Electronics for Analog Signal Processing - II
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Lecture - 17
Frequency Compensation

Yesterday, we discussed about how negative feedback, when amplifier has a single pole, results in an amplifier with wide band; with 2 pole, it results in an amplifier with complex conjugate pair of poles which might go into what is called peaking at high frequencies; and with 3 poles - that is what we consider. It is likely to go into instability; that the poles might now lie on the right half of the S plane. So, this has to be prevented.

So, how do we prevent this? That means, for this to be prevented, we found out that the loop gain, that is in this particular case, the loop gain is A into Beta; if it has 3 poles, A naught divided by 1 plus S by Omega 1, first corner frequency.

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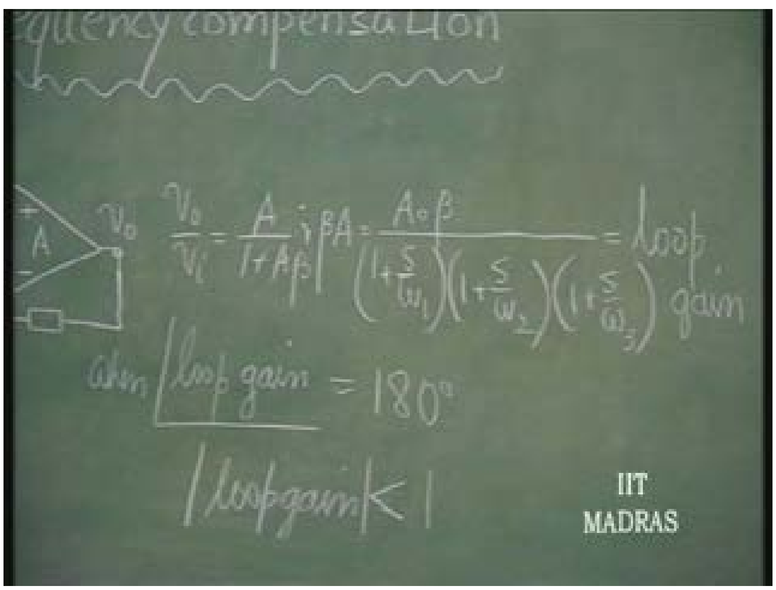

This is magnitude of A versus...this is Omega 1. Here, it falls at 20 decibels per decade; here it falls at 40; here it falls at....minus 20 d B, d B per decade; 60 decibels per decade. This is Omega 2; this is Omega 1; this is Omega 3.

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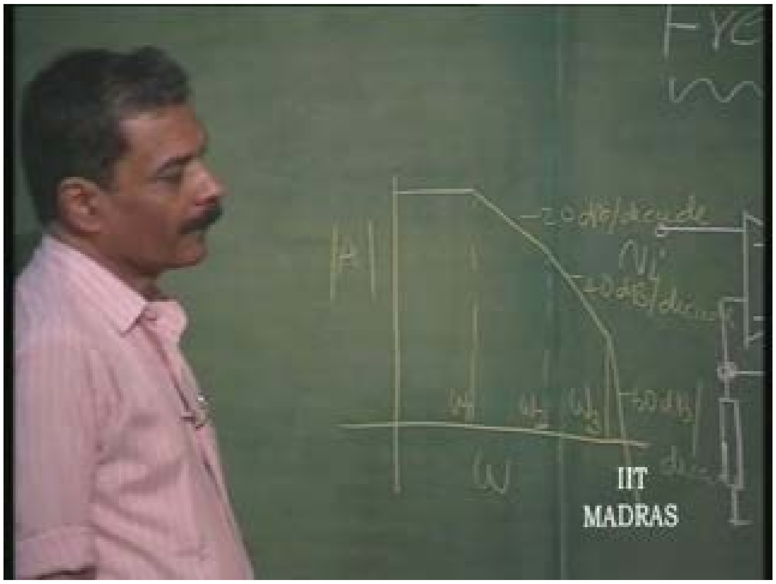

Such a situation, the loop gain...when a phase shift is equal to 180 degree, the magnitude of loop gain has to be less than 1.

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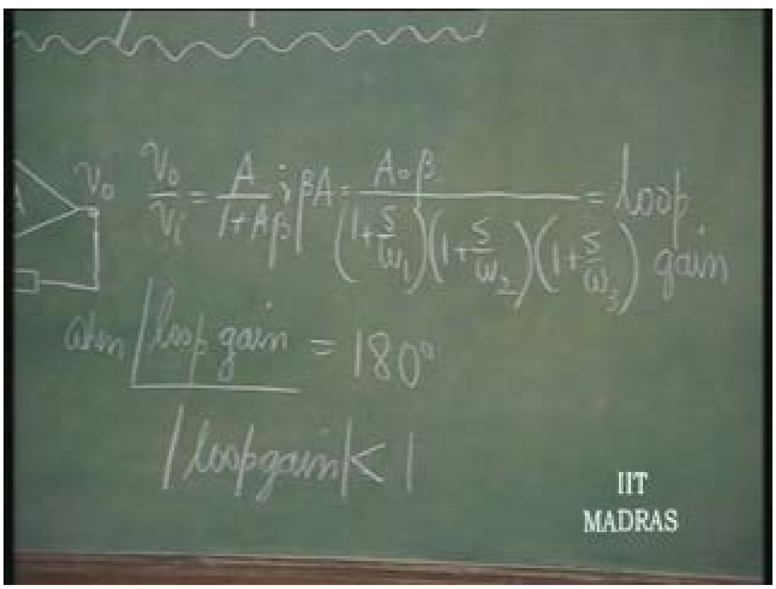

Then, even though there is positive feedback, that is not going to instability because, the fact that the loop gain is less than 1, thereafter. So, how do we make sure that this is going to be satisfied?

Now, phase shift of loop gain is the same as phase shift of A because Beta is passive resistive network and therefore there is no phase part for that. So, phase shift of A which is nothing but...corresponds to the phase of this; A naught by 1 plus S by Omega 1, 1 plus S by Omega 2, 1 plus S by Omega 3.

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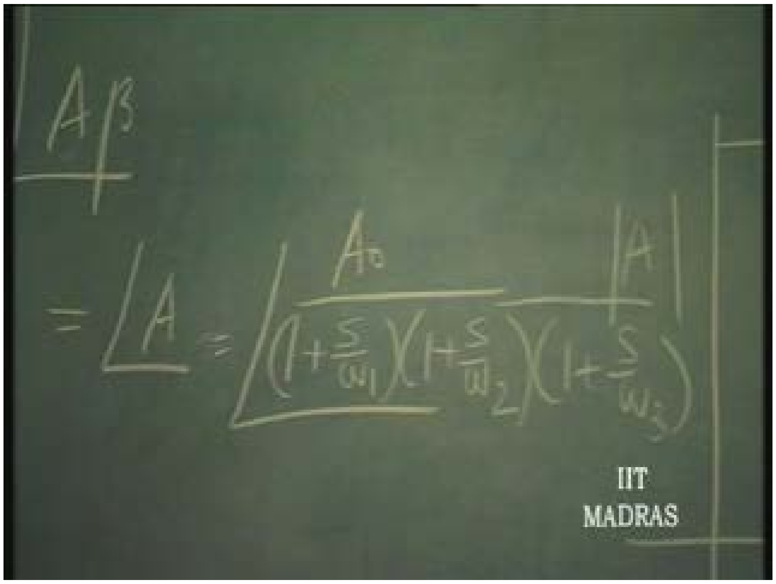

So basically speaking, this can be written as A naught divided by 1 plus S into 1 by Omega 1, plus 1 by Omega 2, plus 1 by Omega 3, plus S squared into 1 by Omega 1 Omega 2, Omega 2 Omega 3, plus 1 by Omega 3 Omega 1 plus S cube into Omega 1 Omega 2 Omega 3.

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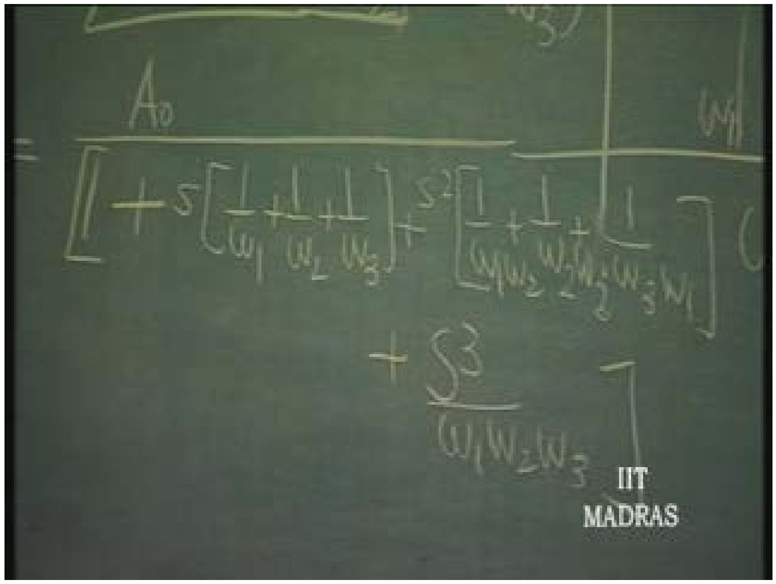

This is the denominator function and we should consider the phase of this. The phase of this will correspond to the imaginary part which is...you put S is equal to j Omega. So, we get j Omega. This is minus j Omega cube. Then, Omega square actually. This is Omega, j Omega square, actually. That is minus Omega square. This is going to be minus j Omega cube.

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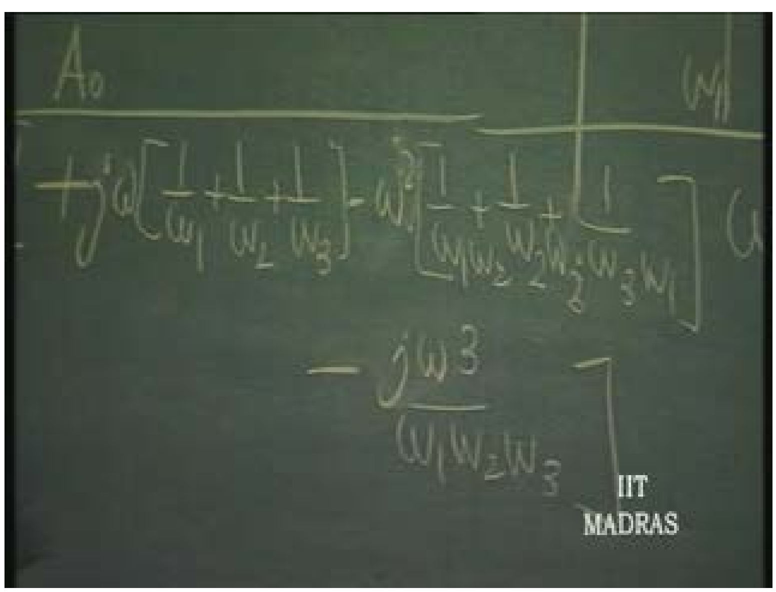

So, as far as the phase of this is concerned, phi is tan inverse, imaginary part divided by real part. So, Omega by 1 by Omega 1 plus 1 by Omega 2 plus 1 by Omega 3 minus Omega cube divided by Omega 1 Omega 2 Omega 3; that is the imaginary part; divided by the real part – 1 minus Omega squared into, 1 minus Omega squared into, 1 by Omega 1 Omega 2, Omega 2 Omega 3, Omega 3 Omega 1. This is the phase part.

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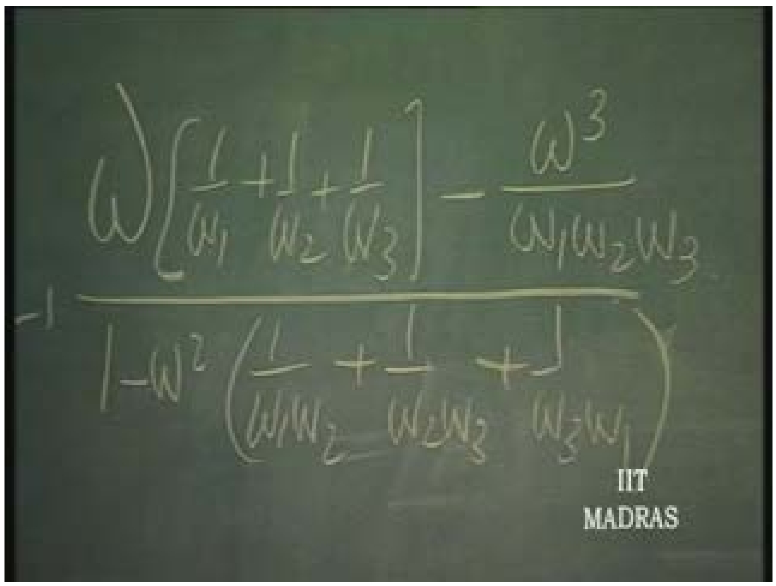

So, you can see that from this, this phase should become equal to 180 degree or tan 180 degree, which is nothing but zero. This happens when the numerator of this... actually, this is tan phi. That should become equal to zero; then the numerator becomes equal to zero. That happens when Omega naught squared is equal to Omega 1 Omega 2 Omega 3 into 1 over Omega 1 Omega 2 Omega 3.

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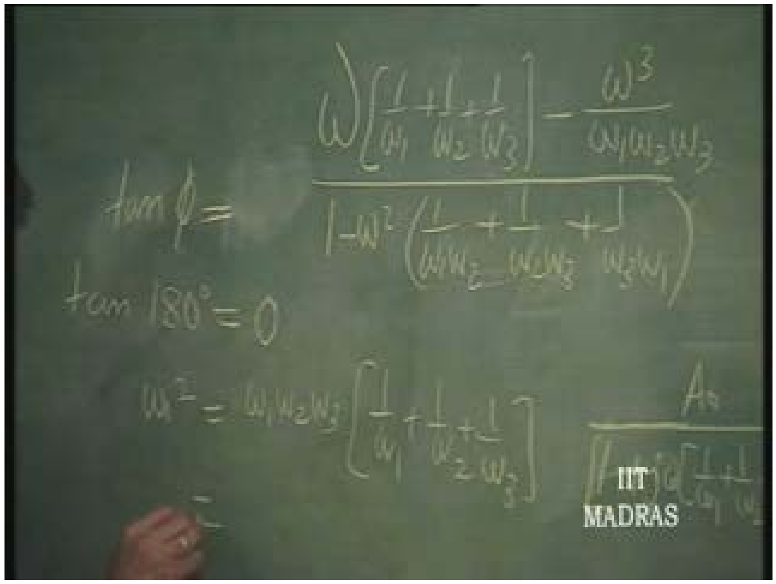

Or, this is Omega 1 Omega 2 plus Omega 2 Omega 3 plus Omega 3 Omega 1. That is the frequency at which phase shift of this loop gain becomes equal to 180 degree; this is the frequency; Omega naught squared.

