Electronics for Analog Signal Processing - II
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Lecture - 3
Negative Feedback (Contd...)

So, in the last class, we saw how negative feedback can be used in the design of near ideal controlled sources, using non-ideal controlled sources. This is an important application of negative feedback, the most important application.

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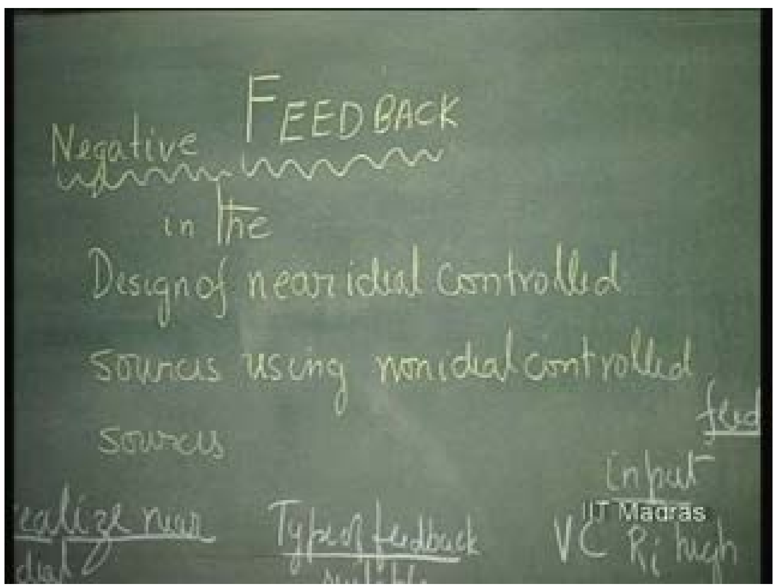

That...you have a non-ideal controlled source; you want to convert it into near ideal controlled source, if you adopt appropriate feedback... Now, what is appropriate feedback? That is what we are going to discuss in this tab, tabular column which we had earlier seen.

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To realize near ideal, what kind of source you want to realize? Do you want near ideal voltage control voltage source or current control current source or voltage control current source or current control voltage source, which ideally can be represented only by these parameters. That we have seen. g - V C V S; h - C C C S; y - V C C S; z - C C V S. What we mean is that all the other parameters will go towards zero except for the forward transfer parameter, which only exists as far as these ideal sources are concerned.

Now this idealization - how is it going to be achieved? The type of feedback that is suitable for V C V S is obviously h feedback. Now, how is it h feedback?

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Voltage controlled means input impedance is high. Voltage source means output impedance should be low. When you bring another network, the only way you can boost up the input impedance is to bring it in series. When you bring another network, the only way you can bring down the output impedance is put it in shunt. So, this arrangement has series at the input. The feedback network is series at the input and shunt at the output.

So, this kind of thing is called h feedback. Why? Obviously, h parameter is measured with output shorted and input open. When you short the output, automatically, the feedback network and the amplifier network are separated out because arrangement is in shunt at the output. So, when you short the output, the feedback network automatically separates out from the amplifier network.

When you open it at the input, again, the feedback has no influence on the amplifier. So, h feedback is the one that is adopted in order to get ideal voltage control voltage source. Mathematically also we concluded, h parameters add... in this feedback arrangement. h feed parameter of the amplifier gets added to h parameter of the feedback network. And then, if you have the h matrix, when you convert it into g matrix which is the inversion of the h matrix, you see Delta h coming and influencing every parameter. It is like loop gain; Delta h is similar to loop gain.

So, h, that is, g i for example, is going to be h naught divided by Delta h. g naught for example, is h i by Delta h. g r is nothing but minus h r by Delta h. g f is minus g f by Delta h. So, every one of the parameter gets modified by a factor Delta h; and within Delta h, we have what is called loop gain coming into picture. So, that is how we are able to modify these g parameters and make g i, g r and g naught go towards zero and g f go towards a stable value.

So similarly, current control current source ideally defined only by h parameter. The type of feedback in order to realize, idealized current control current source is g feedback because... current control means R i is low; current source means R naught is high. Low impedance at the input can be obtained by shunt arrangement. High impedance at the output can be obtained by series arrangement. So, this is shunt at the input and series at the output.

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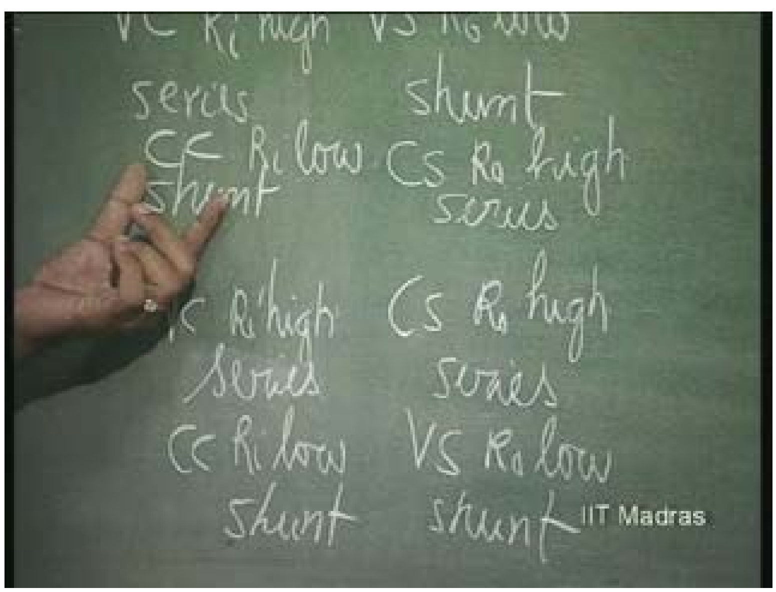

