Basic Electrical Technology
Prof. Dr. L. Umanand
Department of Electrical Engineering
Indian Institute of Science, Bangalore

Lecture - 8
Analysis Using MATLAB

Hello everybody, in the last session we discussed how we go about getting the state equation of any circuit whatever be the complexity and then we discussed about what we want to do with the state equations with the mathematical model. Once you have the mathematical representation of the circuit you would like to analyse it, you would like to know the features of the circuit, and the c characteristics of the circuit.

All these you can obtain by studying the mathematical model. Previously one used to do it manually by hand, plot the graphs or do the solutions of the equations by hand all these bull work; today they are done by software and there are lot of software available which makes this job much easier and then you can focus your attention more on interpreting the results and how to synthesise these circuits based on these results.

So therefore, in this session; or in the previous session, this session and in future sessions we will be using one particular software called MATLAB, MATLAB and Simulink. The MATLAB/SIMULINK environment is what we will be using and we had a peak at this MATLAB software in the last session. In this session we will use that MATLAB environment to obtain the waveforms in the various domains the three domains: the time domain, the frequency domain and the pole-zero domain; in all these domains we will like to get the information of the particular circuit. But to the software what we are going to give as input will be the mathematical model in terms of the A B C D matrices of the state equation that will be our input.

Let us take an example. Like in the last class we shall take the example of the simple RC circuit first and then work on bit more complex circuits.

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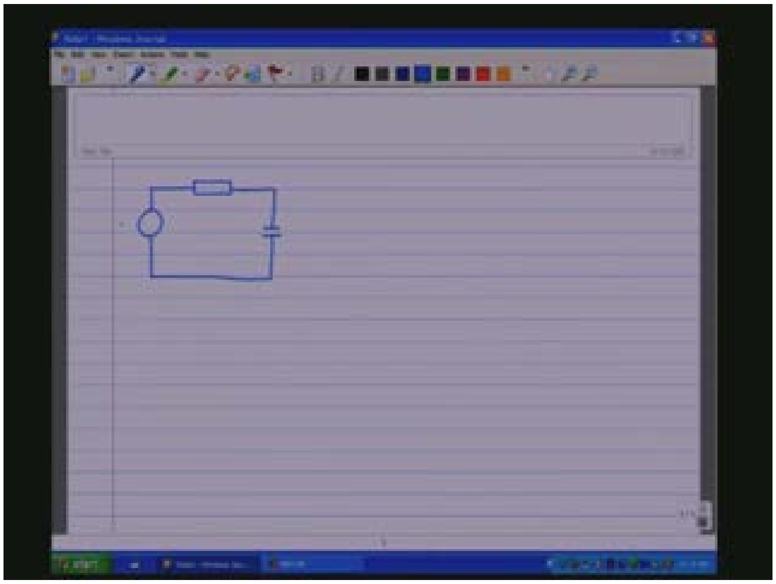

This is an AC circuit which is having a V i source, you have the capacitance C and a resistance R here (Refer Slide Time: 3:55). And in this circuit you have a state variable which is V c and it has only one energy storing element that is the capacitance and therefore only one state variable V c and therefore only one differential equation describing the circuit and that is dV c by dt we have worked this out many times previously minus 1 by RC this is the A matrix into V c plus 1 by RC this is the B matrix into V i.

So, for now let us say V c is the output the output voltage, the voltage across the capacitor that you want to see and this is obtained like that and there is no D matrix which is basically zero. So we have to feed in the A matrix, the B matrix, the C matrix and the D matrix. These are the four matrices that you have to always feed in whatever may be the system because all the systems are describing the standard state space form which is x dot is equal to Ax plus Bu Y is equal to Cx plus Du.

And normally to study the system in the time domain the step response is a key response that gives almost all the characteristics of the system in the time domain. Now that we have the state equation we need to give values for the parameters Rs and Cs so let us give some values for this particular example. Let us say we take this as 10 ohm and let us say we have a capacitance of 100 Microfarads and then apply it and then see what are the responses. So we would like to see we would like to first plot the time axis and obtain the amplitude of course to give an input V i which is a step and if a step input is given what happens to the output this is what we need to study. So output in this case is V c and this is V i so this is called the step response and from this we can study the various characteristics which we will look later on.

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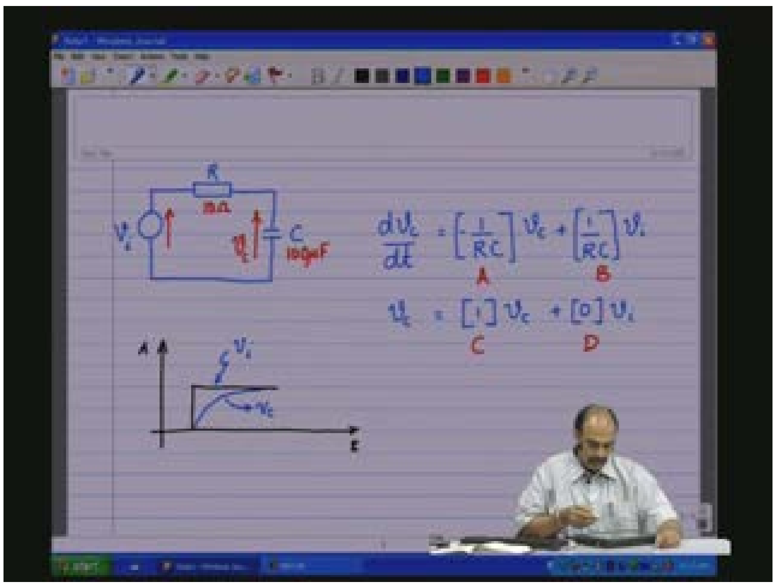

So now we go into the MATLAB domain. So as I was describing yesterday this window what you are seeing (Refer Slide Time: 7:35) is the MATLAB command window, this is the main workspace of MATLAB and this is where you will be keying in the commands and the functions and the MATLAB operates as an interpreter so whatever you are keying in that line that line is executed immediately.

So here I will just open an edit window so that it becomes easier for us to key in the various parameters; I will just park it here.

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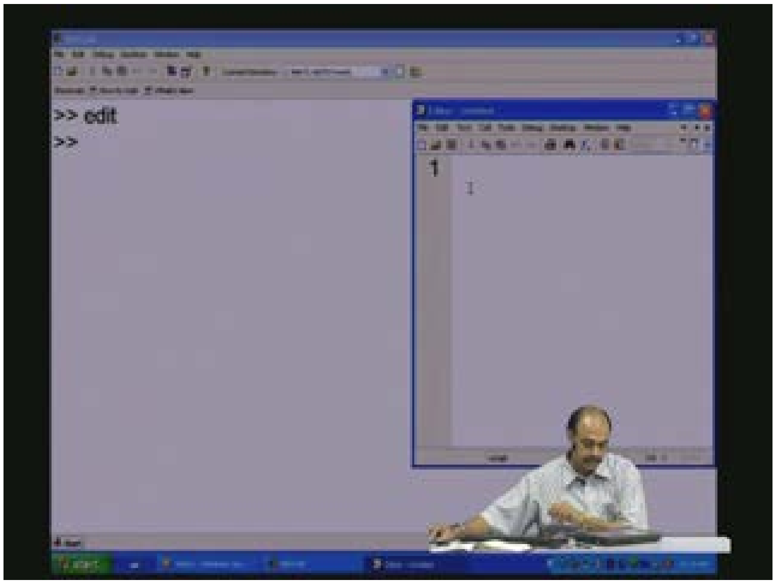

So what are the parameters we have?

Parameters R equals 10 ohms for this circuit, I am not giving the units yes only the numeric value and C is 100 Microfarad so 100 into 10 to the power minus 6 is V minus 6 so R and C are given and now I will define the A B C D matrices in terms of the parameters of course. So now we have the A matrix which is given by minus 1 by R into C matrix close and the B matrix equals 1 by R into C matrix close and C matrix in this case is 1.

You will see the C matrix will change depending upon what you want to monitor what you want to sense and we will probably sense some other variable later on and then see what happens to the C matrix and the D matrix. And the D matrix is in this case for this particular output that you want to sense that is the voltage across the capacitor is just zero.

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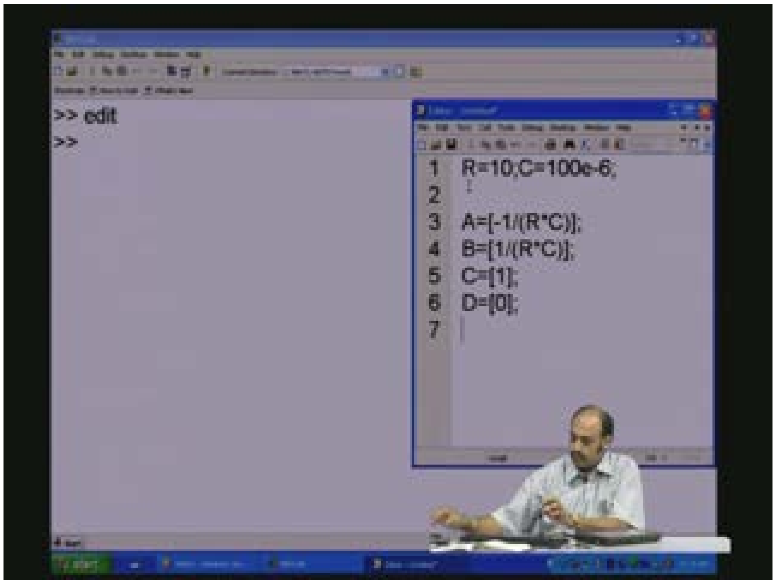

Now this is the model that you will be giving two MATLAB so let us copy this and I will go to the MATLAB command space, give this model and that is it. Now the model is there in the MATLAB workspace.