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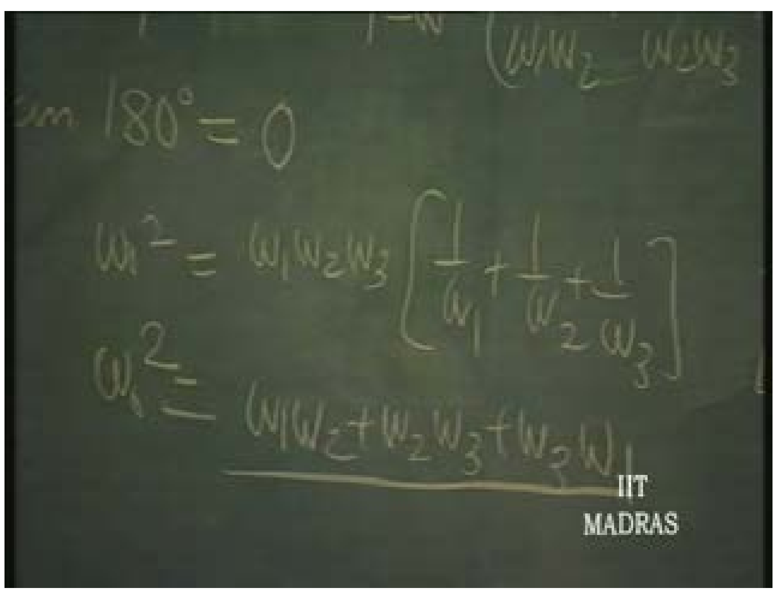

At this frequency now, what should happen is the magnitude of A Beta should be less than 1. So, we have to substitute for the magnitude of A Beta. So, that means magnitude of A Beta divided by... this phase shift has become equal to 180 degree; and this frequency corresponds to this value; at which point, the imaginary part is zero. So, only the real part is there. So, the magnitude becomes 1 minus Omega squared divided by this. So, 1 minus Omega naught squared. So, Omega 1 Omega 2, plus Omega 2 Omega 3, Omega 3 Omega 1. So, that is the frequency at which this happens; the phase shift becomes this into 1 over Omega 1 Omega 2 plus 1 over Omega 2 Omega 3... So this, magnitude of this should be less than 1. So, the magnitude of this is going to be predominantly governed by this ratio here.

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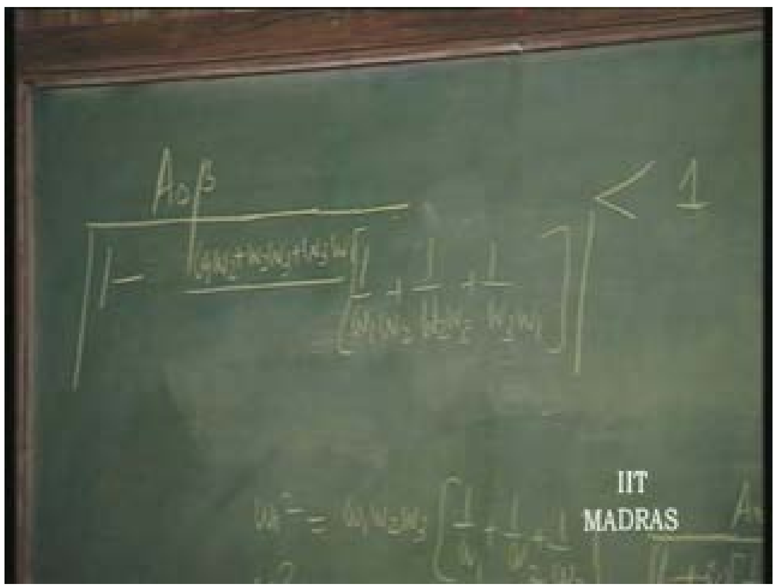

This actually... Omega 1 Omega 2 plus Omega 2 Omega 3 plus Omega 3 Omega 1, into 1 over Omega 1 Omega 2 plus 1 over 2 Omega 3... It is a number. So, that should be pretty huge such that A naught Beta which is pretty high...this becomes negligibly small, this 1; divided by this is going to become less than 1. So, this is what should happen in a negative feedback amplifier. So, how do we make this?

If Omega 1, Omega 2, Omega 3 are already fixed at very high frequencies, if Omega 1, Omega 2, Omega 3 are already fixed at very high frequencies, this particular thing, it may be difficult to achieve for any reasonable high value of A naught Beta. That means, invariably, in any negative feedback situation, it is going to oscillate; or, it might work only for A naught Beta which is very small. That means Beta which is very small. A naught Beta, if it is very small, A naught being very high, Beta has to be very small. That means, there is very little of negative feedback...in such situations only, this will work satisfactorily.

If you want this to work for all Betas, that is what a general purpose operational amplifier is used for; for all Betas, because it is going to be used for a variety of designs. You have to make this get satisfied for the worst case; and the worst case situation is when Beta is the highest. So, if it is stable for Beta is the highest, it will be automatically stable for all other Betas, which are less than that value. So, Beta equal to 1 is the worst case situation. So, if Beta equal to 1 this is satisfied, this quantity is less than 1, automatically for Beta less than 1, it is more than satisfied.

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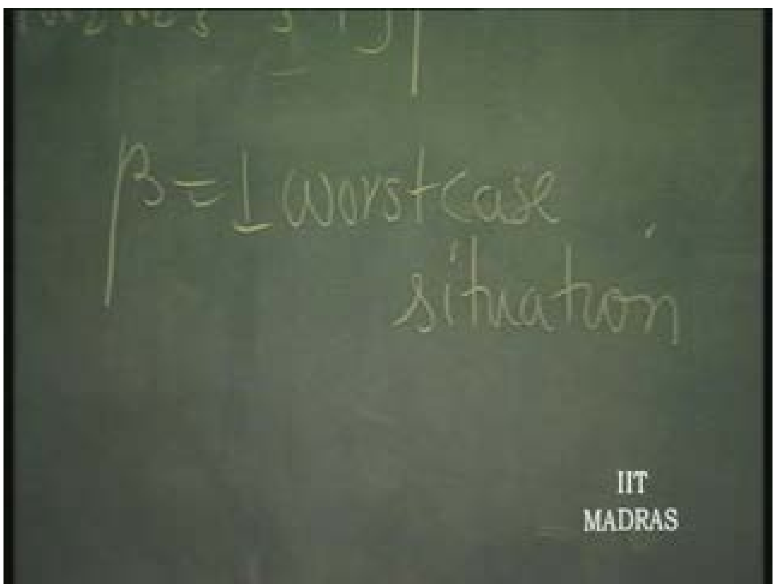

So, what we do is, we will make Beta equal to 1 and we will try to satisfy this condition. This is the condition that is to be satisfied. This Omega 1 Omega 2 plus Omega 2 Omega 3 plus Omega 3 Omega 1 divided by 1 over Omega 1 Omega 2 plus 1 over Omega 2 Omega 3 plus 1 over Omega 3 Omega 1, should be much less than 1. Now, this can be written actually as Omega 1 plus Omega 2 plus Omega 3 by Omega 1 Omega 2 Omega 3; just another way of writing the same thing.

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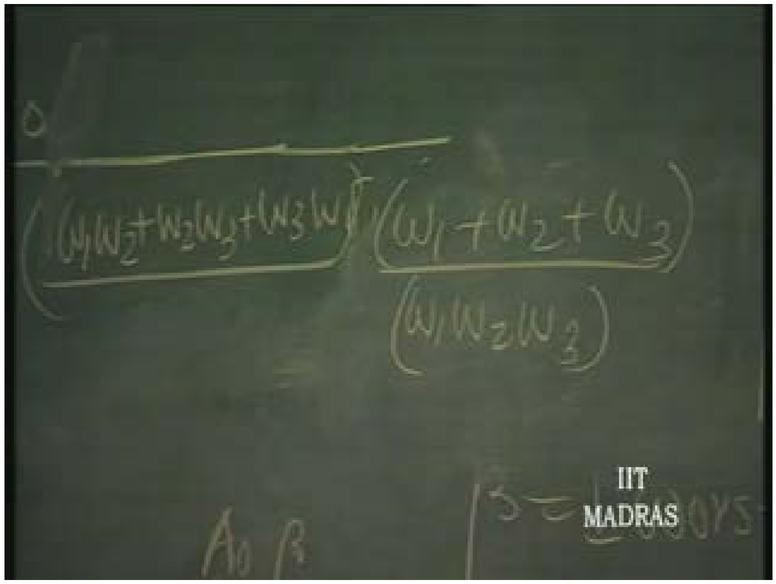

...which means, this can be further written as very simply 1 over Omega 1 plus 1 over Omega 2 plus 1 over Omega 3. This is therefore summation of all the 3 poles divided by summation of the inverse of the poles; so, multiplied by summation of inverse of the poles. So, this is what should happen.

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Normally for this to happen, this is going to be negligible; and therefore essentially, the magnitude criteria is going to be governed by this.

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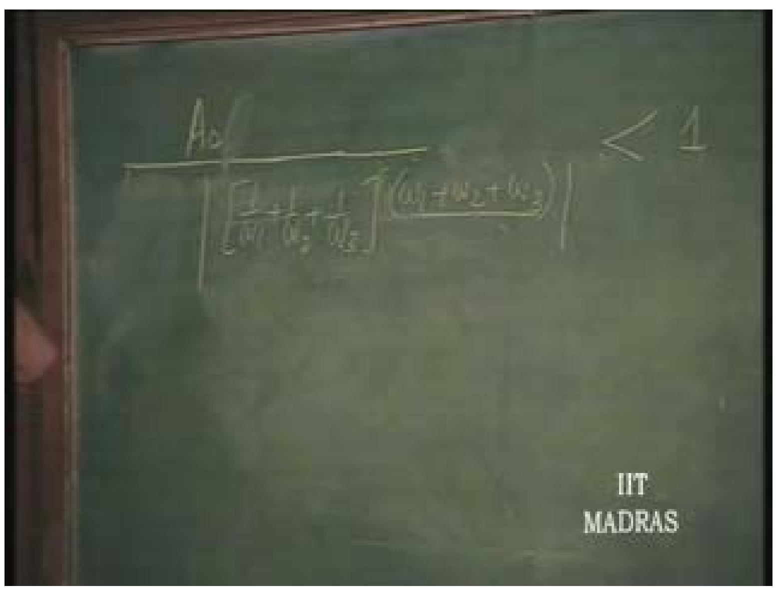

So, in which case, actually speaking, one of these poles has to be made dominant. This can be easily satisfied. If, let us say, Omega 1 which is already the somewhat dominant pole compared to all the others is made very dominant, equal to Omega d such that Omega d is much less than Omega 2 Omega 3.

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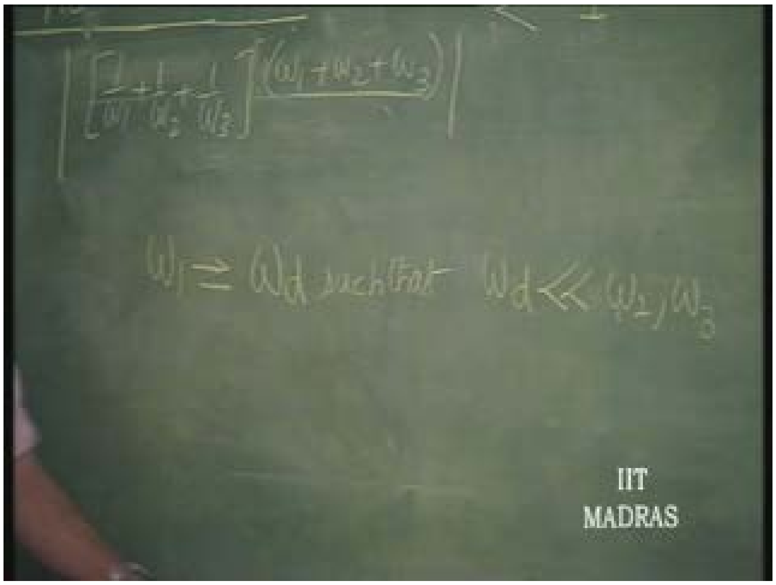

That means I am going to locate this fairly early here so that the attenuation is primarily due to this at 20 decibels per decade; and when this starts coming into picture, the gain has fallen into less than 1.

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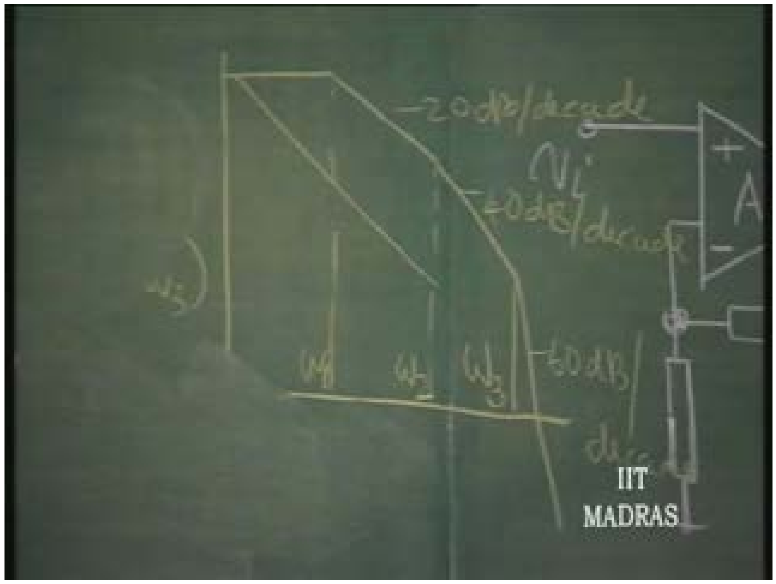

This is that is called by dominant pole compensation.

