Analog Electronic Circuits
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Lecture – 95
Effect of Feedback on Frequency Response (Part – A)

Dear students and participants, welcome back to our NPTEL online certification course on Analog Electronic Circuits myself Pradip Mandal from E and EC department of IIT Kharagpur. Today's topic of discussion it is; it is continuation of feedback circuit and what we will see that the Effect of Feedback network on Frequency Response of the forward amplifier. So, if we recall the our overall plan.

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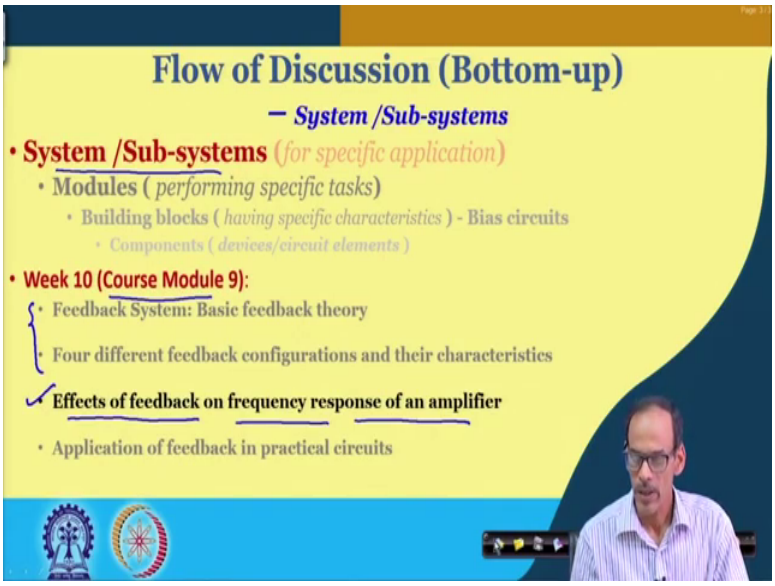

So, we are according to our schedule we are in week 10 and the it is module 9. And at present we are system and subsystem level of electronics analog electronic circuits. And as I said that we already have started feedback system and four different configurations we have seen. And today what we will see that change of frequency response of a of an amplifier due to the presence of feedback network.

In general, we can say that it is valid for even other linear circuit, but our specific focus it will be on amplifier. And also the when you say frequency response, it is primarily our focus it will be on gain of the amplifier, but that is also applicable for impedance. In fact, that is applicable for with other gains also current gain, transconductance, transimpedance and so and so. So, our discussion today it is relatively generic and we will see that how the frequency response changes due to the presence of feedback circuit.

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The concepts we will be covering today it is primarily how the locations of the poles are getting changed, in the feedback system and that is due to the location of the amplifiers poles and also the poles of the feedback network. We shall focus on the situation where the amplifier may be having one pole or maybe it is having two poles or maybe three poles. And also, we will be considering cases where feedback network may not be having any pole only the amplifier maybe having pole or maybe the amplifier as well as the feedback network may be having poles.

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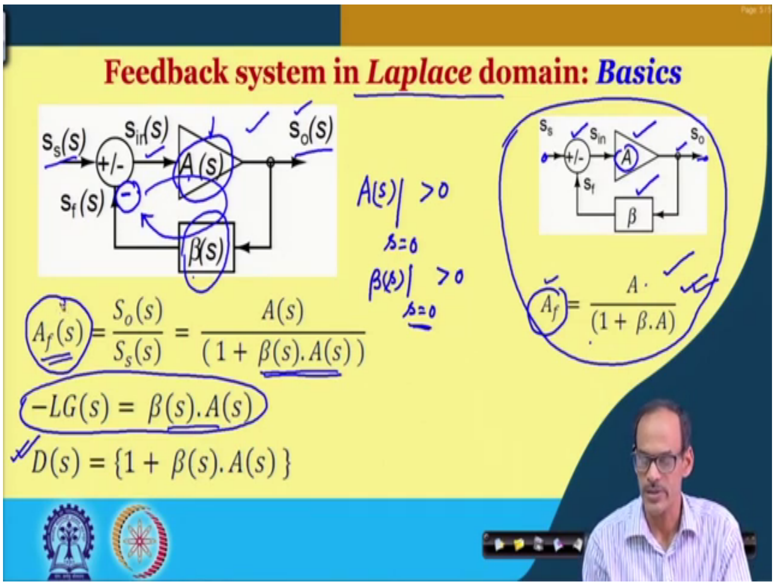