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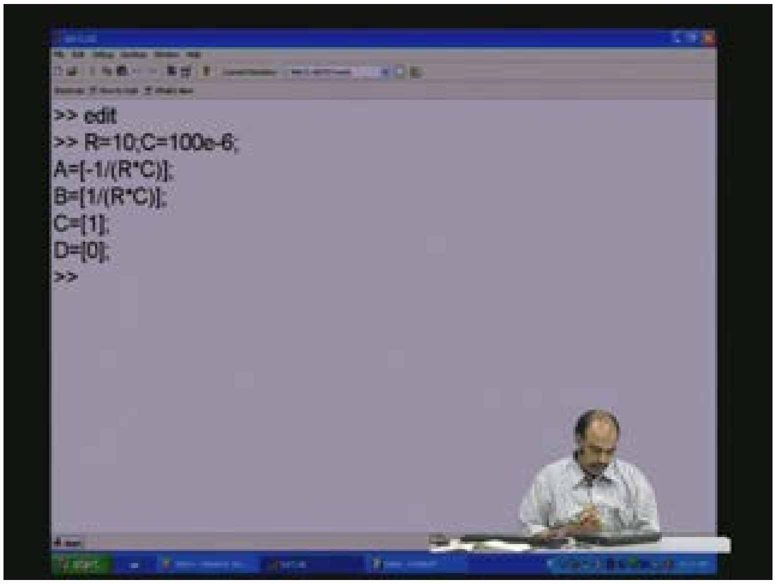

I will clear the screen just to know that all the variables are there. You see that A B C D R all those variables are there. Now there is one particular issue; there are two variables here C; one is for the C matrix and one is for the capacitance so we cannot mix the variables and therefore I will go and change this C as C 1 instead of C and we make this as C 1, make this as C 1 so that there is no confusion about the variables and we again load the model and see.

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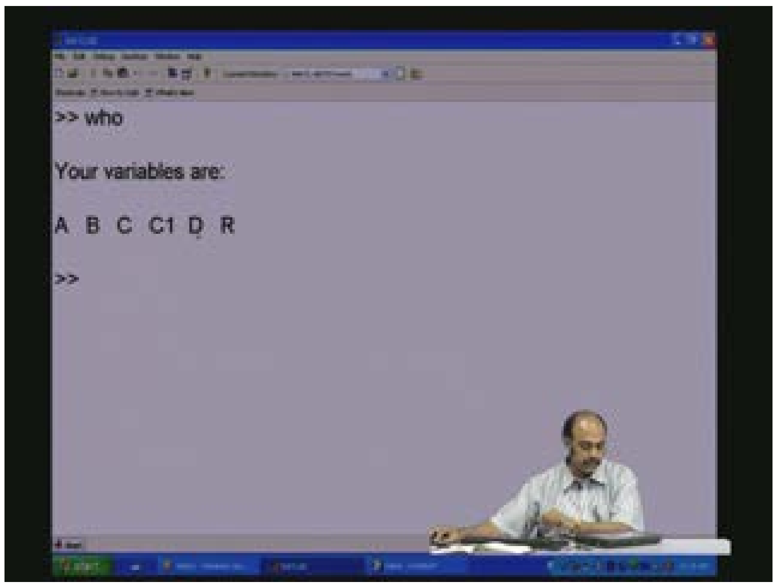

Hence, now we have the A B C D matrices; C 1 and R are the parameters. Notice that MATLAB is case sensitive so it can recognise the difference between the upper case and the lower case. Now we do the first step in this analysis which is the time domain. So to do the time domain let us see the step response. There are various responses that one can get. But for the purposes of understanding now we will do the step response. So to do that we give the step function; I will input A B C D matrices this is the model and let me also plot the grid. So now, on giving this to the MATLAB it is supposed to execute and give you the output OA form.

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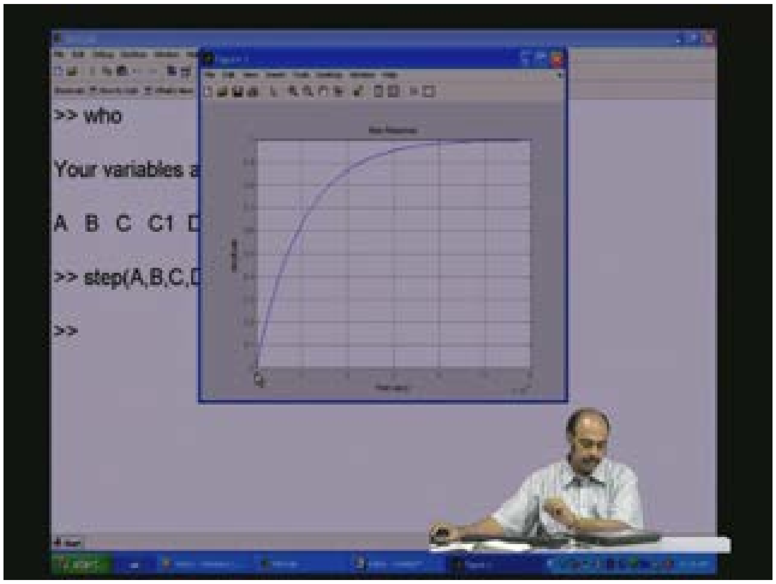

You see this is the step, this is the unit step 0 to 1 this is the step and you see that the waveform the output is rising in this fashion towards 1. So you have the amplitude, the time, you have the grid you can read of what this is about 6 milliseconds so 6 into 10 to the power of minus 3 so you can read of the rise time that is around the 90 percent something like 2 to 2 1/2 milliseconds for this particular frame.

Now you can do a comparative study. For example; you can hold this plot let us say hold this plot so the current plot is held it is not disturbed and let us change some of the values. For example; let us say instead of 100 Microfarads let us make this 10 Microfarads. So, after having 10 Microfarads we again load the fresh model to MATLAB, paste, yes.

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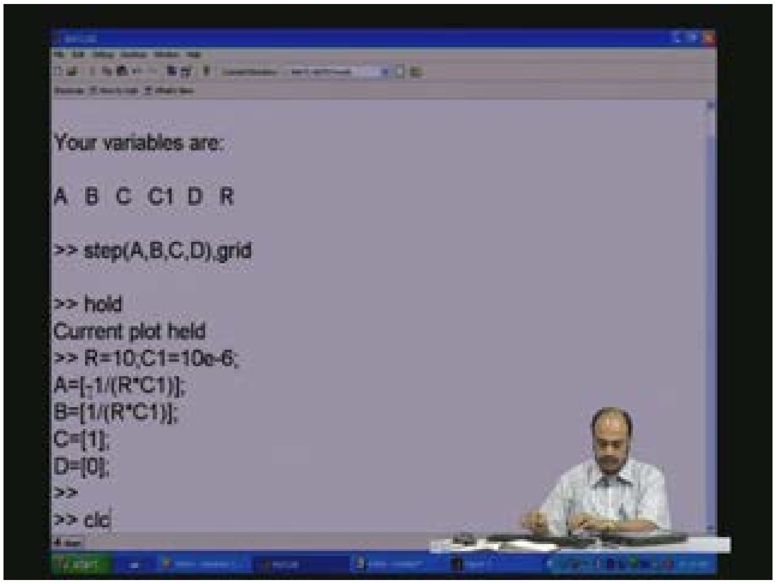

And then again we give step A, B, C, D along with grid. So if we go back and look at the figure you see that this was the earlier waveform blue and in this green colour you see the waveform that we now got with this changed parameters here. Now we have reduced the capacitance C and therefore the time constant RC time constant is reduced and therefore this will be faster. So you can expect it to be faster. You see that it raises to 90 percent something like 0.25 milliseconds against around 2.5 milliseconds in this case. So this is how one goes about doing the analysis in the time domain using the step response. There are various parameters of course which we will like to see.

We will take up few examples and we will know as we go about doing the examples what are the things to look for. And one of the important thing that I was saying is the rise time and another important thing is how long it takes to settle down or reach steady state and another important thing is this is a first-order system and therefore there is no overshoots, there could be overshoots if you have LCs, the resonance effect then you will see that this can overshoot like that and then damp out. So these are some of the things that you will be looking for and trying to tune when you are doing your time domain analysis.

Now coming to the……… yeah I would like to point out to you that you let us copy this figure, go to our notes and let us insert the figure here, no no it is no it is alright. We now go to the next part which is the next domain which is the frequency domain. Let me make some space here, we shall delete that (Refer Slide Time: 16:32).

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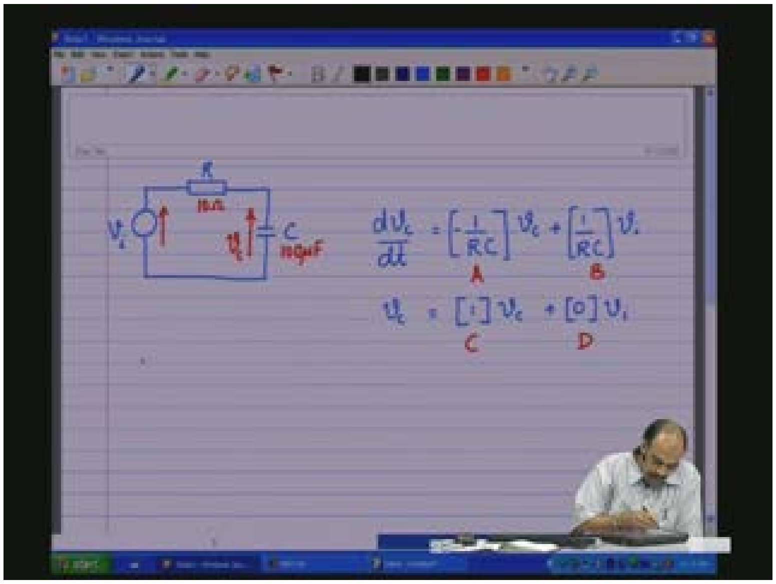

Now, in the frequency domain we like to plot one is the magnitude versus frequency, the other is phase versus frequency this will give you the total information in the frequency domain. Frequency omega is in radiance per second, omega is in radiance per second. So one is the magnitude let us say mag and the other is the phase versus frequency. So we would like to see a waveform as what is happening to the magnitude as frequency changes and also what is happening to the phase as frequency changes. These are some of the issues that we would like to address.