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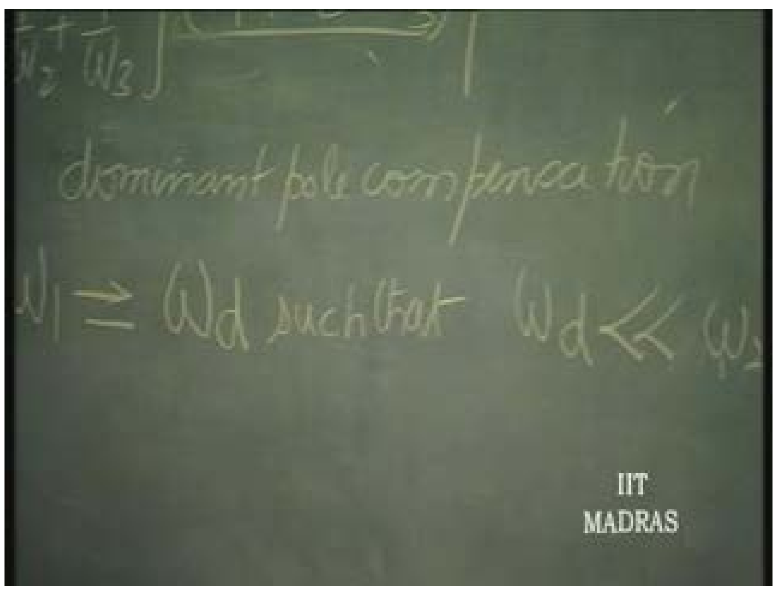

So, what is done is one of those poles, one, this is made dominant so that the frequency dependent characteristic within the useful range... What is the useful range? – as long as the gain is greater than 1. So, as long as the gain is greater than 1, only one pole comes into picture. The other poles now comes to picture only after gain falls to less than 1.

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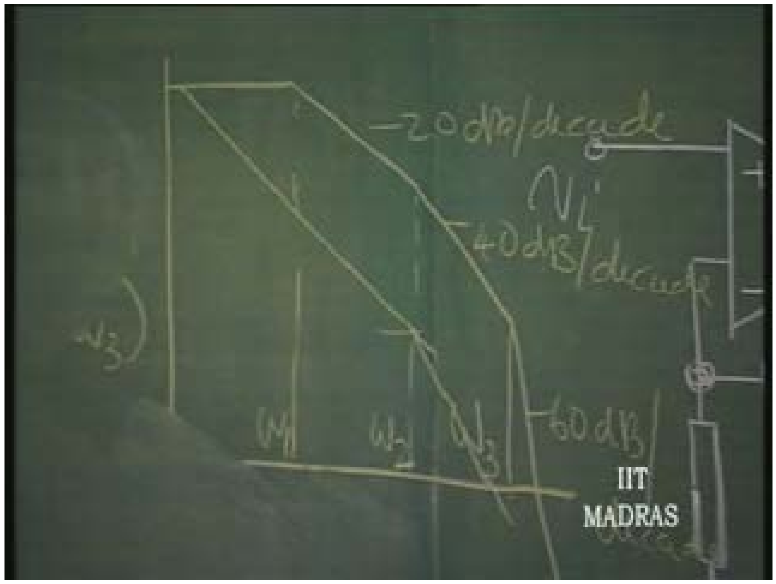

That is what this expression will do. If Omega d is chosen such that it is much less than Omega 2 and Omega 3, in this summation, you will have Omega d plus Omega 2 plus Omega 3. Omega 1 is going to be replaced by Omega d and Omega d is much less than Omega 2 Omega 3. Therefore, this is approximated as Omega 2 plus Omega 3; and here Omega, 1 over Omega d becomes dominant.

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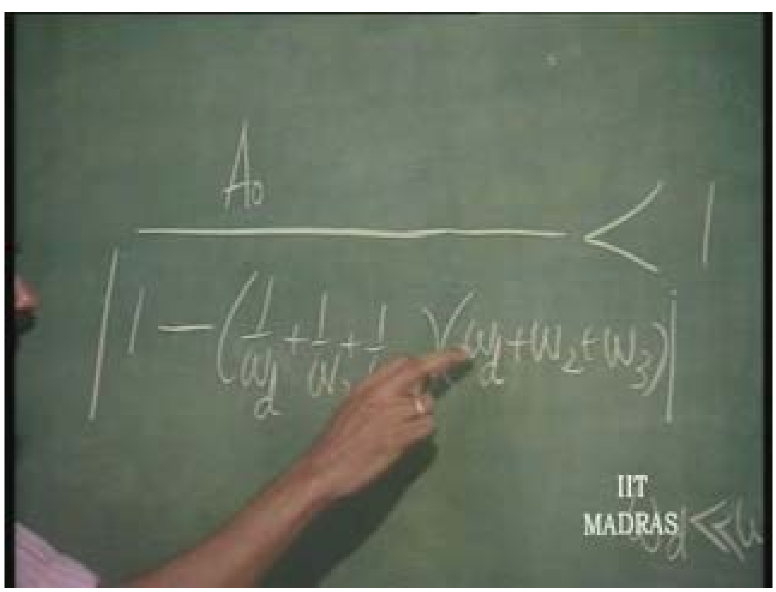

So, this becomes that and this 1 becomes negligible compared to this because this is very low compared to Omega 2 plus Omega 3; and therefore, this can be ignored. So, this Omega d goes to the top. Therefore, Omega d is much less than Omega 2 plus Omega 3 by A naught. That is the choice of the dominant pole.

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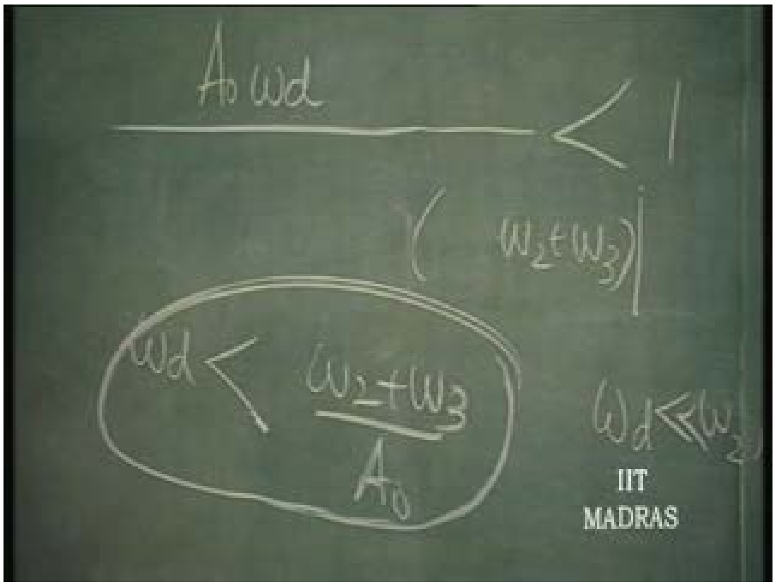

Consider Example 15 for the frequency compensation.

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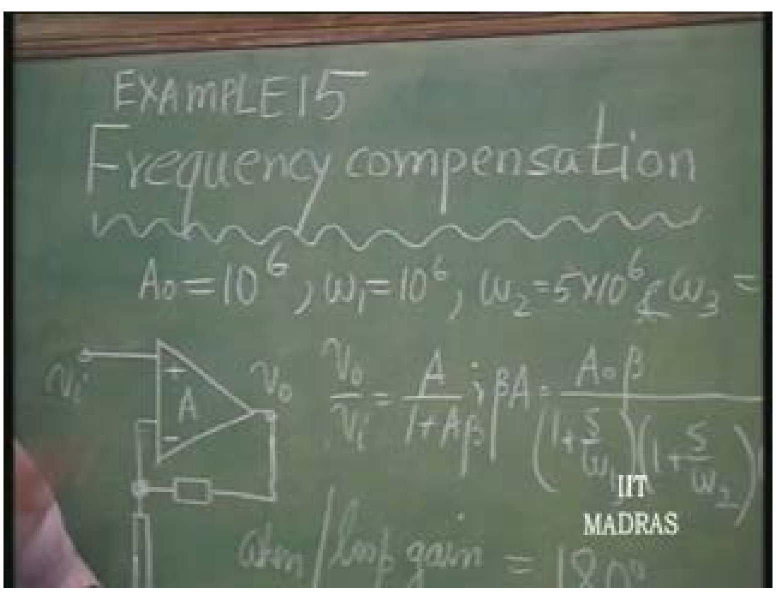

A naught for the amplifier is 10 to power 6, D C gain; Omega 1, first corner frequency 10 to power 6 radians per second; Omega 2, 5 into 10 to power 6 radians per second; Omega 3, 10 to power 7 radians per second. So, the amplifier with feedback is given here. This is the Beta network; R a R b R a by R a plus R b.

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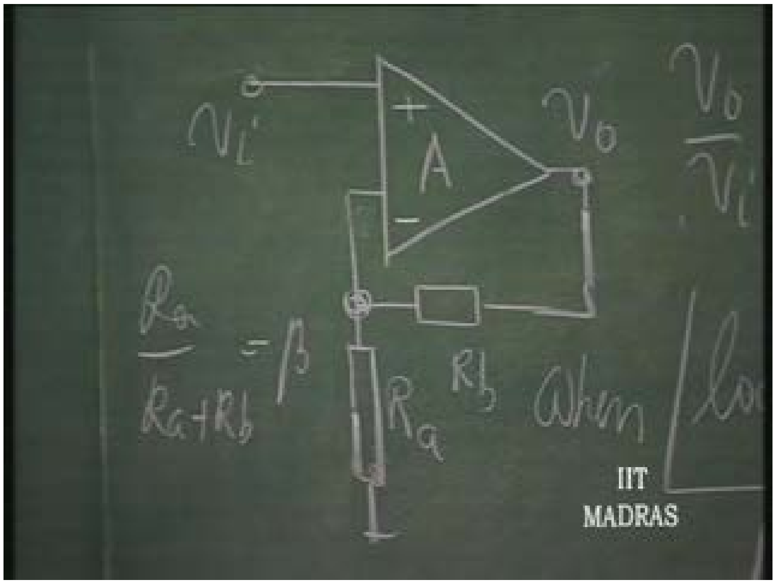

First, verify frequency stability. What does it mean?

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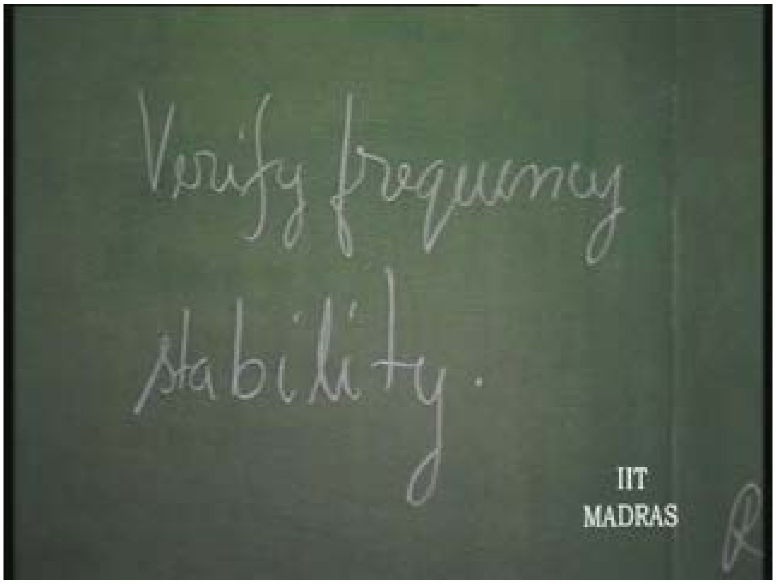

Verify whether A naught into Beta, that is, A into Beta... when the phase shift of A into Beta is equal to 180 degree, the loop gain is less than 1. Verify this.

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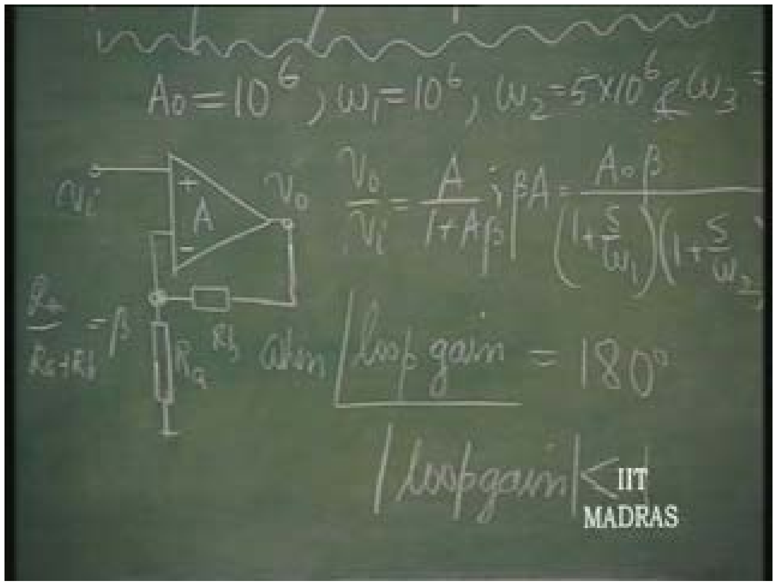

If it is not so, then...if it is not stable, shift Omega 1. That is equal to 10 to power 6 so as to make it stable for all values of Beta. So, this is the problem.

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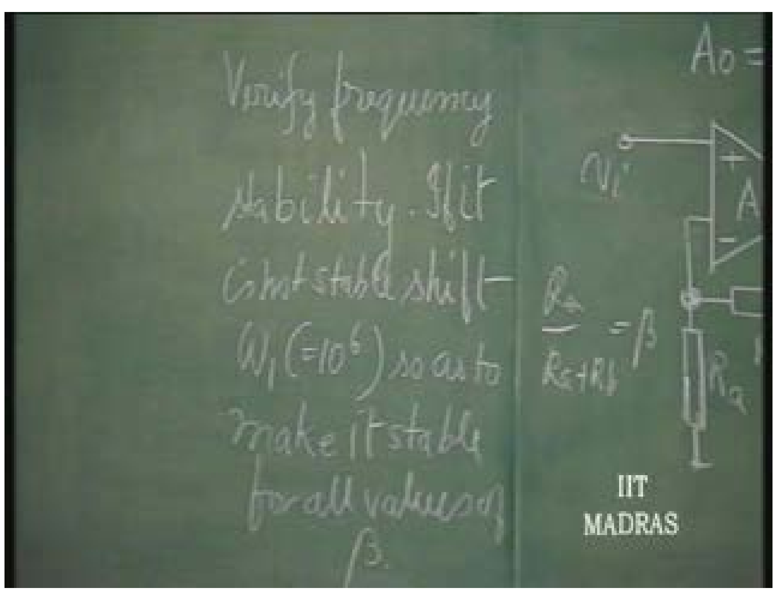

If we now adopt the same method that we did just previously, we can come to know that 10 to power 6 now... Beta, we will take it as 1. This is A naught, this is Beta, first case situation, we will take. That divided by 1 minus Omega 1 plus Omega 2 plus Omega 3.