Such a parameter which is having a measurement with input shorted and output open is nothing but the g parameter. And therefore, g feedback is suitable for that. So, g parameters get added. g parameter of the amplifier gets added to g parameter of the feedback network; and then h parameter gets modified by the loop gain so that all except h f go towards zero. So, this is current control current source.

Similarly, if you want to design a voltage control current source, the feedback that is to be adopted is z feedback. The voltage control current source by itself, ideally being expressed only in terms of y parameter, we have voltage controlled indicating R i high. Things are in series at the input; and current source being R naught high, things are again in series at the output.

So, this is series, series, feedback. But, I would rather prefer to call it always z feedback because impedances come in series when they get added. So, y parameters get modified by the loop gain and we achieve voltage control current source. Similarly, current control voltage source is ideally expressed by z parameter. The type of feedback that you have to give is y feedback and that is because current control means R i is low; voltage source means R naught is low. Things are in shunt at the input and shunt at the output. This is also called shunt, shunt, feedback; and this y feedback modifies the z parameters making z f get stabilized and all the other parameters go towards zero.

So, this is the summary of how negative feedback can be utilized for designing near ideal sources from non-ideal sources. Let us take an example now to illustrate this.

A voltage control voltage source is represented by the following matrix. This being voltage control voltage source, this non-ideal voltage control voltage source is expressed in terms of its g matrix. So, 1 over 20 K - g i. g f is 100. g r is zero. g naught is 10 K.

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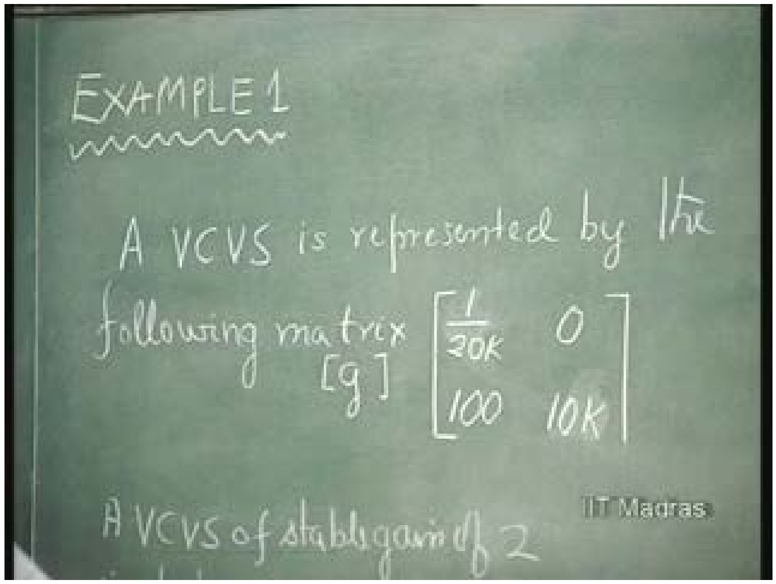

Once again, this is expressed by means of a g matrix. This non-ideal voltage control voltage source, it has input resistance of 20 K; but g naught is 1 over input resistance; output resistance of 10 K. This is short, short circuit output resistance. Input is shorted; but input does not have any influence because feedback factor is zero. This is not having any feedback.

Similarly, this is open circuit input conductance. So again, because of the fact that feedback is zero, there is no influence of output on the input. So, this is 1 over 20 K. This is 10 K and this is nothing but g f, which is nothing but the open circuit voltage gain. Output is open. So, it is open circuit; V naught over v i. So, this is 100.

So, this is typically the kind of amplifier which we have designed using transistors - VJTs and FETs, etcetera. An open circuit voltage gain of 100 you could easily get. An input impedance of about 20 K; output impedance of 10 K. This is representative of the single stage. That is, of course, single stage - the gain will be negative. So, if you couple it on to another stage with another inversion, you will get a gain of 100 very easily.

So, two stage amplifiers cascaded with input impedance of 20 K and output load of, output impedance of, 10 K. So, this is a practical situation. I want...a V C V S of stable gain of 2 is to be designed. A V C V S of stable gain of 2 is to be designed. Design a suitable feedback amplifier. Now, I am saying this suitable feedback amplifier, you decide as to what should be the type of feedback.