Now, let us come to the first case before we go into the first case again we like to recapitulate what we have discussed. In fact, we have discussed this kind of situation where this is the forward amplifier, this is the feedback network and then, we do have signal mixture and then we do have signal sampler.

And the forward amplifier gain it is A and the primary input to primary output gain what we call feedback system gain A f and as we know that this feedback system gain it is A divided by 1 plus beta into A. In fact, this equation is very powerful it is applicable not only in time domain, it is also applicable in frequency domain. So, today's discussion it is primarily in Laplace domain, in the frequency domain.

And this equation in Laplace domain also it is valid. So, if we concentrate the feedback system in Laplace domain, then each of these say transfer function particularly A and beta is having frequency dependency and the transfer function now it is getting represented by A s and beta s and likewise the signal may be having frequency dependency and so and so. But then even in this situation the feedback system transfer function defined by primary output to primary input it is A divided by 1 plus beta into A and you may also recall that minus of A and beta it is loop gain.

Namely once you go through this loop whatever the transfer function it will be experienced by the signal, A beta and a minus sign here maybe we do have a negative terminal here. So, the loop gain what we are discussing it is it is also having a direct dependency on whatever the poles we do have in the A. So, the effectiveness of this feedback network or the loop gain to change this transfer function of the feedback system is also, it also depends on the location of the poles and of course, we do have the desensitization factor.

Now, in our foregoing discussion we shall assume that this system it is negative feedback system which means that here to here we the signal it is experiencing 180 degree phase shift and also we are assuming that a at s equals to 0 frequency, it is positive. And likewise beta at s equals to 0, it is also positive and this negative sign indicates that under dc condition which means that s is equal to 0 under dc condition the system it is negative feedback system and the system is stable.

So, we will be discussing about amplifier which is linear circuit and in presence of negative feedback the linear system remains linear. But of course, depending on the situation location of the pole may create some issues which it will be discuss later, but let us try to see one by one. Suppose this a is having one pole then what is the what is its influence on the location of the pole of the feedback system?

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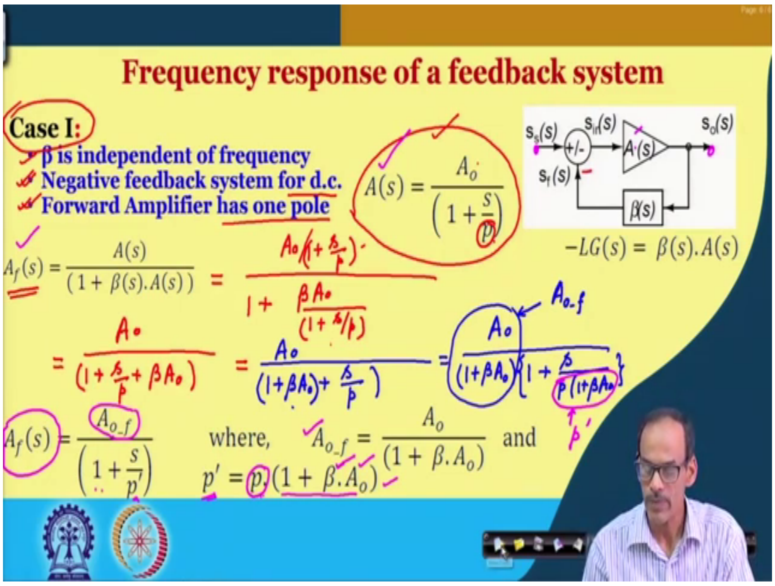