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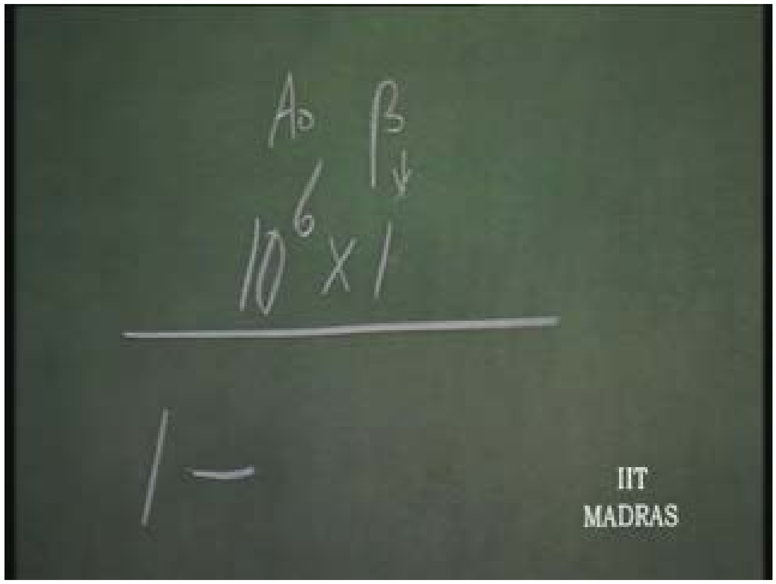

What is that? Actually, frequency at which phase shift becomes equal to 180 degree is root of Omega 1 Omega 2 Omega 2 Omega 3 Omega 3 Omega 1 as we derived earlier. So, this is root of 1 plus 5 plus 10, into 10 to power 6, which is 4 into 10 to power 6. That is the frequency at which phase shift...so many radians per second. That is the frequency at which phase shift of this, A Beta becomes equal to 180 degrees.

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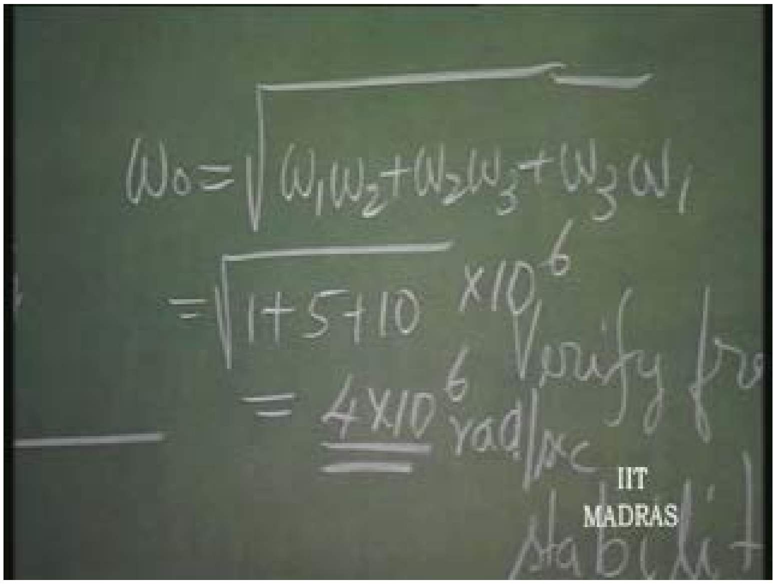

If you substitute this... Just a minute. Not this. I am sorry. I think it is not correct. It is going to be 1 into 5 which is 5, plus 5 into 10 which is 50, plus 10 into 1, into 10 to power 6. Omega 1 Omega 2, Omega 2 Omega 3, Omega 3 Omega 1; 1 into 5, 5 into 10, 10 into 1; so, 55, 65, almost root 65, about 8. That is understandable.

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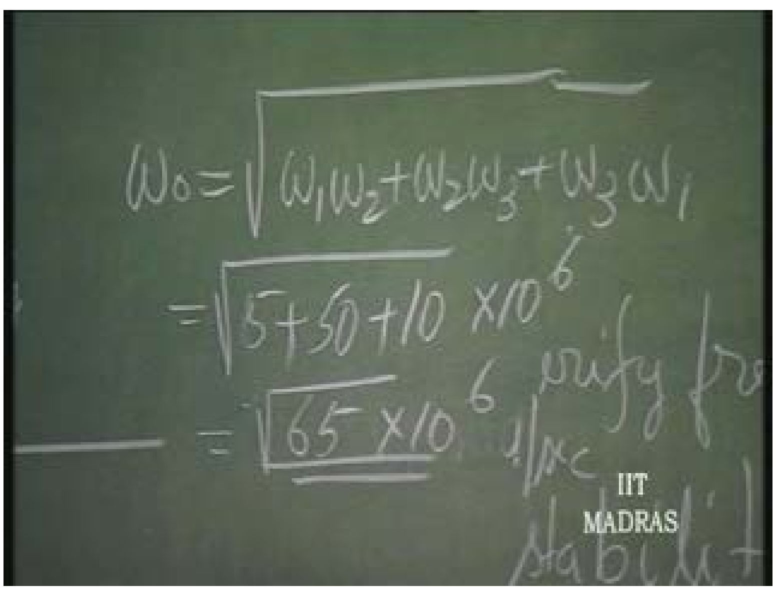

Beyond 1 megahertz, phase shift is already 90 degrees. Beyond 5 megahertz, phase shift is likely to be 180 degree. It should occur within 10 radians, 10, 10 megaradians per second. So, between 5 megaradians per second and 10 megaradians per second; that is around 8 megaradians per second, the phase shift has become equal to 180.

Here, the magnitude of this is Omega 1 plus Omega 2 plus Omega 3, into 1 over Omega 1 plus 1 over Omega 2 plus 1 over Omega 3, at this frequency. That we had found out.

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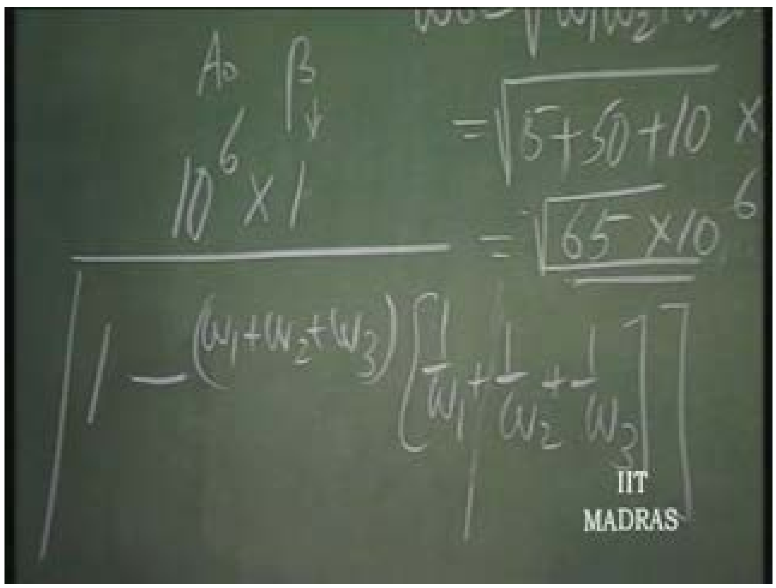

So, what is this? 10 to power 6 divided by 1 minus, 1 plus 5 plus 10 to 1 by 1 plus 1 by 5 plus 1 over 10.

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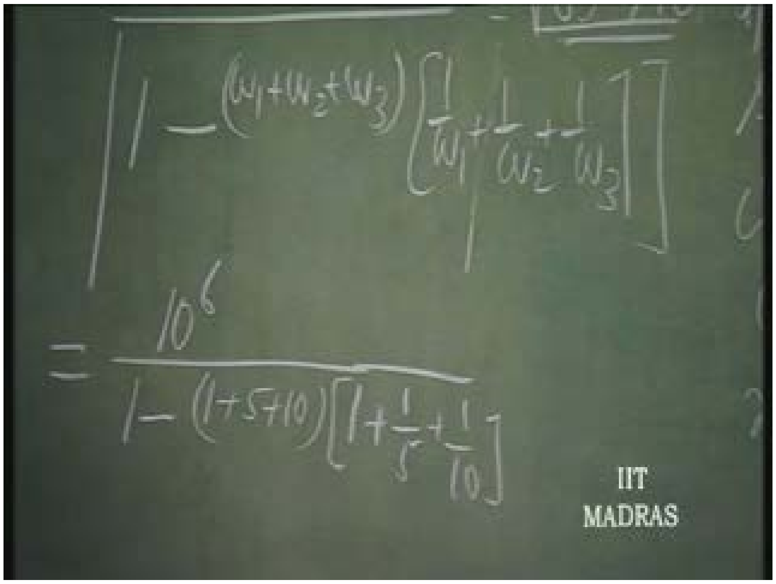

...which is going to be 16 into 1 point 3.

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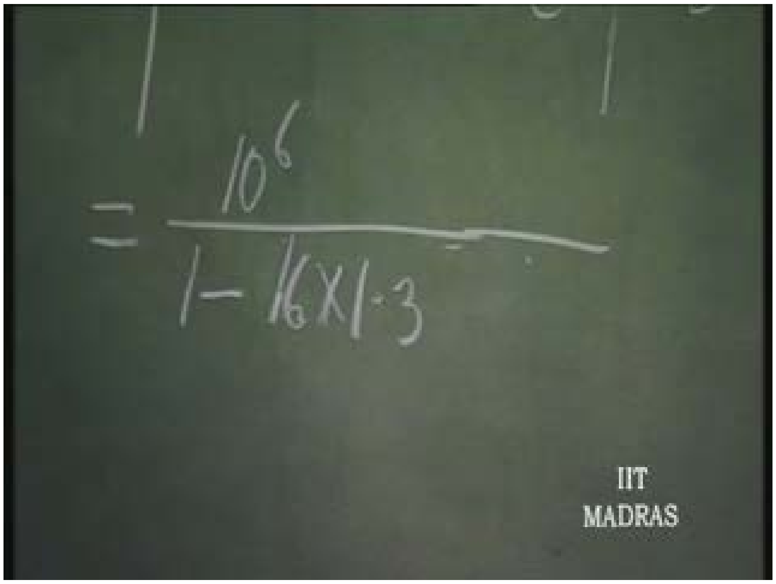

...which is going to be 20 point 8.

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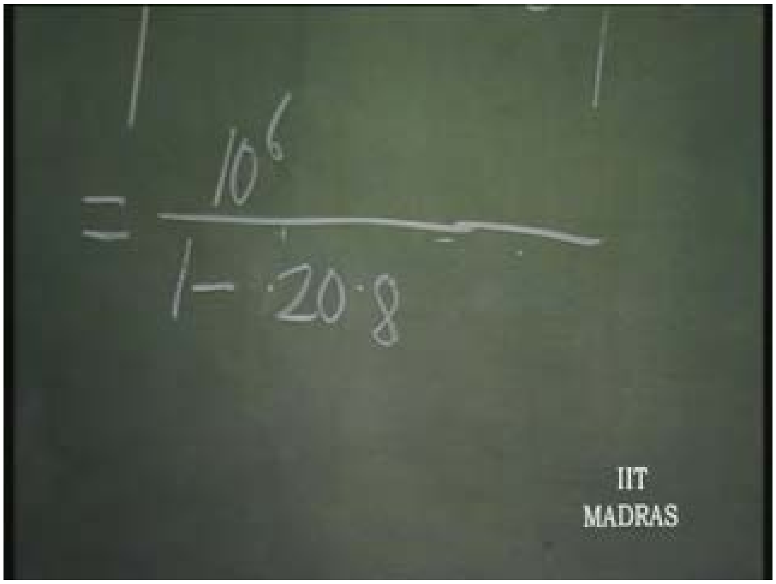

That means the magnitude of this is now, minus 19 point 8, 19 point 8. So, this is definitely not less than 1. This is definitely not less than 1. This is 10 to power 6. When it will be less than 1? Had we selected a gain which is less than 19 point 8, this would have been less than 1. That is, A naught itself should have been less than 19 point 8; then, this should have been less than 1. In this case, this is not less than 1. So, unstable for any Beta. So, we have to make it stable.

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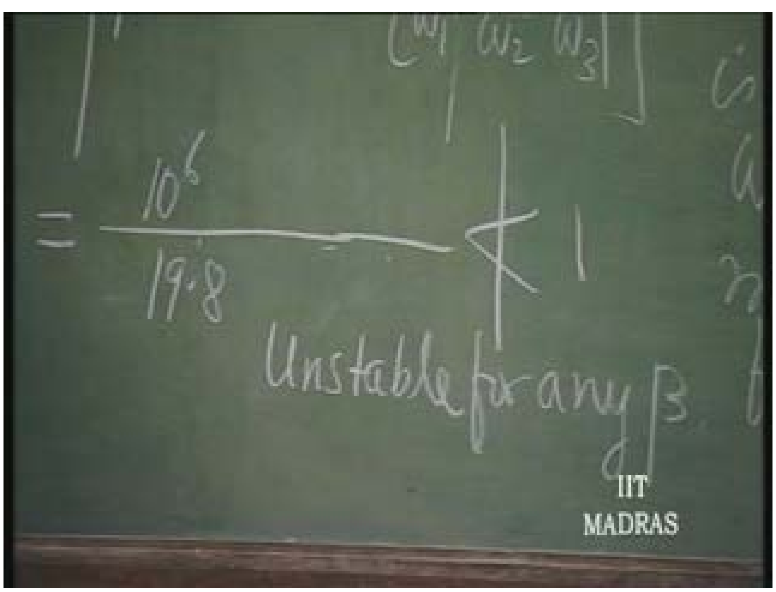

So, what they suggested is shift Omega 1 which is 1 megaradians per second so as to make it stable for all values of Beta. So, we will make this Omega d. This is unknown. Omega 2 and Omega 3 are fixed. So, shift this such that it is stable.

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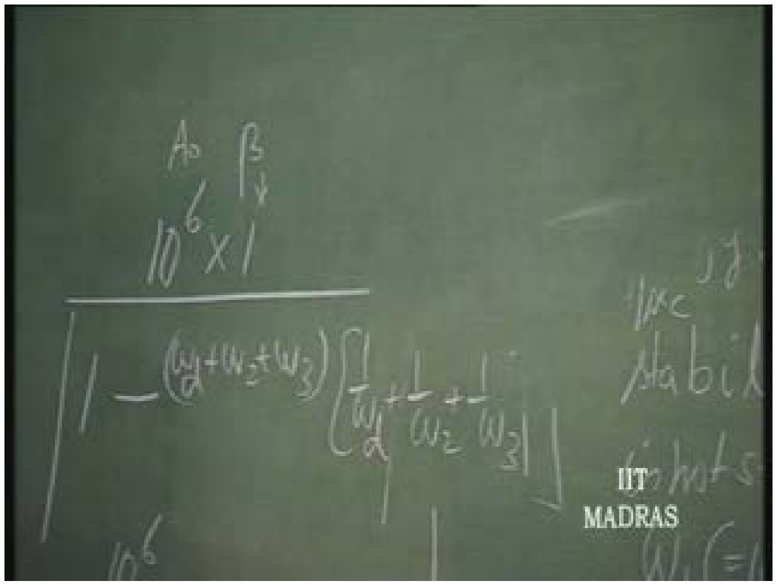

Now, if that is the case, Omega naught is again equal to root Omega d into Omega 1 plus... Sorry. Omega 2 plus Omega 3 plus Omega 2 Omega 3.