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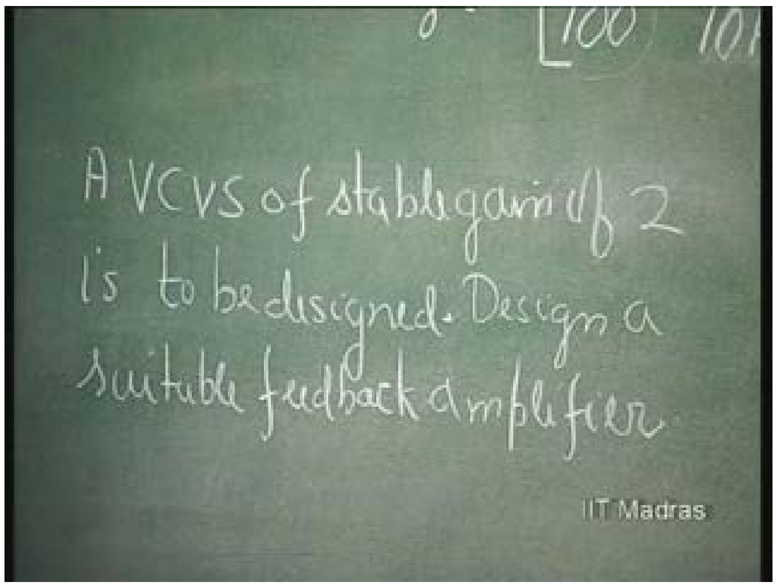

What should be the type of feedback? We are designing V C V S. The parameter that is ultimately of use is the g parameter. The type of feedback is obviously h feedback.

Because I want to boost up the input impedance further and reduce the output impedance; and therefore, things should be in series at the input and shunt at the output. Series at the input, shunt at the output; which means...

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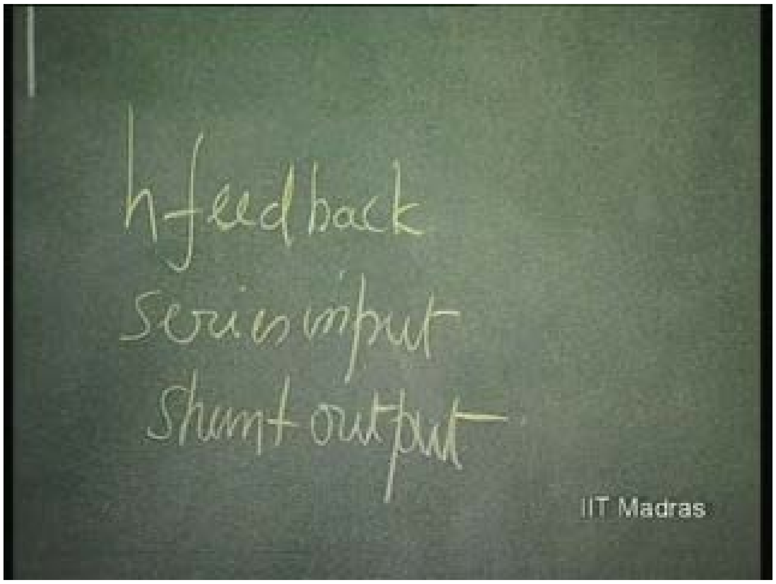

Let us consider that this is my amplifier. I am going to put it down in terms of actual equivalent circuit now. 20 K is the input resistance. This is the amplifier. 10 K is the output resistance and it is represented as a voltage source; and the voltage gain, open circuit voltage gain when you are not loading the output, is 100. So, this is 100 times v i. This is the equivalent circuit representation which you very well know. We have dealt with this kind of things earlier, given the matrix.

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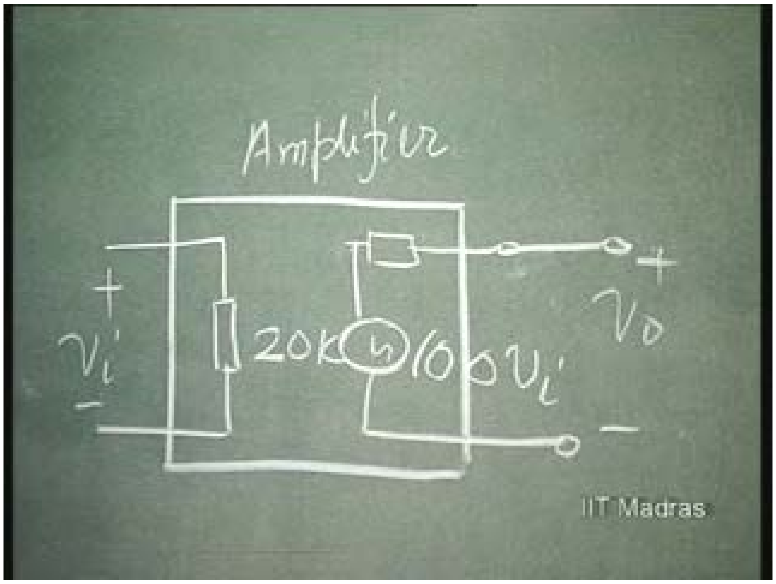

Now, we have to have the feedback for this. This is the feedback network which we are introducing. How are we introducing this? It should be in series at the input. So, I put it in series and it should be in shunt at the output. That is, output voltage is common to both; input current is common to both. And when it is in series, input current is common; when it is in shunt, output voltage is common. So, what is the feedback network?