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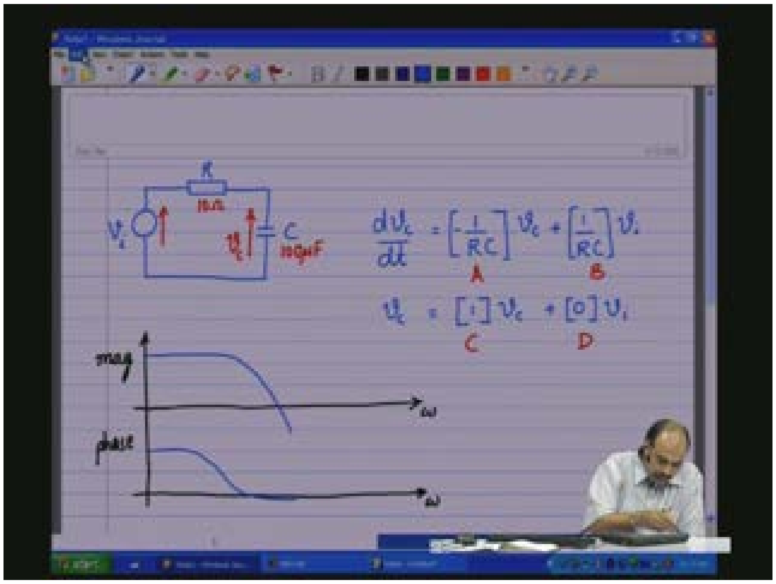

You see that there is specific amplitude at this particular frequency. What it basically would mean is that if you apply an input this is normally given in terms of gain or attenuation in DB, the input gets amplified by this gain or attenuated by this particular gain whatever it is at this particular frequency. So you can get the gains at various frequencies and as frequency changes the gains are varying. So, almost all circuits will act as a filter in the sense that they give different gains at different frequencies. So the gains change as the frequency changes and that gives you as such the behaviour for harmonics. Therefore, for harmonics what is the kind of output that you would get if there is distraction or a non-sinusoidal waveform or different frequencies at the input.

Likewise for the phase also we would like to see what happens to the phase; it may be zero phase to start off with and then gradually go on and become 90 degrees at this particular spot or minus 90 degrees depending upon the circuit or how you define the convention. Hence, these two together define your frequency response or the frequency plots and this is generally obtained using what is known as the bode plots. There are other frequencies response plots, photo series plots all those issues but still the bode plots gives you the frequency response plots for the circuit or the system.

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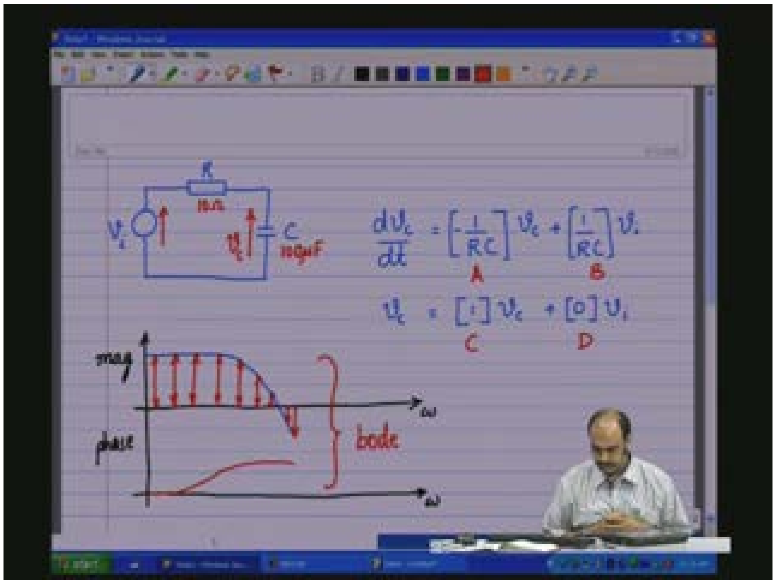

Now we go to the MATLAB domain. We already have the A B C D matrices as given here. We again start with let us say 100 Microfarad the earlier one, copy that, and let us paste it so we have the model.

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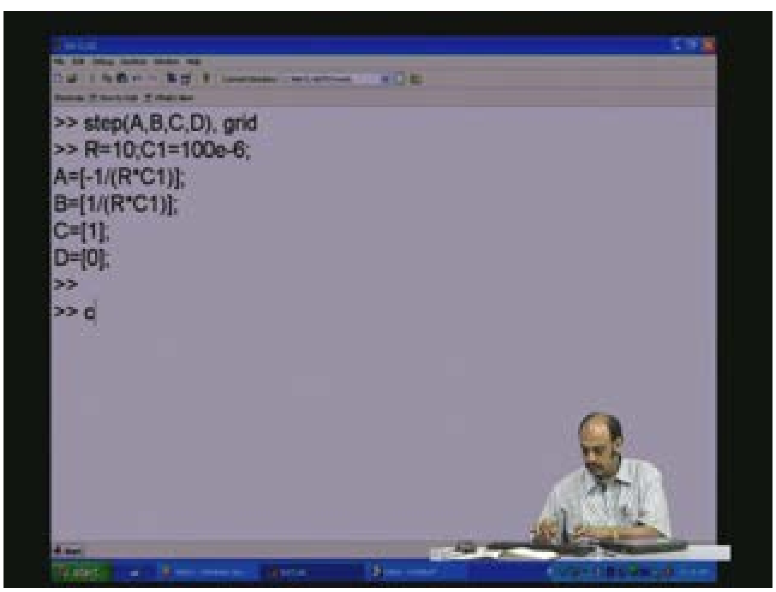

Now we want to see the frequency response I will use bode A B C D and the grid so it calculates and it gives a plot. You see I told you that we are having two plots: one is the magnitude plot versus frequency; the other is the phase in degrees versus frequency. So in this particular diagram you see this blue line (Refer Slide Time: 20:57) this is the way the gain varies the gain would vary as it changes. In dB means 20 log the gain. So whatever the gain the output by input so logarithm of that one into 20 so 20 log base 10 the gain is the dB which is being plotted here. so when you say it is a 20 dB you talk of 10 by 10 attenuation minus 20 dB means at this frequency varies by 10 attenuation and minus 40 dB means at this point there will be a hundred times attenuation. So if it is plus it is amplification and if it is minus it is attenuation. So this particular circuit does not attenuate at this.

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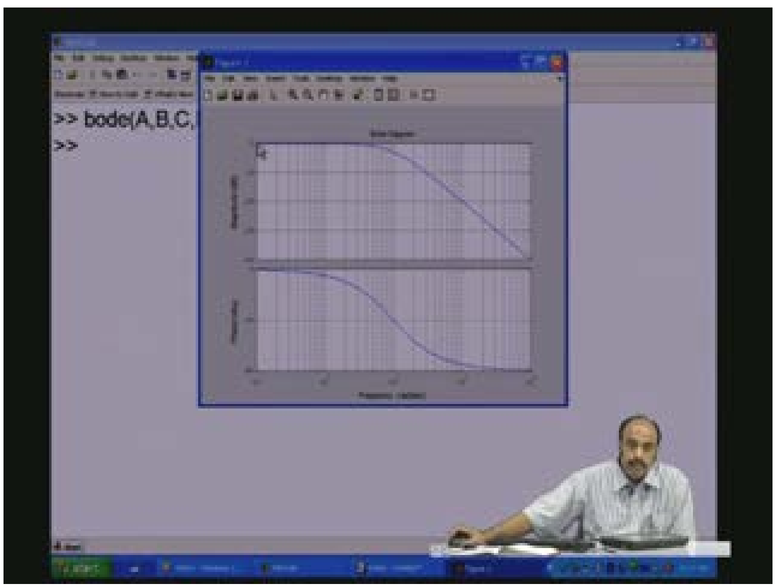

When you say 0 dB during this portion the circuit does not attenuate. Meaning whatever is applied at the input it comes to the output but as the frequency starts increasing then it starts attenuating more and more and as frequencies becomes higher and higher it starts attenuating more and more. In fact, it is also evident when you go back to the circuit, have a look at the circuit you see here (Refer Slide Time: 22:16) this is the capacitance and we are talking of output across the capacitance. So what is interesting is capacitance blocks DC so it has a very high impedance to DC, there is absolutely it is like open circuit for DC. So during the DC portions that is during the DC portions here (Refer Slide Time: 22:41) this is the DC portion, when the frequency is zero it is DC and the frequency keeps increasing it becomes higher and higher frequency.

During the frequencies which are DC and close to the DC there is this capacitance is something like an open circuit so whatever you apply at the input comes to the output. And during the portion when the frequency starts increasing still much higher the capacitance starts giving lower and lower impedance. Ultimately at very high capacitance or high frequencies this will act as a short and the output will go towards zero and therefore the attenuation keeps going. That is how the meaning would be of this particular gain waveform.

And look at the phase that is there is a phase shift between the input and the output. So if you give a phase shift of some…….. if you give a particular waveform some particular angle, with respect to the input the output is not phase shifted at this near DC and 0 near DC frequencies but the phase shift is gradually increasing in the negative direction because it is a capacitance and ultimately goes to 90 degrees when the frequency becomes pretty high. This means that at very high frequencies when it is truly behaving more the capacitance and the resistance is swamped out it is a capacitive load and therefore you have a 90 degree phase shift so this is the meaning.

Therefore, both the magnitude and the phase is important when you have to discuss the response of this circuit to any input waveforms in the frequency domain. This is the bode diagram or the bode plot.

