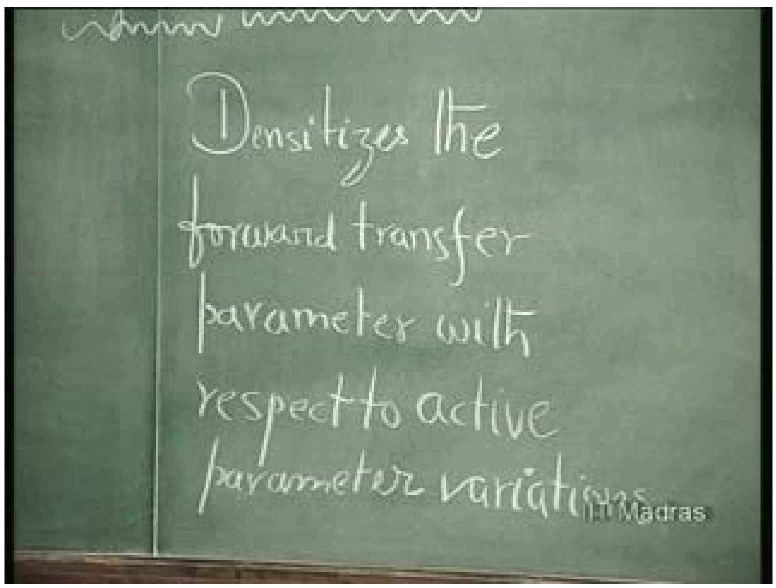
Electronics for Analog Signal Processing - II

Prof. K. Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology – Madras

Lecture - 2
Negative Feedback

So, in the last class we saw how feedback, particularly negative feedback desensitizes the forward transfer parameter, whatever it is, gain, with respect to active parameter variations. So, this is the important aspect of negative feedback amplifier design.

(Refer Slide Time: 01:26)

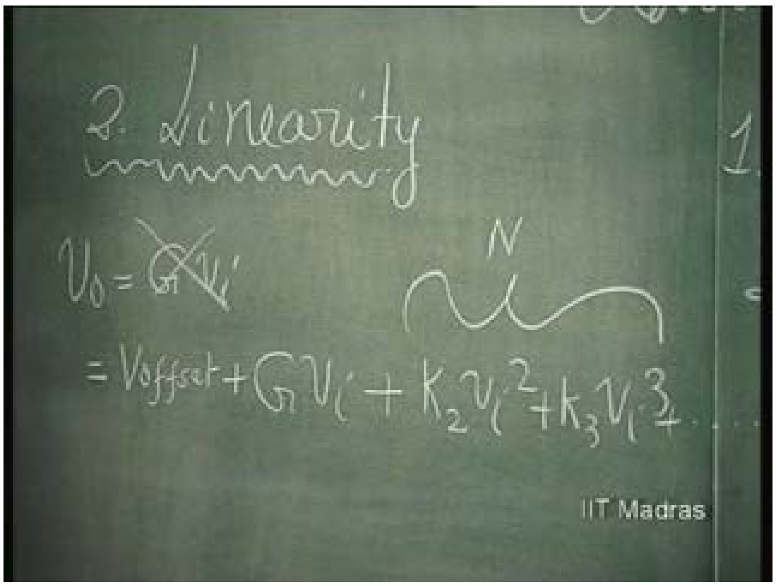


Now, the second aspect of amplifier design which we will now consider is regarding linearity.

This is the first aspect; the second aspect is linearity. What happens is that because of negative feedback, the system becomes more linear. It can handle larger signal levels at the input without distortion occurring. Now, how does this take place? Let us explain this to sort of illustrate how linearity is going to improve.

V naught is going to be, let us say, G times V i, before feedback. Now, this is not the case when non-linearity comes into picture. V naught is then equal to...this is not the case...V offset; that is, a function which is independent of V i; that is called offset voltage. Then, we have linear output. Then we have non-linearities which will be...all terms like K 2 times V i square, K 3 times V i cube, all these things are non-linearities.

(Refer Slide Time: 04:09)

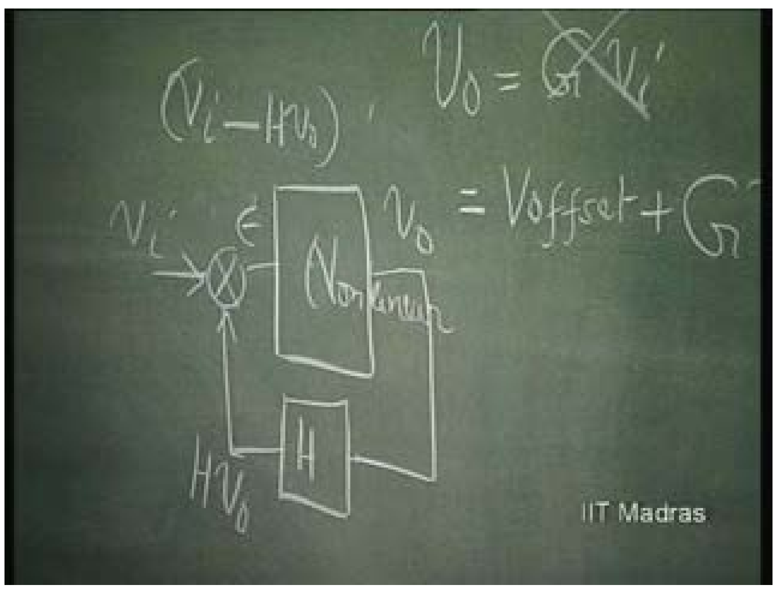


In the design of this, we had earlier seen. These...all these things, higher order terms, these are non-linearities. Any amplifier is going to work in an active region where this is dominant and non-linearities...this K 2, K 3, etcetera are minimal. The operating point will so chosen that V offset is zero, K 2 is very nearly zero, K 3 is very nearly zero, for a certain signal level only; but as signal level increases, all these non-linearities play their part. So how, in a negative feedback, this can be reduced?

I am considering only for voltage feedback; it is applicable equally well for current feedback or any other feedback. Now, this is illustrated here by taking now a feedback configuration here.

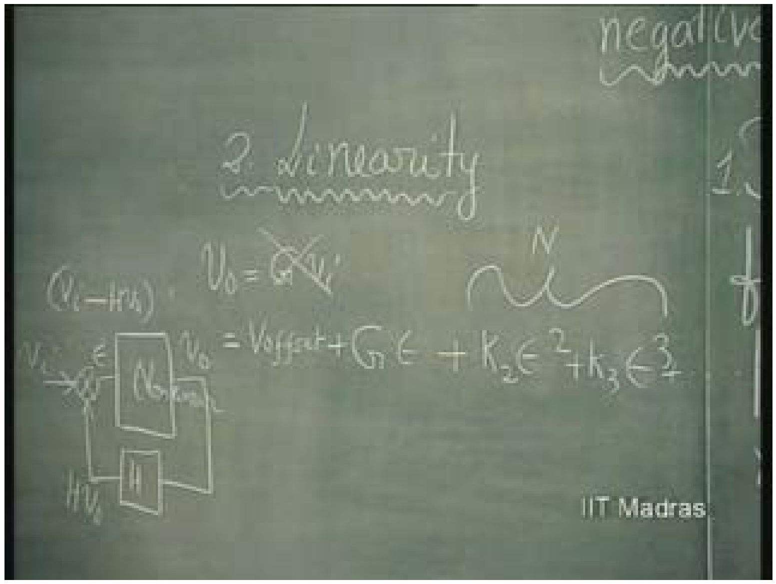
This is not linear. It is governed by this function; V naught and V i. It is governed by this function now. This is non-linear. So, now I give feedback H. V i is going to be this and this is only going to have error here, which is H times V naught. This is linear. We are assuming that this is non-linear and this is linear because this is made out of passive components here. And so, we afford to make this very linear. So, this error is nothing but V i minus H times V naught. So, instead of V i, now we are going to substitute V i minus H times V naught.

(Refer Slide Time: 06:27)



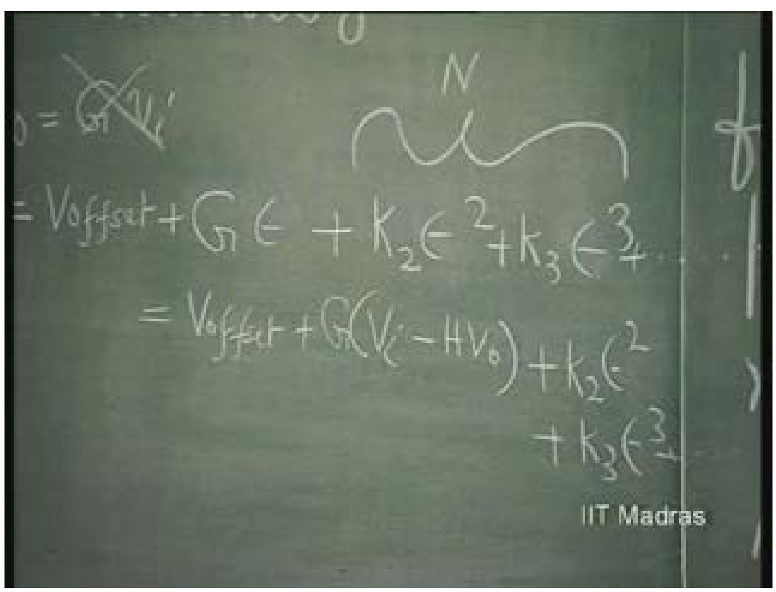
So everywhere, we have to only put here the error epsilon; epsilon square, epsilon cube.

(Refer Slide Time: 06:39)



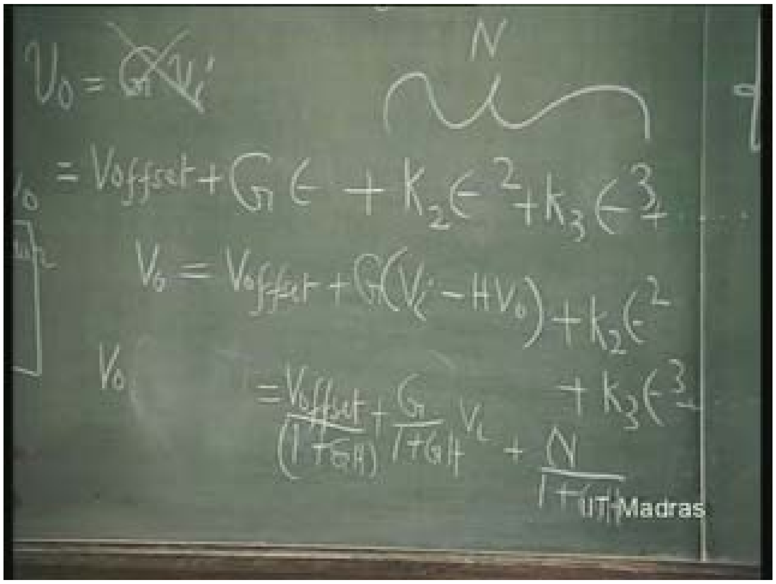
And a good feedback...this thing, this error is going to...towards zero. That means this quantity is going to be made very small. What is this error? This is going to be V offset. This error G is V i minus H times V naught. This, we will write for this and all these things are going to be still there, so on...