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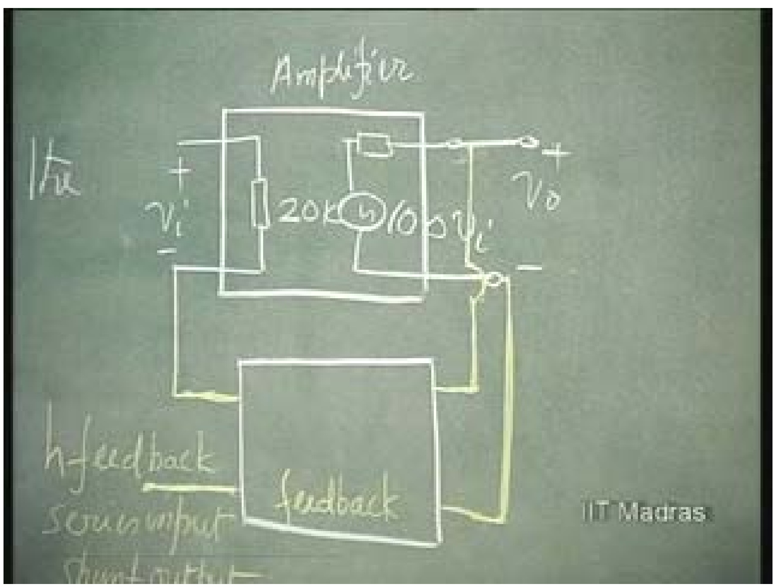

This should be passive and I want a gain of 2. That means, we have seen that, ideally speaking, if I want a gain of 2, I should have a feedback factor of half because we have seen in our earlier expression, if the loop gain is high, the g f is going to be 1 over the feedback factor. This we have seen. So, gain is required to be 2. That means we have to have a feedback of half.

So, let us see. So, I am going to put, let us say, a resistance network here. So, feedback factor...half is necessary for a gain of 2. This is always 1 over the feedback factor, if the loop gain is infinity.

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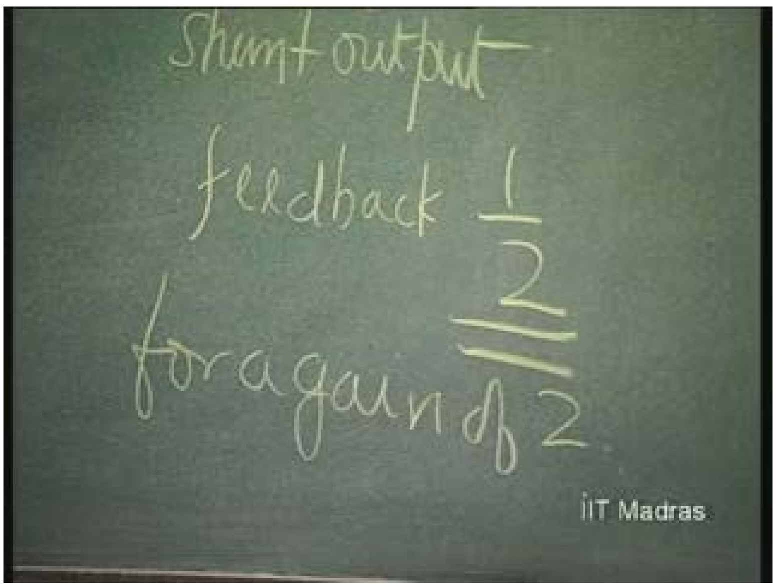

So, since we do not know the loop gain, we will assume that the loop gain is infinity and try to design the feedback such that the gain of 2 is obtained with infinite loop. Now what happens? So, this is, let us say, 10 K I will take; 10 K, just as an illustration, so that it has all the impedances here we have will be impedances which cannot...we ignore. They will be of the same order so that the loading effect is automatically coming into picture.

So, no approximation whatsoever is made in this analysis. That is what I want to illustrate. So, I am purposely putting 10 K, 10 K. Otherwise, I would have put here an impedance network such that the output impedance is not affected by this impedance. That means, this if it is 10 K, I would have put a total impedance of greater than 100 K. But here, I am not doing it purposely so as to illustrate also the effect of feedback network impedance on the total amplifier performance.

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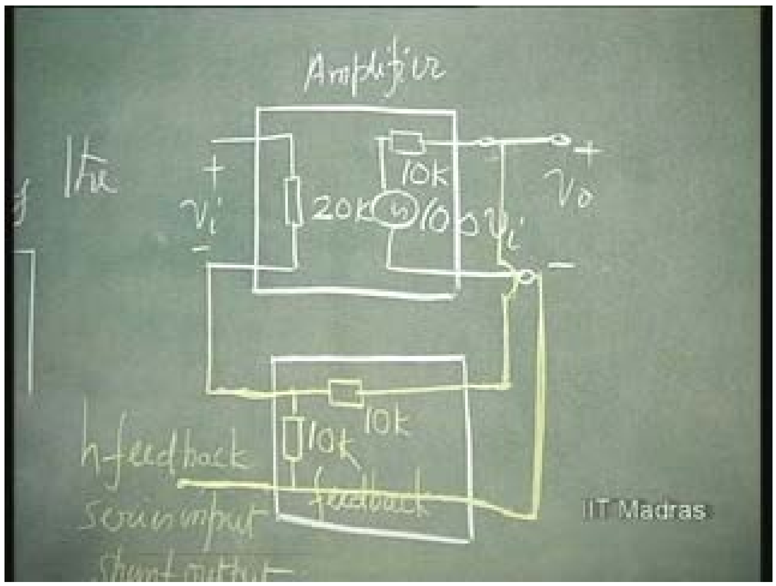

So, 10 K. 10 K is... take. Then I get a feedback factor of half for a gain of 2. Now, let us see what is going to be the composite what? - parameter we have to use. in order to easily work out the feedback amplifier design? We say that the type of feedback that is to be given is h feedback. This is h feedback and the parameter to be used is h parameter.

