Control Engineering
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Lecture - 41
Compensator Design using Frequency Response Plots

Yes friends, with the discussion on the feedback performance characteristics over we can now switch over to the design problem and I think the best we can do is to take up the lead and lag design through examples because the lead and lag design through root locus method have already been introduce to you. You will recall a lead compensator has, I mean both the lead and the lag it is a pole zero pair; in the case of a lead if you recall there is a zero followed by a pole and in the case of a lag a pole followed by a zero as far as the left-half plane is concerned. I think I can make the sketch here and you will surely recall that.

This used to be the situation (Refer Slide Time: 01:45) when we used to take up the problems on root locus method a zero a compensator zero and at a sufficiently large distance used to be a pole so it means if I consider this to be 1 over tau, this I can say it is minus 1 over alpha tau naturally alpha will be less than 1 and the transfer function of a lead compensator let me call it D(s) can be taken as s plus 1 over tau over s plus 1 over alpha tau with alpha less than 1.

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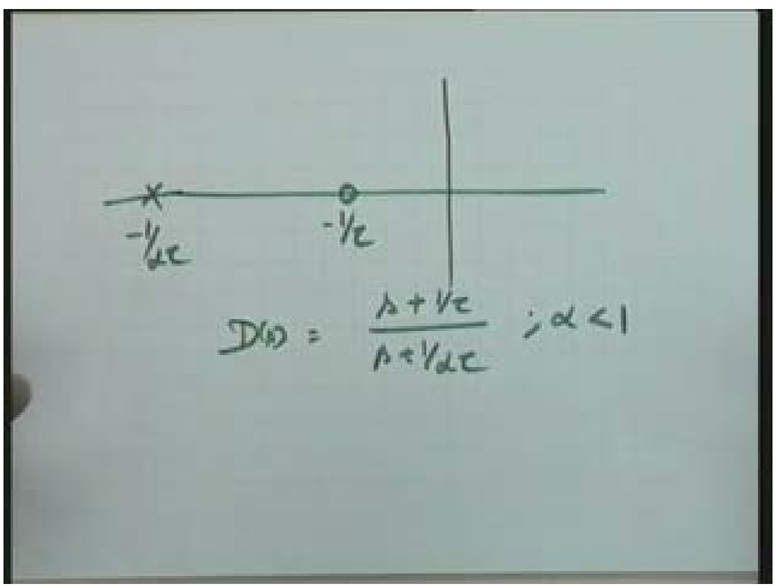

I think let me go ahead with the lead compensation; I come to the lag compensation after the discussion on the lead compensation is over. We have seen in the root locus method as to how to place the 0 and the pole appropriately so that transient performance of the system is improved, that was the objective. I mean we used to pull the root locus towards the left so that it passes through the point which is our desired point which is the point corresponding to the desired closed-loop poles and that point used to correspond to zeta and omega N. Now let us think in terms of frequency domain. Zeta and omega N if they are specified I will say that using second order correlations these indices have been translated to phase margin let us say M r, omega b or equivalent indices. In my examples let me take that the phase margin and K v and let us say omega b these are the three important specifications and any other specification could be checked whether it is met with or not. If these specifications are not met in that particular case you have to enter into the design cycle you have to take another trial point and using the new trial point you have to make the calculations again.

So you see that I now want to go ahead with the design of D(s) that is getting the values of tau and alpha so that performance requirements on K v, phase margin and omega b are satisfied. I like to say that in addition to the flexibility on tau and alpha I have the flexibility on the gain also; after all I can put an amplifier stage with the compensator. So instead of saying that we have two parameters we have in fact three parameters: K c, tau and alpha. But as we did in the root locus method what I do is the K c parameter I take up with the uncompensated system. I will calculate the value but I call it a parameter of the uncompensated system the only thing is that once the parameters K c, tau and alpha have been obtained then at the realization stage I will see whether K c is totally coming from the compensator or is partially coming from the plant itself and partially from the compensator that will be just implementation.

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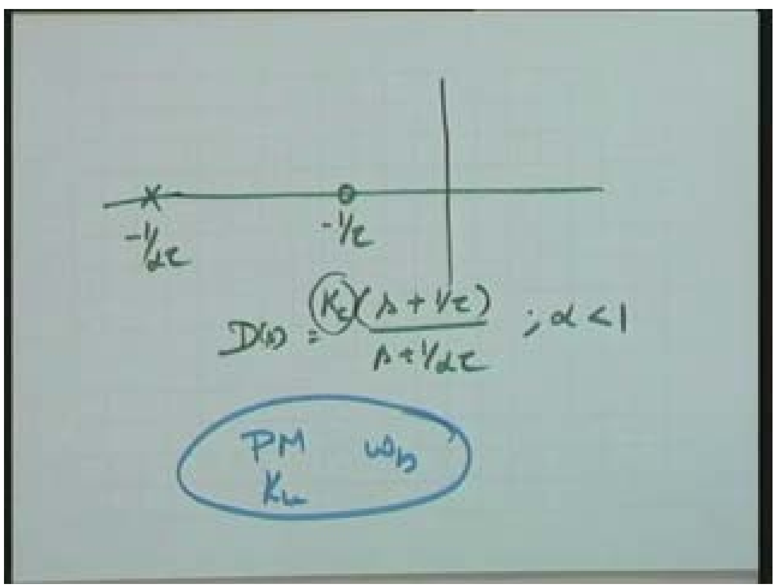

I have three parameters and K c I take to the uncompensated system in that particular case I will say that I have a transfer function KG(s) so that the K parameter is available there for adjustment and I have a transfer function D(s) so that the parameters alpha n tau……. I think yes, one change another change I make in……..(Refer Slide Time: 5:10) since I am now working in the frequency domain please see I call it K c (tau s plus 1) divided by (alpha tau s plus 1) this is more convenient for me this is the gain K c here. That is, I am writing the compensator transfer function in time constant form because in the frequency domain that is more convenient. This K c is not the same case you can call it K c dash, it is a different K c but still I take this K c to be taken along with the uncompensated system so that as far as the definition of compensator is concerned it has two parameters tau and alpha K c will be taken care of at the implementation stage.

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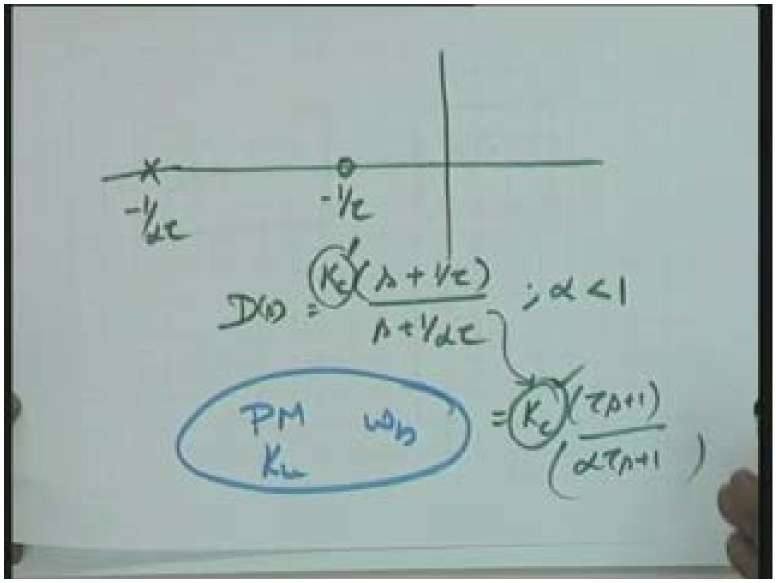

Therefore KG(s) is the plant model and here is the compensator (Refer Slide Time: 5:57) and D(s) now I am writing tau s plus 1 divided by alpha tau s plus 1 and here is my feedback system please. Get me the values of K tau and alpha so that the requirements on phase margin, bandwidth and K v the velocity error constant are satisfied or any other have a constant it depends upon the type of the system I am handling.

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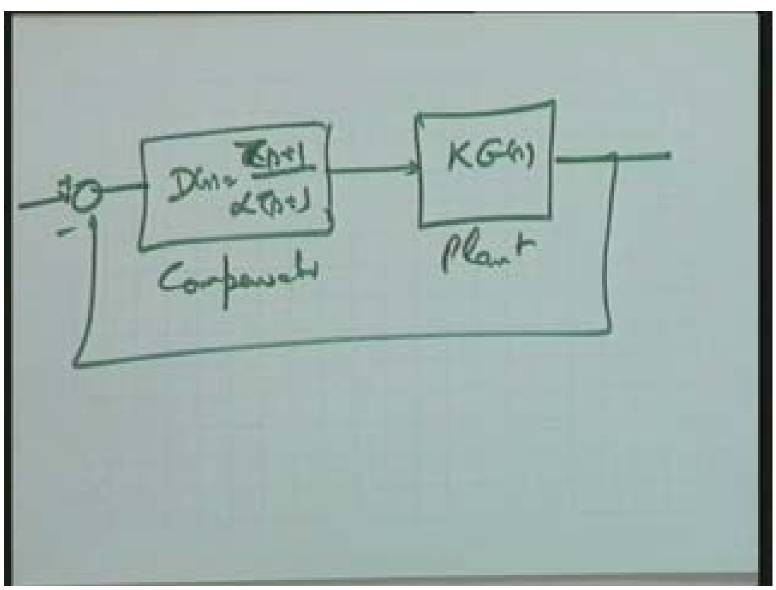

Now first I will like to study the frequency domain characteristics of D(s). Just this very example will take us to the design algorithm as well, the characteristics of D(s). So let me write this as D(j omega) is equal to j omega tau 1 plus j omega tau 1 plus j omega alpha tau. Help me please give me the magnitude and phase characteristics of this. let us see how this is going to behave; what contribution this particular compensator is going to give to the Bode plot or the frequency plot of the uncompensated system this is what I want to see; what contribution does it give, what way we are going to design the parameters tau and alpha so that we are able to shape the frequency response of the total system.