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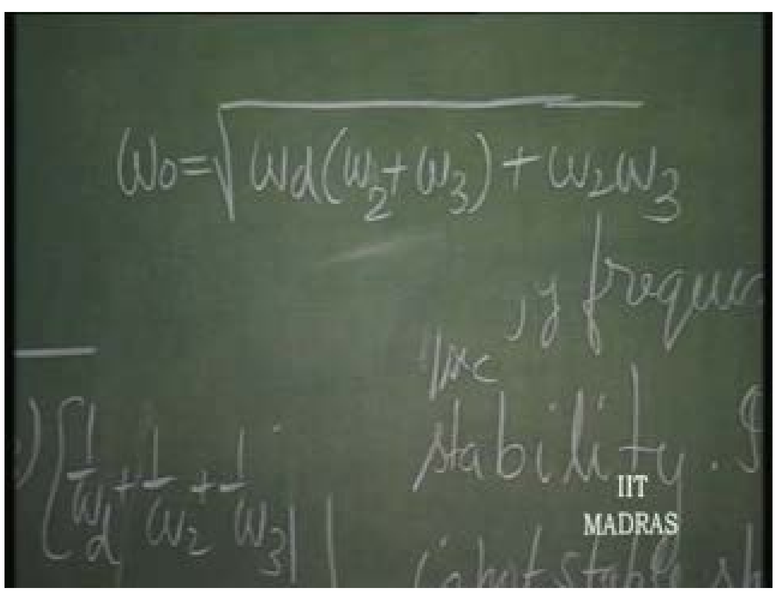

So, out of this, you would notice that Omega d being very much less than Omega 2 and Omega 3, the frequency at which phase shift becomes 180 degree, becomes totally dependent upon Omega 2 and Omega 3.

In other words, we can also look at it this way. If Omega d is dominant here, this would have contributed its phase shift of 90 degree and further contribution of 90 degree is determined by location of Omega 2 and Omega 3.

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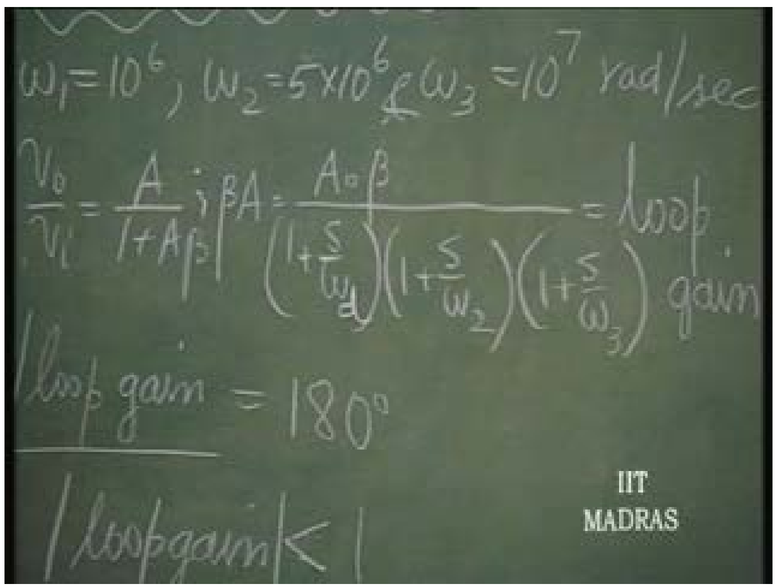

So, it will be nothing but square root of Omega 2 and Omega 3. The frequency at which the phase shift becomes equal to 180 degree at Omega naught, because Omega d is the dominant frequency. That means, this is much less than Omega 2 comma Omega 3.

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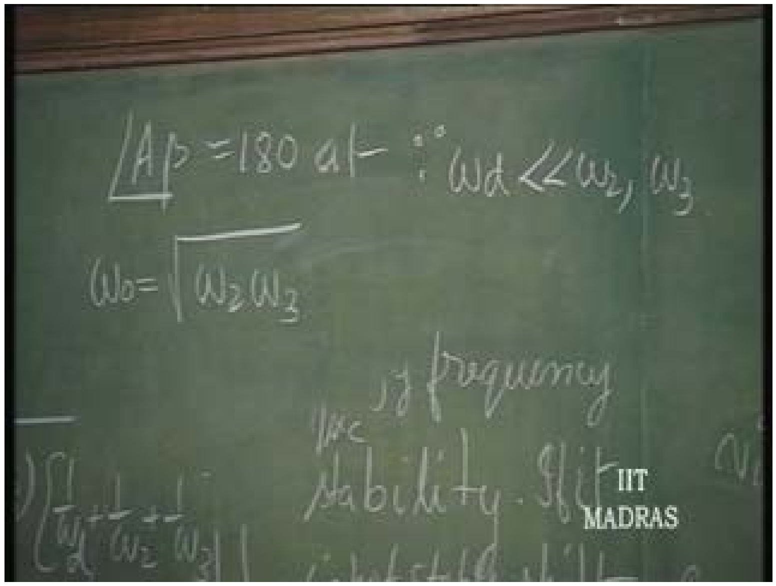

So, I think... So, Omega d is going to become negligible. Come back to Omega 2 plus Omega 3. Here, 1 over Omega d becomes dominant and therefore in this magnitude... this magnitude is what we should count.

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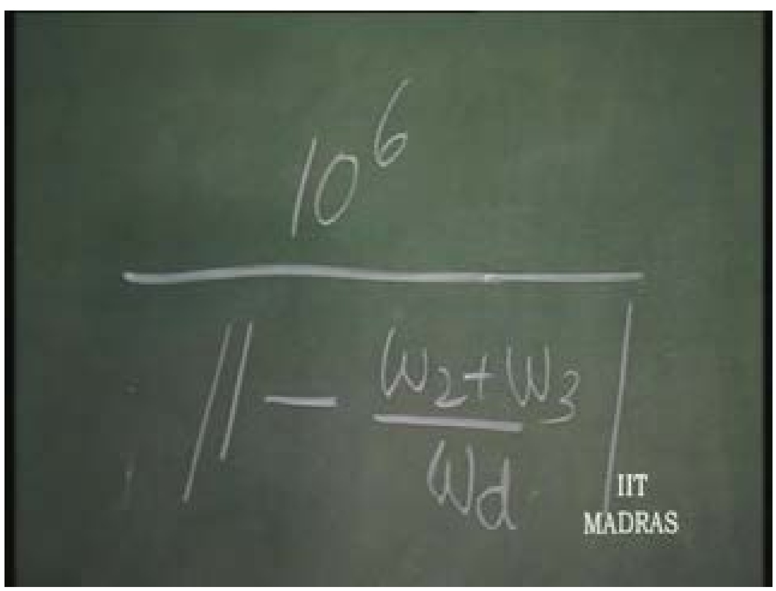

Omega 2 plus Omega 3 is 5 plus 10 megaradians. So, this is something negligible.

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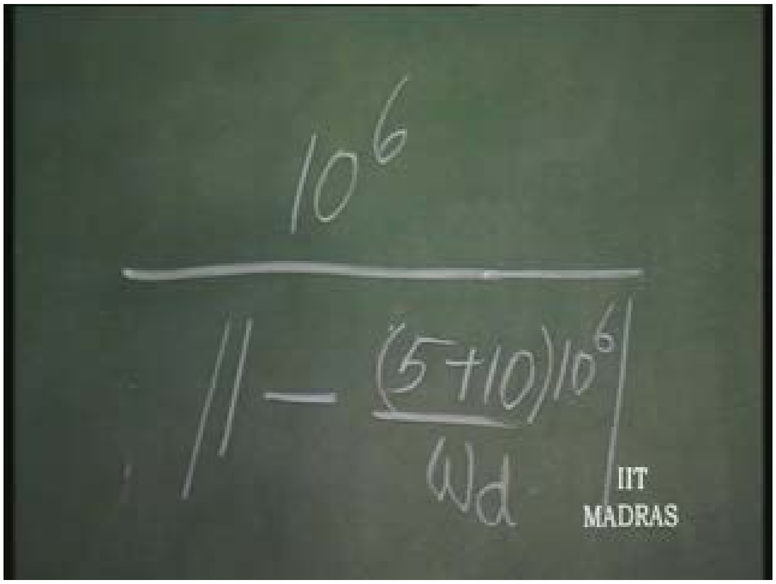

So, the magnitude of this is same as this. Therefore, Omega d goes up. That should be less than 1. So, 10 to power 6 gets cancelled with 10 to power 6. So, Omega d should be less than 15 radians per second. That is the answer.

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That means the dominant pole should be less than 15 radians. Let us say it is 14 radians; or, let us say 10 radians. Then, it is very safe and the amplifier gain is represented as A equal to 10 to power 6 divided by 1 plus S by 10 radians. This is the thing throughout this.

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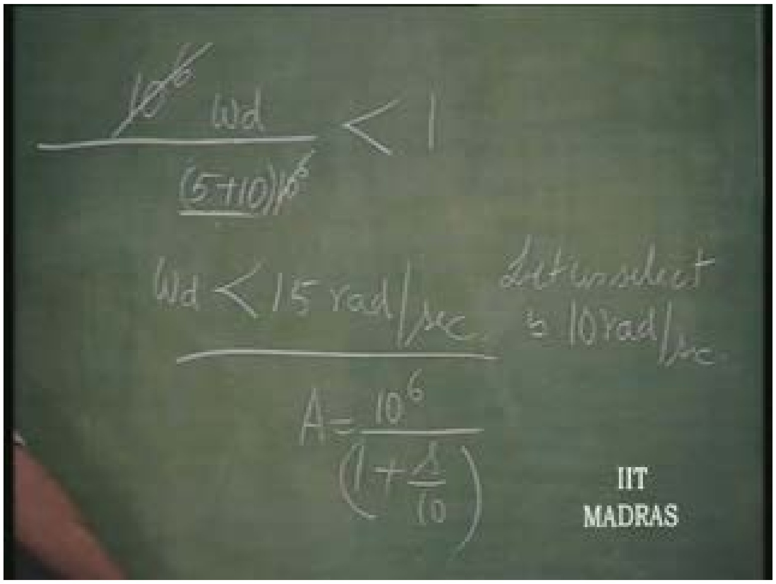

So, this is what is called as dominant pole compensation; and if we select anything less than 15 radians per second, it is going to be assured stability for all values of Beta, including Beta equal to 1.

So, this is how you actually design circuits to give dominant pole compensation. In fact, since you have done it for all values of Beta, including the worst case value of Beta equal to 1, if you are designing a specific amplifier, it is not a good design because it is considering the worst case situation, Beta equal to 1. That means unity gain amplifier is the worst affected configuration in negative feedback. Beta equal to 1 corresponds to unity gain amplifier; and if you are designing gain of 100, you need not really be constrained with this kind of situation. You could select a higher value of Omega d.

For example, if instead of Beta equal to 1, Beta equal to 1, you are designing for Beta equal to point 1, then here in this expression, it is 10 to power 6 into point 1, into point 1; which means this will go to 150 radians per second; and therefore, we could select this as a 100 radians per second.

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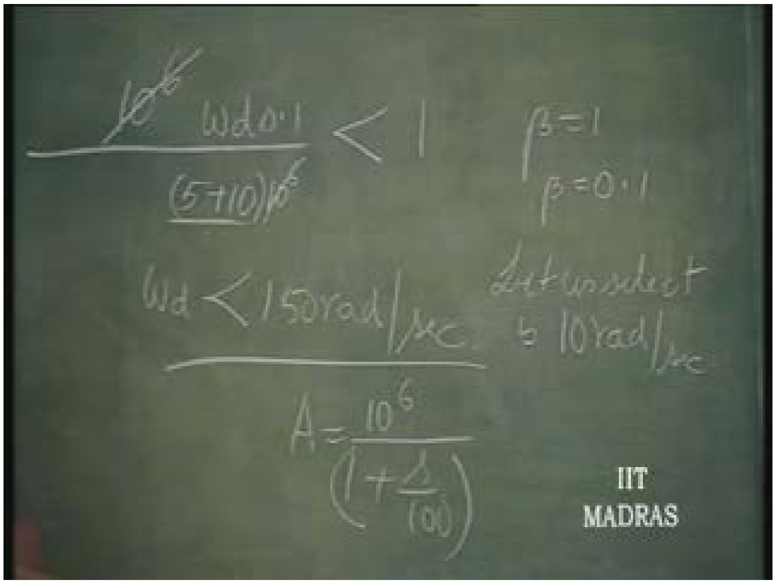

So, if you are designing a specific amplifier with gain, then you can design for a specific value of feedback. Then it is a good design, giving you a wider bandwidth. If this is 100, and you are designing it for a gain of point 1 or so, then gain into bandwidth product which is 10 to power 6 into point 1 is 10 to power 5; and the bandwidth is going to be 100 into 10 to power 5. This kind of thing. So, band width of this amplifier is going to be more if the dominant pole is chosen carefully, depending upon the negative feedback amplifier you want to design.

Now, let us illustrate the difference between the design of a general purpose amplifier and design of an amplifier where compensation is going to be external, that is going to be done by you. Example 16 illustrates this.

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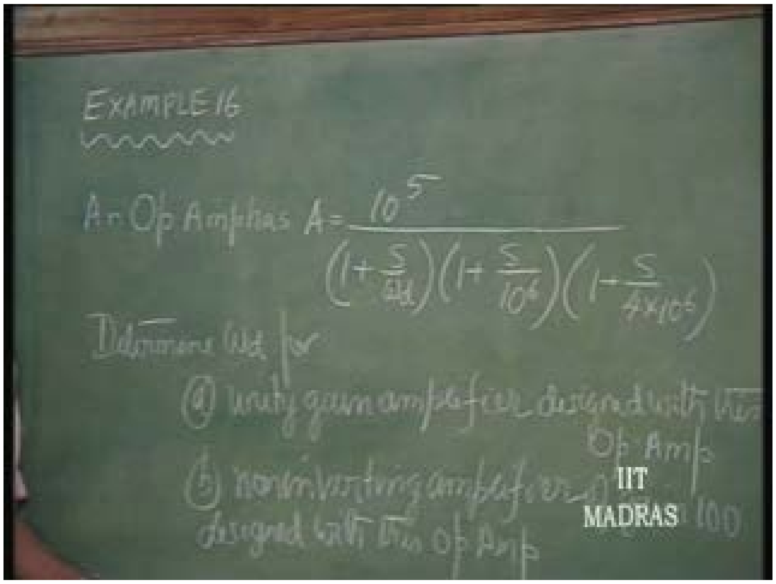

An op amp has A equal to this. That means this is an externally compensated op amp. This is not internally compensated. That is, flexibility has been given to you to fix Omega d depending upon the design; whereas in what is called as 7 4 1, general purpose op amp, Omega d is already fixed. You do not have any control, so that, under all negative feedback situations, it is going to work satisfactorily. So, it is designed for the worst case situation of unity gain amplifier; whereas in an externally compensated op amp, this is left as a choice for the designer. So, how do... how does the designer exploit this to his advantage?