(Refer Slide Time: 07:17)



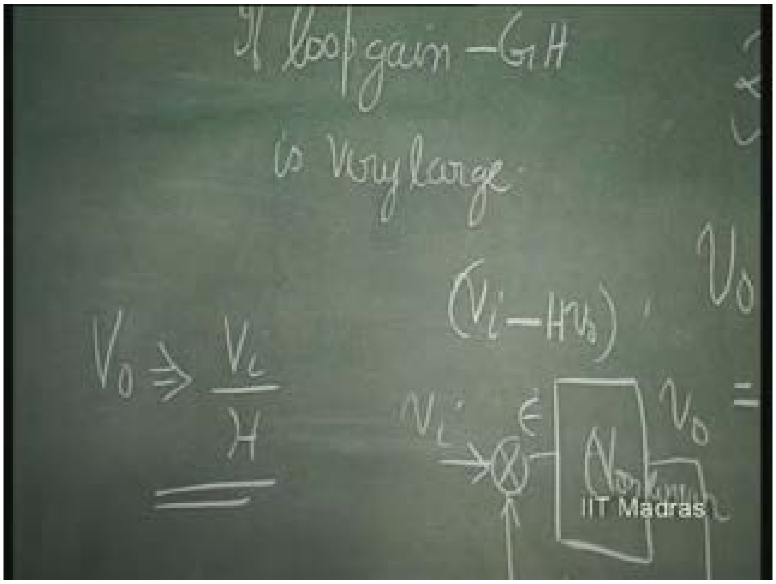
So, V naught therefore is equal to this. So, V naught into 1 plus G H, we will take this along with this, is now equal to V offset plus G by 1 plus G H into V i. Remember? This is what we got in the earlier feedback... This offset is also going to be divided. Now, if I divide the whole thing by 1 plus G H plus...all these non-linearity also is going to be divided by 1 plus G H.

(Refer Slide Time: 08:07)



So, if the loop gain which is minus G into H here is very large, then we can see here that V naught is going to be essentially equal to V i by H, what we got earlier also. Perfectly linear.

(Refer Slide Time: 08:45)



And all these factors including offset will go towards zero. So, these factors will get very low because 1 plus G H is very high. Here, this will become equal to 1 over H, becomes linear, independent of G.

So, this establishes very clearly that in any negative feedback system, the offset voltage is reduced after negative feedback goes towards zero; and the non-linearity is also reduced. The system becomes more linear. Now, this is an important aspect of, again, amplifier design. So, it can now handle larger signal level at the input before distortion can set in. One thing however you should note is, the gain is reduced; and therefore, the voltage level that is required at the input to bring the output to the same level as before, is going to be higher.

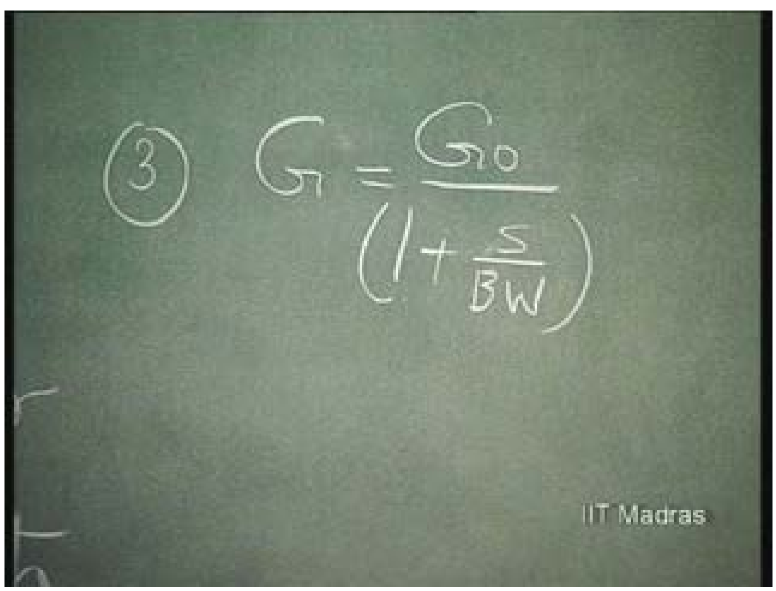
But even though it is higher for the same output level, now you have lower distortion in the case of negative feedback amplifiers than in the case of open loop amplifiers. So, this is to be borne in mind. So, linearity is improved and you will note that any improvement occurs by a factor of 1 plus G H. That means, the loop gain factor comes into picture in every improvement that occurs in all these things.

So, this is the second important conclusion that we arrive at, saying that, in any negative feedback system, the amplifier, forward transfer parameter is desensitized with respect to variation in active parameters, number one. Then, it is also going to have low amount of offset voltage and non-linearity associated with it. So, that means anything that we add externally now, all these things apart from the signal will get reduced. Even the noise generated is going to get reduced. Offset can be also treated similar to noise that is internally created.

So, because this offset may be temperature dependent and it might be varying with respect to time in an arbitrary manner; so, it is equal to certain amount of noise. So, even the noise that is generated within the amplifier is also reduced by a factor dependent upon the loop gain. So, this aspect of amplifier design, negative amplifier, feedback amplifier design is an important criteria which must be always borne in mind.

Let us consider the third aspect of amplifier design. This is, if for example, G is not a sort of constant factor with respect to frequency. G is dependent upon frequency. Let us consider that there is a bandwidth connected with gain. So, G is equal to G naught divided by 1 plus, let us say, S by, let us say, bandwidth.

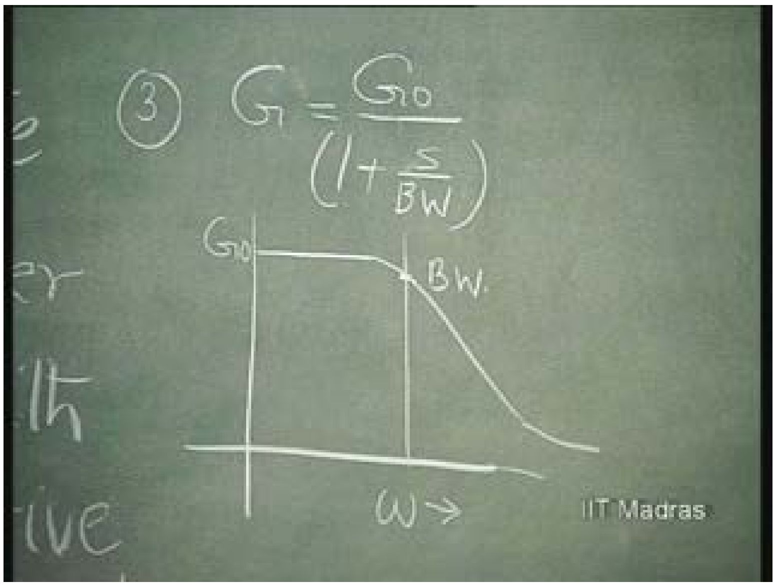
(Refer Slide Time: 13:10)



So, this is saying that the gain function is going to have gain constant at low frequency; but as frequency increases, it will be falling at, let us say, a rate of 20 decibels per decade; and that is a single pole system.

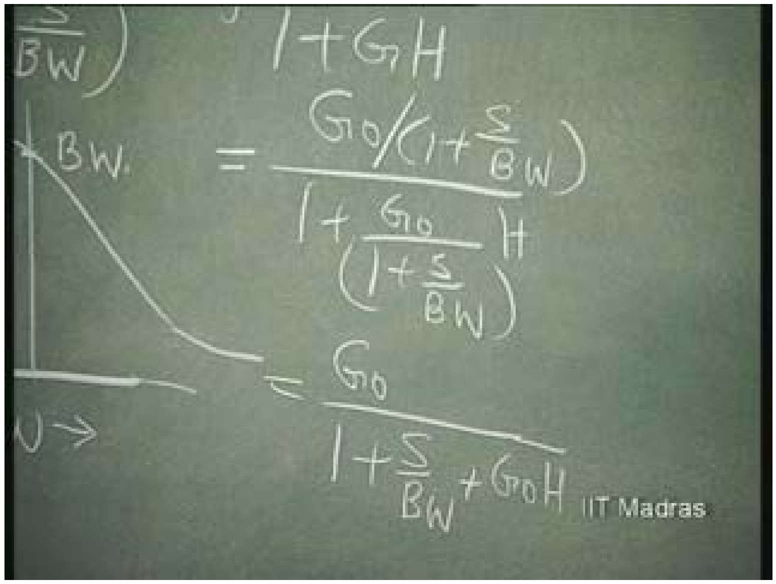
So here, this is nothing but the bandwidth; and it falls to 1 over root 2 times G naught. So, this aspect we had considered when we discussed about amplifiers. This could be anything: gain, transresistance, transimpedance, voltage gain or current gain; it does not matter. Then, what do we do? We give feedback.

(Refer Slide Time: 14:08)



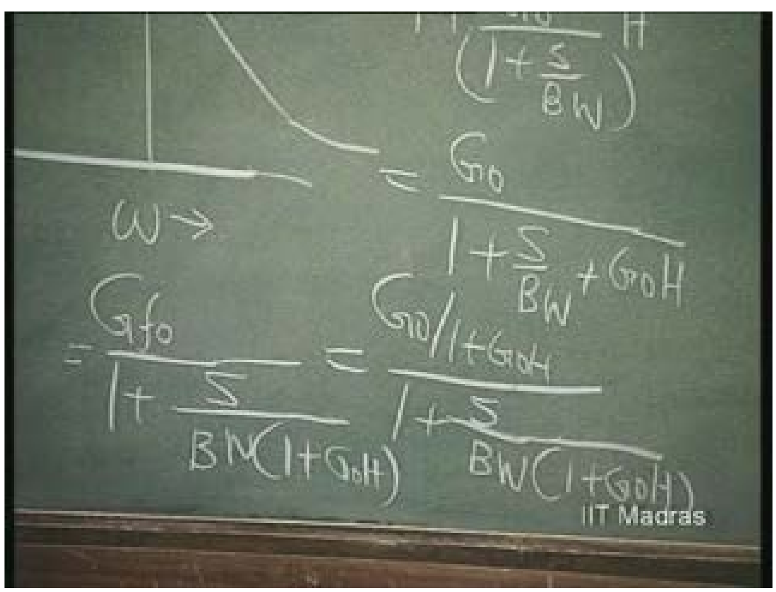
So, gain after feedback is equal to gain before feedback divided by G into H. So, what happens here? We cannot consider that this is substitute for G, this value; G naught divided by 1 plus S by bandwidth. So, 1 plus G naught divided by 1 plus S by band width into H. This can be written as G naught by 1 plus S by bandwidth plus G naught H.

