Analog Electronic Circuits
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Lecture - 72
Example Phase - Margin Calculations

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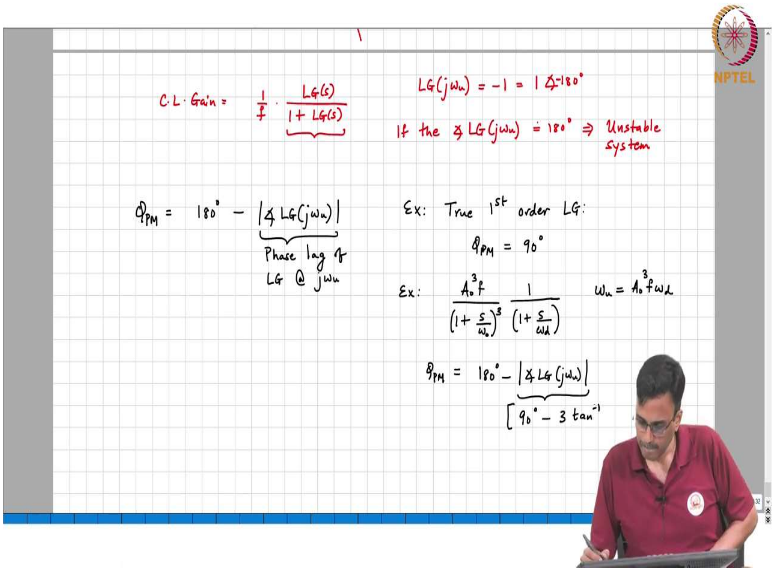

Alright. So, let us do some simple examples, a true first order system. What is the phase margin? What is the angle of the loop gain function? What is the phase lag of the loop gain function at the unity gain frequency if we had a true first order system? 90^o. So, how much margin do we have for the loop to become unstable? We can add 90^o before the loop becomes unstable.

So, this phase margin for a first order system is 90^o, ok. Then let us say a second example. So, let us say we have A_o^3 f/(1 + s/ω_o)^3 (1 + s/ω_d). So, what is ω_u? Assuming that the unity gain frequency is much smaller than ω_o, ω_u is A_o^3 f ω_d.

So, the phase margin therefore, is nothing but 180^o - the angle of the loop gain the angle of the loop gain at jω_u. And, what is the phase lag of the loop gain at the unity gain frequency? Yeah. So, they are basically two components. Due to the dominant pole what is the phase lag? Due to the dominant pole what is the phase lag?

Student: 90^o.

90°, right, that is due to the dominant pole.

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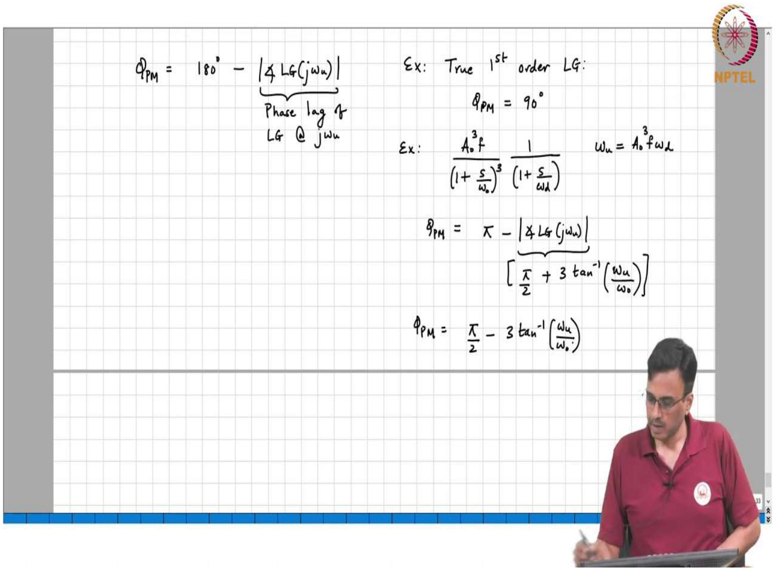

Actually, I should not do everything in radiance then we should do this also in radiance. - 3 $\tan^{-1}(\omega_u/\omega_o)$. So, what is the phase margin, is $\pi/2$ - 3 $\tan^{-1}$ (ω_u/ω_o). So, now, let me ask you this question.