Therefore, if I make the Bode plot sketch for this, this is omega, this is db please see that in this particular case your magnitude is 1 so I go up to 0db here what is the next corner frequency it is omega is equal to 1 by tau and here is a corner frequency omega is equal to 1 by alpha tau; so which way I go please; plus 20db or minus 20db? It is plus 20db because this corner frequency is because of a 0 so I take this way up to this point and then here it becomes horizontal because the pole adds up a slope of minus 20dbs per decade. So, after this point it is going to be 0dbs per decade. So I have omega is equal to 1 over tau omega is equal to 1 over alpha tau and this becomes the magnitude characteristics of the lead compensator I have with me.

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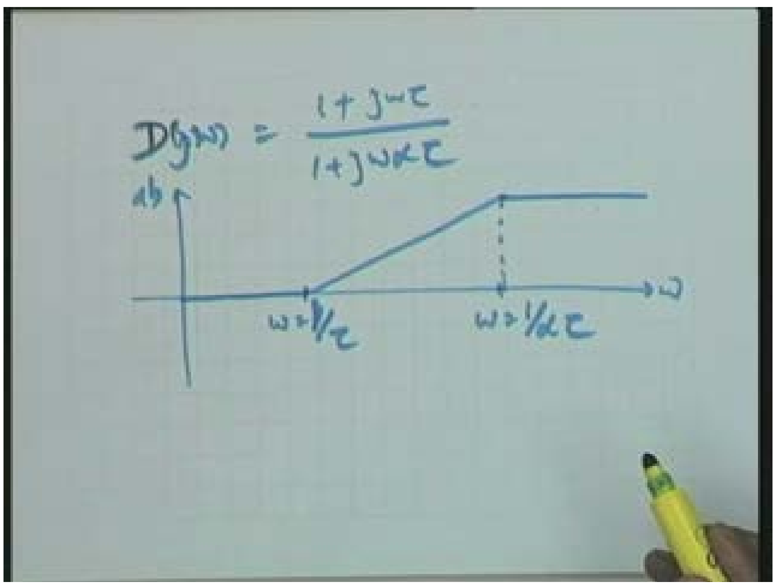

The phase characteristics let us see omega; in this particular case tell me please, help me what type of phase characteristics do you expect. Since alpha is less than 1 your phase angle alpha is tangent inverse omega tau minus tangent inverse omega alpha tau. This is going to be your phase angle and therefore in this particular case the phase characteristics will be of this type. The phase characteristics in this particular case is of this type; this is your frequency here the cut-off or the corner frequency and the frequency here (Refer Slide Time: 8:56).

You will note this is your 0 degrees. Please note why the name lead compensator has been given to this. It adds a leading phase angle; here is a positive angle. It adds up a leading phase angle to the overall phase angle of the system, your designing and this is the feature of the lead compensator which we are going to utilize in our design. This is the feature of the lead compensator.

Well, couple of questions to you. Can you get me the frequency at which this angle is maximum let me say the maximum value is phi m. The maximum value is phi m and the frequency at which it occurs is omega m. let us try to get the value of this particular frequency. The couple of parameters which I will require in my design I am taking your help to get those parameters phi m naturally will come from the phase angle. So what I am going to do is I will take the derivative of the phase angle with respect to omega that will give me omega m I will substitute this omega I am over here to get the value of phi m. Let us do that.

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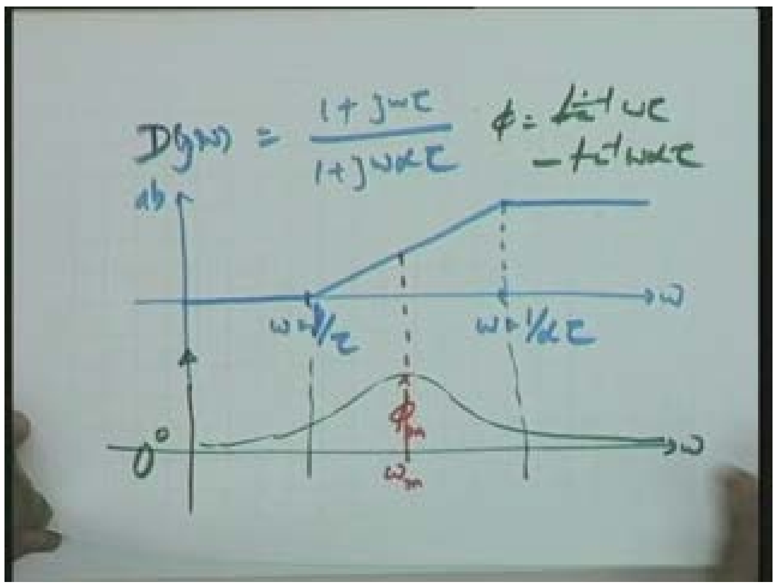

Phi is equal to tangent inverse omega tau minus tangent inverse omega alpha tau. Tangent phi becomes equal to…… yes, omega tau 1 minus alpha over 1 plus yes alpha omega square tau square please. This is the value of tan phi I am getting. Now let me take the derivative of this with respect to which parameter I am interested in omega with respect to omega and set it to 0. So, taking d phi by d omega equal to 0 from this equation gives me omega equal to omega m the frequency at which the maximum phase angle occurs. I leave this expression to you to calculate; the value is 1 over tau into 1 over alpha tau under the root.

You please recall, what is 1 over tau and 1 over alpha tau these are the two corner frequencies. So if omega m is equal to 1 over tau into 1 over alpha tau under the root it means it is geometric mean of the two, you may please see; 1 over tau and 1 over alpha tau the frequency at which the maximum occurs it is the geometric mean of the two corner frequencies it is easy to remember that way it is 1 over tau is this 1 over alpha tau is this (Refer Slide Time: 11:32) so multiply and take the under root of this.

It is this frequency at which the maximum occurs please. Now, if I substitute this frequency in the phase expression I will get the value of phi m and let me arrange that phi m in this form; sign phi m is equal to 1 minus alpha over 1 plus alpha simple calculation for your please to check sign phi m is equal to 1 minus alpha over 1 plus alpha.

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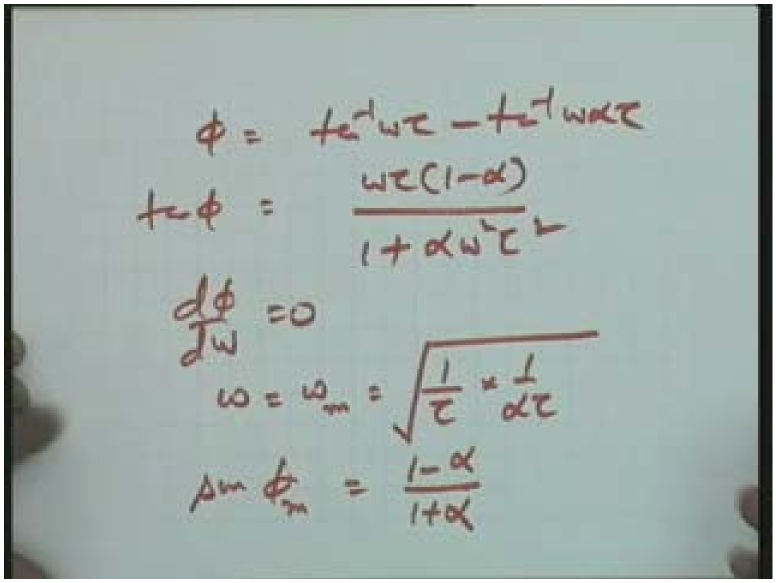

Still manipulation of this is needed because I am interested in alpha this can be manipulated to get me the value 1 minus sign phi m divided by 1 plus sign m please. this is the value of alpha in terms of phi m; phi m is the maximum phase angle and I will be using this expression in my design and please set in your mind as to how did I get it I have taken the derivative of phi with respect to omega and from there I have got be maximum value of phi and omega at which it occurs the maximum value of phi in terms of alpha I get I have manipulated this to get the value of alpha in terms of phi m because in this form I know I am going to use the equation in design.