So, to start with let you consider case I, what we have in this situation it is yeah. So, when you say case I we assume that beta it is independent of frequency. So, we can say that beta is remaining constant and in the system, it is negative feedback system in dc condition and let you consider that forward amplifier it is having a transfer function which is having only one pole. Which means that A s can be written in this form, A naught is the low frequency gain or you can say almost in the dc condition, what is the gain and then it is having a pole at s is equal to p rather s is equal to minus p.

So, this pole it is left off pole and of course, the system is stable. Now, if you recall that the feedback system transfer function assuming it is having a minus sign here it is A s divided by 1 plus beta into A s and A s it is given here and beta is independent of frequency.

So, if you write the expression of this A s here what we are getting in the numerator it is A naught divided by 1 plus s divided by p and in the denominator we do have 1 plus beta into A naught divided by 1 plus s divided by p. Now, this factor we can take it here and so this factor it will be coming in the denominator of denominator. So, that part it is getting cancelled here. So, what we will be having here in the numerator it is A naught.

And in the denominator we do have 1 plus s divided by p plus beta into A naught. Now, further if we rearrange this equation what we can do here it is the constant part we can take it aside. So, namely in the numerator we do have A naught and in the denominator we do have 1 plus beta into A naught plus s by p. Now, if I take this part this part it is a constant part outside, so what we can get it is in the numerator again A naught and in the denominator with if I take 1 plus beta into A as a common factor. What will we be having here it is 1 and then we do have s divided by p multiplied by 1 plus beta into A naught right.

And then what you can say that this part it is independent of frequency and let you call this is the gain of this feedback system at low frequency and let we denote this by say A naught underscore f. And this part on the other hand if you see here this part we may say that this is the new pole and we may denote this by say p dashed. So, what we can get here it is that transfer function of the feedback system, it is having low frequency gain A naught f were, A naught f it is defined here divided by 1 plus s divided by p dash.

So, this p dashed is the location of the pole of the feedback system which is of course, it is function of p and also it is getting multiplied by 1 plus beta into A. So, this is this is what we do get that the location of the pole of this feedback system starting from primary input to primary output, it is a function of the location of the pole here and also getting multiplied by 1 plus beta into A naught.

So, as I say that in this case this is and this is independent of frequency, this is also independent of frequency which means that the location of the p dashed it is clearly it is a shifted version of this p ok. So, if you look into the bode plot of the feedback system namely if we sketch the gain and phase of this A f and along with probably the gain and phase of A and the loop gain you can find very interesting correlation.

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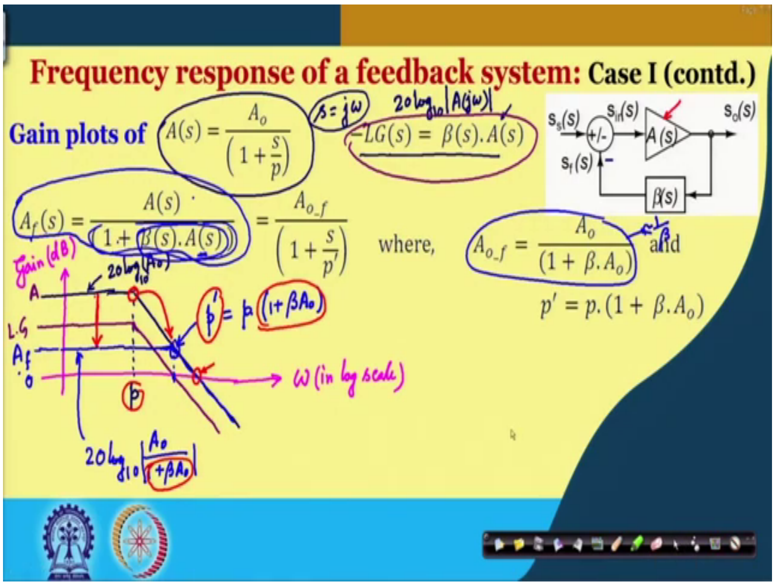

So, in the next slide let we continue on that. So, let we try to make a plot of this A for a location of pole p. So, first of all we are going to plot gain. So, the y axis it is we are considering it is in d B scale linear scale, but it is data is getting converted in the form of decibel and x axis it is omega in radian per second and in log scale. So, if I consider this plot for say to start with let you consider A.