(Refer Slide Time: 14:56)



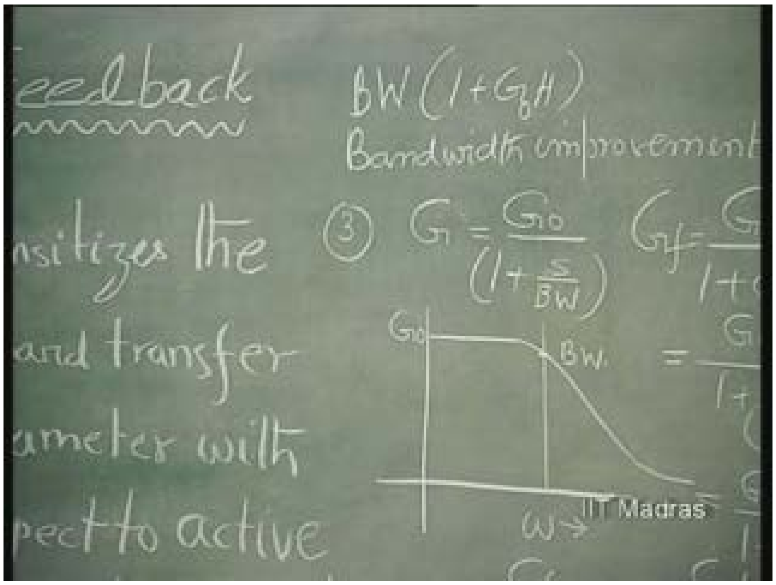
Dividing the numerator as well as the denominator by 1 plus G naught S, G naught by 1 plus G naught H divided by 1 plus S by bandwidth into 1 plus G naught H. Important factor to be noted. The gain with feedback is equal to G f naught which is G naught by 1 plus G naught H which would have got if it is frequency independent. So, the gain with feedback, that divided by 1 plus S by new bandwidth is old bandwidth into 1 plus G naught H.

(Refer Slide Time: 15:50)



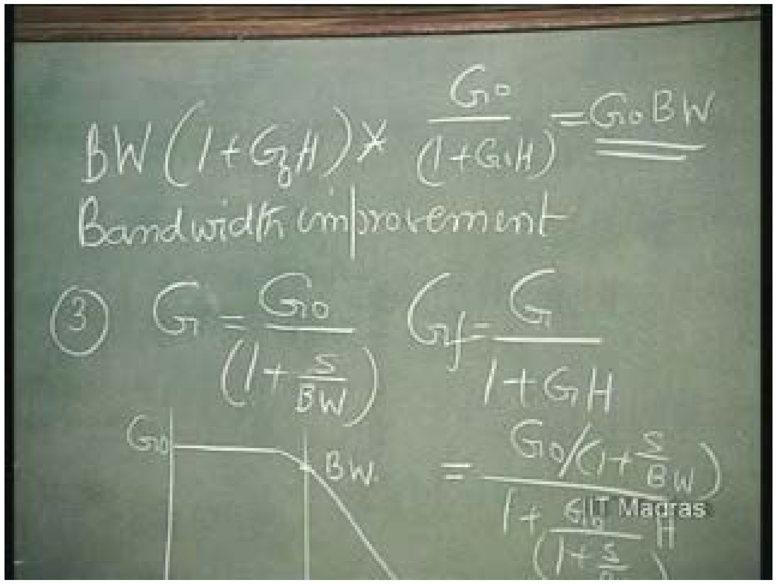
So, the bandwidth improves by a factor of 1 plus G H. I told you, all improvements occur by a factor of 1 plus G H. So, bandwidth improvement. So, if original amplifier, open loop amplifier, with gain equal to G naught was usable up to bandwidth B W, this is usable up to a bandwidth of B W into 1 plus G naught H.

(Refer Slide Time: 16:47)



If you note that gain into bandwidth of negative feedback amplifiers... What is the gain? This G naught into 1 plus G naught H is the gain after feedback. So, G naught into 1 plus G naught H is the gain after feedback; and this is the bandwidth. Gain into bandwidth is a constant. Gain into bandwidth is a constant; G naught into B W. So, this factor into...always a constant, equal to G naught B W.

(Refer Slide Time: 17:23)



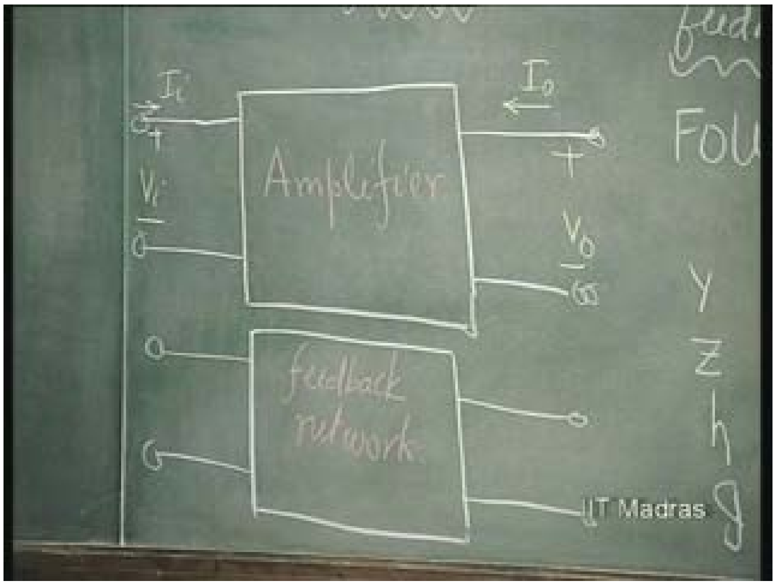
So, whether this is another important conclusion in negative feedback, the gain into bandwidth remains always a constant. That means, if I have an open loop amplifier with 1 megahertz bandwidth, having a gain of 1, that will have a bandwidth of 100 Kilohertz when it has a gain of 10. Is this clear?

When it is a gain of 10, it has a bandwidth of 100 Kilo hertz. When it is a gain of 100, it has a bandwidth of 10 Kilo hertz. When it is a gain of 1, it has a bandwidth of 1 megahertz. So, gain into bandwidth is a constant factor. So, these three are the three important factors associated with negative feedback. What are they? Sensitivity - number one, linearity - number two, bandwidth improvement - number three.

So, we will further consider the same effect in general in the case of the parameters h, y, z and g. These are the basic amplifier configurations, which... What happens in the case of h, y, z and g? What are the different types of feedback which are possible as far as the feedback is negative; and how things improve in the case of the various parameters?

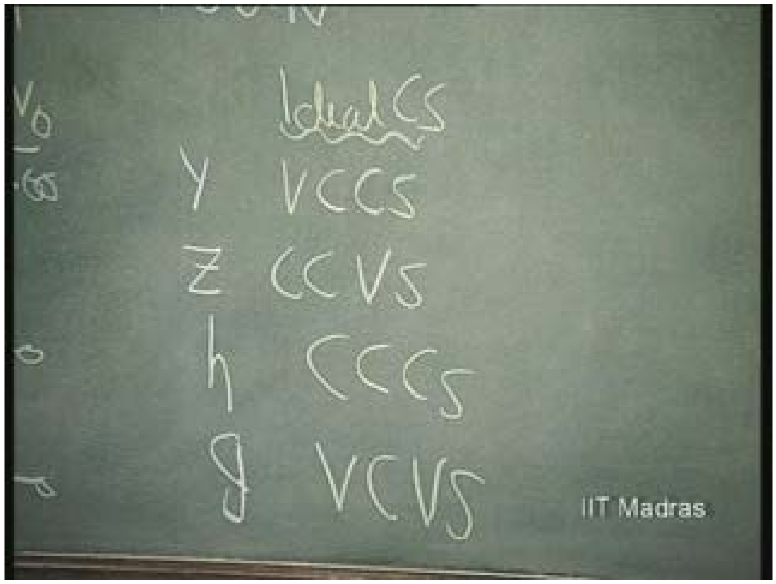
Let us now consider the two port network that we had earlier used for discussing amplifiers. We said, amplifier, ideal amplifier, has two ports: input port and output port and can be categorized as belonging to four types of control sources: voltage control voltage source, current control current source, voltage control current source and current control voltage source. And these ideal amplifiers belonging to these four categories can be only uniquely defined by one of the four parameters.

(Refer Slide Time: 19:45)



For example, g parameter will ideally define a voltage control voltage source, ideal; h parameter will ideally define a current control current source; and y parameter will define a voltage control current source; z parameter will define an ideal current control voltage source. So, these ideal sources, control sources, can be only defined by these parameters, respectively.

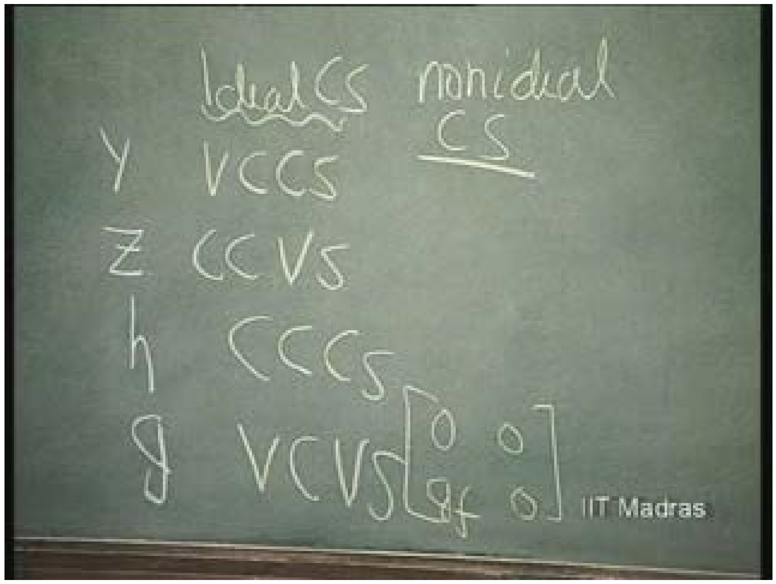
(Refer Slide Time: 20:51)



This we had understood in the beginning of the course. Now, how do we give feedback to these amplifiers which are non-ideal? Let us say therefore, we have a situation of non-ideal control source. So, when voltage control current source is non-ideal or current control voltage source is non-ideal or current control current source is non-ideal or voltage control volt...voltage source is non-ideal, what does it mean?