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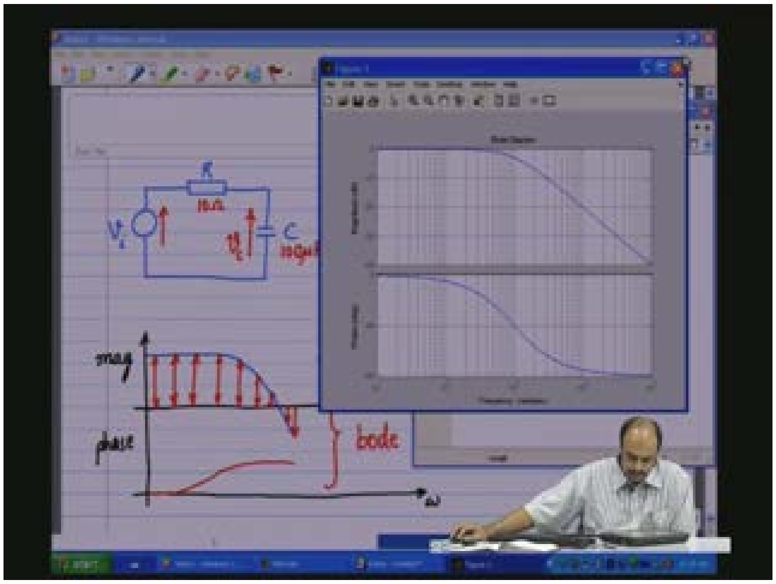

Now coming to the third aspect; what is the third aspect?

The third aspect is on the pole-zero plots or the pole-zero domain. So we like to also analyse the system in that domain. you should know that the system is the same, the circuit is the same, the parameters are the same and the circuit and the system is existing only in the time domain however you can view it in these three major domains that is the time domain, the frequency domain and PZ or the pole-zero domain to get many other characteristic information about the circuit which will help you in tuning the circuits, designing the circuits much better.

So in the pole-zero domain we like to get the plot of the S-plane. This is the S-plane, this is the omega axis, (Refer Slide Time: 26:02) the y axis, this is called the sigma axis or the real axis; this is a complex plane, you can say sigma and J omega axis because it is a 90 degree phase shift.

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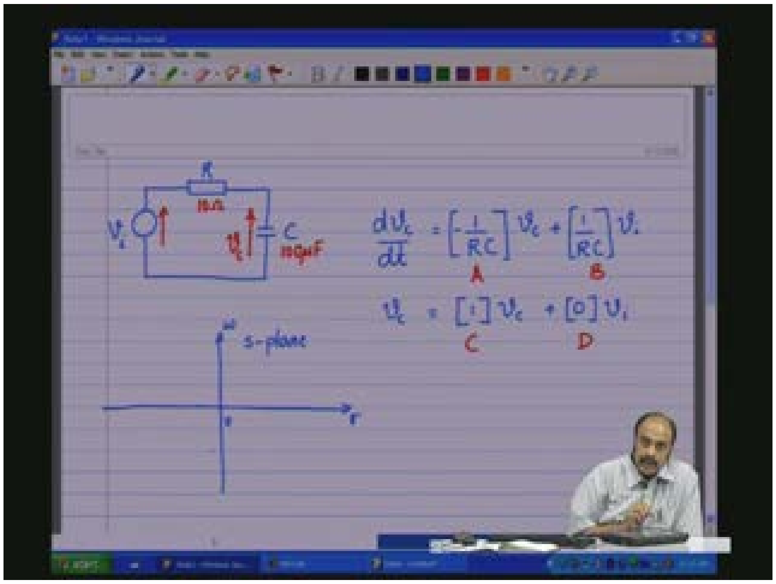

Now in this S-plane, as I was mentioning in the last class only the right half of the S-plane is important sorry I said right now only the left half of the S-plane is important as I mentioned here; important in the sense that all physical systems will have their poles and zeros located in the left half of the S-plane because that is the stable region, this is the stable region and the right half of the S-plane implies that if you have a pole on the right of the S-plane you will have an exponent to the power of whatever A or B T and then you can have a growing exponent which is in an unstable condition and that is why this region the right half of the S-plane is called the unstable region.

So all physical systems that exist in nature have to be stable and therefore they will have their corresponding poles and zeros in this region and not here (Refer Slide Time: 27:32). So, if you, by mathematical modelling find a pole in the right half of the S-plane you have to make doubly sure that whether it is a physical system or not because you are now dealing with an unstable system and we probably will get most of the time a plot the complex of the complex plane corresponding to the left half of the S-plane.

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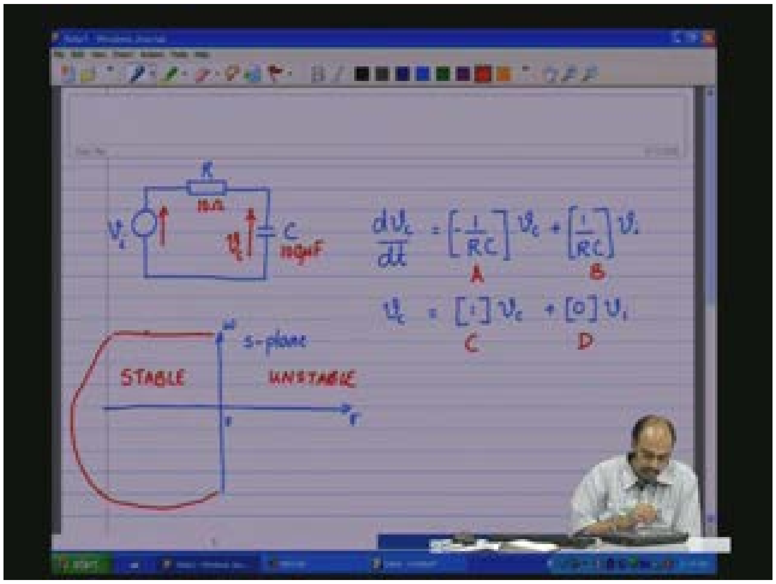

Now let us see what would what are the things that are to be plotted. One thing that you should note that this is a system which has only one state variable, one differential equation and therefore there is only one route to the characteristic equation or one eigenvalue and therefore there will be only one pole and that one pole will be on the real axis because if you have a pole a complex pole then you have to have a mirroring mirror image also.

Let us now look at the third domain which is the pole-zero domain. Now here again we go back here and see that we have the parameters. We take the model, paste it here and then you have the model in MATLAB. There is one function called pzmap p zmap or pole-zero map this is the function and to that function we input the model A B C D and let me give grid.

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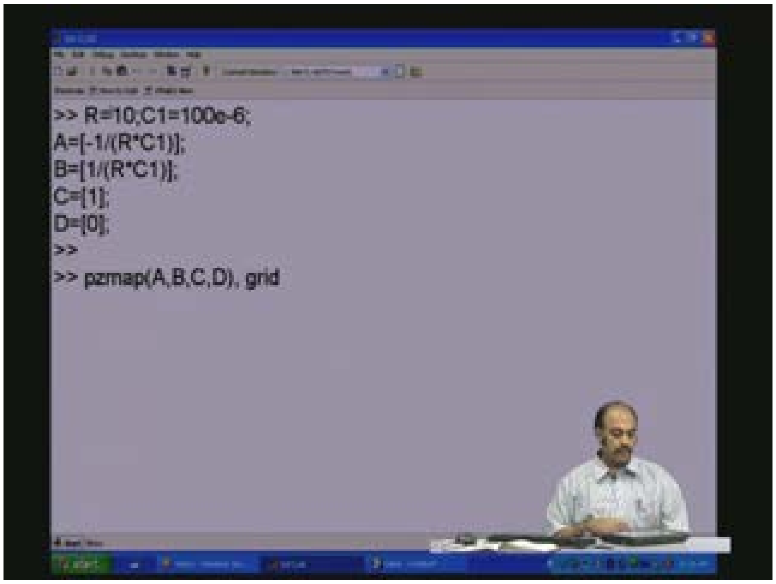

So you see that the S-plane……… and here like I was saying this is zero and then all going negative which means only the left half of the S-plane; the right half of the S-plane is not shown here because there is nothing there to show, there are no poles there. So all the poles are located of course here in this left half of the S-plane and that is at this point (Refer Slide Time: 30:05). Are you able to see this blue X mark here? That is the location of the pole for this circuit.

Now this contains lot of……., of course vertical and horizontal lines and also radial lines. What it basically means is that if there are complex poles these radial lines indicate the damping; if it is on the real axis it is well damped over damped in fact and if it is on these radial lines there will be some oscillation before it gets damped and there will be………….. in fact these lines were as you start going towards the imaginary axis or the omega axis you will have larger amounts of oscillations but which will have a rate of decay which will gradually decay depending upon whatever the projection value is on the x axis.

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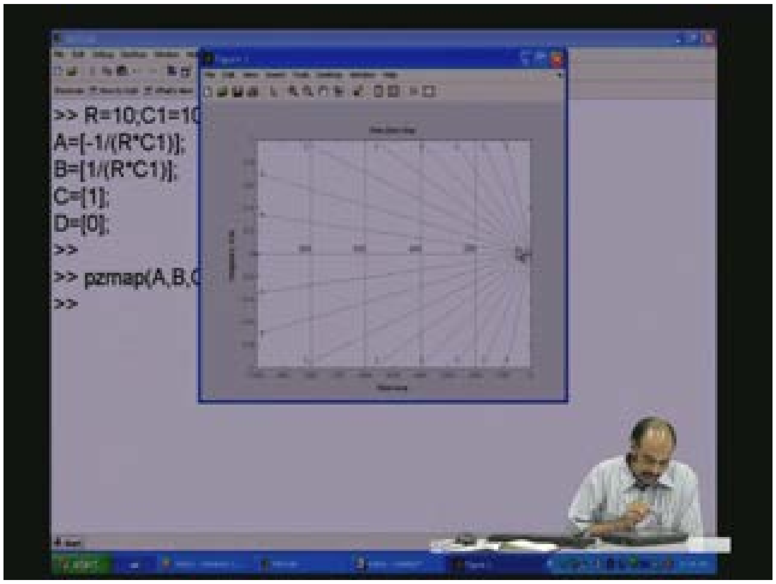

Now let me just hold this plot and after holding this plot let us change the value of the capacitance C 1 to 10 Microfarads; let us copy that, paste that here and now you have the new model in place, clear the screen now just before that we again look at the figure and then see that this pole is at minus 1000 and if you now see for the new model with changed parameters you see that there is a pole here at minus 1000; the pole of the changed one the one which you see here in green is at minus 10000 (Refer Slide Time: 32:23). It means that the pole is much further away from the imaginary axis and therefore it is faster.