Let us see why? So, I want the composite h parameter of this now. Then, convert it into g. So, let us see how we can evaluate the composite h parameter. You will also see how the composite h parameter of this can be evaluated.

Composite h. It is very easy to evaluate composite h parameter because the parameter, the h parameter, simply adds. That can be illustrated here. How do I evaluate h i, for example? h i. What do I do? I short the output because h i is nothing but short circuit input impedance. So, I short the output.

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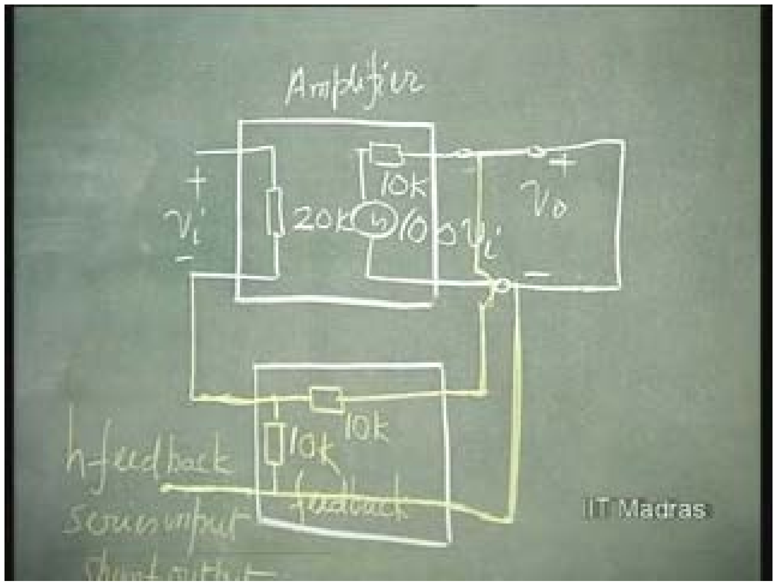

Then you see, this 20 K will be coming in series with 10 K shunted by 10 K, because this has been shorted. It is, in effect shorting this. So, 10 K will come in parallel with 10 K. So, 20 K. That was h i of the amplifier; and h i of the feedback network is nothing but 10 K parallel 10 K. That is 5 K. Is this clear? This has been shorted because the output is shorted. Output is common to both. So, 10 K comes in parallel with 10 K. So, it is so easy to evaluate the composite h parameter because these two things come separately.

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Then, what else can be evaluated? h f can be evaluated because it is again the short circuit parameter. So, what is h f by definition? I output divided by I input. This is a short circuit current gain. So I output divided by I input, with output shorted.

So, what is going to be I output? Let us see that. I output is this 100 v i with 10 K coming. So, that is a short circuit current of 100 v i by 10 K going in this direction. So, 100 v i by 10 K plus, let us see... This actually...now the v i to be applied is this, because this is the... for the composite network. So, this v i... this... this we call it has v i 1, this is v i 2; because v i 1 and v i 2 will come in series. The total v i is this.

Now, this v i divided by 20 K plus 5 K is the input current. I i...this is the input current, I i. So, this v i divided by 25 K is the input current. Output current is 100 v i by 10 K plus some portion of the input current. What portion of the input current? This v i by 25 K again gets split up as... because, equal currents 10 K, 10 K. So, this v i by 25 K by 2 or v i by 50 K is going to further get on...added to this.

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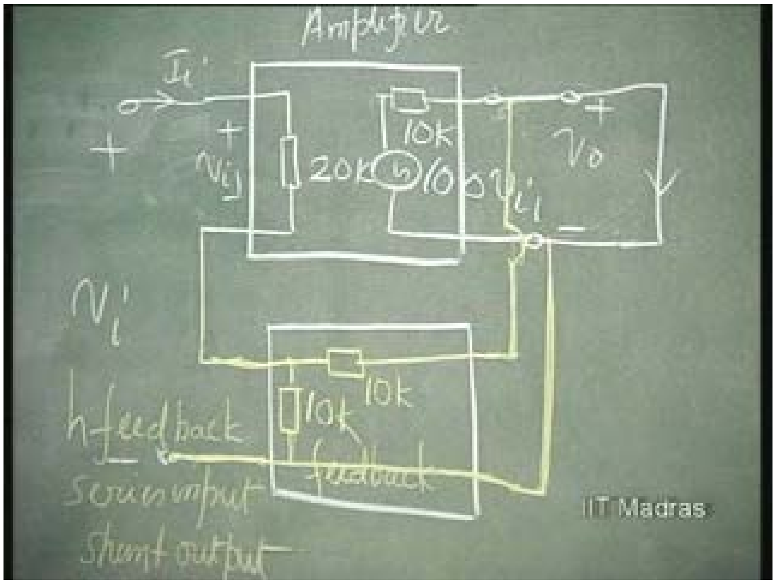