So, A is having a low frequency gain A naught of course, it is converted into decibel d B and then it is having a pole and beyond that it is having a role of like this. So, we do have a pole here p and this is 20 log A naught or simply you can say that A naught converted in d B and so this is the plot of the gain plot of A. Where, of course, s we are replacing by j omega and then we are considering magnitude of A and then we are taking 20 log base 10 A for different values of omega. So, this is what we are plotting here.

So, likewise if you consider the loop gain or minus loop gain assuming we do have a minus sign here, what we are expecting is that this location of the pole of A it is directly getting reflected in the loop gain. So, if I sketch the loop gain here, so beta is less than 1. So, we are assuming this is beta is less than 1 which is of course, this is that is the typical case.

And it is having the same pole and then it is having role of 20 d B per decade. So, this is beta now sorry the loop gain magnitude of the loop gain and this is A. And then if you consider A f on the other hand what we are getting here it is A f in the in the low frequency region we do have a gain which is given here which is A naught divided by 1 plus beta into A, you may say that this is approximately 1 by beta. So, if beta is; beta is less than 1 which means 1 by beta is more than 1. So, if I say this is 0 d B level, so the beta is 1 by beta it will be like this.

So, this is A f A f, but of course, we consider the magnitude of A f and the value here what we can see here it is 20 20 log base 10 A naught divided by 1 plus beta into A naught. And then what will happen here? If you see this equation, so this a it is getting desensitized by this factor. So, as long as this part it is quite prominent namely the loop gain part, then we can say that it is approximately 1 by beta. So, it will continue to remain constant till this part it is coming less than 1.

So, this is the frequency where loop gain it is crossing 0 dB which means that beyond that this part it is very small compare to 1 that is what you can approximate and by the way we are drawing asymptotic gain plot, the actual one of course, it will be deviating. So, almost at this point or beyond this point this A f, it will meet the gain plot of A and beyond this point A f it is trying to continue or rather it is following A.

So, why is it so? Because from this frequency onwards this part it is getting very small. So, if I ignore this part compared to 1, then what I have it is A f equals to A s or A j A f j omega is equal to A j omega.

So, we can say from this point onwards A f it is following A in other words we can say that it is having a bend and this bend it is imposing a pole incidentally that is what this p dashed and this p dashed it is p multiplied by 1 plus beta into A naught. So, in in conclusion what we can say that in the forward amplifier we do have a pole here p that pole it is getting shifted to p dash.

So, apart from the amplifier gain it is dropping from this level to this level, it is also having a consequence that the pole it is getting shifted from p to p dashed. And incidentally in this case the reduction of this gain it is happening by this factor 1 plus beta into A and the increase of this pole location or the pole it is getting shifted by the same factor 1 plus beta into A.

And finally, the gain bandwidth product or unit again gain frequency this is remaining same for A and A f right. So, this is what we are expecting that if there is any pole in A, the corresponding pole of A f it will be getting shifted by this factor 1 plus beta into A. Now, let me try to plot the phase also yeah. so gain we have ok. So, we do have gain plot, no ok. So, let me clear this board and then come back to the gain and phase yes.