As the pole moves more and more away from the imaginary axis the system becomes faster and faster which means this system which has the frequency in radiance per second as 10000 (Refer Slide Time: 32:45) as compared to this system which has a frequency and radiance per second as 1000 will definitely be ten times faster that is what we saw in the time response where with the 100 Microfarads you saw the rise time of 2.5 and in the case of the changed parameter where C 1 was changed to 10 Microfarads you saw that the time rise time was 0.25 milliseconds. So there is the correlation.

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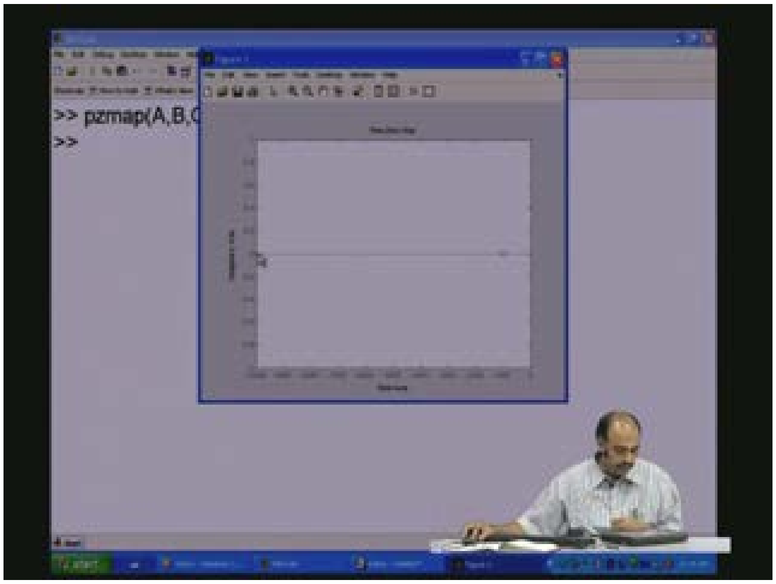

In fact, now you can place the pole accordingly and you get the so that you get an idea of what are these damping things the character of this pole here. The overshoots would be 0 percent if you place it here, damping is 1 frequency and the pole positions which will I mean…………………… so you can position the pole accordingly on the pole-zero plane and then get back what should be the R and C value such that you get this pole condition and thereby you can design your circuits.

This is an example that I showed you (Refer Slide Time: 34:08) there is the R C circuit. But probably you will have to try it out with more examples; but still, however, I will probably do one more example with an RC circuit so that we get more familiar with the operation of the MATLAB in the three domains. We have already done the circuit the R and C circuit and also that I am going to write down which is………..; you have a source, you have a resistance, you have an inductance, you have a capacitance and there is another resistance across C and this is the circuit that I was talking about and then we have done this particular circuit.

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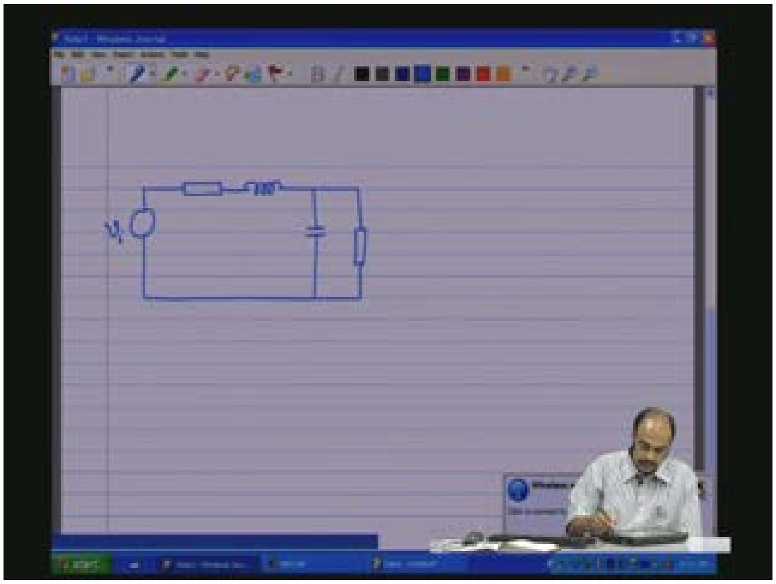

So you have V i the source, you have R 1 L I will call this as C 1 because it should not flash with the C matrix that we are using and this is R 2; and then there were two state variables: we had i L and V c i L and V c.

Now here I will write down the state equations state equation directly because this we have done before. Let me put it down as i L dot V c dot this is the state vector x dot; we had a minus R 1 by L as one element, we had minus 1 by L as one element, you had 1 by C 1 as one element and minus 1 by R 2 C 1 as another element.

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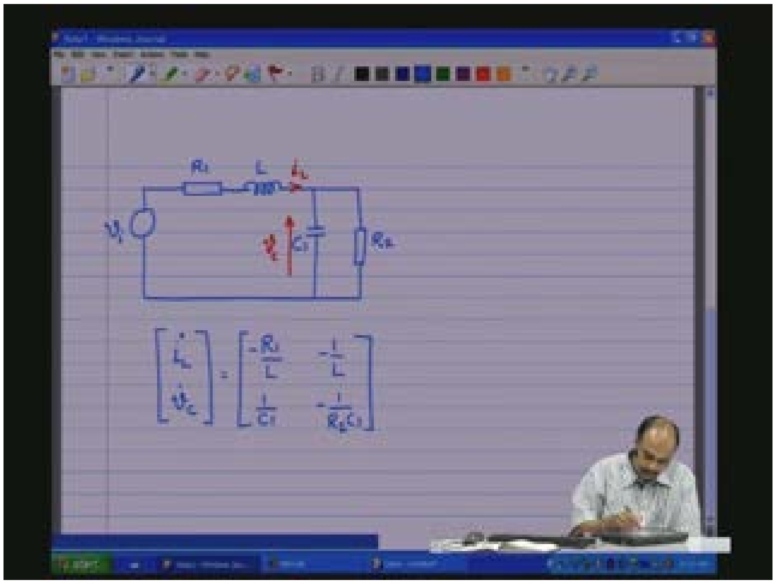

This is the A matrix; we have i L V c, this is the state vector plus we need to write the D matrix which is 1 by L 0 and V i. Now the output; let us say we would like to see the output of the voltage across the capacitance V c, our C matrix becomes [0 1] state vector i L V c plus the D matrix is 0 V i. This is our state equations that we have to input and this is our A matrix, this is the B matrix that we need to input, this is the C matrix and the D matrix and the output is whatever we choose.

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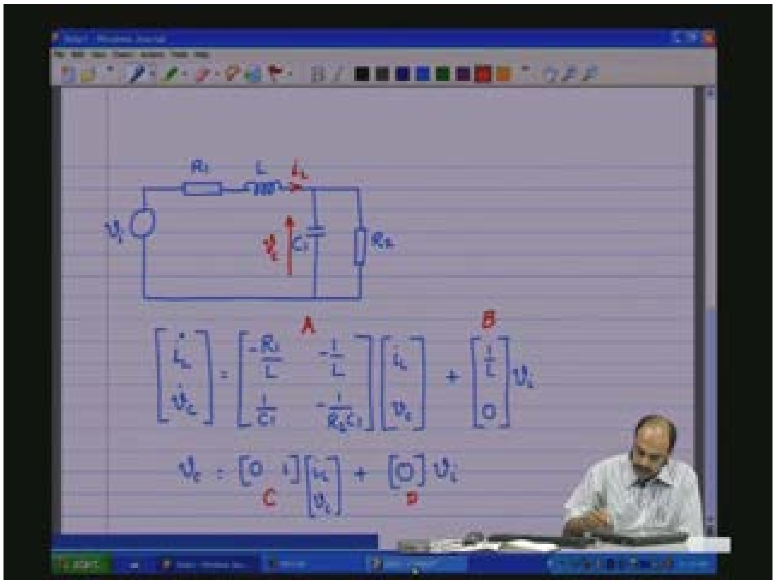

Probably before we even re-edit this, re-edit this model let me get back to the previous page here (Refer Slide Time: 38:31) and just show you that it is very easy to have any other output.

Let us say you want to have output here as i R instead of the voltage across the capacitance i R would be the currents of the resistance which is same as the currents through the capacitance which is nothing but V i minus V c by R. So this is nothing but minus 1 by R into V c plus 1 by R into V i. This is the modified output equation where now you have to give this as your C matrix and this as your D matrix (Refer Slide Time: 39:38) not this. So if you want to see i R as the output we have to give this as the C matrix and this as the D matrix. Let us just have a look at that before we go on further with the other circuit with the LC circuit.

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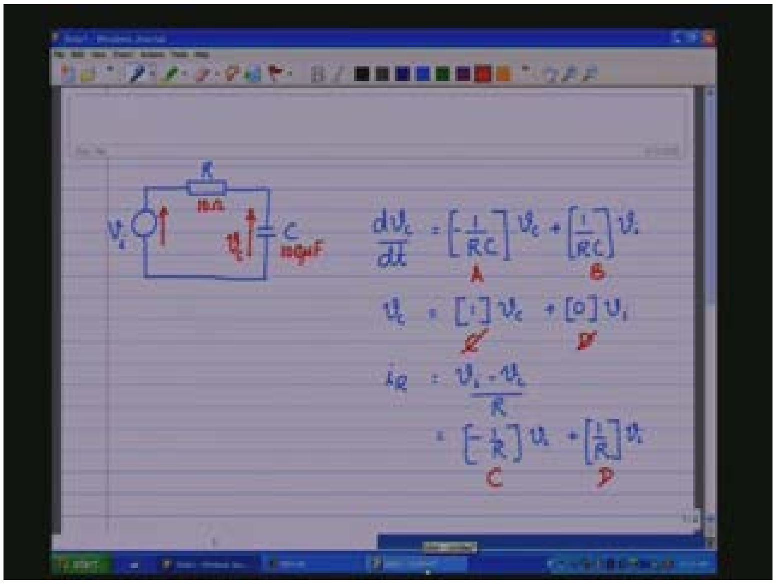

So coming here and into MATLAB C becomes minus 1 by R and D becomes 1 by R and that is it.