So, is this clear? I naught is this current; I i is this current. I naught by I i is h f, short circuit parameter. So, I i is very simply this voltage divided by total impedance, which is 20 K plus 5 K. So, 25 K. So, v i by 25 K is the input current. Output current is... part of the input current will flow here, half of it. So, v i by 50 K plus 100 v i by 10 K. The I naught, of course, is flowing in the opposite direction to this current. So, this current is negative because these, all these currents, will be flowing this way; so, in opposition to I naught; and therefore, this is negative. This is an important aspect.

So, the current gain now is... How much is it? So, 100 into 2 point 5. So, 250 point 5. Is it correct? How much is this? 25 goes up. So, 2 point 5, 250 plus point 5, 250 point 5. Is it clear? v i gets cancelled. This 25 K will go up. So, 25 by 10 is 2 point 5. So, 250. 25 by 50 is point 5. So, h f is 250 point 5, composite h f. So, we have evaluated h i as 25 K; h f as minus 250 point 5.

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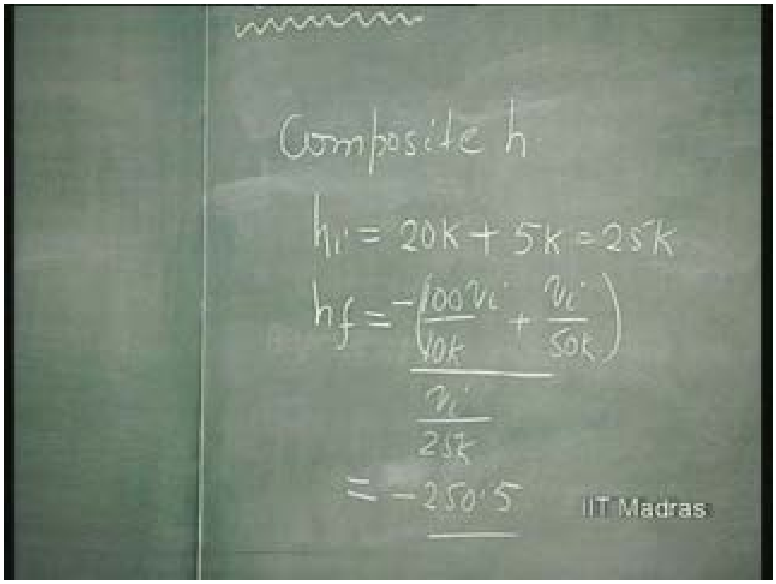

Now, how do we evaluate h r; composite h r and composite h f? h r and h f are evaluated with open circuit input. So, input is open. Nothing is applied here. I i is zero. If I i is zero, v i is zero. If v i is zero, there is no voltage. So, only 10 K is coming into picture; and therefore, what is therefore h? Sorry. h f is already... h naught...h naught is the output conductance with input open. What is output conductance? V naught by I naught. So, that is nothing but... you have 10 K here and this is open; so, you have 10 K plus 10 K here. So, you have 20 K here parallel with 10 K. Is this clear?

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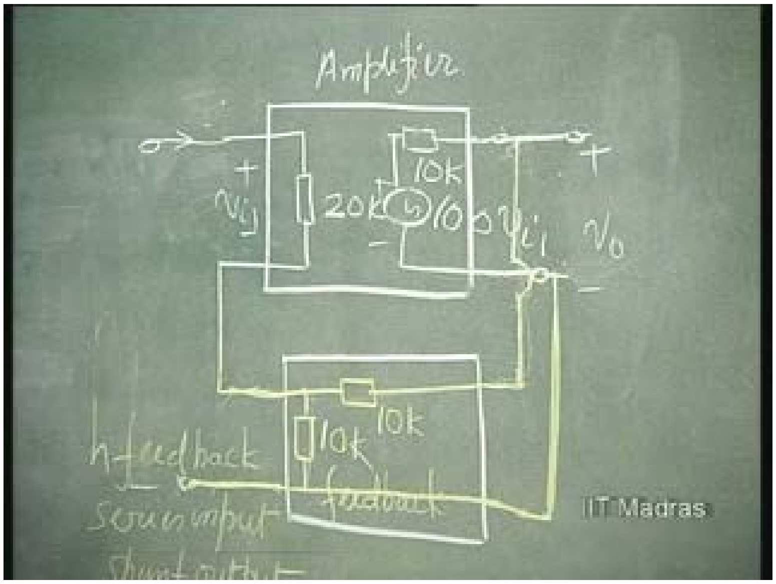

So, what you can obtain as this thing is 10 K and 20 K. Is it clear? So, this is 10 to the power of minus 4; this is again, point 5 into 10 to the power of minus 4 which is 1 point 5 into 10 to the power of minus 4. That many Siemens. This is...just a minute...Yes.