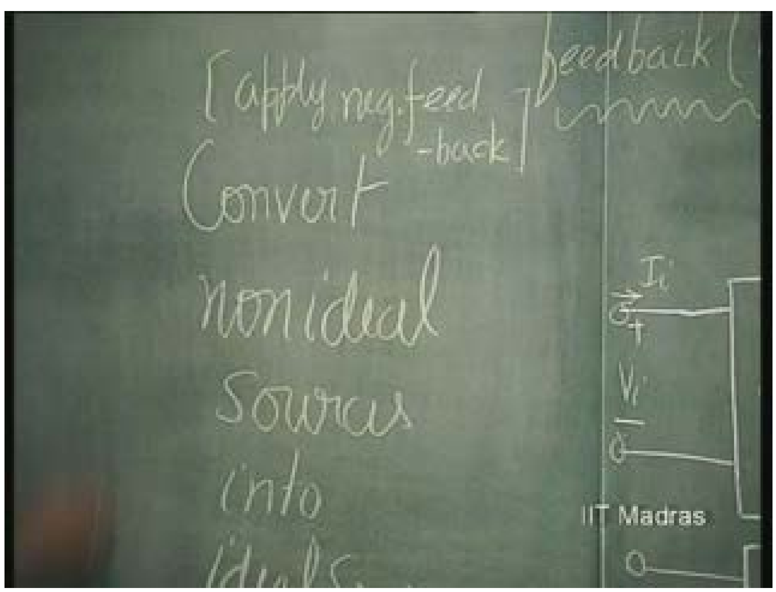
For example, voltage control voltage source is non-ideal. What it means is the matrix parameter - zero, zero, zero and g f; this is the ideal way to represent. That means input admittance is zero or input impedance is infinity; output conductance, that is, output resistance is...this is...voltage source is zero; output resistance...then, reverse transfer parameter is zero.

(Refer Slide Time: 22:08)



Now, if it is non-ideal, these are non-zero factors; close to low value. This will be large; but these will be low values. In such a situation, in order to convert each one these non-ideal sources into ideal sources, negative feedback can be applied. This is the... important... Convert non-ideal sources into ideal sources. Apply negative feedback.

(Refer Slide Time: 23:13)

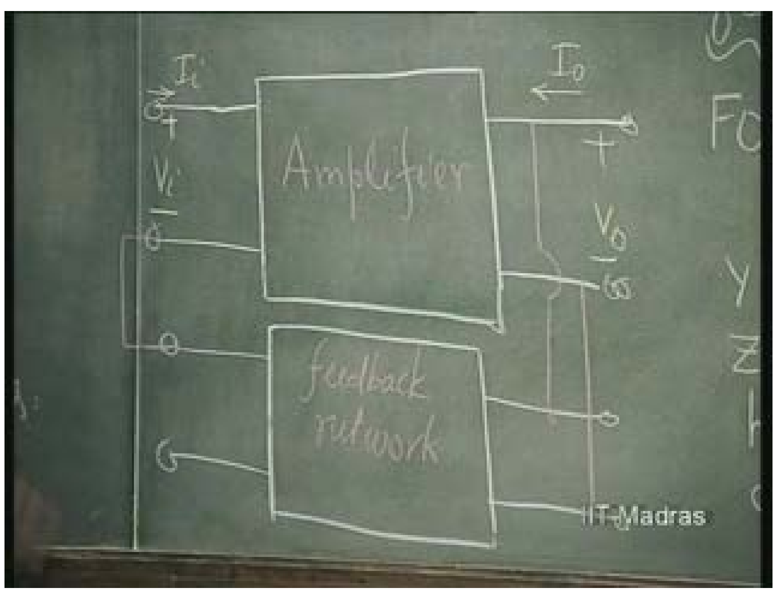


Apply negative feedback. Why? To convert non-ideal sources into ideal sources. Once again, let me, let me explain. A non-ideal source here will always have all the other parameters zero, except the forward transfer parameter, which is going to be large, huge.

Now, in the case of ideal, non-ideal sources, these will become finite, but non-zero; so, we want to make this go towards zero. Then, we have to apply appropriate negative feedback. So, this is the important function of negative feedback. How do we apply negative feedback? Now, if I apply h feedback, if I apply h feedback, let us see... How do I apply h feedback? This kind of thing is defined very easily by the definition of this itself. h feedback...what is h i? h i is input impedance with output short; so input impedance. So, impedances add in series. So, immediately you can conclude that the amplifier network and the feedback network, they should come in series, at the input.

What is happening at the output? At the output, it is going to be again, a voltage source. That means output impedance should come down; input impedance should go up. Input impedance should go up; output impedance should come down. That is what this says. So, it should be in series at the input and in shunt at the output.

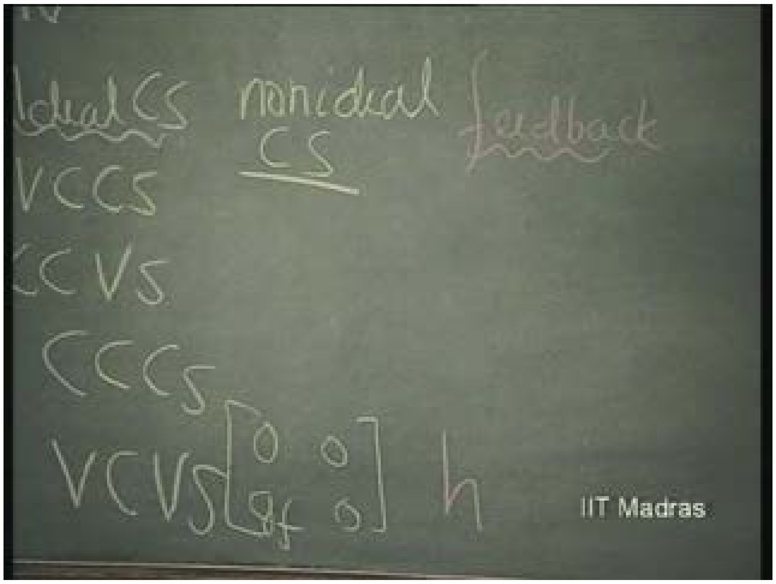
(Refer Slide Time: 25:35)



So, in order to realize a voltage control voltage source, the input impedance should go up; output impedance should come down. So, it should...it should be in series at the input in order to increase the input impedance; it should in shunt at the output in order to bring down the output impedance, in order to make it a voltage source. So, this is nothing but h feedback.

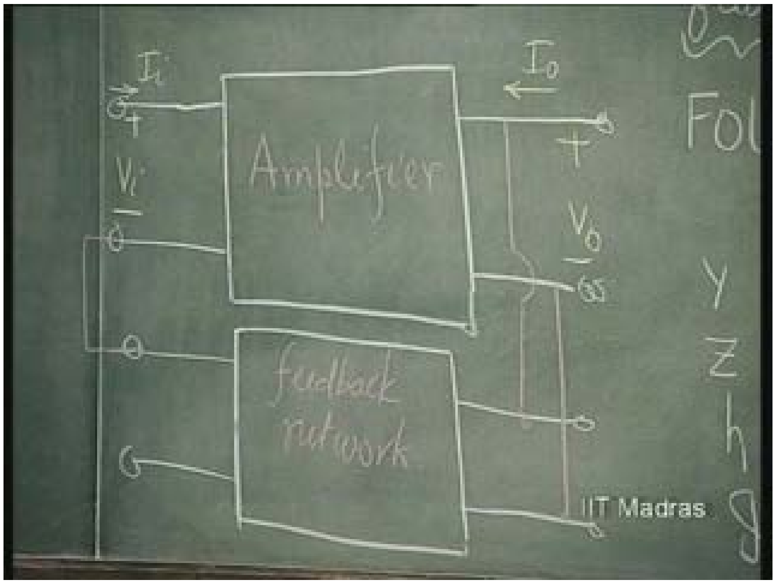
So, in order to realize a voltage control voltage source which is expressed in terms of g parameters, you have to give h feedback.

(Refer Slide Time: 26:22)



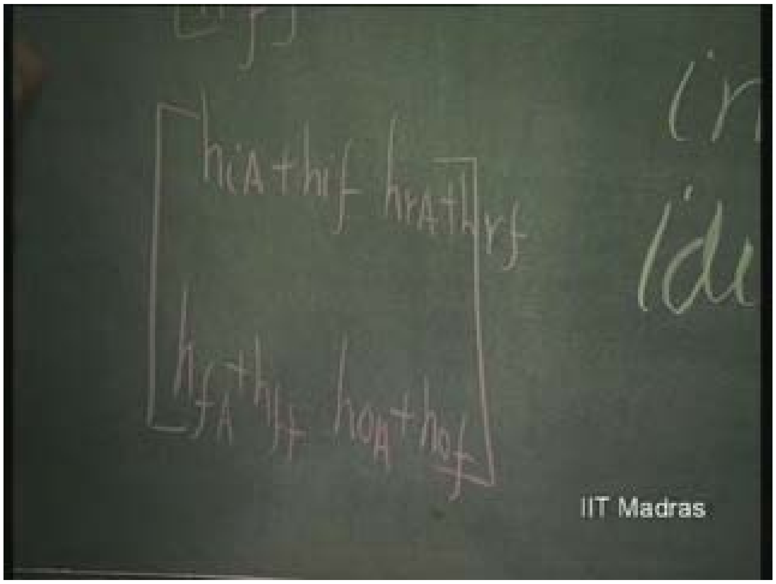
So, you have to give h feedback in order to obtain a voltage control voltage source. Is this clear? Now, mathematically also, it becomes clear. The h parameters add. Here, for this amplifier, since these are in series at the input and shunt at the output, h parameter of this will add with h parameter of this. So, composite h parameter of this structure is going to be h parameter of this plus the h parameter of this. So, let us consider... I am giving h feedback.

(Refer Slide Time: 27:01)



In which case, h parameter of the amplifier and h parameter of the feedback network; these simply add. Or, I can write the composite h parameter as h i A plus h i f and h naught A plus h naught f; h f A plus h f f and h r A plus h r, h r f. That means, these are simply adding up.

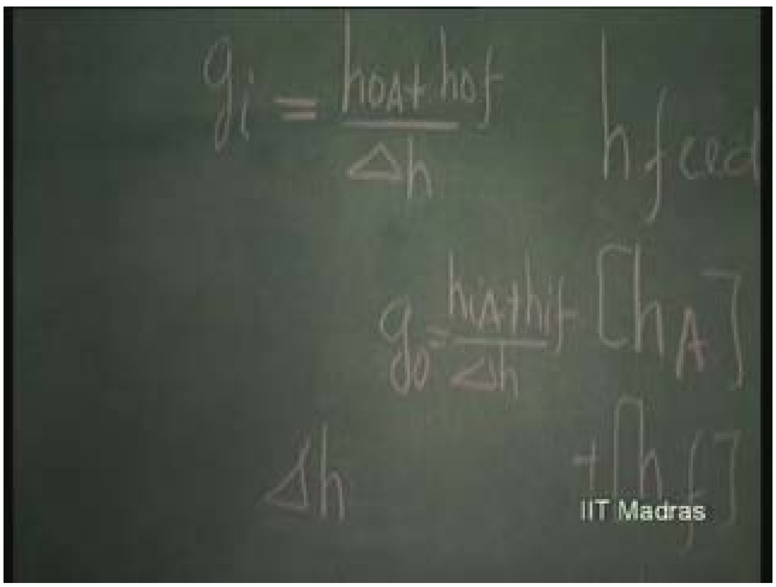
(Refer Slide Time: 27:50)



This is a very easy technique to obtain the composite parameter. If this is in series at the input and shunt at the output, then you know that it is h feedback and simply take the h parameter of the amplifier and add it to the h parameter of the feedback network. Then what happens?