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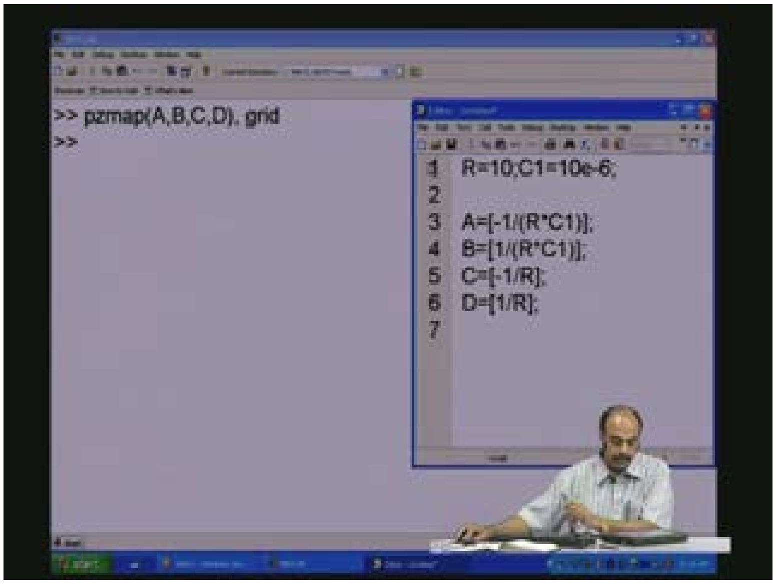

This is the modified thing that you want. Nothing changes in the A and B matrix. What you want to see is only the change that is going to affect the C and the D matrices. So this is the model and you want to see the step A B C D with the grid. So you see the current. Initially there is a high current because there is a step which is high frequency capacity as this is a short V by R. Initially there is no voltage across C. The whole voltage appears across R so 1 divided by 10 ohms 0.1 amps and that start exponentially decaying to zero as the capacitor charges to full voltage. This is the nature of the current waveform throughout.

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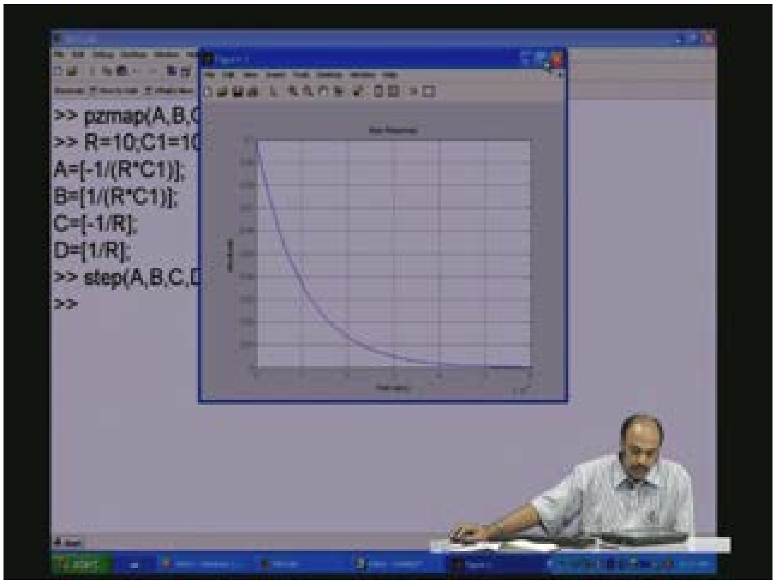
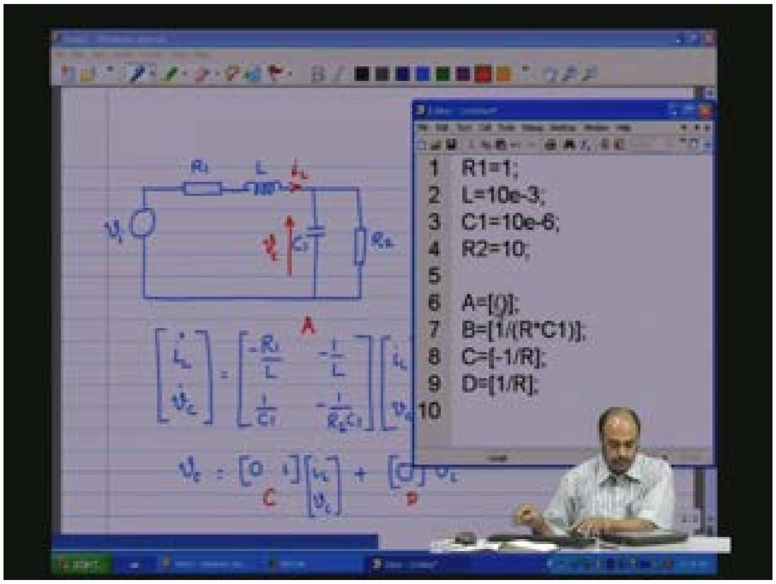


So, as I was saying you can see whatever output you want to see. Coming back to this circuit of interest now which is the LC circuit?

So these (Refer Slide Time: 41:24) are the A B C D matrices that we need to input. So let us go back to the editor here and edit these things. so we need a parameter R 1 and let us say we give a R 1 of around 1 ohm, we need to give L let us make it in this fashion L equals let us say 10 Millihenry which is 10 into 10 to the power of minus 3 or 10 e minus 3 C 1 of 10 Microfarads let us have it and then R 2 equals let us say 10 ohms and we need to modify the matrix here.

(Refer Slide Time: 42:32)



So we see that the A matrix becomes……….. there are four portions in the A matrix, semicolon is the next row so these are the four elements that we want to fill in. So you have first minus R 1 by L in the second position, we have minus 1 by L and then we have 1 by C 1, we have minus 1 by R 2 into C 1. So we have the A matrix. The B matrix the B matrix is 1 by L and 0, contains two positions; the second position is nothing but zero but it is the second row so we have a semicolon and zero and here it is 1 by L (Refer Slide Time: 43:52).

The outputs that you want to see right now of course the C matrix 0 and 1, we want to see V c as the output and the D matrix is 0. So this is the model that we have.

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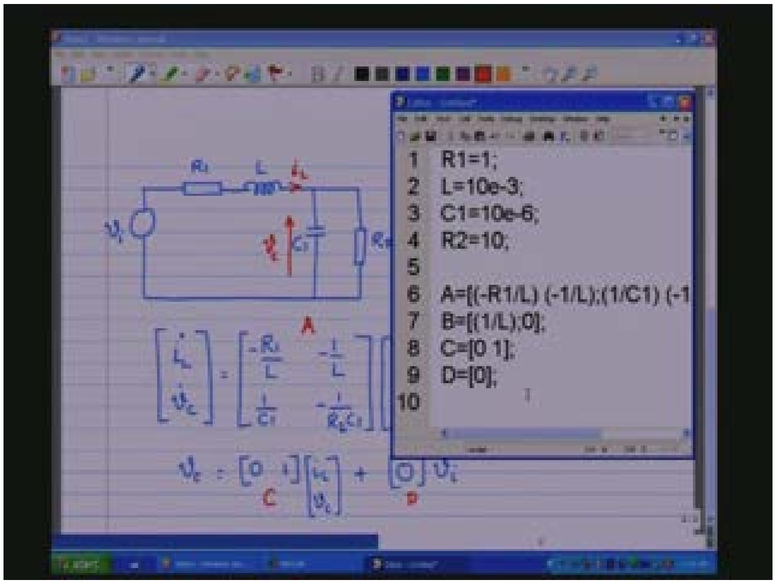

And let us take this model, copy that model, go into MATLAB let us clear all variables, let us clear the screen, paste this fresh model and just to check we have A B C D we have the A B C D C 1 parameter L R 1 R 2.

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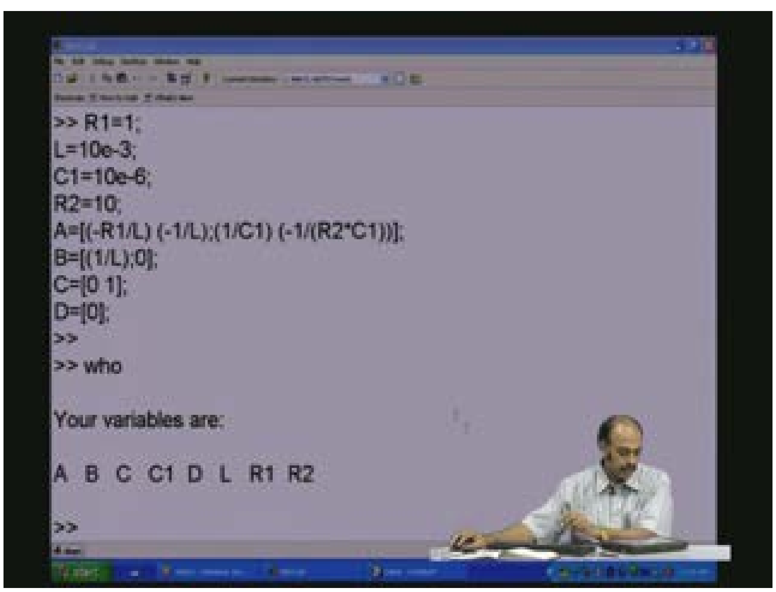

Let me again clear the screen. So let us to the step response step A B C D grid.