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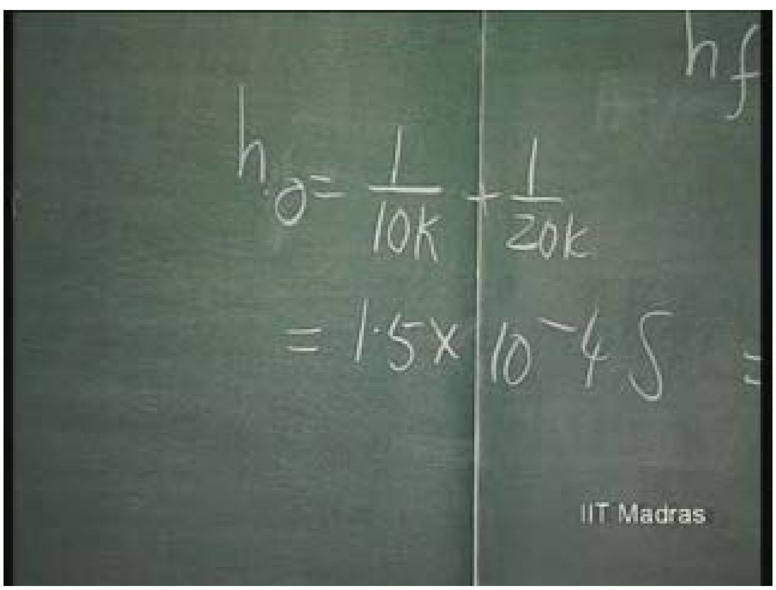

h r now. What is this? h r is the output voltage when the input is open. You apply an output voltage; find out the input voltage. The input voltage by output voltage is the h r.

Now, when you apply V naught, you get half of it here, 10 K and 10 K. So, half of V naught will be appearing here. This is open. So, this voltage is going to be half of V naught. So you get this as V naught by 2. h r is half, plus half; because when this is plus minus, this is plus minus.

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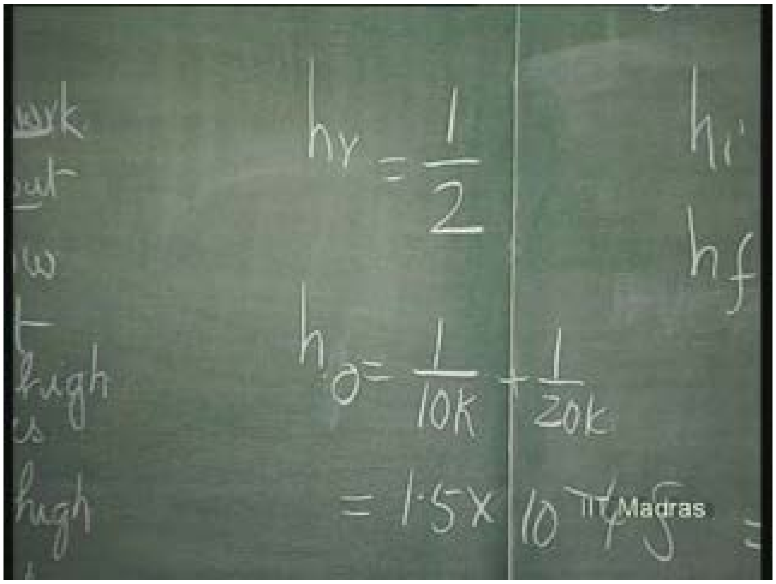

Now again, note one thing. The h naught of the composite structure is h naught of the amplifier plus h naught of the feedback network. h naught of the amplifier is 1 over 10 K. h naught of the feedback network is 1 over 20 K. So, these things are simply adding. Similarly, h r of the composite network is h r of the amplifier which was zero, plus h r of the feedback network, which is half.

Again, h f of the composite network is nothing but h f of the amplifier plus h f of the feedback network. So, all the h parameters simply add. So, if you know the h parameters of the amplifier and h parameter of the feedback network, you can simply add these to get the composite h parameter. You do not have to do it by definition. If you know these parameters, simply add. So now, we have obtained all the parameters of, h parameters of, this amplifier. So, composite h is going to be now, let us rewrite it.

h i is 25 K. This is half; this is minus 250 point 5 and this is 1 point 5 into 10 to power minus 4. Have we calculated all these things properly? Now, then we can go ahead with further calculations.

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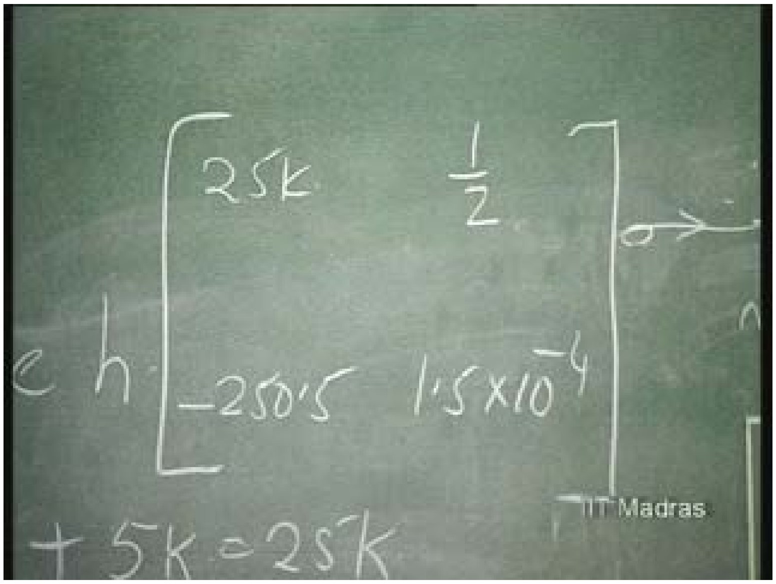

Now that you know that the feedback that you have to apply is h feedback and the composite h parameter has been obtained, you have to just verify whether it is negative feedback. Therefore, for that, let us see the loop gain. So, what is loop gain?