Determine Omega d for unity gain amplifier designed with this op amp. Let us do that. Then aAgain, another person wants a non-inverting amplifier of gain 100 designed with this op amp. How will these two designs differ in terms of choice of Omega d? So, once again, we have the frequency at which the phase shift of this becomes equal to 180 degree. The loop gain is going to be the same irrespective of the Beta value chosen.

So, this is going to be root of Omega 2 into Omega 3. That is 4 into 10 to power 6; that is 2 into 10 to power...that is 6 radians per second. Omega, root of Omega 2 into Omega 3.

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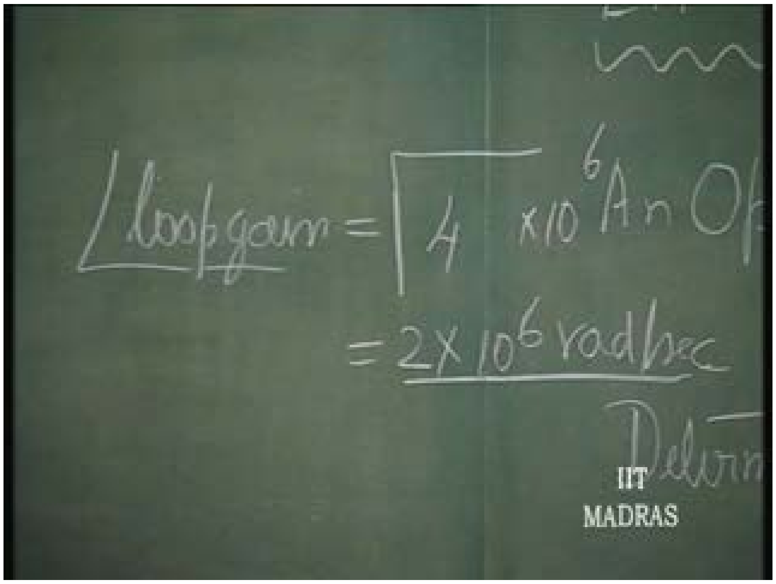

In either case, this is going to be the situation. Only, Beta in this case is 1 Beta; in this case is 1 over 100.

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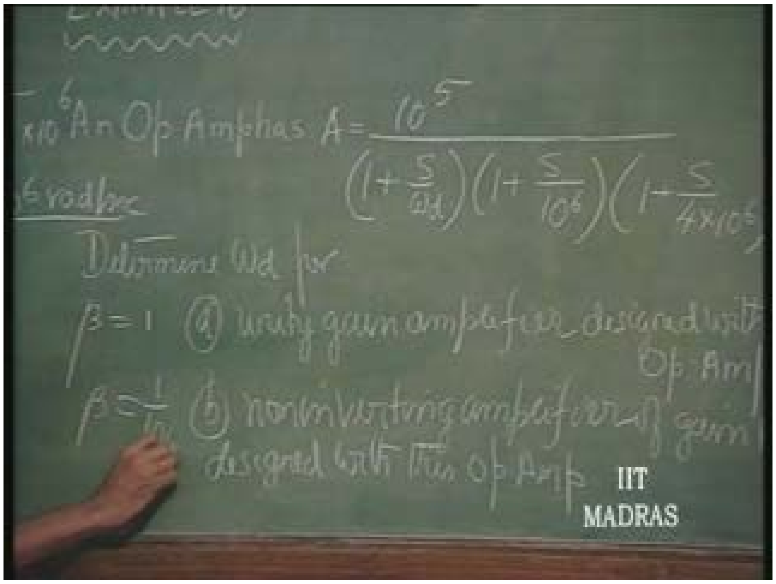

Beta in this case, it is 1, because it is unity gain amplifier, which is nothing but this Beta is 1, this and this design... This is, let us say, 1 K. This is 99 K. So, Beta is 1 over 100.

So, the amplifier gain is 100 here. V naught over V i is 100; V naught over V i is 1 here; and V naught over V i is 100 here. So, this is what has been designed.

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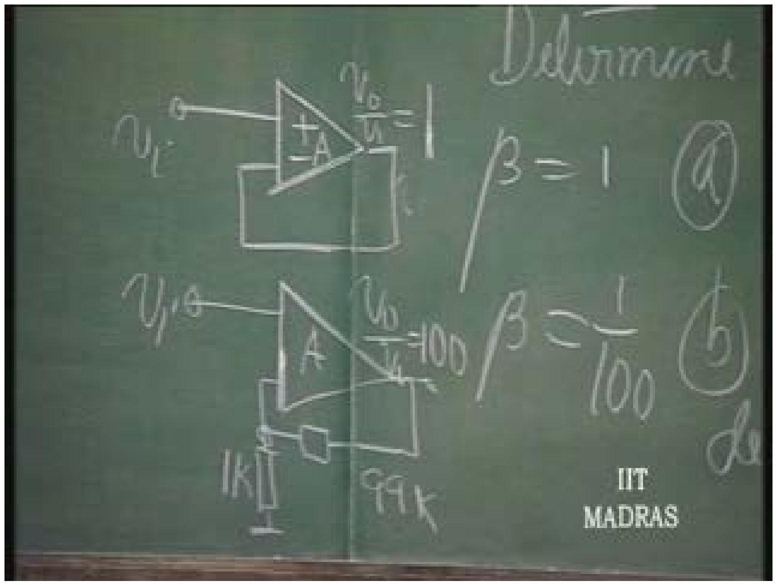

How do I fix Omega d? Now, what is important is A naught into Beta; that divided by Omega 2 plus Omega 3 into Omega d should be less than 1. That is what we have found out from our analysis earlier. So, A naught is 10 to power 5. That is A naught. Beta in first case is 1; and Omega 2 plus Omega 3 is 5; 1 plus 4 which is 5, into 10 to power 6. That should be... that into Omega d is less than 1.

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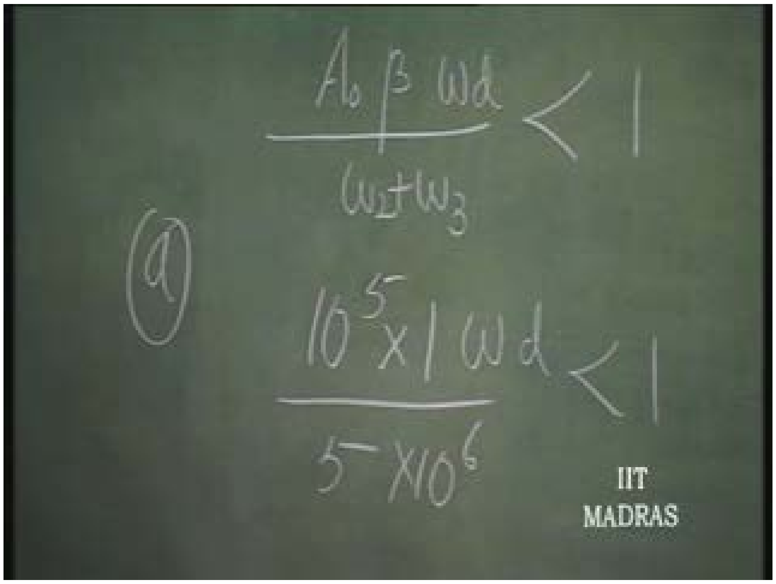

So, what happens here is 10 to power 5. This is 10, 10. So, Omega d is less than 50 radians per second. Without giving much of a margin, we can take take Omega d as, let us say, 49 radians per second. So, let Omega d equal to 49 radians per second.

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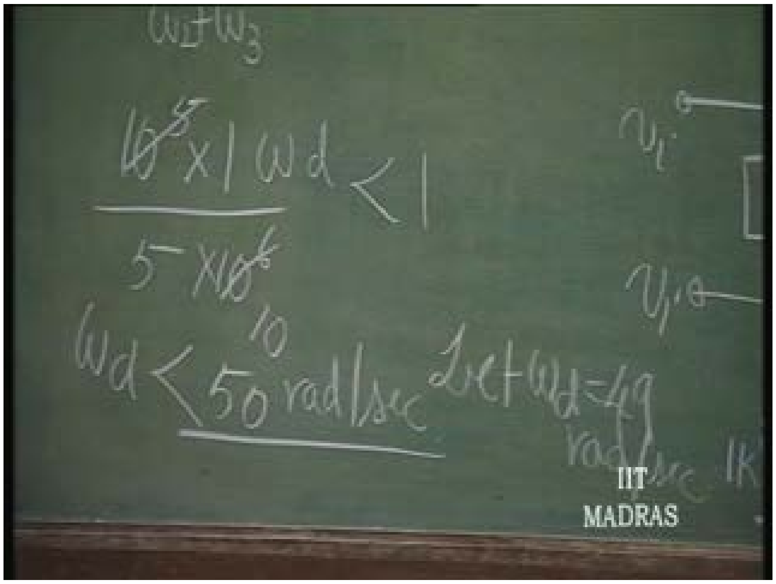

Let us evaluate the gain into band width. Gain is 10 to power 5; gain by net product. Gain is 10 to power 5; bandwidth is 49. So, gain main product is so many radians per second, in this case; 4 point 9 megaradians per second. That is ‘a’ part. Let us now do the ‘b’ part.

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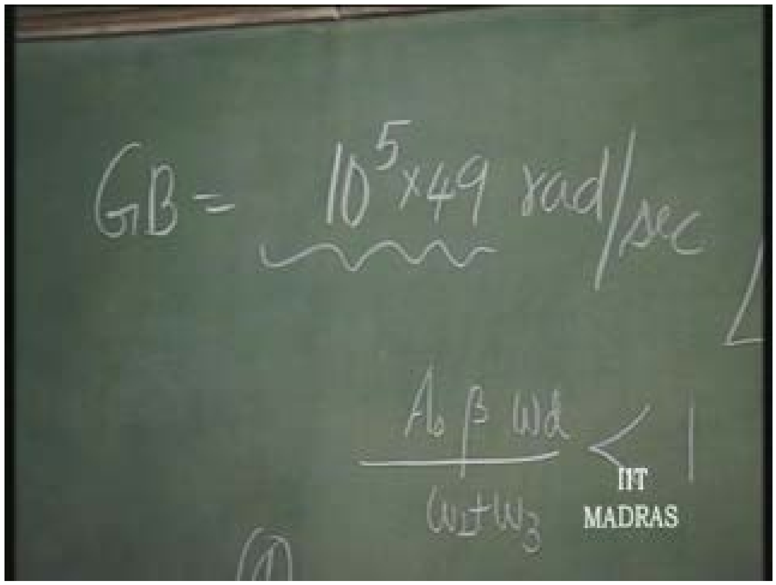

A naught is 10 to power 5. Beta here is 1 over 100. Unlike the earlier Beta which is 1, Omega d into Omega 2 plus Omega 3, is once again 5 into 10 to power 6. So, once again, we have this 10. This should be less than 1; or Omega d here need to be less than 50 into 100 – 5000. So, we can make it actually, let us say, 4900. Let Omega d be equal to 4900 radians per second.

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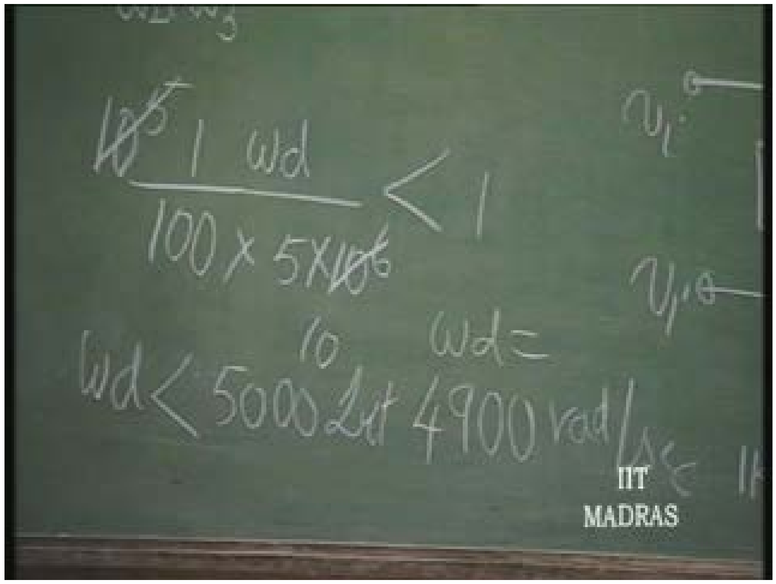

If that is the case, we get here...the G B for this case is 4900 into gain, which is 10 to power 5. We can see therefore, the gain band width product which is the measure of the quality of the amplifier design is 100 times more in the case ‘b’ than in case ‘a’.

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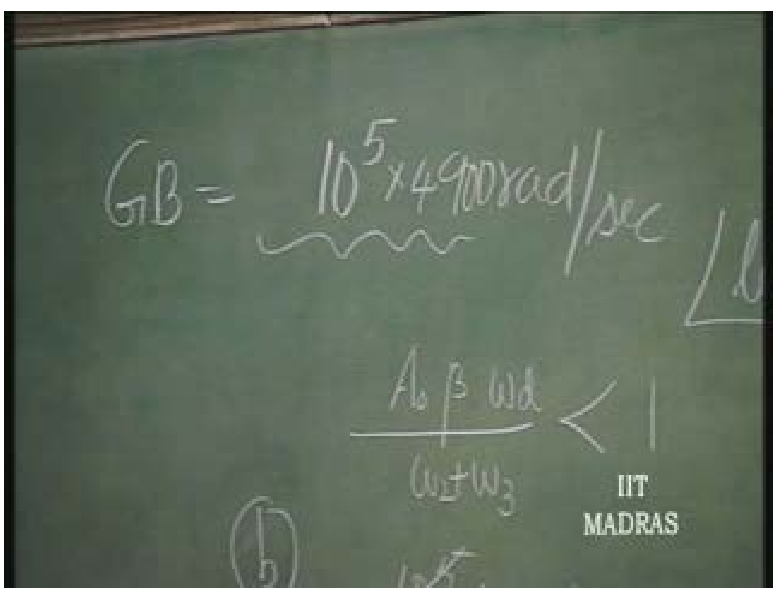

Therefore, if the flexibility of design is left to the person who is designing the circuit, it is more versatile than using unnecessarily the amplifier which has been designed for the worst case, where the gain band width product is going to be constrained unnecessarily.