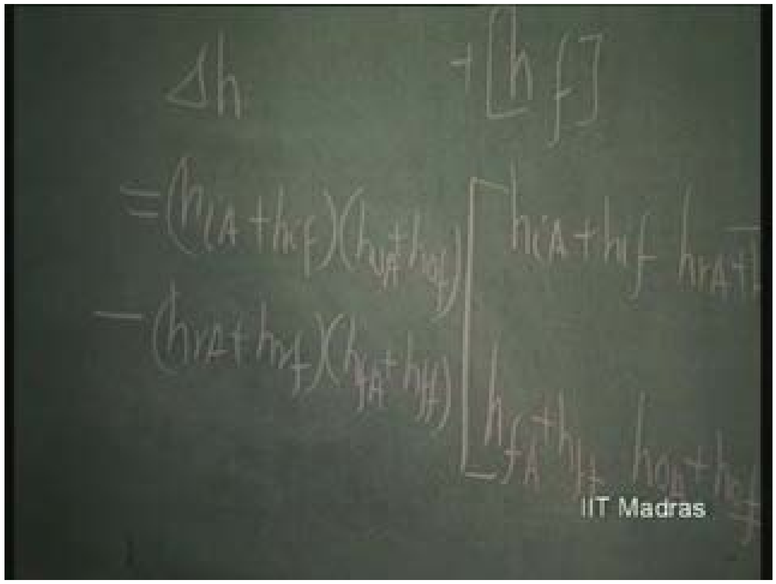
This is the composite h parameter. How will you convert into g? Then you will take the matrix here. You can invert. So, you will take the matrix of this Delta h, determinant of this, and obtain the g parameter. What will be the g i? What will be the g i? g i is going to be... it is going to be h naught A plus h naught f divided Delta h. g o is going to be h i A plus h i f divided by Delta h.

(Refer Slide Time: 29:07)



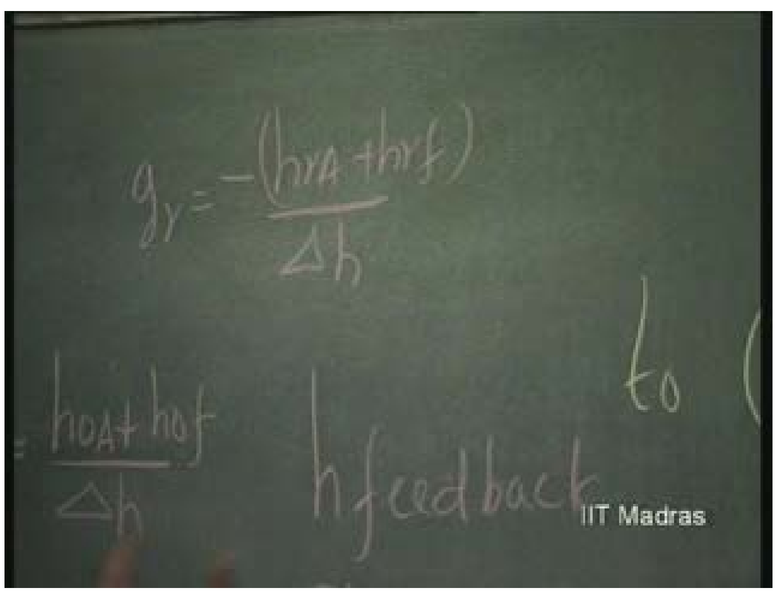
What is Delta h? Delta h is the determinant which is h i A plus h i f into h o A plus h o f minus h r A plus h r f, h f A plus h f f. This is the determinant.

(Refer Slide Time: 29:32)



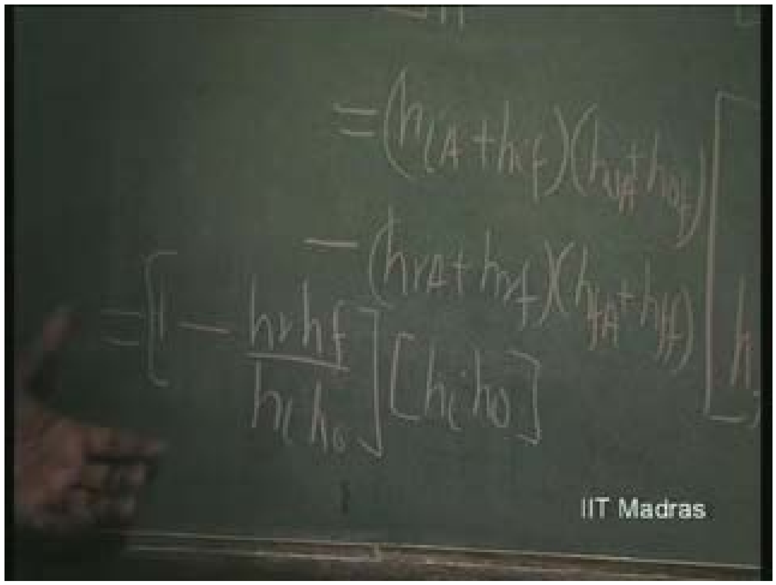
So, h, g i and g naught get modified. And what is going to be...g f is going to be minus h f A plus h f f divided by Delta h and g r is going to be minus h r A plus h r f divided by Delta h. So, these are...this is nothing but the matrix inversion.

(Refer Slide Time: 30:15)



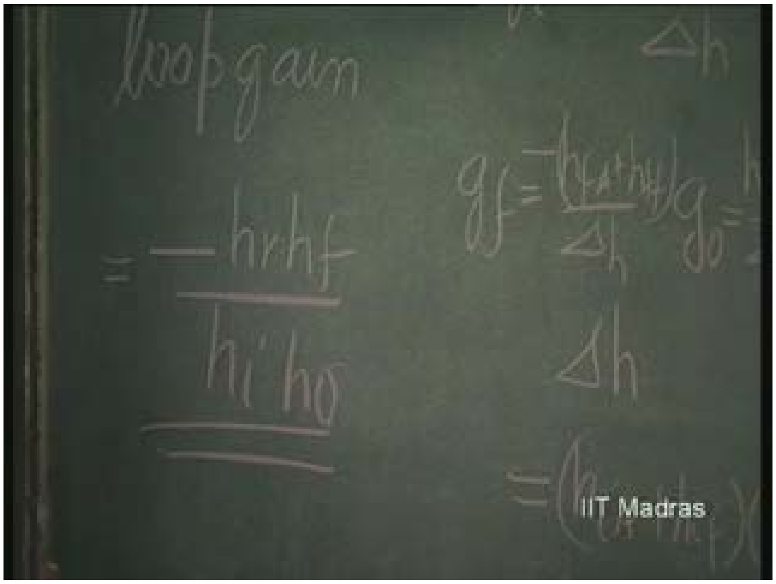
So, Delta h is a constant factor coming in all the parameters. If Delta h is very high, what is Delta h? It is nothing but this, which can be written as 1 minus h r h f by h i h o into h i h o.

(Refer Slide Time: 30:42)



So, this Delta h is nothing but 1 minus... I am taking h i into h o. This is composite h i. This is composite h o. h i into h o - 1 minus h r into h f divided by h i into h o. This is similar to your 1 plus g h fact. So, this is called the loop gain. The loop gain is equal to minus h r h f divided by h i into h o. This is called the loop gain.

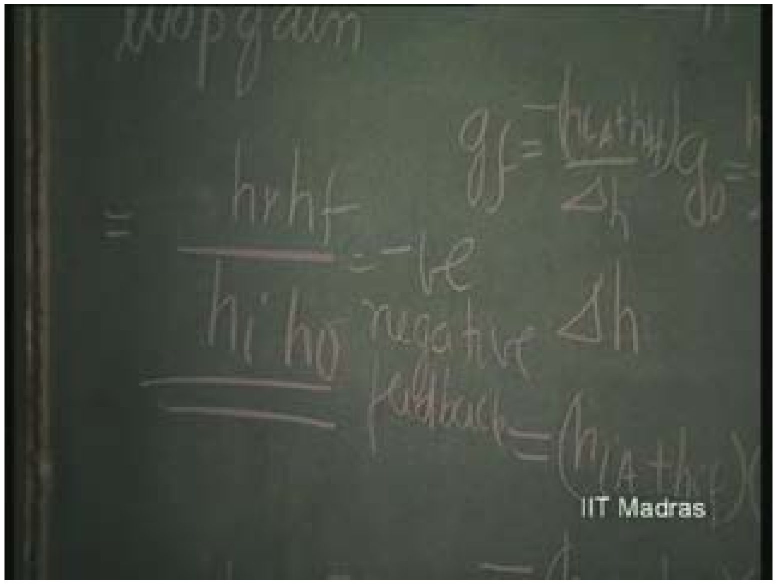
(Refer Slide Time: 31:23)



This, we called as minus g into h. It is the same factor by which all the parameters change. See, if you notice here, this factor divided by Delta h...Delta h involves this. This factor divided by Delta h. Everywhere, the loop gain comes into picture. The loop gain is very high. That means this is going to be very high and it is negative. So, then it is negative feedback. Is this clear?

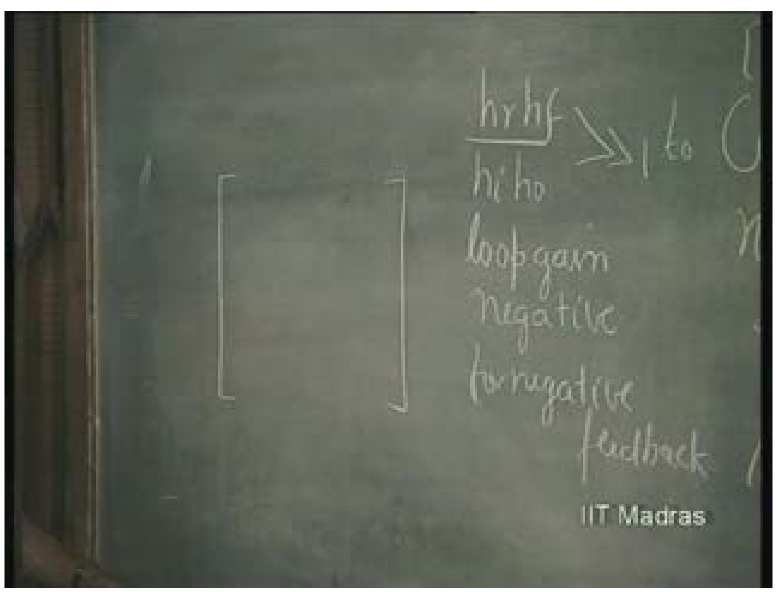
So, this is an important aspect of this thing, our amplifier design. So, loop gain is really h r h f divided by h i into h naught. If this is negative, then this becomes positive; and this is a negative. It is negative feedback. If it is positive, it is positive feedback.

