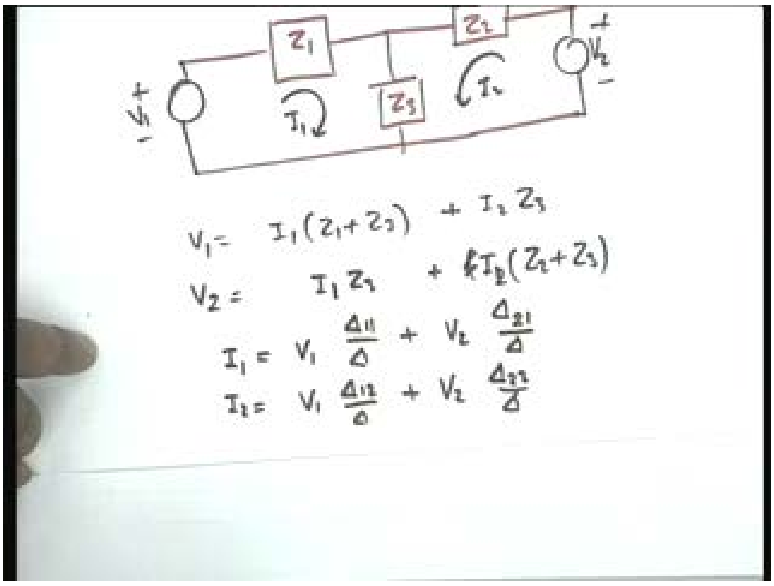

Sir: Minus, both of them are minus. Minus y 1 2 equal to minus y 2 1 is equal to Y sub C. Now, let us take a little more difficult example, that is, we take the T network.

z 1, z 3 and z 2. We are required to find out the y parameters of this network and we shall apply, to find the y parameters of this network, we apply the general procedure. General procedure is, at ports 1 and 2, you connect a voltage generator v 1 and v 2. Then write the mesh equations. Well, there are 2 meshes I 1 and I 2. Write the mesh equations and solve for port 1 and port 2 currents, that is, here, there are only 2 meshes, there could be more if the network is more complicated. You solve for I 1 and I 2 and that should give you the 2, the 4 y parameters.

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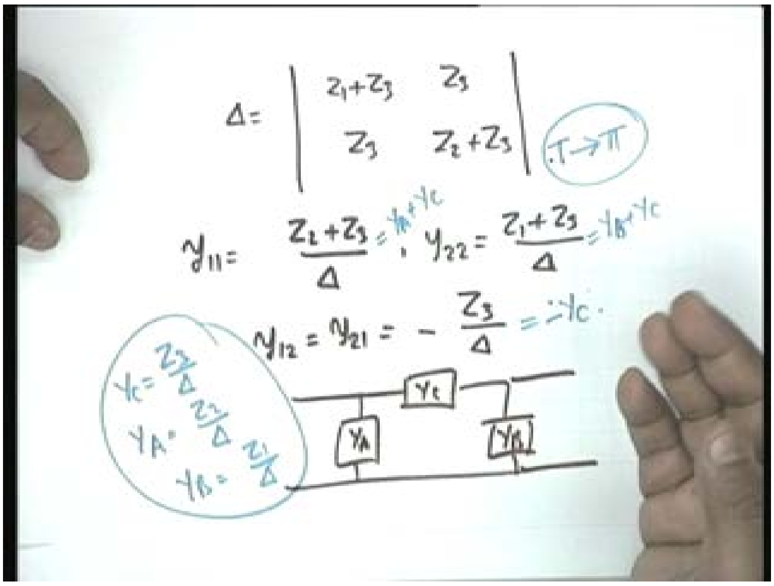

Let us do it. v 1 equal to I 1, z 1 plus z 3, self impedance, plus I 2 z 3 mutual impedance, v 2 equals to I 1 z 3 plus I 1, I am sorry I 2 z 2 plus z 3. So from which I have to solve for I 1 and I 2. I 1, obviously, is v 1 del 1 1 by del, plus v 2 del 2 1 by del, this should be remembered, and the current I 2 is v 1 del 1 2 by del plus v 2 del 2 2 by del, where del is the impedance matrix, del is the determinant of the impedance matrix z 1 plus z 3, z 3, z 3, z 2 plus z 3 and by comparison, you see that y 1 1 is del 1 1 by del and so on.

Therefore, y 1 1 would be equal to del 1 1, so first row and first column goes. z 2 plus z 3 divided by del. Similarly, y 2 2 is equal to z 1 plus z 3 divided by del. y 1 2, which is equal to y 2 1 shall be equal to del 2 1 or 1 2 by del and the sign shall be?

Student: Negative.

Sir: Negative, so minus z 3 by del. Now if any question, if this T network is to be equivalent to the pi, that we had drawn earlier, if this is to be equivalent to this network, Y A Y C Y B, then obviously, what we should do is, we should equate this to, what? Y A plus Y C. We should equate this to Y B plus Y C and we should equate this to, what?

Student: Minus Y C.

Sir: Minus Y C and therefore, we find the values of Y A Y B and Y C. Y C is simply z 3 by del, Y C is z 3 by del

Student: Is minus.

Sir: No minus. It is plus because this is minus Y C, this is minus z 3 by del. Y A would be equal to z 2 by del and Y B shall be equal to z 1 by del. These are the formulas for T to pi conversion, T to pi. z 1, z 2, z 3 are parameters of the T network and Y A, Y B, Y C are the parameters of the pi network. So given, z 1 z 2 z 3, these are the formulas for finding out the parameters of the pi network. We had done the reverse case earlier that is, how to convert a pi to a T and the 2 together, are extremely useful in network analysis and to electrical engineers, in general. We shall close here.