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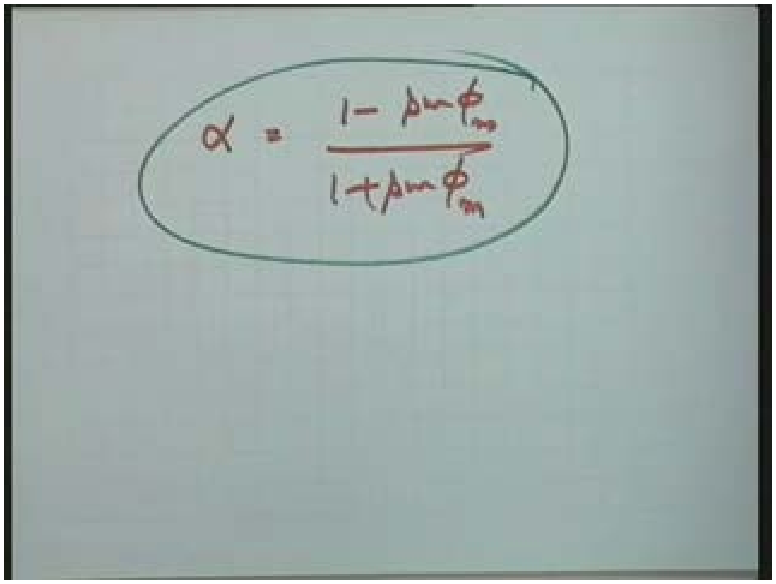

Please see now one more calculation I want to take up. Can you give me this value? Come on, take time, you can take little time and get me this value please. What is the value of this magnitude; what is this magnitude (Refer Slide Time: 13:13)?

Yes, you see that as far as this factor is concerned it is coming from 1 plus j omega t from the 0 as far as this line is concerned or this plot is concerned this plot is coming from 1 plus j omega t and after this corner frequency in the asymptotic plot you have in fact neglected one. So can I say that this particular magnitude db is equal to 20 log 1 plus omega squared tau squared under root and this has been approximated as 10 log omega tau only because for omega tau greater than 1 I have neglected that 1 in asymptotic approximation so it means as far as asymptotic approximation is concerned the equation becomes db approximately equal to 10 log omega tau.

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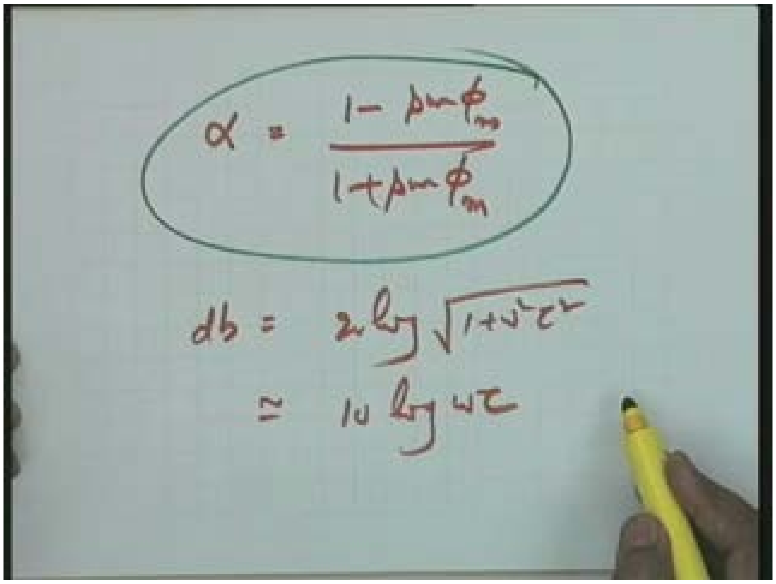

Now help me please; what is the value here (Refer Slide Time: 14:17) take omega is equal to 1 by alpha t so if I take omega is equal to 1 by alpha tau this becomes equal to what no it will become 20 log omega tau. Please see it will become 20 log omega tau because this 2 is coming here. So now if you take omega is equal to 1 over alpha tau what is the value please 20 log 1 by alpha. So I get here (Refer Slide Time: 14:42 min) the magnitude as 20 log 1 over alpha. Now, if this we have solved give me the value of the magnitude at this point please, the magnitude at this point.[Conversation between Student and Professor – Not audible ((00:14:57 min))] yes, 10 log please all of you verify. If I substitute omega m this value here I get the magnitude at this point as 10 log 1 by alpha this is what I need as the information about the phase lead network about this compensator before I take up the design problem.

I summarize the information now that this is a phase lead compensator a lead network will give a give me this value, an RC network or an Op-Amp circuit that can be taken to give me this characteristic, this provides the phase lead the maximum phase lead occurs at omega m which is the geometric mean of the two corner frequencies and the maximum phase lead is related to the parameter alpha and this relation is given by this (Refer Slide Time: 00:15:44 min). At this particular frequency (Refer Slide Time: 15:46) the magnitude is 10 log 1 by alpha this is the magnitude and the maximum value you are getting is 20 log 1 by alpha.

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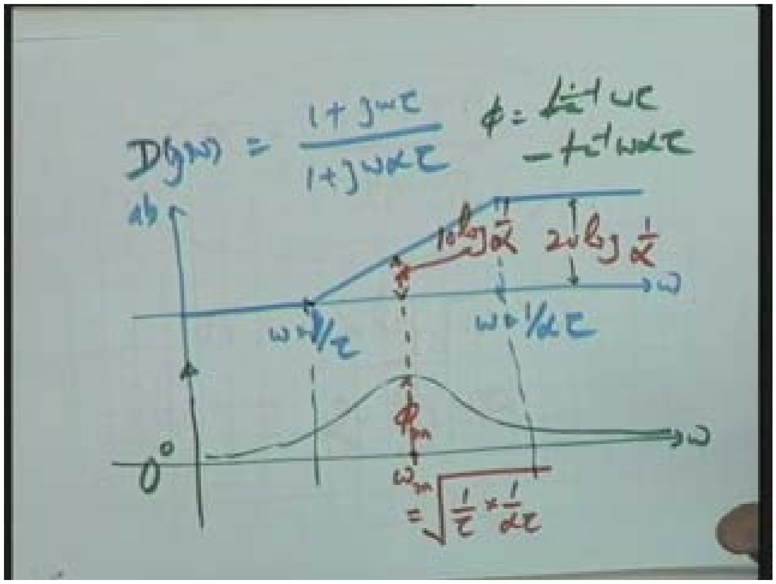

Keep this in mind; if this is well set in your mind in that particular case the design problem will quickly follow there will not be any problem at all. And as a design problem I take a situation of a type-1 system. Let me take this as the design problem that is your uncompensated system G(s) is equal to K over s(s plus 1) and the requirements are K v is equal to 12 and phase margin equal to 40 degrees please help me; K v is equal to 12 and phase margin is equal to 40 degrees is the requirement. There may be additional requirements on bandwidth as well that we will check. But let us first meet the requirements on phase margin and system K v.

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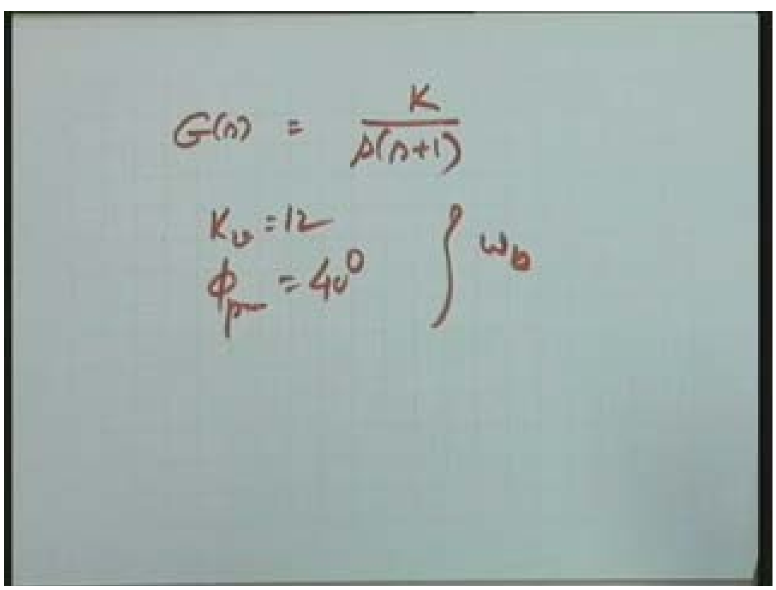

Now you see the steps please. The steps will follow easily from this example itself. I am not listing the steps I will save time here because the example will make the steps very clear. The very first step I want to take is you design your K so that your K v requirement is satisfied. Please give me the value of K to satisfy the K v requirements then the value of D(s) I am going to introduce should not change the K v of the system that we have to keep in mind.

Please help me what is the value of K I should take to satisfied the K v requirement?
It is 12 and how about the effect on D(s)? Please tell me whatever D(s) you take will it change the value of K v keeping in mind that your D(s) is tau s plus 1 divided by alpha tau s plus 1 keeping in mind that your D(s) is tau s plus 1 divided by alpha tau s plus 1; it will not change. Please see your K v will not change that is why your K v is set once for all and I am taking in this example K v equal to K equal to 12. So one parameter is decided by K v. So this decision I have taken on K v. Now I have to take on the phase margin decision and therefore I need the plot of the uncompensated system first.

G(j omega) equal to 12 over j omega (j omega plus 1) this is the value. Please make a rough sketch. You know how to make it 12 by omega will be a line of minus 20dbs per decade and this is a pole which will add another line of minus 20dbs per decade so this becomes the magnitude plot of the uncompensated system with this as a minus 20dbs per decade slope and this as minus 40dbs per decade slope (Refer Slide Time: 18:40) and you know that this corner frequency is omega equal to 1 and I can make the phase angle plot also.

For this particular case the phase angle as you know is minus 90 degrees minus tangent inverse omega. I am giving you the rough phase angle plot. At this frequency I want to get certain phase margin so this is the phase angle plot. As you know it will be tangential to minus 180 degrees axis it is clear from here. It is a type-1 system which will be tangential on this side to minus 90 degrees axis and on this side to minus 180 degrees axis so this becomes the phase plot for me for this particular system. I hope this is clear.