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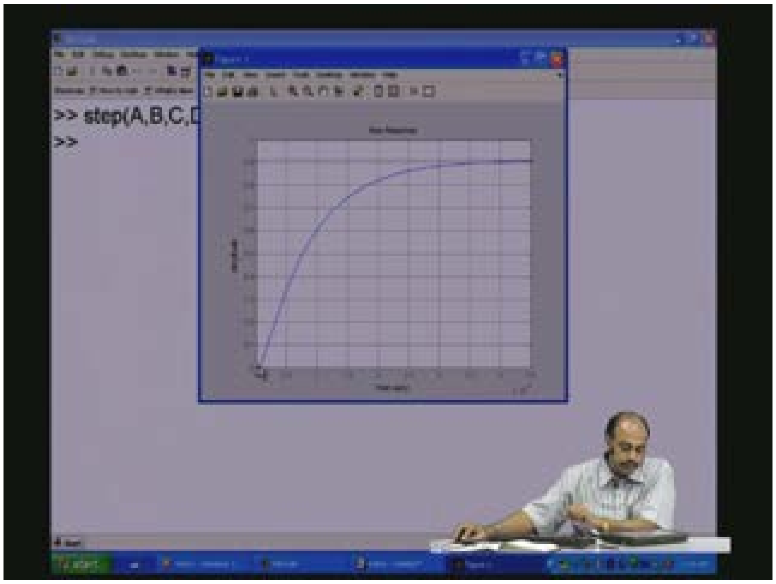

So this is the step response that is the output in this case is V c the voltage across the capacitance. So the voltage across the capacitance would behave in this manner if you apply a unit step of 0 to 1 like this at the input. So you see that there is an error as I start going to the steady state, the remaining voltage is dropped across R 1.

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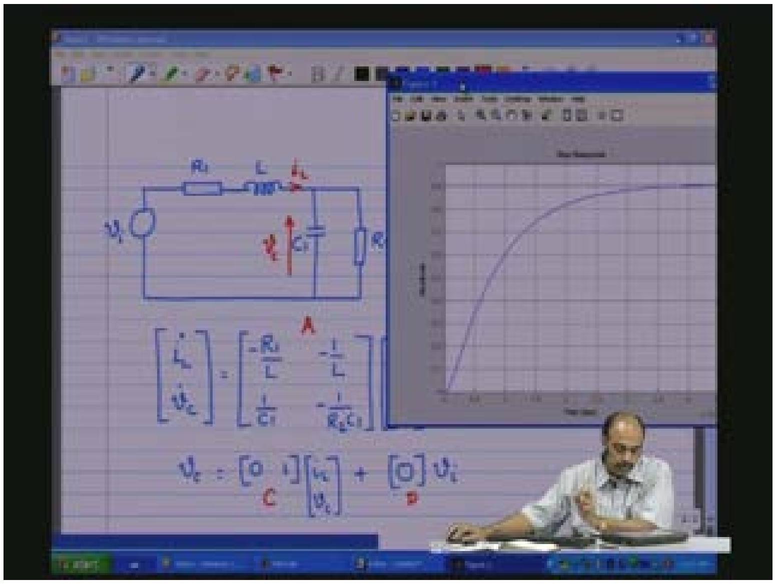

If you look at the circuit simultaneously you will see that here the voltage is 0. Initially capacitor is a short, the inductor is open, all the voltages will be dropped across this and zero voltage yeah starts with 0, then as time progresses the capacitor gets charged through the current here and the voltage builds up, the voltage starts building up and in the steady state that is in the DC condition capacitor is opened once it is fully charged and during that time R 1 and R 2 share because this is 1 ohm and this is 10 ohms so 10 percent goes to R 1 and the remaining 90 percent goes to R 2. So this is how one………. and the rise time is as given here so it takes roughly something like 4 milliseconds 4 milliseconds to reach 90 percent.

Now let us see what happens if we change the parameters. So let us change this R 2 parameter let us make it higher let us say 100 ohms. So this 100 ohms we copy, go to MATLAB, paste that one and this is the new model.

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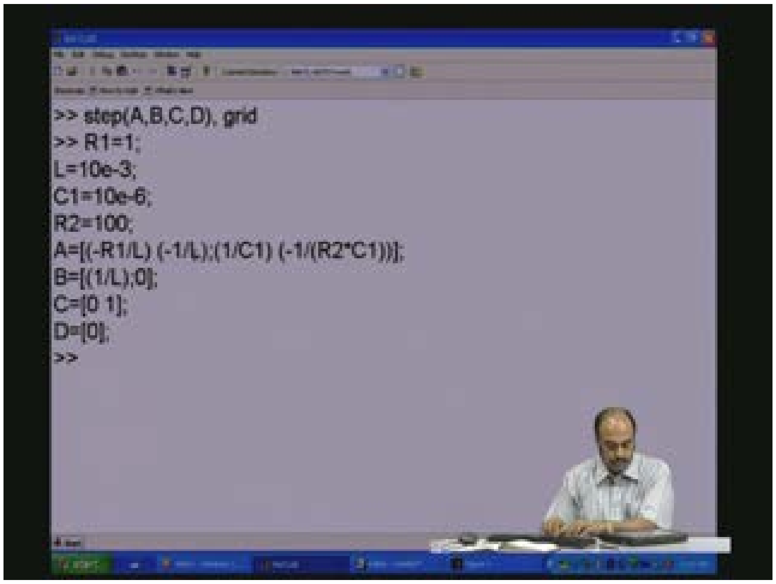

Let us hold the previous plot. So the previous plot is held and then again we give step A, B, C, D and let us see the grid. So now if we see the figure; you see very nice and interesting, this was the earlier figure nicely damped, no oscillations, the moment we change the parameter R 2 you are having overshoots beyond 1 and then gradually it is damping to 0. It rises quickly but shoots beyond the one beyond the value 1 and then you have the damped frequency of oscillation as shown here.

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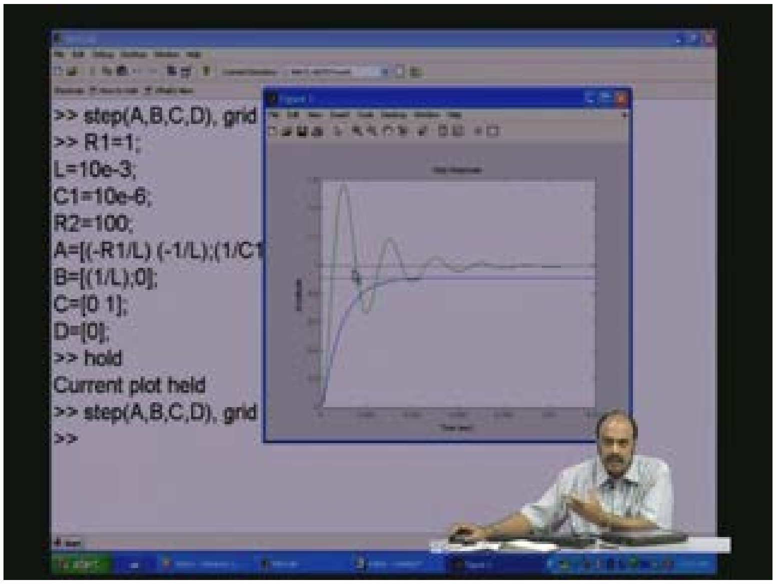

Now what is causing this?

From the time domain it may not be so very evident. Probably we may have to look at the frequency domain and the pole-zero domain. The pole-zero domain will give a very interesting result. Here you will see that the poles………… now here there are two energy storage elements therefore there are two state variables and therefore it is a second-order system therefore there will be two pole. So the number of energy storage elements is going to directly influence the number of the poles. So, if there is n energy storage elements there will be n poles. There are two energy storage elements.

In this situation both the poles should be somewhere close to the real axis or on the real axis and here because you are getting overshoots you will see that the two poles start moving towards the imaginary axis and they become complex. One is at the positive upper and one is at the lower portion which is the negative; one indicating the capacity effect, one indicating the inductive effect. So, if you have any such oscillation you should have two effects which is the capacitive and the inductive effect which is what we are having in the R and C circuit. So this is the interesting point that you will see once you just keep varying the parameters. Let us look at the frequency plot also.

So let me go back, let me start in the same way. We had the original 10 ohms, let us put back that model, copy, I will paste that model in MATLAB and we have the model then. Let me put bode A, B, C, D grid so this is the bode plot.

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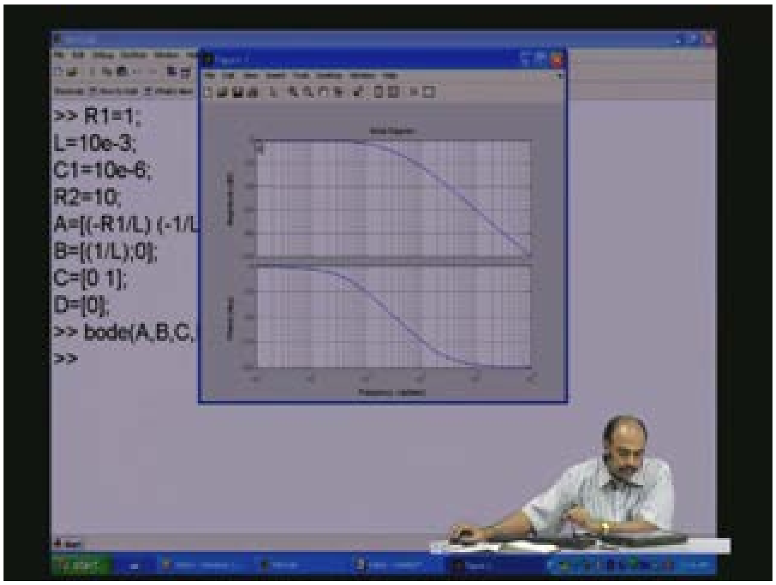
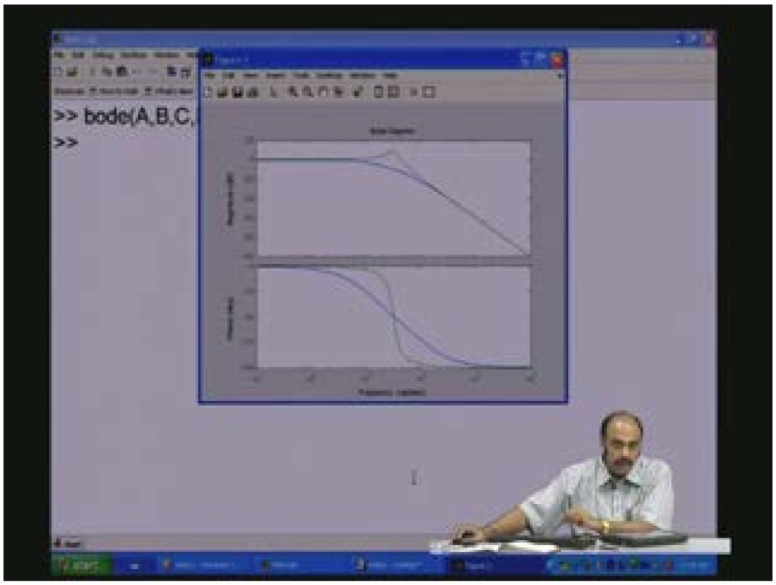


Now one thing that you should notice here is that of course though it looks very similar to the RC circuit the slopes are different. Here (Refer Slide Time: 50:30) this slope is for one decade, from here to here it has gone down by 40 dB whereas in the earlier circuit for one decay from here to here it could have gone down only by 20 dB so the slope was minus 20 dB per decay whereas here it is decreasing at a much faster rate so it is a much sharper filter.