(Refer Slide Time: 32:33)



So, this aspect of design is important. Now, let us summarize the whole thing. If loop gain... What is loop gain? h r h f divided by h i into h naught. This is called the loop gain. This is negative; then it is negative feedback. If it is positive, it is positive feedback. So loop gain, if it is very high, if it is much greater than 1 and it is negative feedback, then you will note that all these parameters which are getting modified... Let us see.

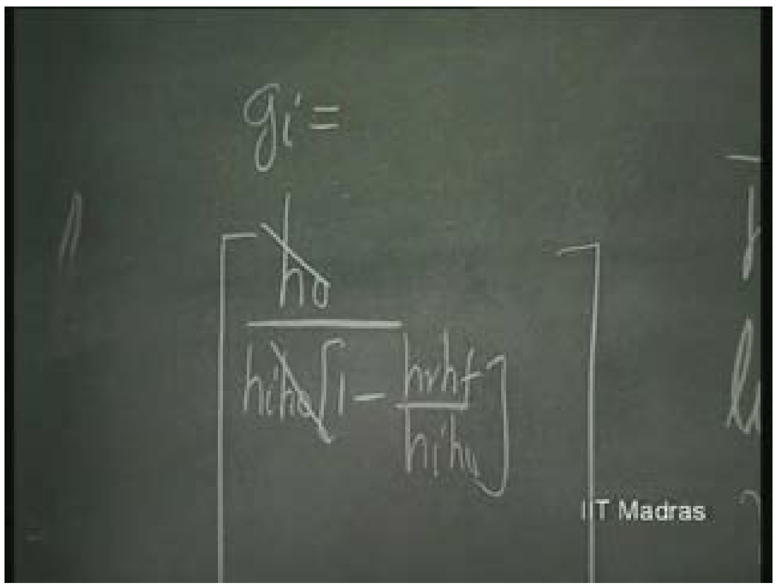
(Refer Slide Time: 33:51)



The first parameter is, that this is h naught divided by h i h naught into 1 minus h r h f divided by h i into h naught. This is the g i. This is equal to g i.

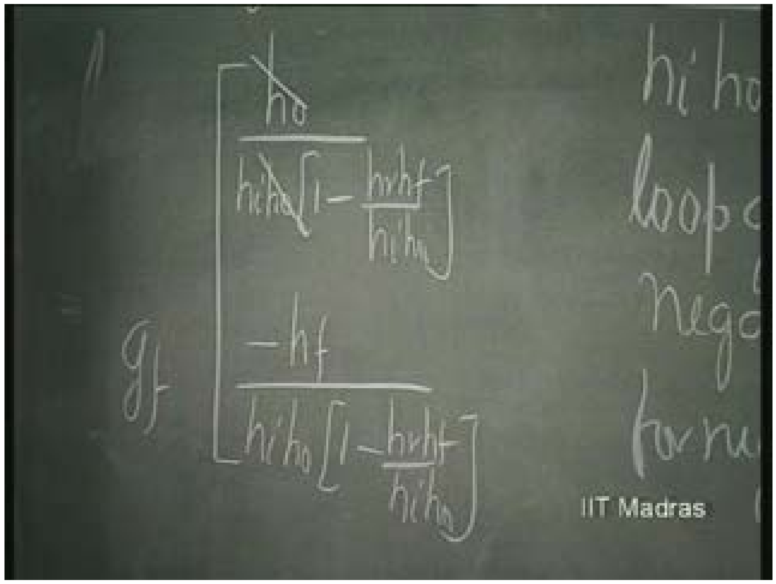
Earlier, we had written the same thing. So, h naught gets cancelled with h naught. See what happens to the parameter. g i is equal to 1 over h i into 1 minus h r h f by h i h naught. So, input impedance increases. This is input impedance. It increases because these are coming in series; and therefore, g i goes towards zero. This factor is going to become very high. Therefore, this 1 over this goes towards zero because of negative feedback.

(Refer Slide Time: 34:53)



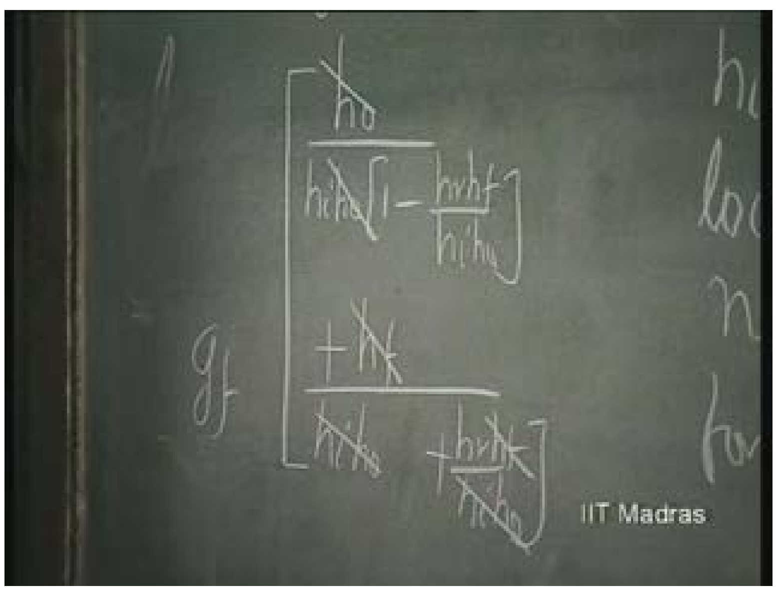
So, this is g i and the other factor here is going to be minus h f divided by h i h naught into 1 minus h r h f by h i h naught. This is going to be our g f now.

(Refer Slide Time: 35:16)



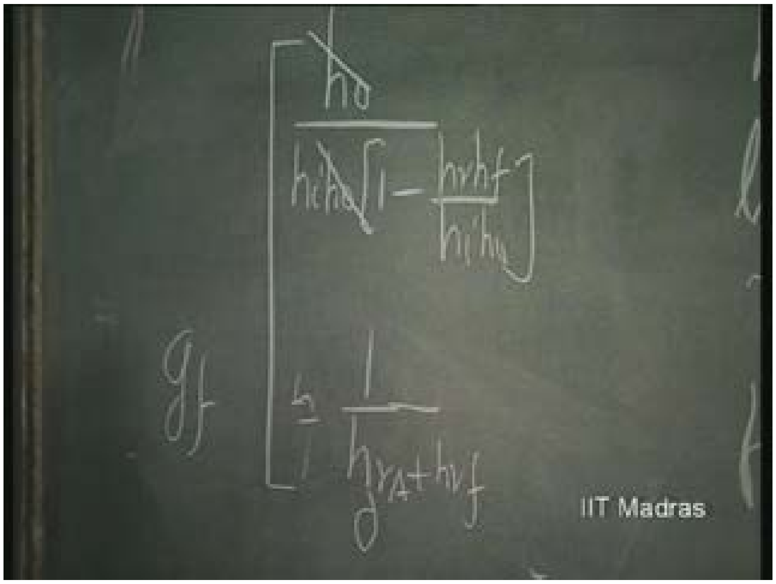
So, if this factor is very large compared to 1, we can ignore 1. So, we can ignore 1. So, what happens? h i h naught gets cancelled with h i h naught. h f gets cancelled with h f. This becomes plus and therefore the entire g f becomes equal to 1 over h f, h r.

(Refer Slide Time: 35:49)



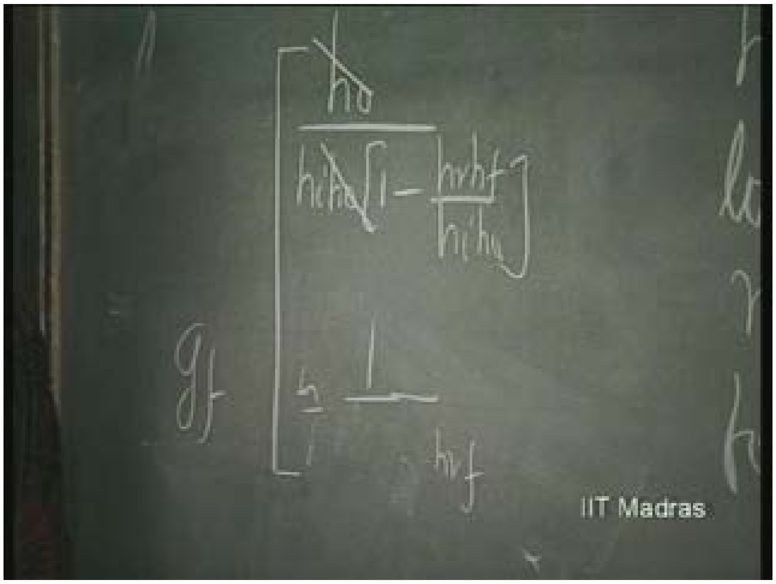
So, this is an important thing. This whole thing goes goes to 1 over h r and what is... What is h r made up of? Please remember. It is composite h r; h r amplifier plus h r feedback. So, h r amplifier plus h r feedback.

(Refer Slide Time: 36:16)



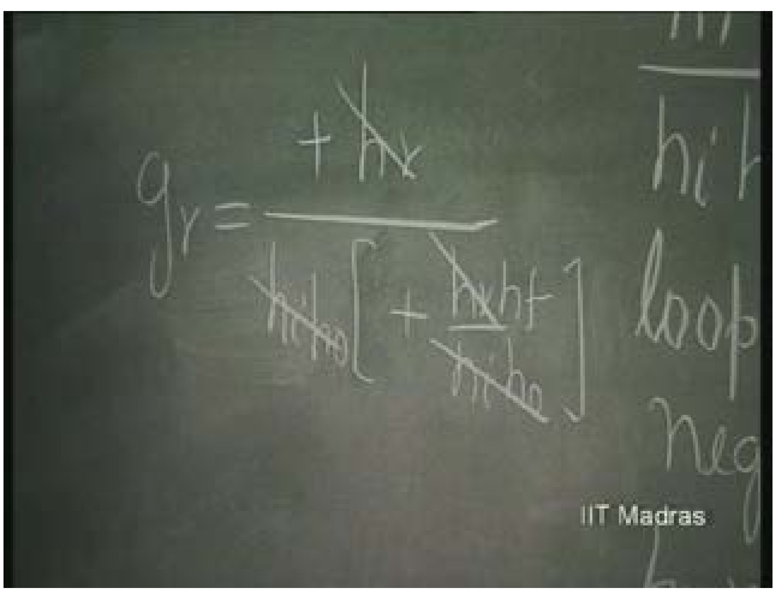
So, h r amplifier is very nearly zero. There is no feedback in the amplifier. It is feed forward structure. So, this is very nearly zero. So, h r feedback network is what fixes up the g f. So, this is an important aspect of negative feedback. The input impedance goes up; we have demonstrated here. The forward transfer parameter gets stabilized at a value corresponding to 1 over h r f.