As far as uncompensated system is concerned I have got the gain plot and the phase plot, the Bode plots that is the semi-log paper plots I have got. Now let me see the phase margin of the system. I have got the data in my notes. The phase margin in this particular case is equal to 15 degrees. So it is short by how many by 25 degrees you see I need 40 degrees and this is 15 degrees so it is short by 25 degrees.

Now you see the adjustment please. As I told you if you get this example very well the procedure will be well set. Now what I can do; you see your plot of the lead compensator (Refer Slide Time: 20:13) and if I cascade a lead compensator the two plots will get added up because of the Bode characteristics because of the Bode characteristic you see the two plots will be added up. Now you please notice this point very carefully. What I can do is that place this……. please you are disturbing me gentleman you are disturbing me please and my attention gets diverted do not speak please……. this omega m is the frequency so this particular thing this magnitude (Refer Slide Time: 20:46) I want to have this phase lead this phase lead I can place at this particular point please; you can just see this phase lead I can place here so it means what I can do is that this omega m can coincide with this point and I can design my system in such a way that phi m is equal to 25 degrees my phase margin will be realized.

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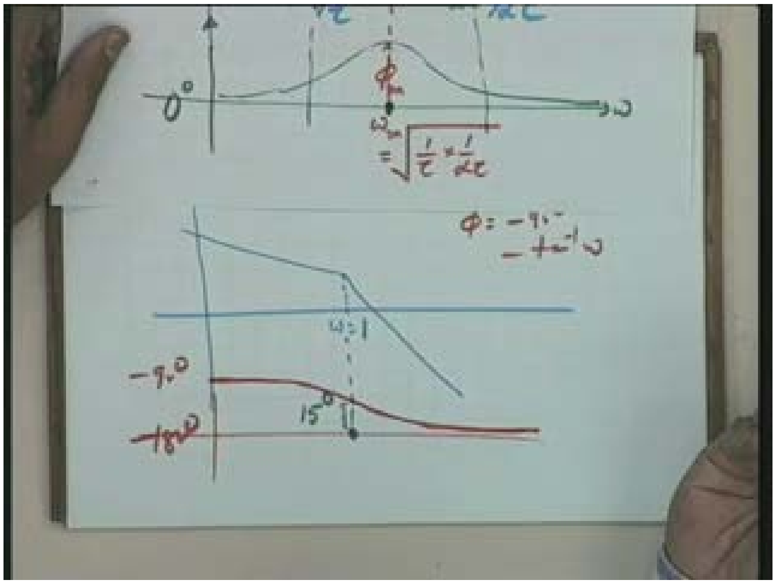

Anyone who can think of the problem involved in this please; think of the problem involved in this. I am placing phi m here the maximum phase value is equal to 25 in that particular case the net angle at this particular point will become 40 which is the desired phase margin but I envisage a problem. If I do this I fear that the phase margin will be less than 40, could you think of the reason please? [Conversation between Student and Professor – Not audible ((00:21:38 min))] Yes, please see that when you are adding this phase at this particular frequency you are adding the gain as well and if you add the gain to this the crossover frequency is getting shifted to the right that is also showed to the right not to the left that is also set you see that if you add phi m at this particular point the magnitude gets added to it and the crossover frequency gets shifted to the right.

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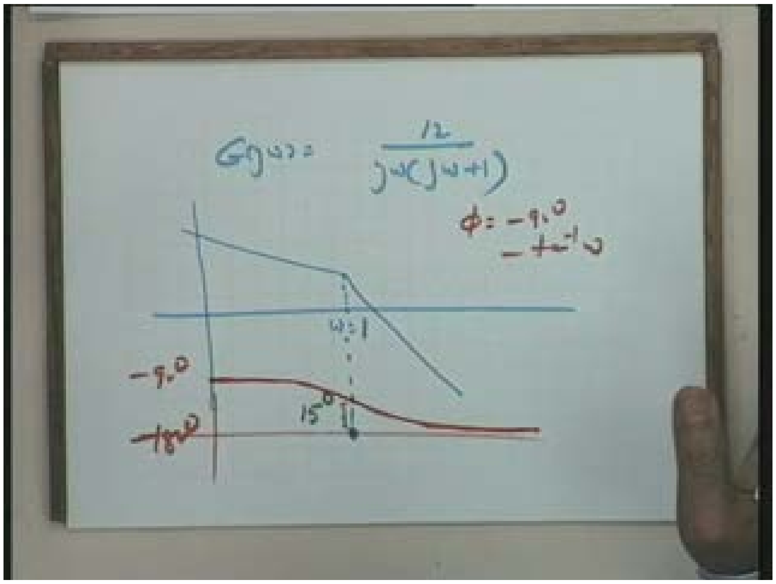

What is the consequent effect?
The consequent effect is this that suppose it gets shifted to this point tentatively let us say; you have calculated your 25 degrees hoping that the uncompensated system is providing 15 degrees to you you see but now since the cross over frequency gets shifted the contribution of the uncompensated system has reduced from 15 degrees to the value you do not know you see exactly you do not know but it is a trial and error and design you can approximate it roughly to 5 to 10 degrees.

[Conversation between student and Professor….. ((Sir in that incorrectly it should be)) ((00:22:45 min)) oh yes oh yes I am sorry. Yes, you are very right, you are very right. Yes, I have taken the corner frequency here; this is 15 degrees (Refer Slide Time: 23:01) the gain crossover frequency of the uncompensated system is this and you want this is let us say 15 degrees this will get shifted because of the addition of the total magnitude and therefore the contribution of the uncompensated system will reduce. This is the safety margin we will like to take beforehand because its exact value I do not know beforehand. So, if the safety margin you have taken does not work the only thing is that you have to re-enter into the design cycle and couple of trials will give you the final result.

The guideline is this that okay 5 to……… and you see the guideline is also provided by the open-loop plot. If you see that there is a sharp fall off so naturally larger margin should be taken that is all it is provided here; if the fall off is not that sharp smaller margin will do because after all it is this fall it is this slope which is going to give you the idea as to how much the safety margin should be taken (Refer Slide Time: 23:59). But let us assume that I take a safety margin in this particular problem I have taken a safety margin of 5 degrees so what do I do? I require a phi m the maximum phase lead of 30 degrees instead of 25 degrees hoping that this shift will give me the final phase margin o at least 40 degrees. With this hope I am giving an additional phase angle of 5 degrees here.

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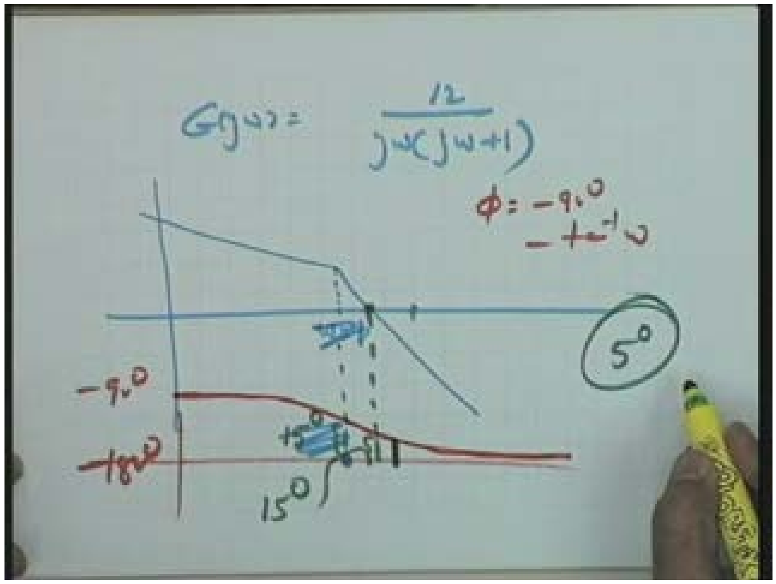

Therefore I can say the phi m the required phase lead is equal to phi s the required phase margin or phi pm you can say we have used pm required phase margin yes minus phi 1 the phase angle of the uncompensated system plus epsilon the safety margin will you do please? phi l phi m the maximum phase angle I require is equal to the required phase margin minus the phase angle of the uncompensated system plus the safety margin that is why I am writing here 40 minus 15 plus 5 equal to 30 degrees. So this 30 degrees of phi m I require and hence I can get the value of alpha now, you see one parameter is set.

You will see from this design the statement I made the frequency domain design is very powerful because the type of trial and errors you made in the root locus design that much trial and error is not involved here. So you see by this adjustment of this phase angle you have got one parameter alpha, K you have already got from K v now alpha I get equal to 1 minus sin 30 divided by 1 plus sin 30 is equal to 0.334 this is the value of alpha I get. The only parameter left is tau.