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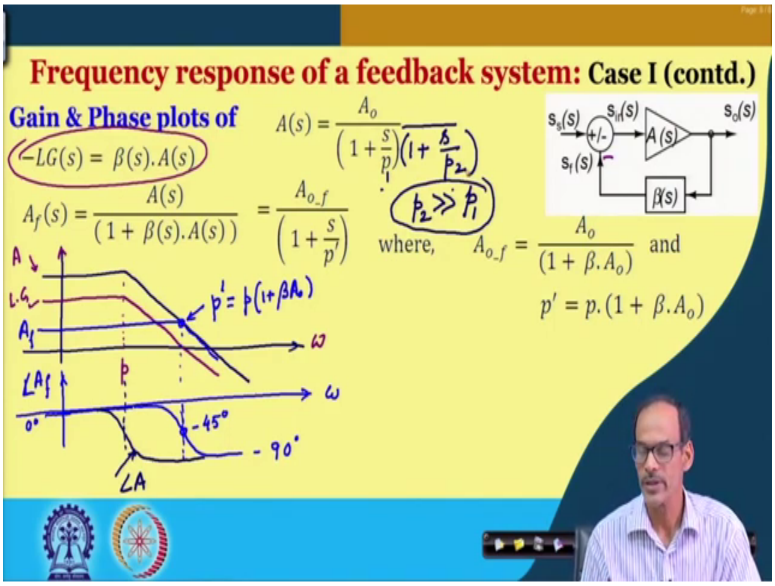

So, if I consider gain and phase together as we said earlier. So, let me quickly redraw the gain part. So, A it was like this and then loop gain it was; loop gain it was beta into A with a minus sign and so this is the loop gain part and then this is the location of the pole. So, this is loop gain, this is corresponding to A and then you also have sketched A f and what we said is that beyond this point; beyond this point A f it is continuing or rather following A. And we can say that the corresponding pole p dashed is p into 1 plus beta into A naught.

Now, if we are plotting the phase; phase for A f what we can say that let me plot the; plot the phase angle of A f. So, if you see here till this frequency the phase it is almost 0 and then once it is approaching to pole, it will be getting shifted to minus 90 degree. So, it is going from 0 degree to minus 90 degree and at the location of the pole it is minus 45 degree.

If you compare the original phase or rather phase of the mean forward amplifier, its pole it was at p and its phase it was rolling at p and of course, it was going towards 90 degree. So, this is the phase for A and the blue color it is the phase of A f. In fact, this phase it is same for the loop gain also; however, if you put say loop gain with this minus sign instead of starting from 0 degree it will it is supposed to start from minus 180 degree or 180 degree. So, that is the change of the phase and gain plot.

Now, if we consider a situation where suppose this a it is having two poles namely say p 1 and maybe one more pole p 2 and then we can try to see what may be the situation. So, that we call it is case II and to get a better picture let me start with a situation where p 1 and p 2 they are really wide apart and if I consider p 2 it is much higher than p 1, then we can get a clear picture how the poles are getting shifted ok.

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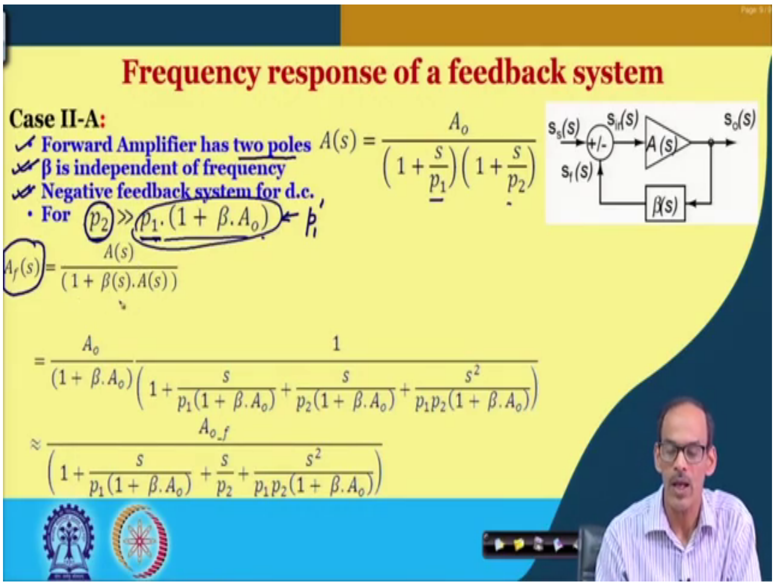

So, in the next case let me try to consider A is having two poles namely p 1 and p 2 and then we can see what is the corresponding location of the pole of the feedback system.