(Refer Slide Time: 36:29)



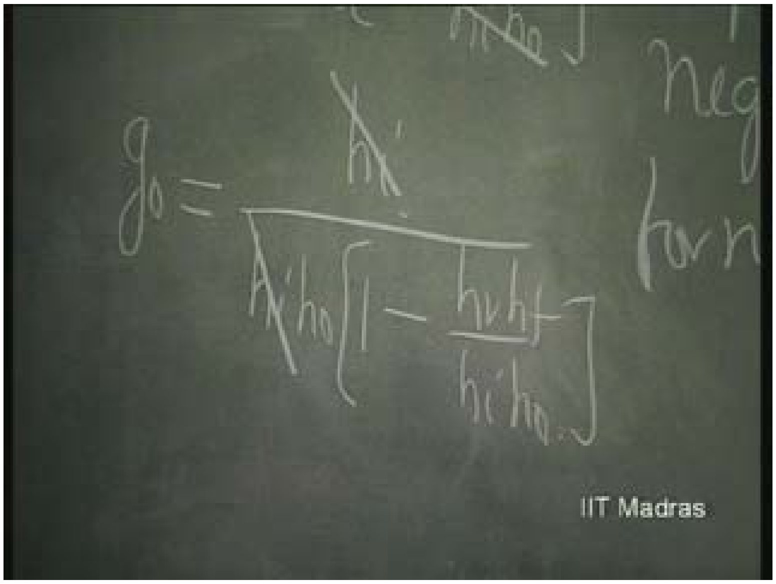
And next, consider what happens to the other two parameters. So, g r is equal to h r divided by h i h naught into, again, 1 minus h r h f by h i h naught. We have already assumed that h r h f by h i h naught is very large compared to 1. Therefore, we can ignore this 1. This is minus. We can ignore this 1. So, this becomes plus, plus; h i h naught gets cancelled with h i h naught. h r gets cancelled with h r. So, g r is equal to 1 over h f. h f is a huge quantity already. So, 1 over h f is going towards zero very clearly.

(Refer Slide Time: 37:40)



Then, g naught, the other parameter, is equal to h i by h i h naught into 1 minus h r h f by h i h naught.

(Refer Slide Time: 38:00)



So, once again, you can see that h naught is the output conductance originally, before feedback; and it is going to improve by h naught into 1 minus h r h f by h i h naught. It is going to get boosted up. The conductance is going to increase. That means, the resistance which is g naught is going to decrease; goes towards zero. It becomes an ideal voltage control voltage source. The output impedance is going towards zero means, it becomes a voltage source.

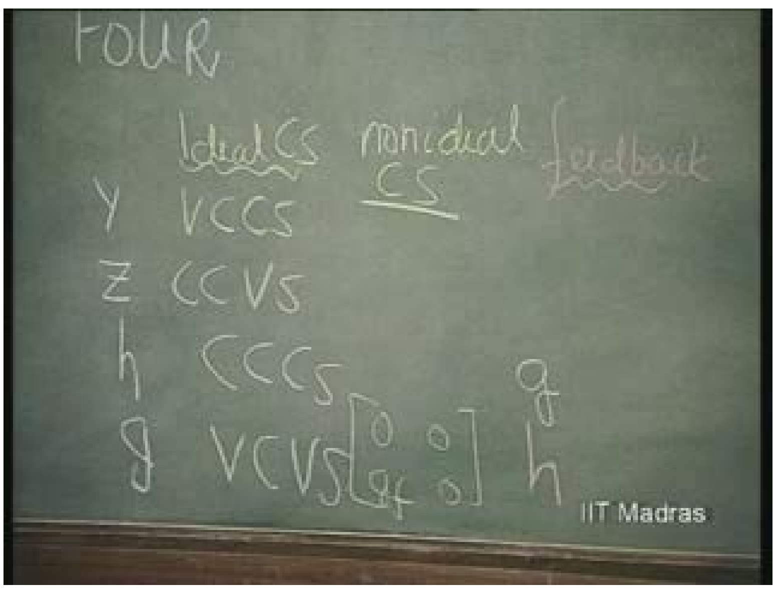
So, all the parameters go towards zero except the forward transfer parameter. So, we have now seen that all parameters go towards zero by negative feedback of the proper kind – h kind – in order that volt, it becomes ideal voltage control voltage source. So, we started with a voltage controlled voltage source which had non-ideal factors. Here, these are not non-zero. This was high and we wanted to make it a good voltage controlled voltage source. Then we give h feedback, remember. So, this impedance, this is actually conductance in g parameter. So, this impedance improved; that means conductance decreased.

This resistance decreased to zero because conductance increased by a factor corresponding to the loop gain. This went further towards zero. This got stabilized, become, became insensitive to active parameters, became dependent only on the passive parameter. So, this is the story of every negative feedback structure.

First of all, how do we recognize whether it is a negative feedback or not? The loop gain should be negative. That is what we established earlier also. In this particular case, the loop gain corresponds to h r h f divided by h i into h naught. That should be negative. Now, if I want an ideal current control current source, what kind of feedback should I give? It is current control; that means it should go towards short circuit.

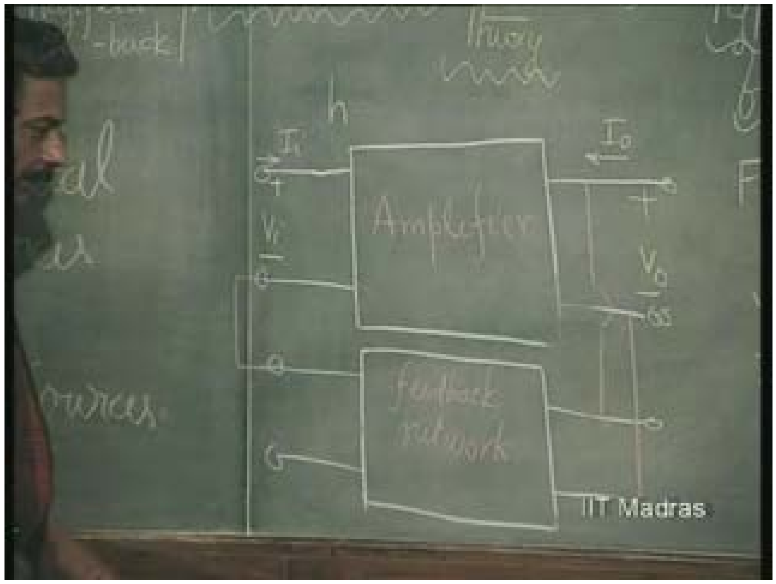
It is current source; its output impedance should get boosted up. It should become a short circuited input. Output impedance should increase. That means, thing should be in shunt at the input and series at the output; which means it is g feedback. This was h feedback. In order to obtain an ideal current control current source, I must apply g feedback. What is g feedback?

(Refer Slide Time: 41:09)



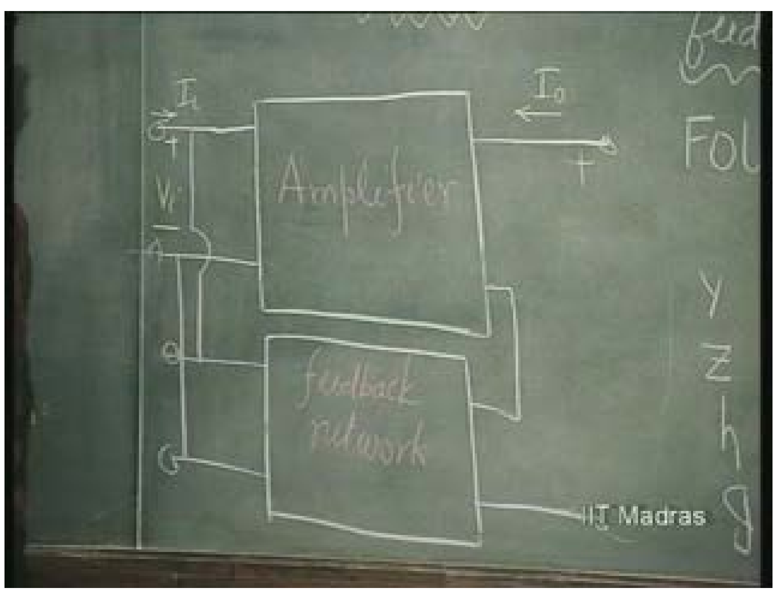
This is h feedback.

(Refer Slide Time: 41:12)



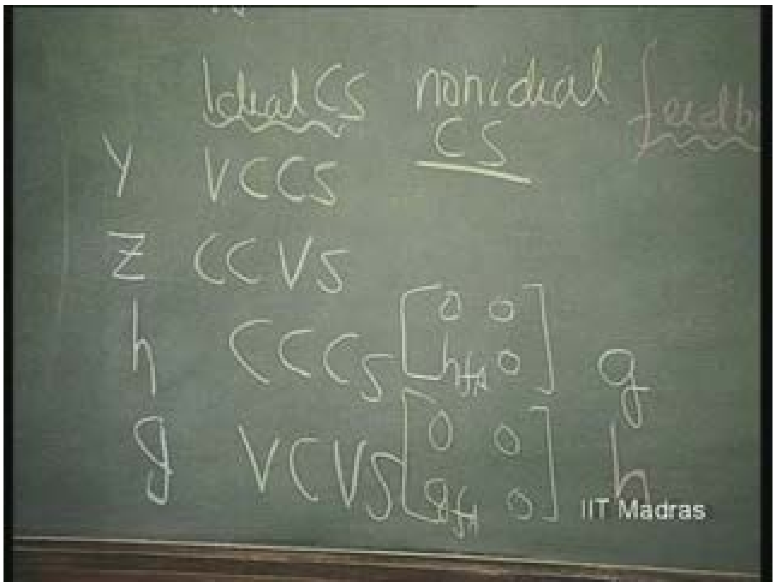
g feedback...I put things in shunt at the input and I connect things in series at the input. So, this is I...where I feed the voltage source; this is where I connect the load now; and this is the composite g feedback.

(Refer Slide Time: 41:40)



What are you doing here? You are trying to realize an ideal current control current source because we had a non-ideal current, control current source. Non-ideal, because these are not zero and we wanted them to go towards zero. Then we apply g feedback. Why g? Because, we wanted to reduce the impedance at the input so as to make it current control and increase the impedance at the output so that it becomes a current source.