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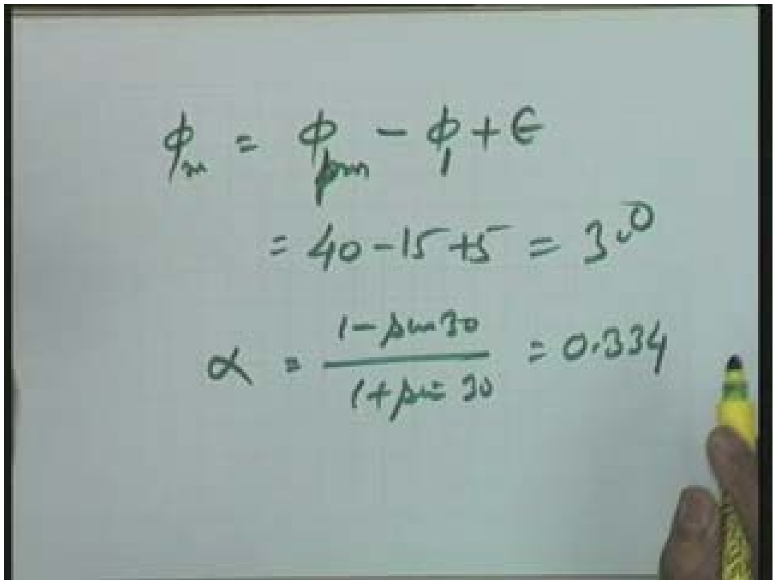

Now, well, if anyone has got an idea how to fix up tau please?

Yes, omega m should coincide with omega gc but which omega gc this omega gc (Refer Slide Time: 26:19) the new one, how do I know what is the new one? [Conversation between student and Professor] …….. ((by shifting a)) that is perfectly alright, no not 20, this value 10 log 1 by alpha because at the maximum phase angle it is 10 log 1 by alpha (Refer Slide Time: 26:27). Please see this much of magnitude will be added at omega m this point may please be noted and see the value 10 log 1 by alpha is 4.8dbs 10 log 1 by alpha equal to 4.8dbs so what should be the point?

I envisage that the new crossover frequency will be at the point where the uncompensated system has a gain of minus 4.8db because 4.8 will be added to it. This is the new gain crossover frequency please; the uncompensated system should have minus 4.8 so that when 4.8 gets added to it it will cross the 0db axis and this will become my new gain crossover frequency and hence now I think you have got the clue. The uncompensated system plot is already with you so you read off this point (Refer Slide Time: 27:31) at which the magnitude is minus 4.8db as per my notes it is 4.6 radians per second.

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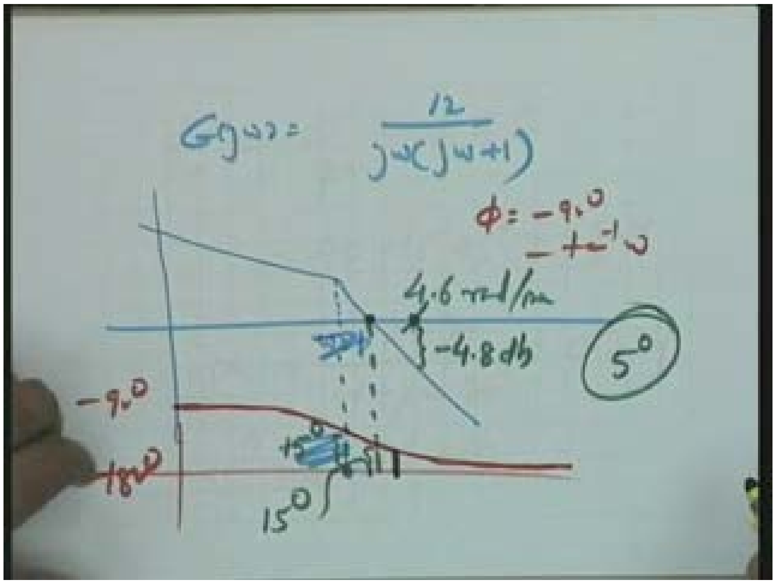

So I now get the value of tau from this expression that let omega m is equal to 1 by tau into 1 by alpha tau under the root equal to 4.6 radians per second. this will give me the value of tau parameter get the value of tau and the D(s) the final result now I am giving you turns out to be 0.376s so this is naturally the value of tau you see 0.376s plus 1 divided by 0.128s plus 1 is the value of D(s) I obtained.

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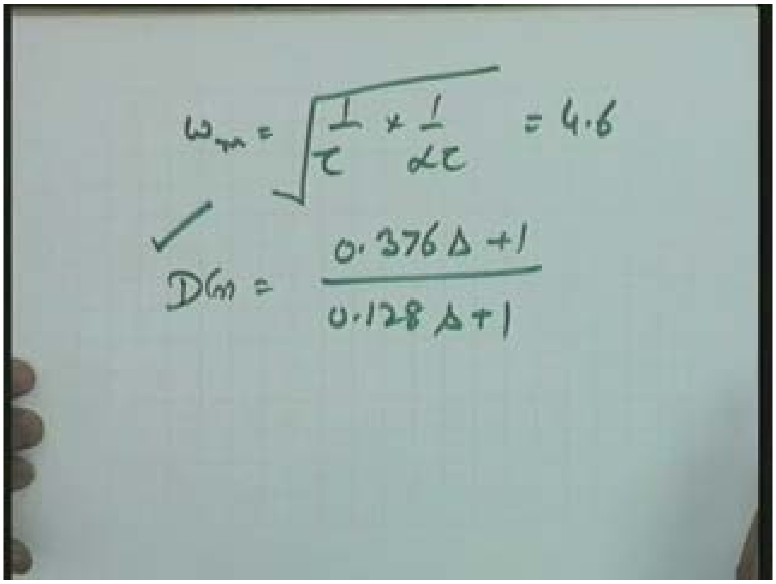

Now you may say that I have to tell you what from the point view of examination also. Do not leave your answer like this because you have made a guess. You do not know whether that guess was satisfactory or not and therefore you make a compensated plot at least couple of calculations to check the phase margin for KG(s) D(s) this is the system now.

What is the system?
K was 12 so 12(0.376 s plus 1) divided by s(s plus 1) (0.128 s plus 1) this becomes your open-loop transfer function of the compensated system. So now I think I need not make a sketch over here I can proceed further because for this particular system you can now make the Bode diagram and get the phase margin. Please note that the entire phase angle curve will not be required. Just see the corner frequency; the cut-off frequency is it equal to 4.6 which you have calculated? If yes calculate the angle that gives you the phase margin. So you have to optimise you see. Do not curse me later if the problem turns out to be lengthy.

You have to optimise on the time. You have to see what is the total effort you require in solving such a problem. Do not make an effort more than that so that you can evenly distribute the time.
So in this particular case for example a check is required. Now you need not give the second trial but at least you should say that look your epsilon value turned out to be wrong and you will like to do it now by taking epsilon larger. If phase margin turns out to be more than 40 degrees there is no problem 42 degrees 43 degrees it is fine and if it is 1 or 2 degrees less then also there is no problem because after all even 40 degrees is a guideline for us only the extensive simulation will tell whether the performance is satisfactory or not.

[Conversation between student and Professor] yes please, ((Sir, if the quadrants are even as K v and phase margin why cannot we take a larger phase of 50 instead of 40)) ((00:30:25 min)) that is right. Please see that he says that that if the requirement is greater than equal to 40 degrees then why not 50 degrees 60 degrees are larger phase margin.

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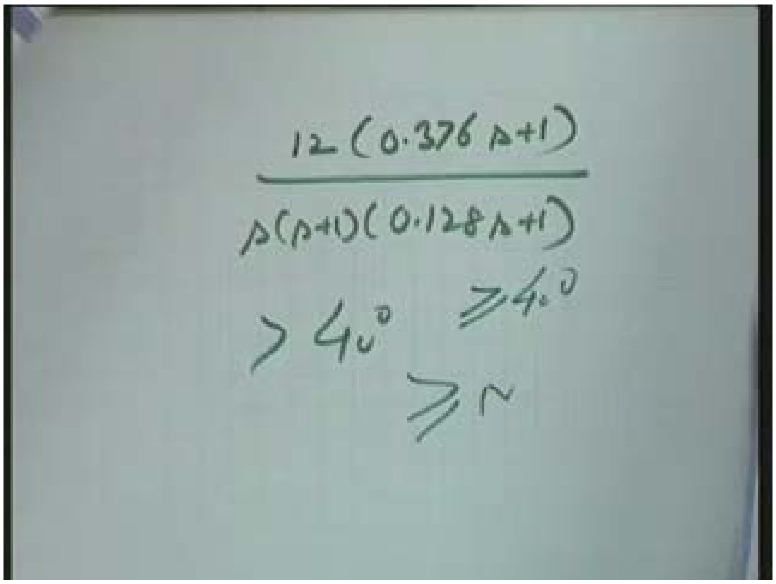

Please see that in this case what is the price you are paying.