So, here again in this case we consider it is negative feedback system in dc condition beta also remaining independent of frequency and the forward amplifier it is having two poles p 1 and p 2. And the this location of the p 2 it is not only much higher than p 1 magnitude wise, but let we consider p 1 multiplied by 1 plus beta naught beta into A naught is also lower than p 2; which means, that we are expecting this p 1 it will be getting shifted by this factor and probably this will be the shifted version of p 1.

And then we like to consider this case where p 2 it is even beyond this location of the pole, then it whatever then we can try to see what may be the situation for p 2 ok. To start with again let we consider A f and the expression of A f it is a divided by 1 plus beta into A and now we do have A it is given here.

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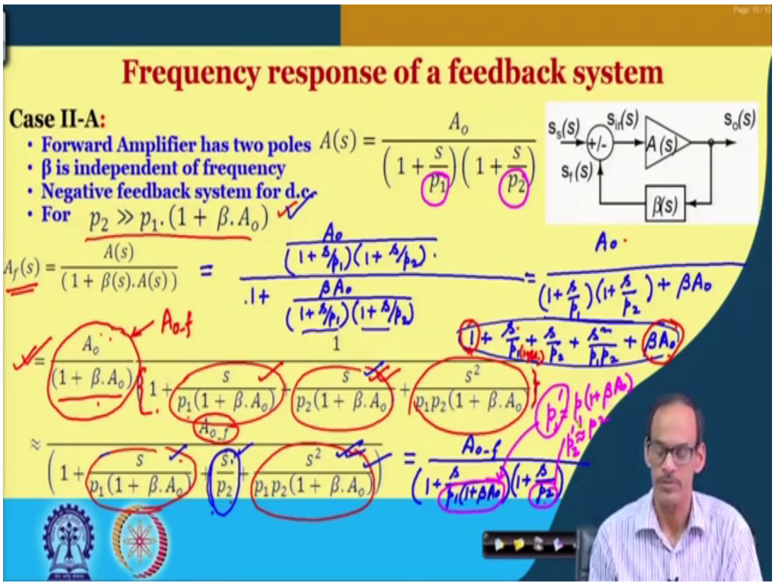

So, let me put the expression of A here. So, what we are expecting in the numerator it is A naught divided by 1 plus s divided by p 1 multiplied by 1 plus s divided by p 2; divided by 1 plus beta into A naught divided by 1 plus s divided by p 1 multiplied by 1 plus s divided by p 2. Now, this part if I put it here, so then from this denominator this factor and this factor they are getting cancelled here. So, what we can get in the numerator it is A naught and in the denominator what we get it is 1 plus s divided by p 1 multiplied by 1 plus s divided by p 2 plus beta into A naught.

So, if you expand this part what we can get it is one second order polynomial which is having 1 then s by p 1, then s by p 2, then s square by p 1 p 2 and of course, we do have this beta into A naught term. So, that is the corresponding denominator we will be getting.

Now, this part as you have done before this part and this part they are independent of frequency, so we can club them together and then we can take this factor outside. So, what we will get? In the denominator we will get a factor of 1 plus beta into A naught like this and in the numerator we do have A naught. So, this entire part it is independent of frequency and then remaining portion what will get here it is similar to this part this part this part, but we do have 1 plus beta into A naught factor. So, that is what we do have here.