So, this problem very clearly illustrates why designer should actually prefer an externally compensated amplifier where Omega d is to be fixed by the designer rather than ask the manufacturer to give an amplifier which works for all conditions. That is a disadvantage in the design.

Now, apart from this compensation which is called pole compensation, this is called pole compensation...

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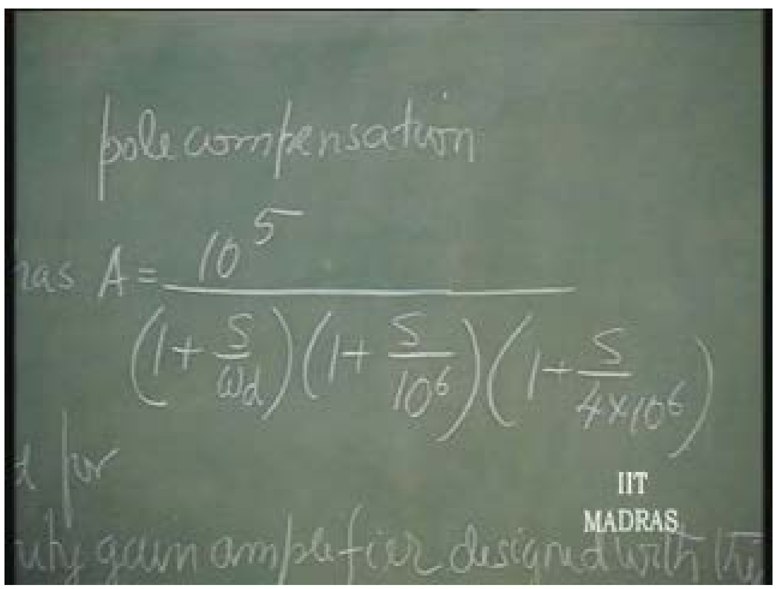

What is the idea of pole compensation? Make the gain dependent only on one pole. These become negligible. These, these will have negligible effect until the gain falls to almost 1.

In another technique, you will have what is called pole zero compensation. That is, instead of introducing a pole like this... Let us say, the pole of this is at 10 to power 5. If I can now introduce here a zero somewhere which can, let us say, cancel one of these, let us say, 10 to power 6, then this system form a third order system, becomes a second order system, and becomes stable.

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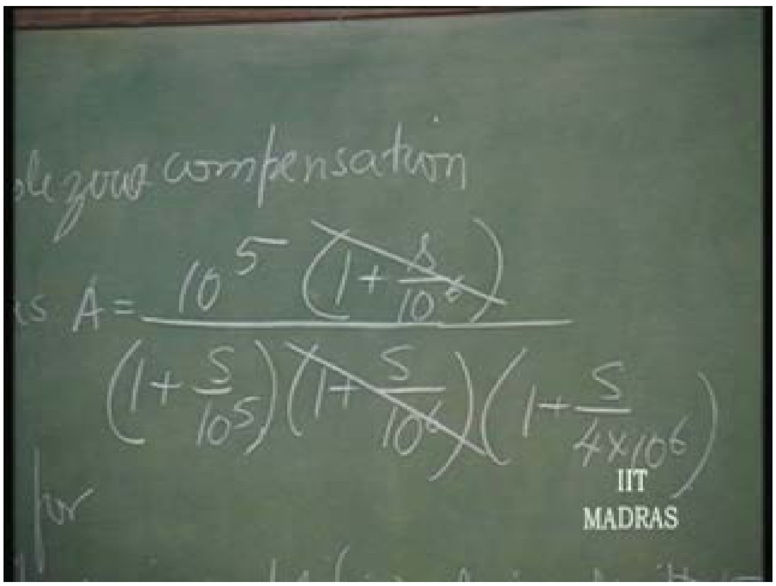

That means if I can introduce a zero, then of course it is very difficult to introduce a zero alone. That is why it is called pole zero compensation. It is good if we can introduce a zero. Then I can cancel it exactly; but the pole zero compensation says, practically in a circuit, we will see...

Whenever we introduce a zero using R C network, we will invariably introduce a pole in this system. So, we might introduce a pole along with this zero. So ultimately, it is only third order; but this pole can get located very far away at very high frequency so that within the useful range, it is still a second order system.

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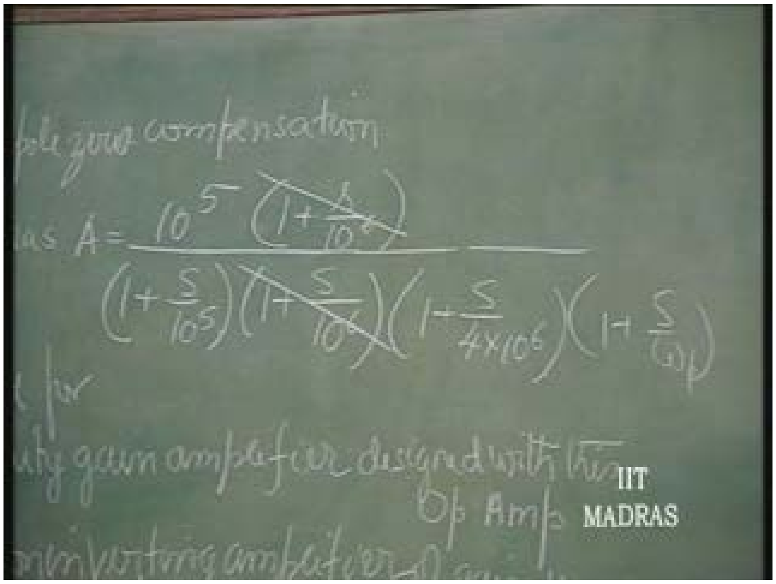

So, this way, you will gain in terms of band width, considerable band width you can get. In all these systems where you are introducing a dominant pole, you are cutting down the band width, so that the gain falls off very rapidly, so as to make it fall off to a value less than one before the other poles take over; whereas, in this system, you are cancelling the effect of poles so that the possibility of phase shift becoming equal to 180 degree never exist; or, it exists at such high frequency that at which point the gain has already fallen to a value less than 1. That is called pole zero compensation. So, these are the various techniques of compensation.

The most popular compensation that is normally used in operational amplifier negative feedback circuit is dominant pole compensation; and that we have discussed in detail.

Just I was describing to you the different methods of compensation. First is called pole compensation. That we have already discussed in detail. This is also called lag compensation. By control engineers, this is called as lag compensation. This is called as... you can...lead lag compensation.

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So, these are the different terminologies used for this compensation scheme. Let us now briefly see how we can give this kind of compensation. If the op amp is already designed or they... if the amplifier is already designed, this is... A is fixed. When will we have problem regarding compensation?

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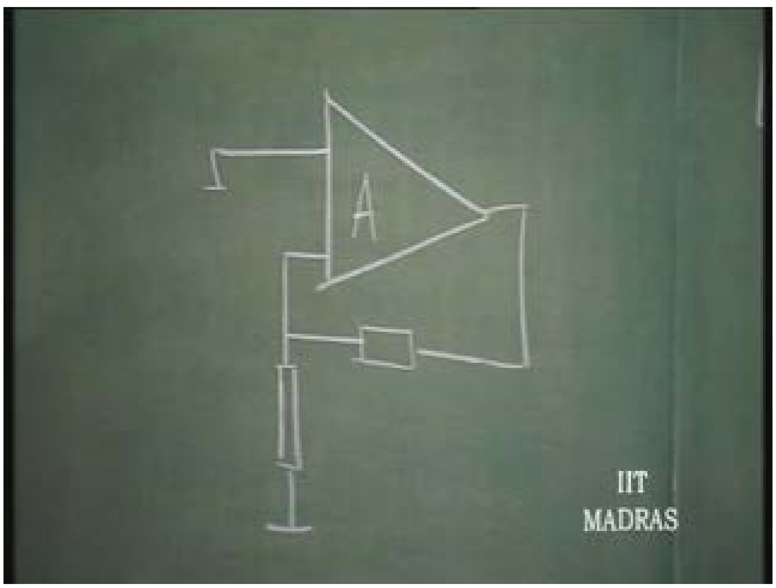

Obviously, A is third order. So, which means, that means, A is equal to A naught by 1 plus S by Omega 1, 1 plus S by Omega 2, 1 plus S by Omega 3. Let us say, I do not have direct influence on Omega 1, Omega 2, Omega 3.

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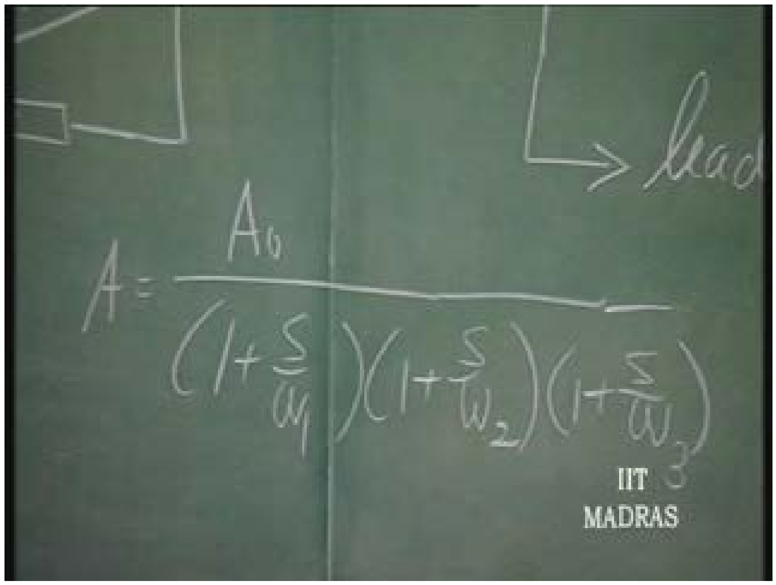

So, how do I now compensate is the first question? Earlier, we have seen where I could interfere with Omega 1. Now the problem is A is fixed as this. I have to now compensate, externally. The internal structure, we do not know; but we are told what is Omega 1, Omega 2, Omega 3. Now, how do I compensate? I can use an external network now. There is a feedback network needed for fixing up the gain. This is called the Beta network that we have. We just said R a and R b; and we said this therefore, A Beta is what matters, as loop gain.

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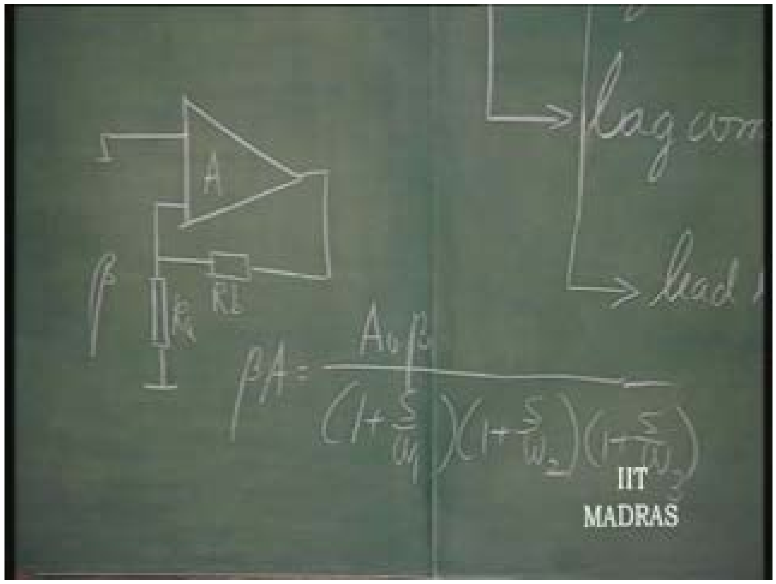

So, we can therefore control Beta now. Beta will not be purely resistive. Beta will be resistive and capacitive. It could be resistive capacitive and inductive also; but normally, inductors are, these days, not used that often for compensation. Inductor will give lead compensation. Capacitor will normally give lag compensation directly.

So earlier, that lead compensation was prevalent because people were using inductors as loads along with the resistors. Then you can directly introduce a zero and compensate. But now, mostly, the capacitors are the ones that are used; resistors and capacitors network. So, if I therefore use this Beta network for compensation, how do I modify the Beta network? That is what is important.

Suppose I put a capacitor here. How does it get modified? If I put a capacitor here, I can now show that if this is C, you will have, obviously, Beta, this as Beta naught; which is R a by R a plus R b, which is what you desire. That will come as Beta naught; but then there will be a pole.

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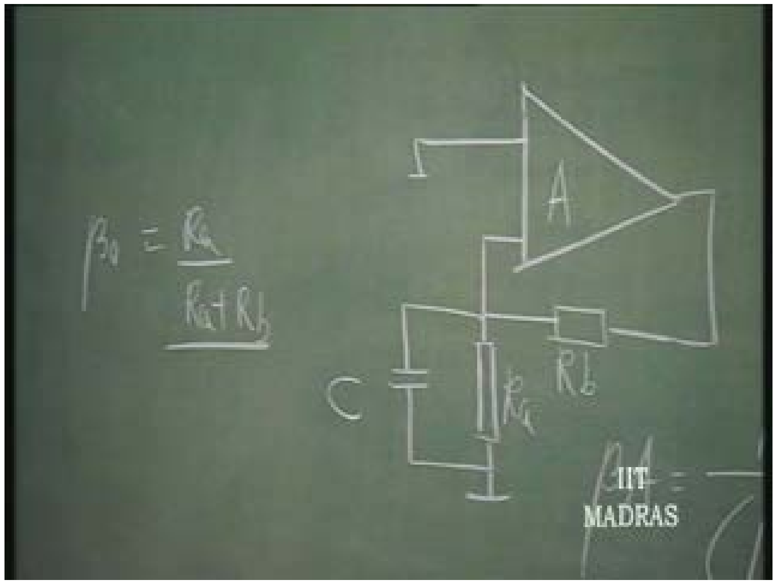

What is the pole going to be dependent upon? It will be therefore, this divided by 1 plus S C. This capacitance comes into it and the time constant which is nothing but... As far as this time constant is concerned, R a parallel R b, the Thevenin's equivalent of resistance between these two terminals.

That is, R a parallel R b. This you can easily derive also from fundamentals; writing this as an impedance and deriving the whole thing. But, this is the easiest way of obtaining the time constant associated with the Beta network.