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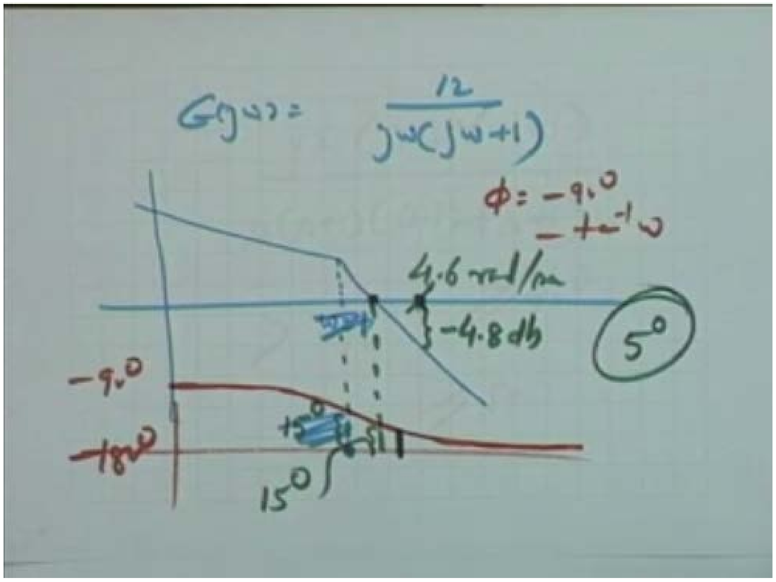

You have yourself said that the crossover frequency will shift; this crossover frequency is an index of bandwidth. The larger this value the larger is the bandwidth. So it means there is a bandwidth limitation you see you cannot ideally speaking the bandwidth should be infinite but the noise filtering requirement may put a limit on the bandwidth. Secondly, larger phase margin may impose some other restrictions also, well; bandwidth is one of the important things you can keep in mind. Therefore, you see that when constrains; when certain specifications are given we normally try to meet these specifications on the boundary so that margin for any other requirement is available. In this particular case bandwidth is the right answer.

Here actually I have not given you the complete problem I simply say that any bandwidth requirement can be checked using Nichols chart. So let me now start, transfer it on the Nichols chart. You can see that a Nichols chart may be required if the problem is asking for bandwidth because you cannot think of getting the bandwidth from the Bode plot though you know that this crossover frequency is somehow an index of bandwidth larger this value larger will be the bandwidth but still the absolute value of the bandwidth you cannot obtain. You will have to make the closed-loop frequency response or you will have to use the Nichols chart to get the intersection with the minus 3db contour that is the value of the bandwidth.

Hence if the bandwidth is not satisfactory, you see, if the bandwidth turns out to be……. if suppose…….. now his question may be please taken care of; if the bandwidth requirement is too large you can accommodate larger bandwidth in that particular case you can re-enter the design and take a larger phase margin no one prevents larger phase margin is better provided your other requirements are also satisfied. So entering into design cycle depends upon the total requirement you are going to take care of as far as the requirements of the user are concerned.

I think I can leave the lead compensator design problem here hoping that the complete design procedure is clear. It is a very simple design procedure; the trial and error is in terms of only epsilon and to see whether your bandwidth requirement is satisfied or not. Naturally you will make one trial from the examination point of view but you should know the procedure and hence I will definitely like the comments to be made at every stage. You have to convey, you have to give the message to me very clearly that if you were required to enter into the design cycle you have the necessary knowledge for that. That is your responsibility to convey it properly.

[Conversation between student and Professor] ((Sir could you please once we have to be made once we have made a)) ((00:33:32 min)) Once we have got D(s) first of all I will like to check the phase margin that is my check on epsilon because after all these are the analytical calculations I have already done. Even in these calculations I have even not taken minus 3db into account may be. So first of all I will like to check whether the phase margin requirement is satisfied or not. And I am telling you; you have now to stretch for 40 degrees, anything around 40 degrees is acceptable. Once this is done it means K v and phase margin requirements have been satisfied. Then if the problem or the user gives you the requirement on bandwidth also translate this data on the Nichols chart the magnitude and phase, not of this but of the compensated system.

First make the Bode plot and phase angle plot of the compensated system, translate this data on the Nichols chart and get its intersection with the minus 3db contour to get the value of the bandwidth. If it is satisfied your design problem is complete if not comment on it appropriately as to what will be your next design trial whether you will like to increase epsilon reduce epsilon what you are going to do that you have to comment on properly. Any question on lead compensator design please?

Next I am taking the lag compensator.
[Conversation between student and Professor……..34:55] You see, in that particular case it means your requirements cannot be satisfied as we read in this case. The lead cascade will also come to satisfy both the requirements simultaneously if you are not able to satisfy it. By one unit it means the complete lead as well as the lag unit that may be required.

[Conversation between student and Professor ((once we work with a asymptotic plot)) ((00:35:14 min))] No, I am making it here that if you are working with the asymptotic plot I do not mind provided you have taken enough care that your final check will give me the required phase margin. It is fine if you think that you will take asymptotic plot but sufficient margin on epsilon but do not make it too much. Suppose you take epsilon equal to 20 as was suggested by him then the bandwidth requirement may not be satisfied. It is up to you whether you make an asymptotic sketch or you take of the errors also. I do not think making errors is a big thing because no calculation is involved after all; no calculation is involved there, you can make you can incorporate the errors and make the actual plot immediately.

Now I go to the lag section or the lag compensator. You recall from the root locus sketch what was our lag compensator a pole here and a 0 close by. So, if I take a D(s) D(s) could be written as……okay in what format we should take let me see: tau s plus 1 I am taking in this format tau s plus 1 over beta tau s plus 1. Naturally in this particular case beta will be greater than 1. The constant k similar argument I am not using here the k has been transferred to the uncompensated system. So this becomes the transfer function of a lag network or a lag compensator tau s plus 1 divided by beta tau s plus 1 with beta greater than 1.

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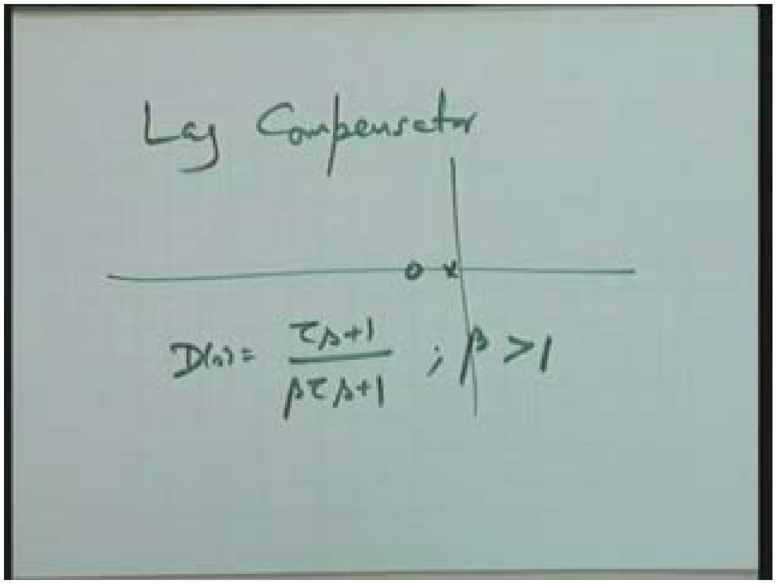

Let me see its frequency characteristics. Similarly, the frequency characteristics I am going to use. So, what will be the first corner frequency please? Omega is equal to 1 by beta tau first and this is a pole (Refer Slide Time: 37:14); since it is a pole I am making minus 20 degrees per decade here and then a 0 plus 20 degrees per decade so naturally it becomes 0db here and I have here omega equal to 1 by tau. So this is omega verses db omega verses db.

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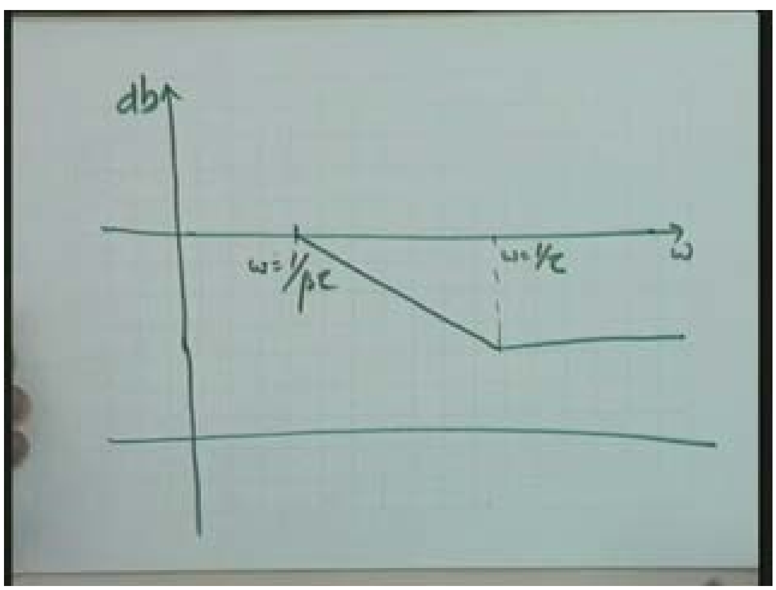

Now let us see the phase angle please. Phase angle in this particular case obviously as you see the angle will be lagging because beta is greater than 1 so let me take a sketch over here omega phase angle is lagging here and this is 0 degrees (Refer Slide Time: 37:59). Now, here before I go ahead though the calculations for maximum phase lag and the frequency at which it occurs can be made……. this magnitude let me first write quickly 20 log beta it can be checked though these calculations can be made but let me make one comment over here the lagging characteristics of the network will not be utilised for compensation rather it is a drawback and we will like to see that the lagging characteristics does not give negative contribution to the system.

What I am going to use I am going to use this particular negative magnitude of the lag network for compensation and hence I am not interested in marking 5 m and the corresponding frequency here this point may please be noted. This region of the compensator (Refer Slide Time: 38:46) is not going to effectively contribute to the compensation I am going to take up and therefore these magnitudes I am not taking. Let us see how do we how do we handle such a situation. I am calming that the phase lag….. it is called lag compensator because of the phase lag network but in frequency domain design the lagging characteristics will not be utilized as you will yourself appreciate when I take a […..39:09….ical] problem.