(Refer Slide Time: 42:07)

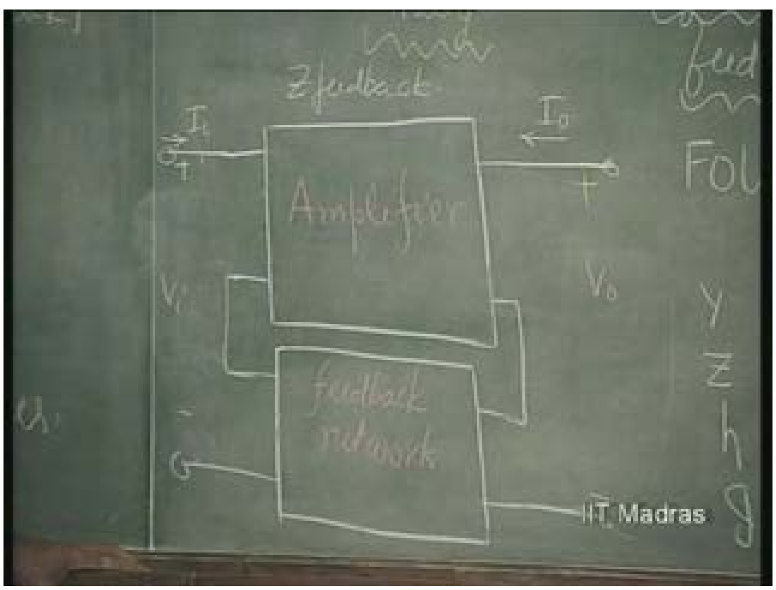


So, this way, if you understand feedback, you will never commit the mistake of connecting these things wrongly. Now, what is the feedback in order to make it a voltage control current source and current control voltage source? So, voltage control current source; this is expressed in terms of Y parameter. That means amplifier will be zero, zero, zero, y f amplifier. So, I should start with Z. That means feedback is Z. How is this y feedback?

(Refer Slide Time: 43:10)

This is g feedback. So now, I will make it y feedback. It will be series at the input and series at the output. This is Z feedback.

(Refer Slide Time: 43:35)



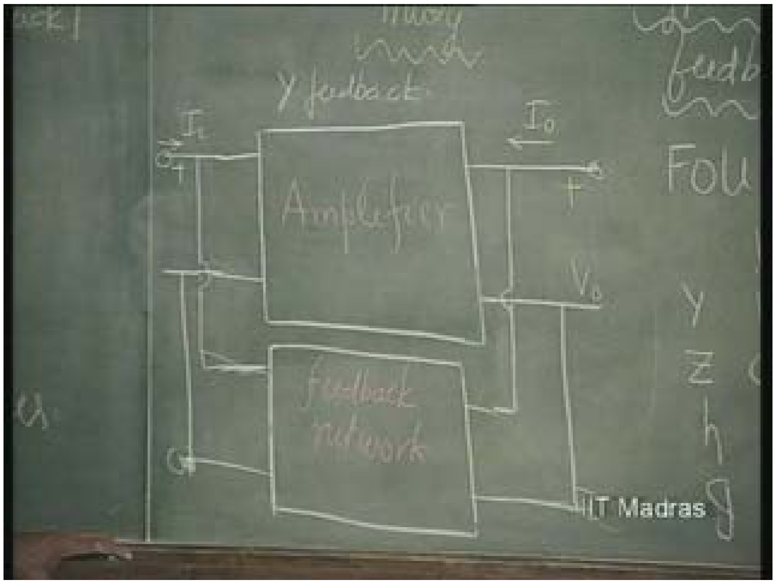
What does it result in? - ideal voltage control current source. What happens? Input impedance increases because it is voltage control; output impedance increases because it is current source. So, you put things in series at the input and series at the output; and Z parameters add. Then convert it into y parameter. In the y parameter, same thing happens. All the other parameters like y i, y r and y naught will go towards zero and y f will become independent of the active parameter. It will depend only on the passive parameter.

Finally, we have the z feedback. That is y feedback; This is z configuration. Amplifier has Z f A, ideal, but these are non-zero. So, we want them to go towards zero. So, we apply y feedback. What is y feedback?

(Refer Slide Time: 44:42)

Things are...it is to be made a current control voltage source; impedance at the input should go down; impedance at the output should go down; voltage source...So, it should be shunt at the input and shunt at the output, shunt at the output. This is what is called y feedback, in order to realize current control voltage source.

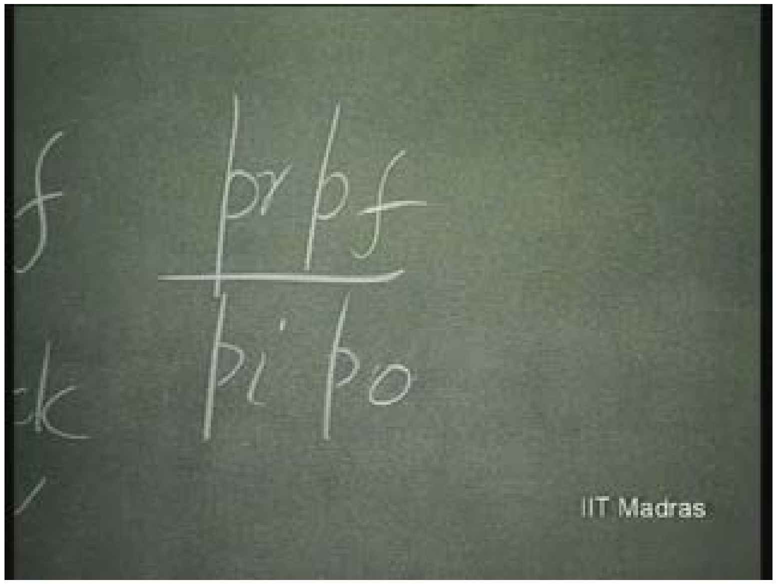
(Refer Slide Time: 45:30)



So, this in general tells us about how we can tackle negative feedback in two port networks. Let us summarize the whole thing. There are four types of feedback. These are: z feedback, y feedback, g feedback, h feedback, respectively giving, if they are negative and if they have respectively high loop gain when given feedback, then, they are going to realize respectively: z feedback realizes y network idealization which is a voltage control voltage source; y feedback realizes z network which is a current control voltage source; g feedback realizes h network which is a current control current source; h feedback realizes g network which is a voltage control voltage source.

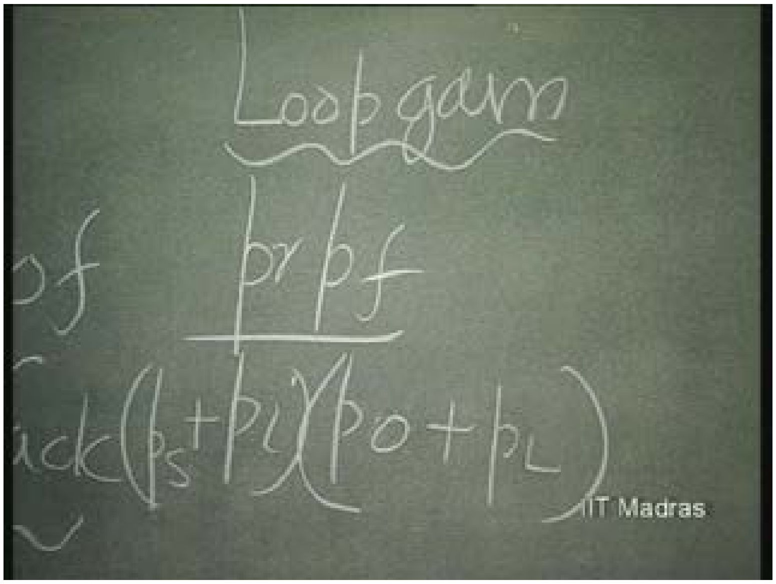
Now, all these things, in general. The loop again is always defined by p r p f divided by p i...p naught.

(Refer Slide Time: 46:51)



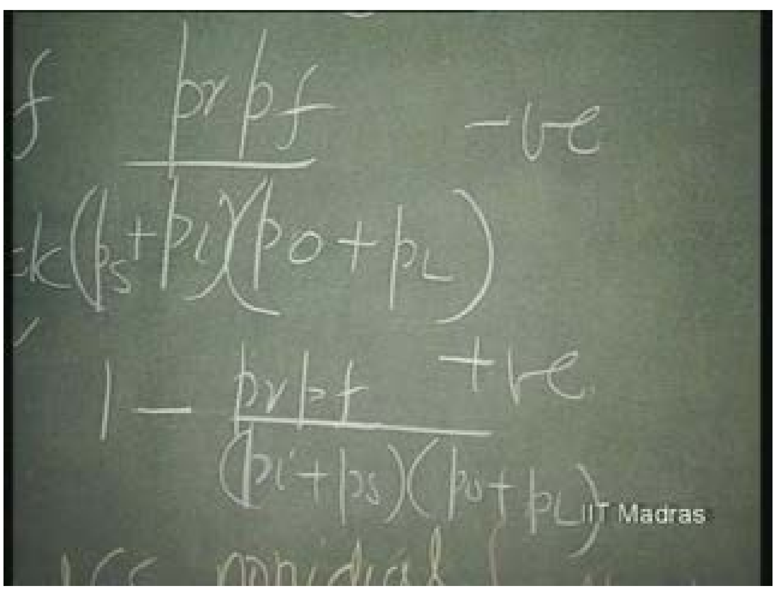
What it means is p r could be h, y, z or g. Again, p f could be h, y, z or g. So, this is immittance matrix representation which I have talked about. So, loop again is always p r p f by p i into p naught. If you take the source effect into consider...consideration at the input and load effect consideration at the output, the loop gain is, in general, loop gain in general in any one of the parameters, is always equal to p r into p f divided by p s plus p i into p naught plus p L. It just depends upon whether the parameters are z, y, g or h. In all these things, it is the same.

(Refer Slide Time: 47:44)



Then, if this factor is negative, then it is negative feedback; if it is positive, that is positive feedback. Then, the factor by which the things improve will always correspond to 1 minus the loop gain. This we had seen; the factor by which things improve.

(Refer Slide Time: 48:29)



If things are in shunt at the input, the admittance level goes down by a factor determined by this. If things are in shunt at the output, again, the admittance increases; the impedance level goes down by a factor determined by this. If things are in series at the input, the impedance level will increase or admittance will go down by a factor determined by this. If things are in series at the output, again, the impedance level will go up; it is going towards current source realization. The factor by which it improves is again the same thing.

So, this is the consistent way we can define all types of feedback and also know what are we aiming for. Are we aiming for design of ideal voltage control voltage source? Are we aiming for an ideal current control current source? Are we aiming for an ideal current control voltage source or are we aiming for an ideal voltage control current source?

In all these things, since the forward transfer parameter is desensitized with respect to active parameter, naturally, the bandwidth also is going up. Desensitization simply means, desensitization with respect to everything: temperature, time, frequency, everything.

So, even with respect to frequency, it is insensitive; or, its bandwidth is improved. Corresponding to this, the bandwidth of g f A is improved. Corresponding to this, bandwidth of h f is improved. Corresponding to this, bandwidth of y f is improved. Corresponding to this, bandwidth of z f is improved.

This is what you have to remember. That, if it is voltage control voltage source, it is only the voltage gain whose bandwidth is improved; not the current gain. Current gain may not have its bandwidth improving. The purpose is not that. Similarly, if it is current control current source, it is only the current gain whose bandwidth is improved; may not be for voltage gain. This is again that is something that you have to understand. Again, if it is z or y feedback, corresponding to impedance and admittance, the bandwidth is improved; may not be for the gains.

So, this is what is to be digested clearly before we go further with examples on this negative feedback; specific examples on negative feedback, as long as you have understood the two port network theory involving negative feedback.