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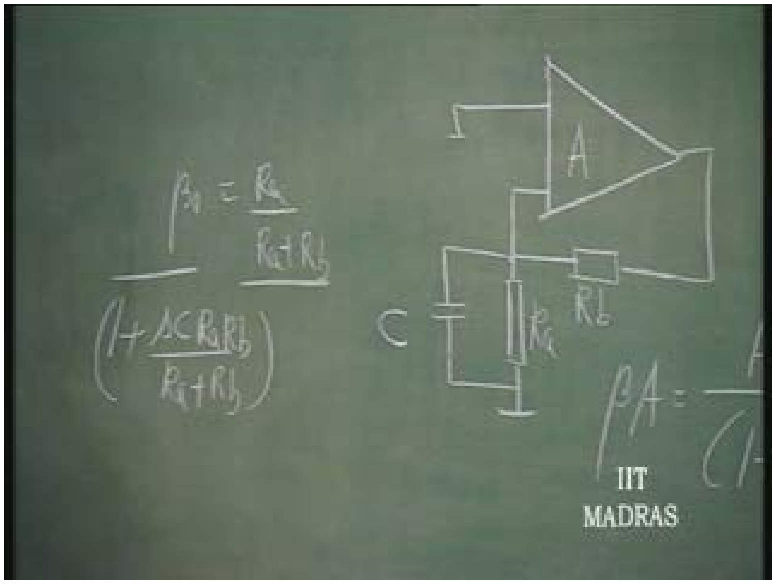

So, it is introducing a pole. So, this is actually speaking, introducing a pole at this frequency. So, I can therefore make this a dominant pole if necessary. If internal structure of the amplifier is not under our control, I can make this a dominant pole because R a parallel R b is under my control. It is only R a by R a plus R b, which is already fixed. So, this is already fixed depending upon what D C gain I would like to have. So, Beta naught is already fixed. So, C into R b can be controlled independently.

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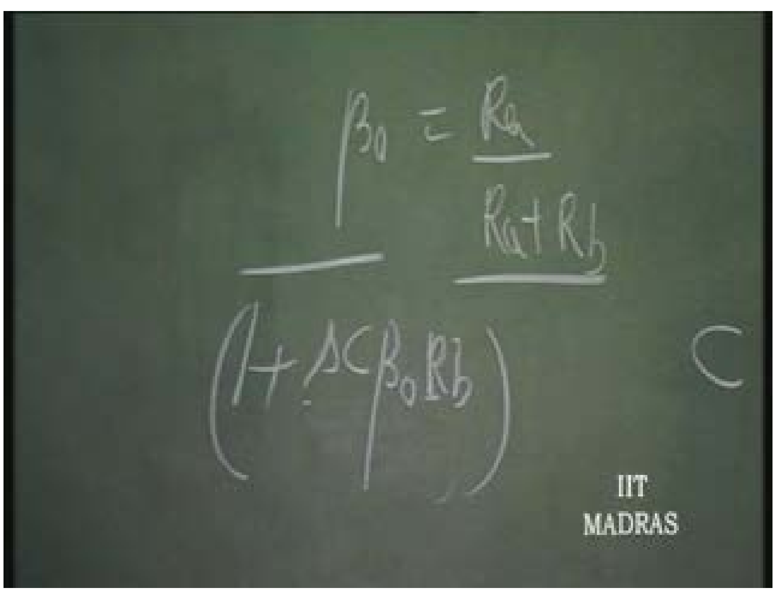

So, this therefore will now introduce 1 plus S by Omega plus a dominant; and what is that dominant here? 1 over C Beta naught R b.

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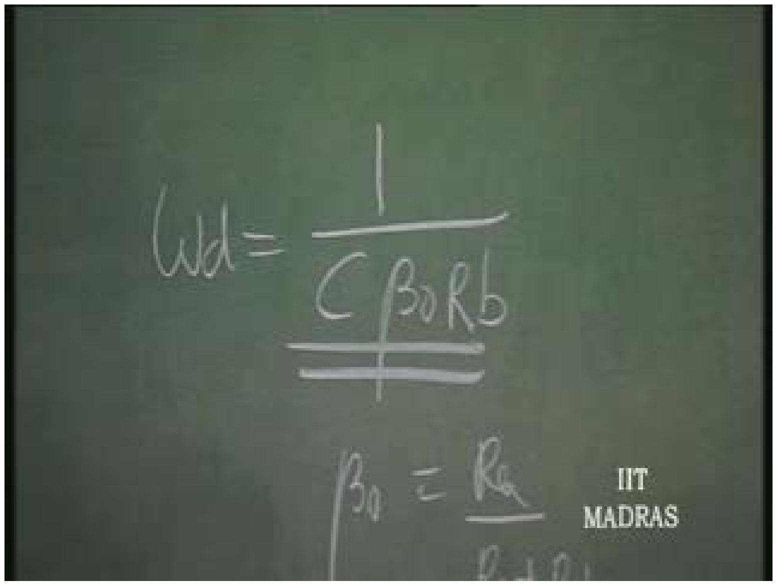

So, just as we did earlier, now again we can find out the frequency at which phase shift becomes equal to 180 degree for this; and find out the magnitude of this loop gain at that frequency; and select Omega d, in order to make the magnitude less than 1 at the given value. This is what is called as pole compensation.

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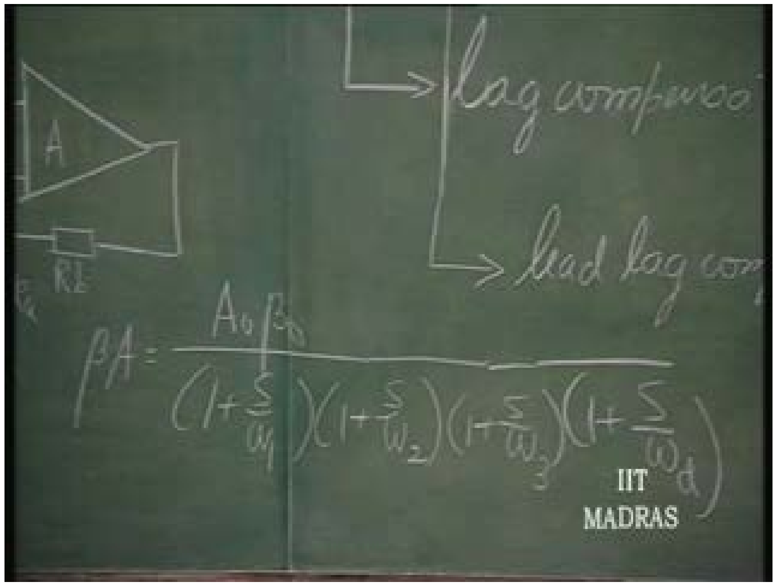

So we can again find out the frequency at which the phase becomes equal to 180 degree. That will be a function of Omega 1, Omega 2, Omega 3, mainly because Omega d is dominant. That would have already contributed to 90 degree phase shift. Now, Omega 1, Omega 2, Omega 3, in combination should contribute to additional 90 degrees. Then, find out the magnitude at that frequency; and that should be less than 1. Based on that, select the value of Omega d. This is the design.

Now, I do not want this pole comp...dominant pole compensation. I want pole zero compensation here. So, what do I do? You can do this kind of thing by introducing a capacitance like this.

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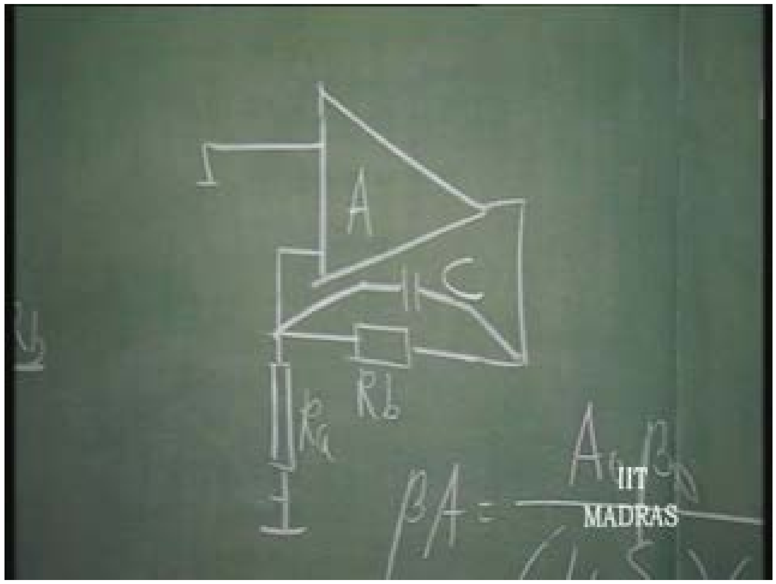

This is what is called lead capacitor, here like this. So, what happens here is Beta naught remains the same.

R a by R a plus R b and it is going to introduce a pole which is again going to be C into R a parallel R b. So, this denominator also remains the same; but it is also introducing a zero you will notice at 1 plus S into C into R b because there is an impedance here. This transfer function is R a divided by R a plus Z. R a by R a plus Z. And Z is R b by 1 plus S C R b. So, if you write, rewrite this, you will see that there is a zero introduced in the numerator.

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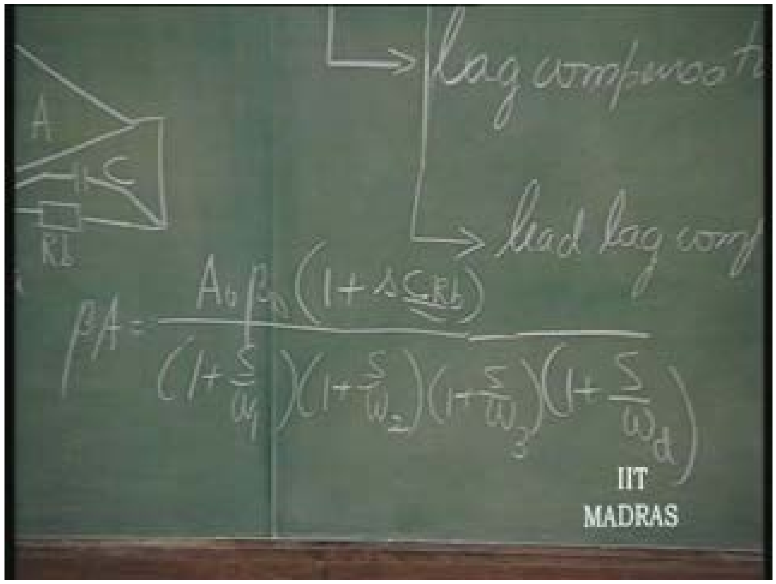

And therefore, this zero that you have introduced can now cancel with one of the poles and this dominant pole at that time should be such that, that that dominant pole, you will see... If this is C R b, this is going to be Omega Z is equal to 1 over C R b and Omega Z is at a lower frequency compared to the dominant pole. So, the dominant pole can be made to lie far away so that R a parallel R b is very small.

So, dominant pole is far away. So, this does not come into picture. This system becomes a second order system thereby making this system stable and giving you a bandwidth of Omega 1 itself. Omega 1 becomes now the dominant frequency. This is not the dominant frequency. This is going to be therefore least dominant. So, this is what is called pole zero compensation.

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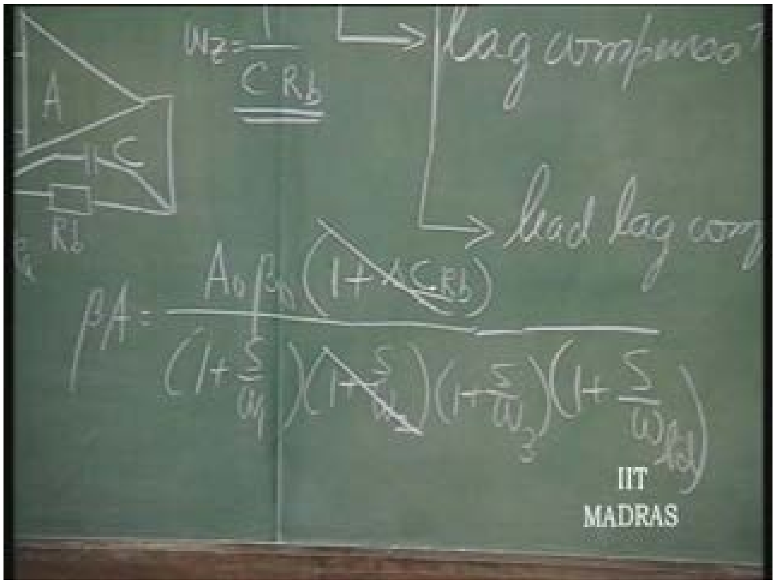

The capacitor is now introduced here. This will introduce a zero at low frequency and a pole at high frequency. Those can be controlled such that you can get proper pole zero cancellation here. Again, this R b can be split and depending upon... if you want a Beta of a certain value and you do not want that to come into picture in the zero, then you can also split it this way; and you can also introduce a pole as well as a zero this way.

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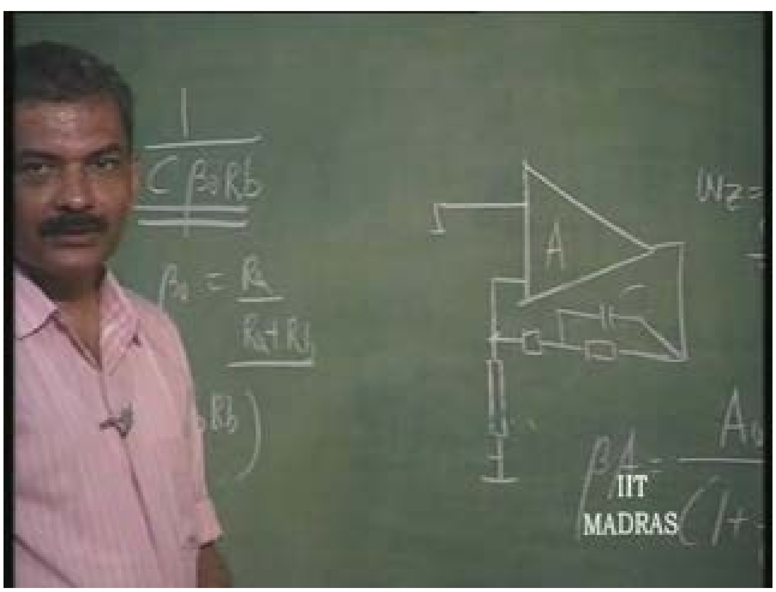

So, these are the various variations possible. Then this Beta naught is going to not directly come into picture in the pole and zero location; we can adjust it accordingly.

So, this is going to complete the discussion on various compensation techniques available. This compensation is adopted for wide band amplifier design; this pole zero compensation.