And then look here, look at the phase waveform (Refer Slide Time: 50:55). It starts with zero and then it is gradually moving towards 180 degrees because you are having the inductance and the capacitance and they provide the 180 degrees phase shift. Because one pole goes up and another pole goes down and then you are having a 180 degrees phase shift between them and that is what is causing……….. so two poles. So each pole is going to add a 90 degrees phase shift, there are two poles and therefore that will be 180 degree phase shift and each pole is going to add a slope of minus 20 dB per decayed filtering action, there are two poles and therefore there will be minus 40 dB per decade filtering action. Let us now freeze this plot. Let us hold the plot and let us change the parameters back again here. Let me make the R 2 as 100 ohms instead of 10 ohms. Let us copy that, paste it in MATLAB to get the new model and then again see the bode plot bode A, B, C, D and grid, you want to look at the grid.

(Refer Slide Time: 52:24)



Now look at the figure here, you see something interesting happening. This is the earlier one the blue waveform, no problems, there were no problems because the two poles were quite close to the real axis and once the poles start shifting away from the real axis it is going to peak, there is a resonant action here and that is peaking which is giving an amplification of the gain and goes down. And you see the difference also in the filtering action. This is a much better filter compared to the earlier one. This (Refer Slide Time: 53:06) falls much more sharply in phase by 180 degrees to 180 degrees so it is not a gradual change in 180 degrees. But magnitude filtering wise they are more or less the same because they are going to have the same minus 40 dB per decade. But phase-wise it is going to jump quite fast to 180 degrees.

Now this resonant action is basically because the poles in the pole-zero domain that is in the S-plane you will see they have become complex poles, from a real pole they have become complex poles because of the change, you could probably see that. So let us see the third domain also. Let me first show you the earlier domain, we make R to 10, let us copy that, let us paste that here, we have the model, now I will make pz map A, B, C, D and we need the grid.

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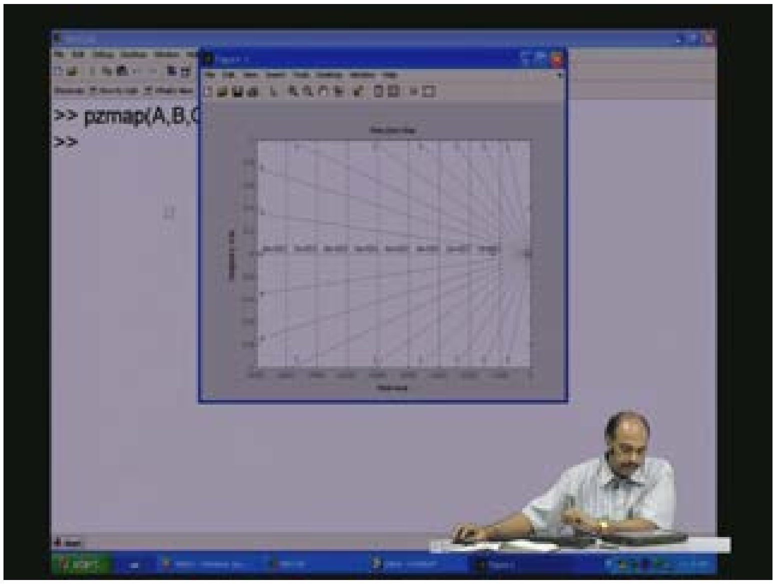

So you see there is one pole here at the frequency of minus 1240 at this point (Refer Slide Time: 54:44) damping is 1 you see it is on the real axis because there are no overshoots and then there is another pole here at frequency of around 8860, again damping is 1, no overshoots. Now let us freeze this and see what happens. You see there are two poles; there are only just two poles. Let us see what happens when we take the second case when the output resistance that is R 2 is made larger which means there is now some oscillation which is going to occur between the capacitance and the inductor, it is now going to act more and more like a resonant tank that is when R 2 becomes totally an open circuit it is just pure LC because R is just 1 ohm so it is a LC tank and therefore it will start oscillating more and more which means these two poles will start moving up and below so you will have one pole here and one pole here and they will start moving towards the imaginary axis more and more as you make R 2 higher and higher. So let us have a look at that.

First let me freeze this plot, hold so this plot will be held (Refer Slide Time: 56:03), let us go to this, let us change R 2. Now R 2 is made 100 ohms let us copy that, go to MATLAB, paste that in MATLAB, and then again I will give you the pz map A, B, C, D and then i want to see the grid along with the grid. So now let us have a look at the plot.

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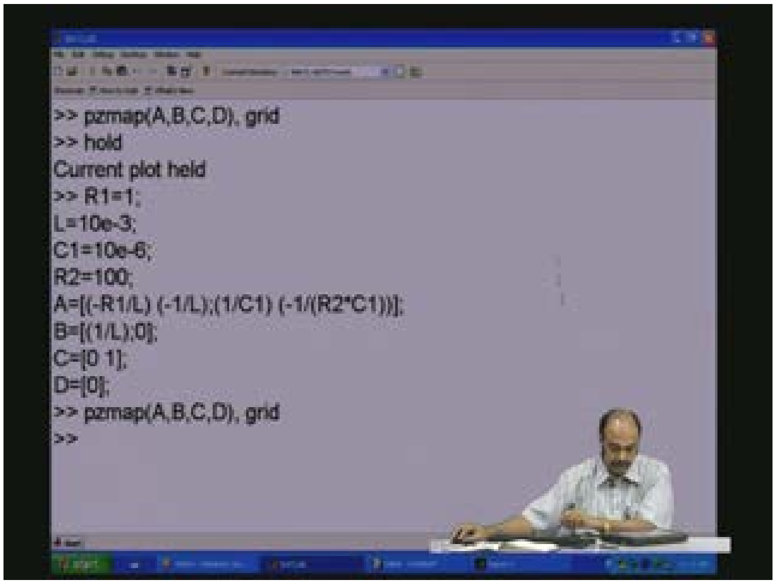

You see the plot here. This was the earlier plot on the real axis and now these two poles the green ones or the ones now after having changed the parameter R 2.

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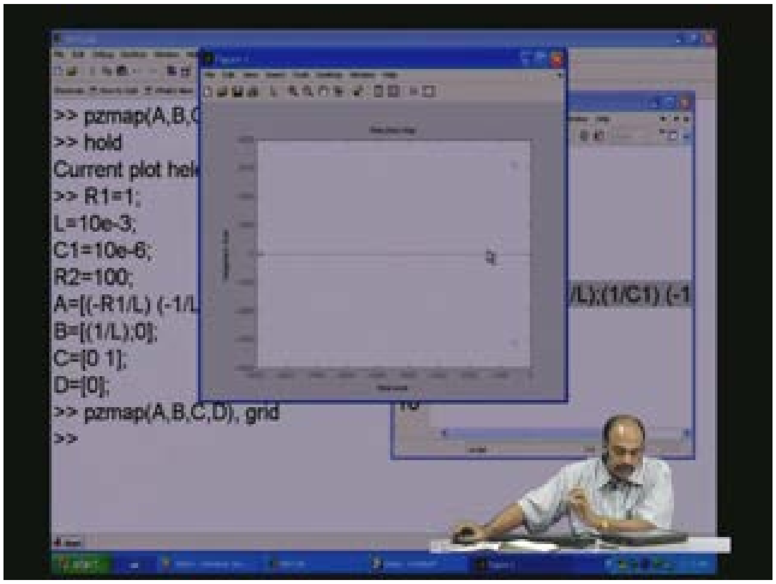

Therefore now as R 2 starts going towards infinity these two poles will become complex poles with a mirror that is why there is a 180 degree phase shift and they gradually start moving towards the imaginary axis which is this axis and become more and more oscillated. this phenomena You see that this phenomena which is exhibited in the time domain gets reflected; the same phenomena can be viewed in different ways in the frequency domain and the pole-zero plot and this will give you exactly what you want to do for design if I want to place the poles at any specific point for specific circuits for specific applications.

So you see that the circuits that we have been discussing (Refer Slide Time: 57:51) and also the models that we modelled in the last session can be put we can put them in model, input the A B C D matrices and view the performance, view the character, view the characteristic features in the three domains that is the time domain, the frequency domain and the pole-zero domain and note that all these three domains are going to give you very useful information about the circuit even though the circuit and its responses are always existing in the time domain.

The variation of the gain with frequency is not very evident in the time domain. The bandwidth is not so very evident in the time domain. The pattern of the pole-zero which will give you oscillation or which will give you that amount of damping is much more easily understandable looking at the pole-zero plot. In fact, in the pole-zero plot you can position like this should be the damping, this should be the position of my poles and work back and then evaluate what should be the value of LCs in the circuit and that will be useful for design. So any circuit can be modelled and once it is modelled that can be simulated and analysed as we have shown here. So with this let us conclude the discussion in this session. Thank you.