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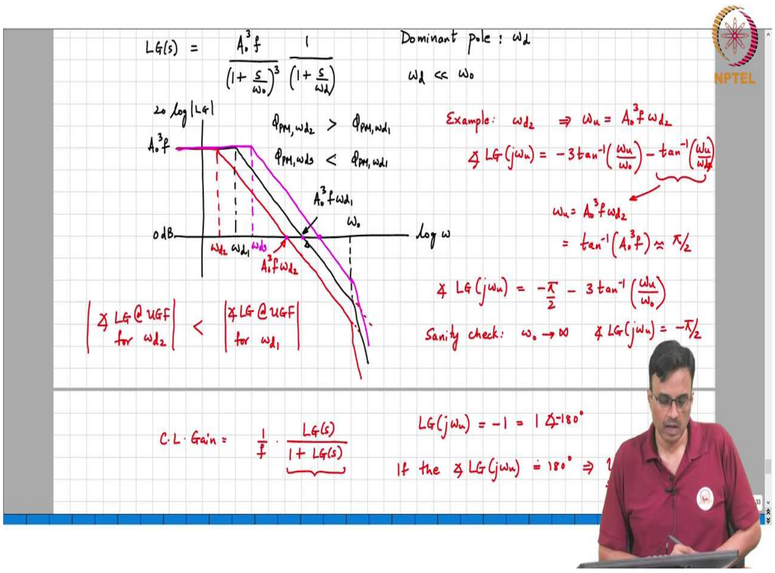

So, φ_{pm} for ω_{d2} versus φ_{pm} for ω_{d1}, which is greater? Which is the choice of dominant pole frequency ω_{d1} ω_{d2} which of them has got a larger phase margin?

Student: $\omega_{d2.}$

ω_{d2}, alright. And phase margin ω_{d3} and phase margin ω_{d1} which of them has got a larger phase margin? ω_{d1} has got a larger phase margin then choosing ω_{d1} results in a larger phase margin than ω_{d3}.

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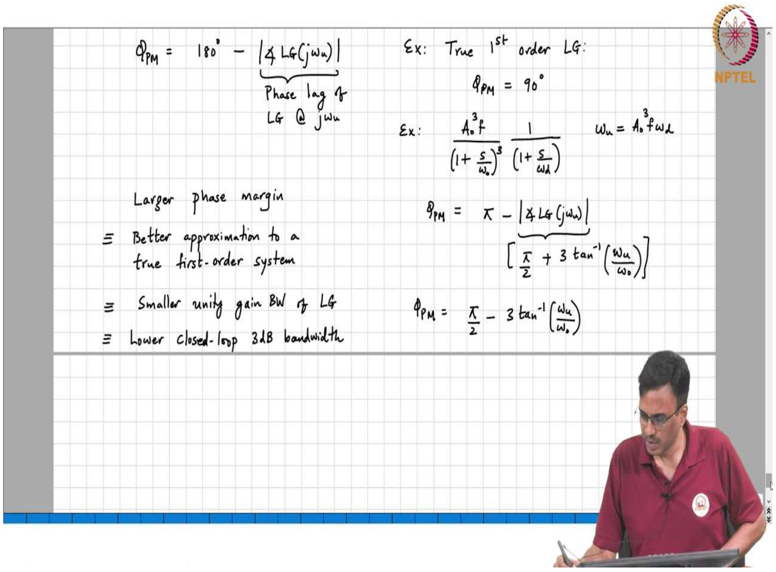

But so, basically larger phase margin is equivalent to saying better approximation to a true first order system which is also, but what are you paying when you get a better approximation to a true first order system. So, basically means smaller band unity gain bandwidth of the loop gain which is equivalent to lower close loop 3 dB band, ok. So, so, as you can see you know like everything in life this is a trade off. If you want a better phase margin you basically lose bandwidth, right. If you want higher bandwidth then you have a poorer phase margin. If you have poor phase margin, what does it actually mean?

So, the smaller the phase margin the closer the system is to instability and you know as you can see for a true first order system the phase margin is 90^o and as then as the phase margin keeps reducing you will basically essentially become closer and closer to the $j\omega$ axis. And, if the phase margin is 0, the two poles are there are two poles on the $j\omega$ axis.

So, as the phase margin becomes smaller and smaller, what comment can I mean the poles are getting closer to the imaginary axis and what comment can we make about the transient response if you have two poles which are very close to the imaginary axis? Yeah, so, if you have two poles which are very close to the jω axis what comment can we make about the pole's transient response? There will be a lot of ringing because the quality factor of the poles is going to be very very high ok. So, now the obvious question is do you know what phase margin we should design a system for right? So, I mean one thing is to say well I want 90º phase margin ok, then what should you do?