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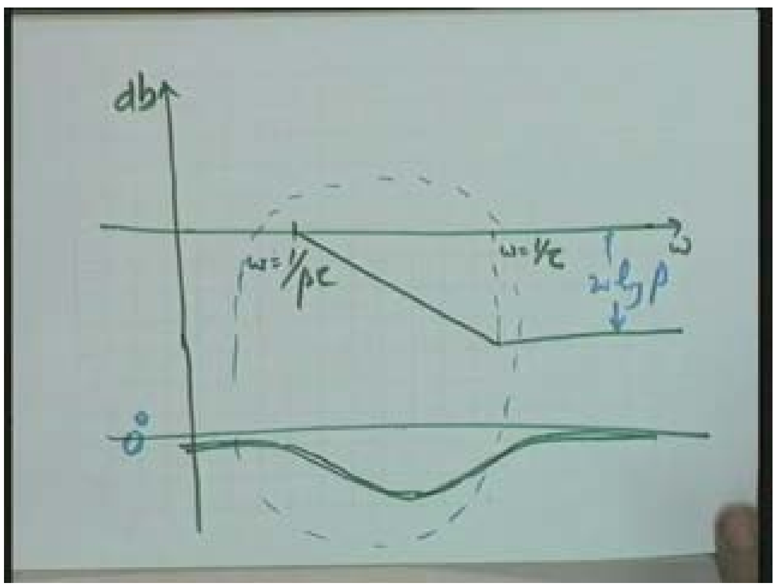

I think I can straightaway go to the problem. Keep this characteristic in mind and we will use these magnitude characteristics to get the appropriate value of the phase margin and the bandwidth or other requirements if imposed.

I take a problem here: G(s) this is not working G(s) equal to k over s(s plus 1) (s plus 4) the problem we had taken up in the tutorial class. Now in this case let me say that G(j omega) I want to get in the time constant form so it is k by 4 it is j omega (j omega plus 1) (0.25 j omega plus 1). For this problem it is given that I require the phase margin equal to 43 degrees, I require the bandwidth equal to 1.02 radians per second and I require K v greater than equal to 5 these are my requirements. My design procedure will be same.

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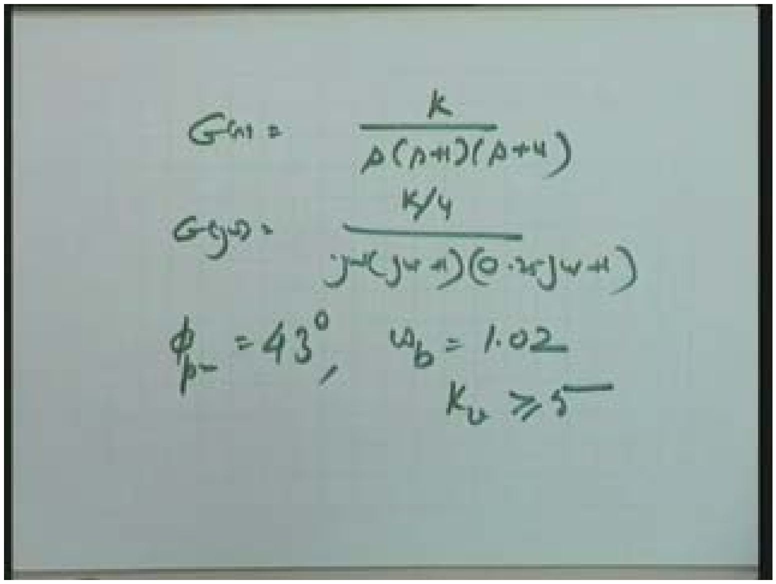

I will first satisfy the K v requirement by assigning a suitable value to k then I will take care of the phase margin; after that I will go to the Nichols chart to check the bandwidth if it is not satisfied I will re-enter with appropriate knowledge obtained from the Nicholas chart. Tuning or readjusting knowledge will be given by the Nicholas chart as to bandwidth is large or small whether I can play with this and the question was that if all the requirements cannot be satisfied then a lag section and a lead section together will meet my requirements on phase margin and bandwidth.

Now I take up, yes, please help me what is k equal to?
k is equal to 20 and K v is equal to 5 naturally will be given by that. In that case I write G(j omega) uncompensated system since k has been clubbed with the uncompensated system it is 5 over j omega (j omega plus 1) (0.25 j omega plus 1) come on make a sketch please. I making asymptotic here to save time but you can use the errors as well. So this is one minus 20 dbs per decade one corner frequency omega is equal to 1 and one more omega is equal to 4. Omega is equal to 4here and omega is equal to 1 here and I have the corresponding phase angle plot here.

Help me please; what are the asymptotes?
I think you will recall the asymptotes we had taken for this minus 90 degrees and minus 270 degrees. So let me draw a line for minus 90 degrees here, a line for minus 270 degrees here and a suitable curve will come let me see what is the phase margin so accordingly I will plot the curve over here (Refer Slide Time: 42:11) this is the phase angle I make for this particular system minus 90, minus tangent inverse omega, minus tangent inverse 0.25 omega I can write here minus 90, minus tangent inverse omega, minus tangent inverse 0.25 omega this becomes my phase angle curve. This is the gain crossover frequency and this particular point I find the phase margin to be minus 4 degrees.

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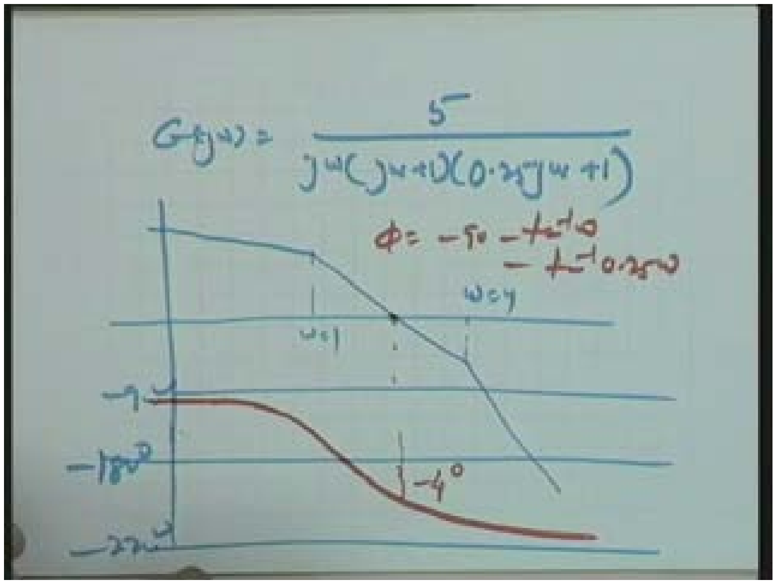

Therefore it means for this particular k value which you have taken equal to 20 degrees which meets your steady state requirements this system has become unstable. However, when I add a compensator the stabilisation naturally will come. The phase margin in this particular case turns out to be minus 4 degrees. See that this is db on this side and here it is omega and phase angle (Refer Slide Time: 43:04).

Now make the adjustments please. I will I think take up this sketch and see what type of adjustments I am going to make in this case. If you look at this red line which is the phase angle curve, please see, if I am able to pull the low frequency region down it is possible to increase the phase margin is it not. If I pull the low frequency region down so that the crossover frequency the gain crossover frequency shifts on the left then the phase margin will be improved will be increased.

One observation here itself should be clear that the lag compensator will always reduce your bandwidth while the lead compensator is going to increase your bandwidth is it all right please because with the lag section you are pulling this down in the low frequency range it means the gain crossover frequency is reducing and I told you that the gain crossover frequency reduction leads to reduction in bandwidth and increase leads to increase in bandwidth and therefore the lag compensator is going to reduce the bandwidth while the lead is going to increase the bandwidth. This point may help you in taking the decision whether for a given design problem you are going for a lead compensator or a lag compensator.

Check the bandwidth for the uncompensated system. If you find that the uncompensated system bandwidth is….. with respect to the required bandwidth you see increase or decrease you can find. Not that if the increase is required you cannot go for a lead compensator. You can see that if it increases then will it approximately lie within the range required. please see that it is not an absolute answer that uncompensated bandwidth you will see if the required bandwidth is larger go for the lead and if it is smaller go for the lag no, you have to see you simply know that your lead compensator will increase the bandwidth and after the increase is it expected that it will lie within the expectable range and if it is expected you can try the lead compensation.

Similarly the decrease; if it is expected that after the decrease it will still lie in the specified range you can go for the lag compensation. So it is only the guideline and suitable guidelines you have to take suitable clues you have to take from here as to your trial is going to be a lead compensator or a lag compensator. So, in many cases if both the phase margin and the bandwidth requirement is not satisfied what you do in that case first you design the lag section because lag section will meet your phase margin requirement and then you add a lead section to meet the bandwidth requirement because the lead section will increase the bandwidth.