So, the expression of A f it is A naught divided by 1 plus beta into A naught and then multiplied by 1 divided by 1 plus s divided by p 1, so and so and finally, what I will like to say that we do have the second order polynomial. Now, let us try to put some approximation to get a meaningful conclusion here.

So, first of all this part as you have done before let you consider it is independent of frequency and let you call this is A naught f, so this is the A naught f. And then as you can see here this second order term let we try to retain as is and this condition indicates that this part it is dominating. So, we are keeping this dominant part, so the linear term we are keeping unchanged at least this part.

And then quadratic part or a second order part we are keeping unchanged, but then this part we are intentionally trying to make some approximation instead of considering this part let you consider s divided by p 2 and that is allowed because compare to this linear term this linear term of course, it is very small under this condition. And why we do this, we are retaining this part that is because if I now, multiply this part and this part together I can get this term.

So, this instead of having this factor if I consider s divided by p 2 and if I ensure that product of this part and this part it is matching with the quadratic term that helps me to do the factorization. So, what we can say here it is numerator is A naught f and the denominator it is 1 plus s divided by p 1 multiplied by 1 plus beta into A naught, then multiplied by 1 plus s divided by p 2.

So, note that we are getting this approximation under this condition. So, now, we can say that this is this is the updated pole and this is also updated pole and interestingly this is we call say p 1 dashed which is p multiplied or other p 1 multiplied by 1 plus beta into A naught which is the case similar to a single pole situation. And then p 2 you may say that now this is a pole second pole of the A f which is again approximately equal to p 2.

So, in summary we can say that A f it is having two poles, but one of the these two poles it is almost remaining same as the location of the pole of A; but then the other pole p 1 dashed it is getting shifted by a factor of 1 plus beta into A naught with respect to original p 1.

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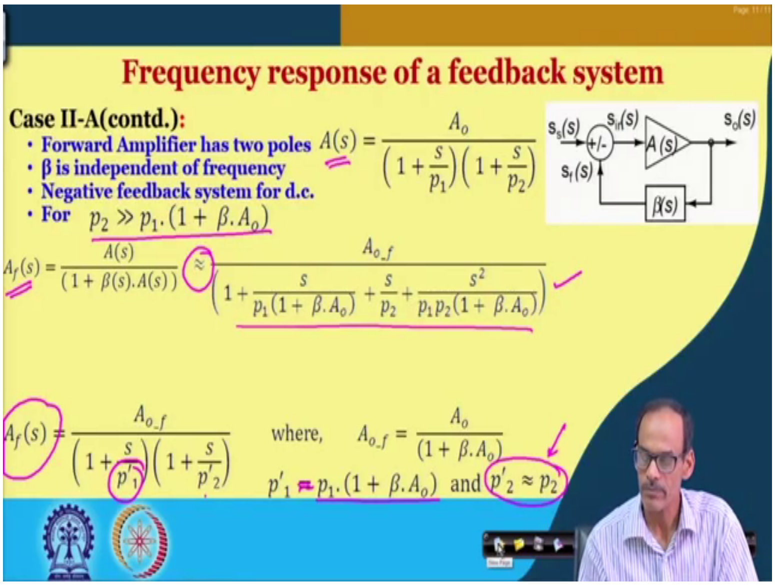

So, the conclusion here it is in the next slide it is what just now we said it is yeah. So, we do have this A f and this is what the approximation we do have and this is helping us for the factorization and as I said that this p 1 dashed it is p 1 multiplied by 1 plus beta into A naught and p 2 it is approximately equal to 2. Why this approximation? In fact, I should say this approximation is basically leading to this approximation.

In fact, we may say this is also approximation, but the it is a fairly a good approximation. Now, if you see the bode plot for this situation namely the gain of A f and A and of course, the loop gain under this condition we can find some conclusion for some information.