No, you do you have a higher order system I mean you cannot wish it away and say I want this to become a first order system, correct? But, if you want a very high phase margin close to 90º, what will you do? The only control you have is on the dominant pole frequency. What will you do to get a large phase margin?

If I choose my ω_d to be, you know, super small, then the phase margin will be close to 90º. But, what does it mean, but as a consequence I now have a really small band correct. On the other hand, if I say I want large bandwidth then I have to keep reducing the phase margin. So, you know how small a phase margin you can have is basically an engineering choice you make.

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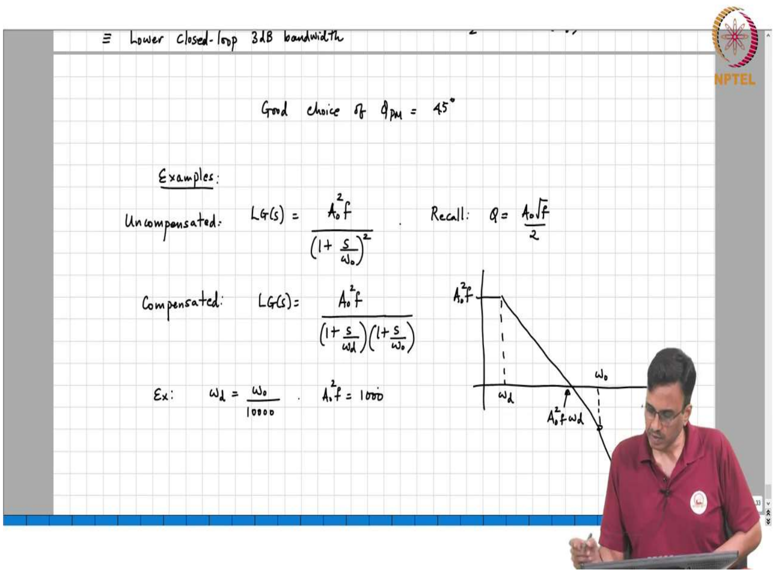

So, a good choice I would say is basically I would say maybe 45º, right. I mean there is nothing wholly it is just a choice I make, right. Some people who are very conservative will say 60º I need 60º of phase margin, right. Some people will say oh, well 60º is too much phase margin. I am losing out on a lot of bandwidth. I will push my phase margin to 45º ok.

And, what you call then somebody else will come and say 45° is just too much phase margin. I am happy with 30° phase margin, right and then you will get even more bandwidth, but the response will start ringing even ok, alright. So, now you know let us put all the stuff that we have learnt you know in some examples.

Remember when we had a second order system the loop gain function was $A_o^2f/(1 + s/\omega_o)^2$, correct and what was the close loop Q $=A_o \sqrt{f}/2$, ok. So, basically this is telling us that well even though the close loop system is stable the quality factor of the close loop system is $A_o \sqrt{f}/2$, ok and that is you know that is not very large I mean that is very large and therefore, there will be a lot of ringing.

So, then we said ok, I mean then what did we say well if you make a high order system look like a first order system then we will have you know it will the close loop system will behave like a first order system, right. So, what did we say? We are going to introduce a dominant pole. So, rather than introducing a new pole which is much lower, it is actually easier to take one of the poles which are already existing and make it much much smaller.

So, basically you say the compensated system is $A_o^2f/((1 + s/\omega_d) (1 + s/\omega_o))$. So, where one of the poles has been made deliberately lower and in circuits that is easily done because you know the poles are all coming because of some parasitic capacitance somewhere. Hey, you can take a big intentional capacitor and put it in parallel with one of the existing parasitic capacitances and therefore, one of those poles can become dominant, right?

Now, if you look at the Bode plot now, what will it look like if we have to choose the unity gain frequency, right? So, this A_o^2 f ω_d must be much smaller than ω_o this is ω_d ok, alright. So, if so, for example, if ω_o or ω_d is chosen such that it is say $\omega_o/10000$, ok and A_o^2 f is say 1000, ok. So, what comment can you make if we had the uncompensated system what would the Qof the close loop system be?

$\sqrt{1000}$ is about 33 or something by 2. So, we will have a closed loop Q = 15 if we did not compensate the system, what should we expect now? If we should be expecting to do much better because this now behaves like a first order system, right. So, what is the so, what is the phase margin?