You can really in that case one can do one can divide the phase margin requirement to be compensated; you can split that into two parts because you know that the lead compensator also provides a phase lead. So you can really split the requirement of the phase margin into two parts. Let us say you require 60 degrees. If you require total if you compensate it total by lag compensator what will happen the gain crossover frequency will have to come deep into this side it means actually the bandwidth will be drastically reduced if you compensate it total by the lag section. But if you say I will require a lag section only for 30 so what will happen it will slightly go down for 30. So 30 degrees phase margin can be obtained by lag compensator and remaining 30 degrees you treat the lag compensated system as an uncompensated system for the design module of lead compensator and provide an additional phase margin of 30 degrees so your gain crossover frequency will also shift and hopefully the bandwidth requirement will be met; it is a trial and error procedure you try and get the values of both lead and lag.

Therefore the standard……. you see you will recall, in the root locus section our practice was to first design the lead section and then go for the lag. That is first you meet the transient response and then you design the lag section so that it does not disturb your root locus plot. Here it is this way you first design the lag section, partially meeting the phase margin requirement, slightly decreasing the gain the gain crossover frequency and hence the bandwidth then design the lead section meeting the remaining phase margin requirement and hopefully increasing the bandwidth to the desired value.

Therefore now I switch back to the lag section procedure. Now you can help me please what shall I do. Now you just see that if I take…. let me first of all get the frequency at which the phase margin is how much I need I need 43 degrees. Let us say that this is the cut-off or this is the gain cut-off frequency at which the gain crossover frequency at which the required phase margin of 43 degree will be obtained. This is 43 degrees so now what do you want; you want this particular plot to be shifted down by this much of db. I need your attention please here this much of db the idea should come from you. This much of db (Refer Slide Time: 48:44) if I add because it is a log plot it can be added so that the total plot comes down the crossover frequency is given by this point and hence a phase margin of 43 degrees will be realised.

Let us say that I match this frequency at this particular point (Refer Slide Time: 00:49:01 min) intuitively I am saying what are the problems involved in it? I will like to put it at this point and not at this point why; it is because let me give the maximum attenuation at a time you see why do I give the partial attenuation; this is the maximum attenuation possible, this is the maximum db by which I can bring it down so naturally I will be interested in this region. The only thing is this that this region extends from omega is equal to 1 over tau to infinity so what point should be taken that is important.

Can you give me some clue here; what point should be taken? I mean you give me some qualitative idea. Should it be omega is equal to 1 over tau or should it be a very very large value or it can be anything that is the idea I want.

[Conversation between student and Professor……. ((place the value)) ((00:49:46 min)) what could be what is the reason why twice ((because we do not want to do in very large)) ((00:49:51 min)) why ((the bandwidth is)) ((00:49:46 min)) let us see. The idea is fine but with respect to the phase angle you just see please.

Again you have taken 43 degrees without the contribution of phase lag. In this case it is a negative contribution. So let us say if you take at this point this much of phase lag will be added. So it means the 43 degrees which you have taken you will not be able to obtain 43 degrees it could be 35 degrees. So one thing is there that even less you see, my plot is not accurate, so at the corner it is a substantial phase lag at the corner frequency you see. My plot is not to scale it is a substantial phase lag at the corner frequency. So the clue could be that why do not you take it very far away, if you take it very far away in that particular case what will happen the value of……..in this particular case it will be there but 1 over tau and 1 over beta tau which you are going to realise using RC components the components you will not be able to get appropriately it is the realisation problem that you want that 1 over tau and 1 over beta tau should be proper and that demands that 1 over tau should not be taken very far away because in that particular case the realisation problem comes and there are no quantitative guidelines; the qualitative guideline is this that if this particular point at which it is 43 degrees……. first of all instead of 43 degrees you take 43 degrees plus epsilon; assume that some phase lag will be anyhow added; assuming this phase lag here you take it as 43 degrees plus epsilon and in this particular case let us say in this particular problem I have taken that epsilon to be 12 degrees so it means I want to take a point at which it is 55 degrees and not 43 degrees and I find that point in my notes that point is given as 0.52 radians per second.

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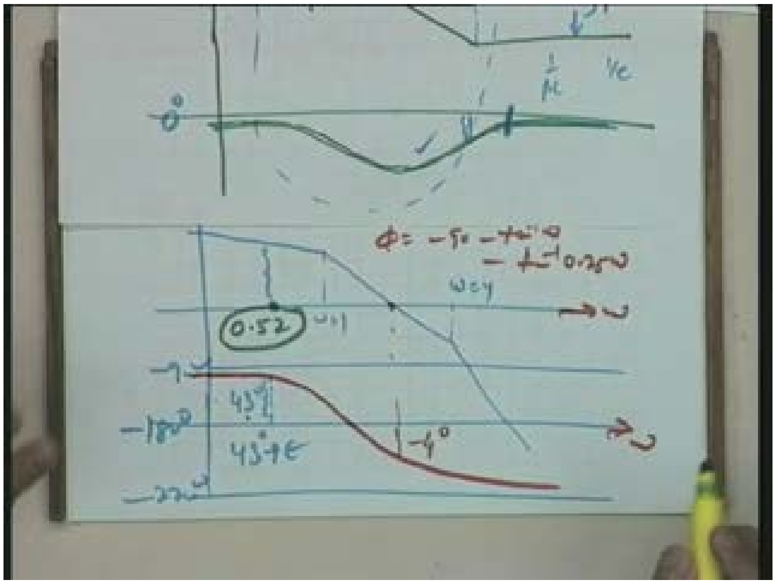

So please note; first of all I have taken care that the safety margin should be taken for this phase lag and this again there is no quantitative guideline you have to get appropriate value by trial and error. So, very large value for the obvious reasons should not be taken because your bandwidth will reduce drastically. So in this case 12 degrees I have taken because this is the final design and 55 degrees the corresponding value is 0.25. The qualitative guideline is this that this frequency should match approximately the frequency which is this 1 over tau you have taken (Refer Slide Time: 52:45) or this particular point you have taken you place this particular point about two octaves below this particular point you see this point please two octaves. That is you take it divided by 4 this is again just a qualitative guideline it may or may not work but mostly it works.

This is 0.25 so it means you place this frequency this frequency which is the corner frequency two octaves below this point so this point you already know this point is 0.52 and now you have got the answer the answer is this that 1 over tau equal to 0.52 by 4 and that by 4 is a qualitative guideline to you, you may like to take one decade below different guidelines depending upon the problem, depending upon your experience. You see; if you are working with the CAD software you may try different viewpoints but the procedure should be well said. So I take two octave in this example to give you some numerical answers so I take now 1 by tau is equal to 0.25 by 4 and therefore one parameter is set in this particular case.

Now how about the other parameter; help me please; how do I get the other parameter?
The other parameter should come from this (Refer Slide Time: 54:14). Please see; this much of attenuation, this much of minus db you want and this much of minus db should equal this value (Refer Slide Time: 54:19) two octave below you have already taken so this point (Refer Slide Time: 54:26) is already available to you. What is this point let me take, it is 0.13….. it was obvious it is 0.13, it is 0.13 so at 0.13 you read off the value and this as per my notes is equal to 20dbs. So it means you want this much of attenuation and therefore I get the other parameter 20 log beta should be equal to 20 which gives me beta equal to 10 and hence both the parameters

are available the total design in this case is D(s) is equal to 7.7s plus 1 divided by 77s plus 1 with beta and the other parameter available to you.

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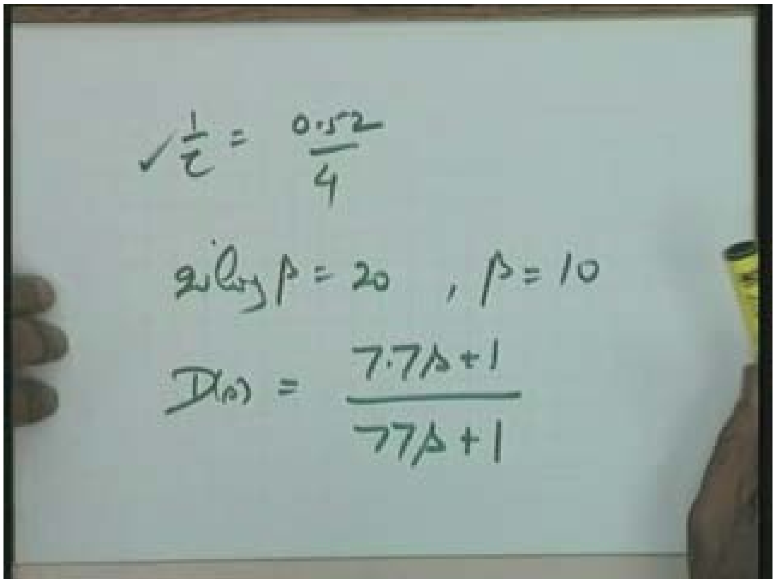

Now all the other comments are identical to the first case. That is you cascade your D(s) to the uncompensated transfer function, get the Bode plot of the overall system and see that the effect of the phase lag is too….. that is the value of epsilon has been appropriately taken and you are able to get the required phase margin of 43 degrees around 43 degrees with the value of epsilon we have taken and one more check and that check is that of gain crossover frequency, the check is that of bandwidth. If there is a slight variation required in the bandwidth in that particular case may be by adjusting epsilon you may be able to meet. But if there is a big gap between the bandwidth you have acquired and the bandwidth desired then it is an indication that whatever design you have made treat this design as an uncompensated system and go ahead for the lead section so that the total lag lead compensator is available to you.

I think with this through these examples I have conveyed the procedures and I hope the procedures should be clear and with this we close our discussion of this particular course. Thank you very much for your cooperation.