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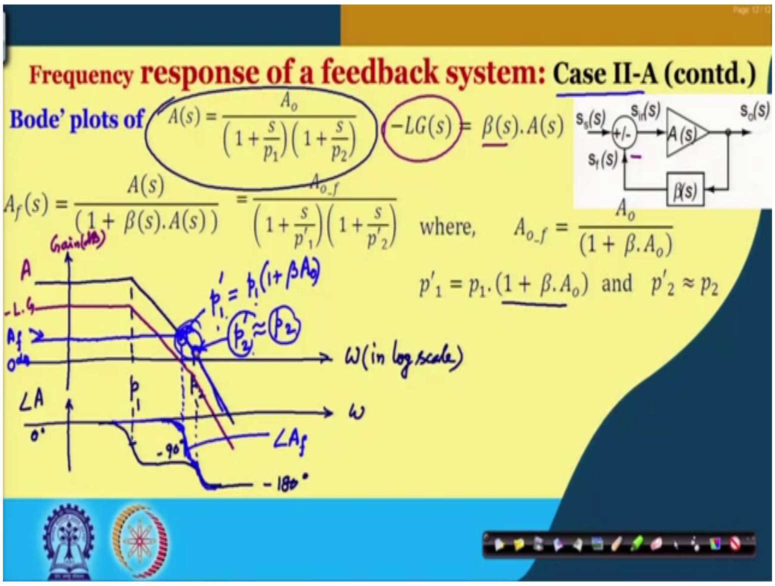

So, in the next slide let we try to make the gain plot. So, if I consider a yeah, so let me start with A and this is omega in log scale and this is gain in dB. So, to start with if I consider this A, we do have a pole here at p 1 and then we assume that and the corresponding second pole it is sufficiently high or located at very high frequency. So, it is having a pole here say p 2 and here it is p 1.

And it is such that we assume that once this p 1 it is getting shifted by this factor we are assuming that p 2 it is even beyond that. So, now, if I plot the loop gain, so if I consider this minus loop gain beta into A and again beta it is less than one and it is independent of frequency. So, what we can say that the pole of the loop gain it is essentially pole of A itself and then it is going down like this.

So, this is the minus of loop gain plot and this is A, this is gain in dB as you have discuss before. Now if I consider A f and what you are expecting depending on this value of beta which is less than 1. So, the loop the feedback system gain it is approximately 1 by beta which is more than 1 which is above this 0 d B. And it is again it is continuing to this value till it is hitting the A and beyond this point it is continuing to be A or rather it is following A and then of course, we do have the second pole here.

So, we can say that this corner it is representing the first pole of A f which we call say A 1 p 1 dash and this is equal to p 1 multiplied by 1 plus beta into A and beyond this one of course, we do have the p 2. So, we do have we call it is p 2 dash which is very close to this p 2 ok. And if you consider the corresponding phase what we can see here if I start with A phase it is starting with.

So, this is phase of A say. So, at this point we do have the phase getting rolled off to 90 degree and then again we do have the second pole. So, while it is approaching to the second pole it is going one more step to minus 180 degree. So, this is minus 90 degree this is minus 45 this is minus 135 starting with 0 degree.

Now, if I consider a A f on the other hand, so this is the gain of A f in d B and its pole it is here. So; obviously, its phase it is continuing till it is approaching to p 1 dash and here you can see that it will be having a step here and then probably it will be having the other one. So, depending on the spacing or separation of this p 1 dashed and p 2 dash, it is having essentially either two step or maybe these two steps may be very close to each other.

So, this is the phase of the feedback system A f right. So, that is how the poles of A it is influencing the pole of the feedback system. Now, the natural question is that suppose this one p 1 dashed, which is say p 1 multiplied by 1 plus beta into A if it is comparable with the original p 2, then what kind of things we do expect here?

So, we will be talking about similar kind of case we call case II B and case II A we are considering p 2 it is beyond this one. Whereas, case II B we will consider this p 1 dashed it may be comparable with p 2 or it may be beyond that. And then what happens whether this pole it will be remaining there or whether there will be some other changes that we like to see. But before that let me take a short break and then we will come back so.