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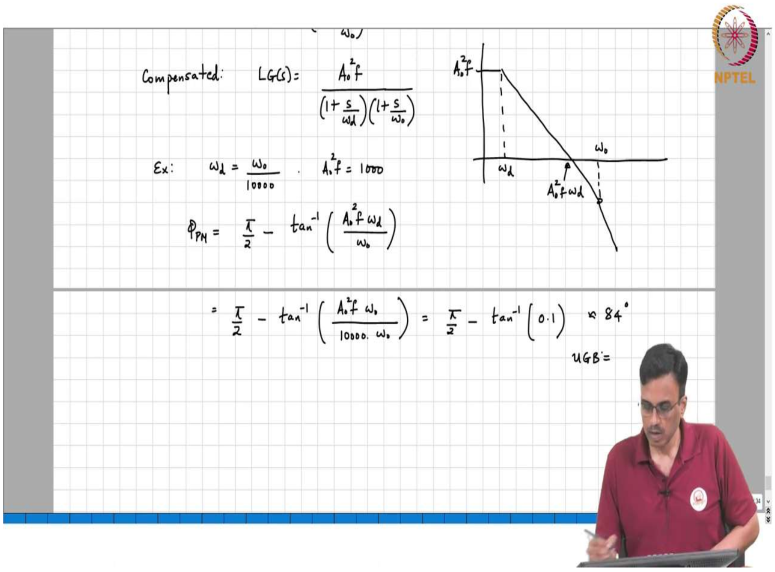

Is 90^o - $\tan^{-1}$? So, what is the unit gain frequency in relation to ω_o? It is A_o^2 f ω_d/ω_o which is nothing but $\pi/2$ - $\tan^{-1}$ A_o^2 f ω_d is what? A_o^2 f ω_d is $\omega_o/10000$ ω_o which is $\pi/2$ - $\tan^{-1}$ A_o^2 f is 1000, ok. And, $\tan^{-1}$ 0.1 is roughly 0.1 that is you know and 0.1 radians. 0.1 radians is how many degrees?

How much? Something like 60^o, right. So, the phase margin is not 90^o right it is smaller by some 60^o or so ok. And, this is right so, basically in this case the close loop bandwidth. So, the phase margin is about 84^o, ok and what is the unity gain bandwidth of or the 3 dB bandwidth of the close loop system?

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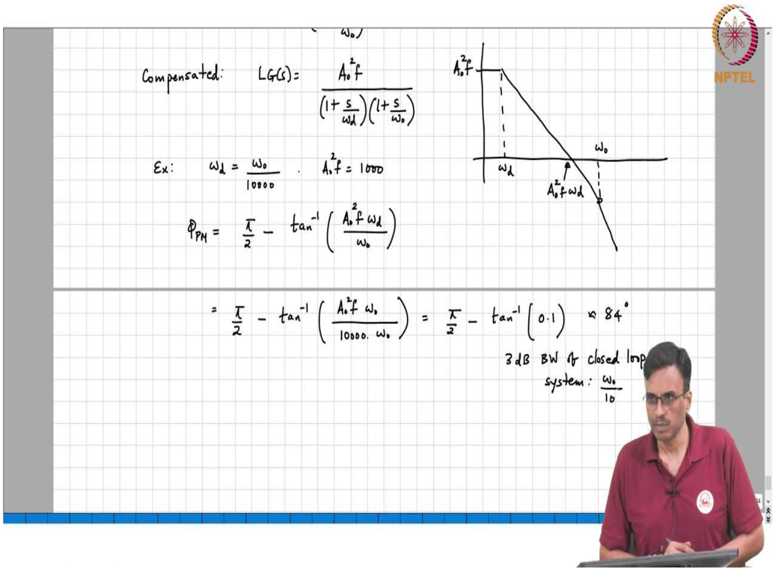

In terms of ω_o what is it? Or in terms of ω_d what is the 3 what is the it is $\omega_o/10$, correct. Ok. Now, if I if the dominant pole was made you know 2 larger right, what would be say about the you can you will simply look at it and tell me quickly what the phase margin will be? So, it is $\pi/2 - \tan^{-1} 0.2$. So, that will become you know another say 6^o smaller approximately.

So, the phase margin is now smaller than what it was before, but what comment can you make about the 3 dB bandwidth of the close loop system ω_d has increased by a factor of 2. So, the 3 dB bandwidth will become twice as large, right and, but then you see that you have paid for 6^o and phase margin, you have paid the price of having the bandwidth, right.