Loop gain is nothing but h f into h r divided by h i into h o. h f is minus 250 point 5. h r is half. Therefore, h f into h r is minus 125 point 25. Correct? This into this divided by this into this. This is in Siemens. This is in K, which is 10 to power of 3 ohms. So, what do you get? 25 into 1 point 5 into 10 to power minus 1; or 2 point 5 into 1 point 5. Is it correct? 3 point... 2 point 5 into 1 point 5. 3 point 75. So, please find out this. 125 point 25 by 3 point 75. 33 point 4.

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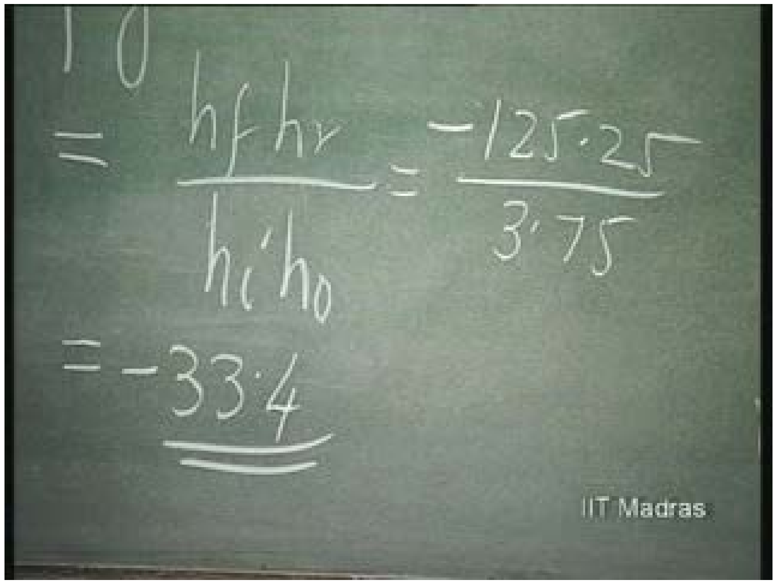

So, this is indicating that it is negative feedback. The value of this should be negative. So, it is negative feedback and it should be much greater than 1. Then only the feedback is effective. If it is much greater than 1 and negative, then the negative feedback is very effective. That means, it is definitely going towards its idealization.

So, now that we have found out the loop gain, let us find out the composite g parameter, which will clearly tell me whether it has gone towards idealization. If it has really gone towards idealization, these factors should be closer to zero than before. This was anyway zero. These two factors will go closer to the zero than before. Earlier, the impedance was...that is, 25 K. This is 1 by 25 K. That is not for the composite structure. Now, 1 by 25 K; that is including the other one and the output impedance was also pretty high, of the order of Kilo ohms.

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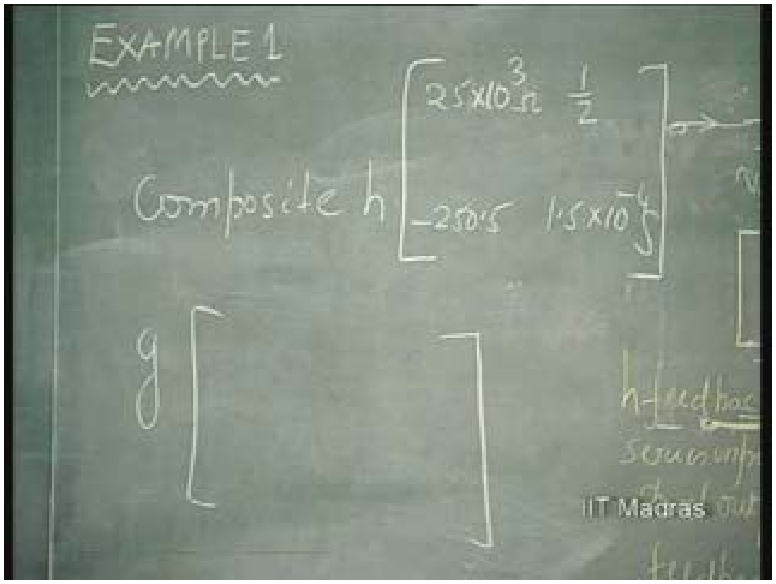

Now, let us see... How do we do this? The g i is nothing but 1 point 5 into 10 to power minus 4 divided by Delta h. Delta h is nothing but this into this. That is, this into this minus this into this. That is going to be 3 point 75, isn't it? This is 3 point 75 plus 125 point 25. This is equal to 129. Is this clear?

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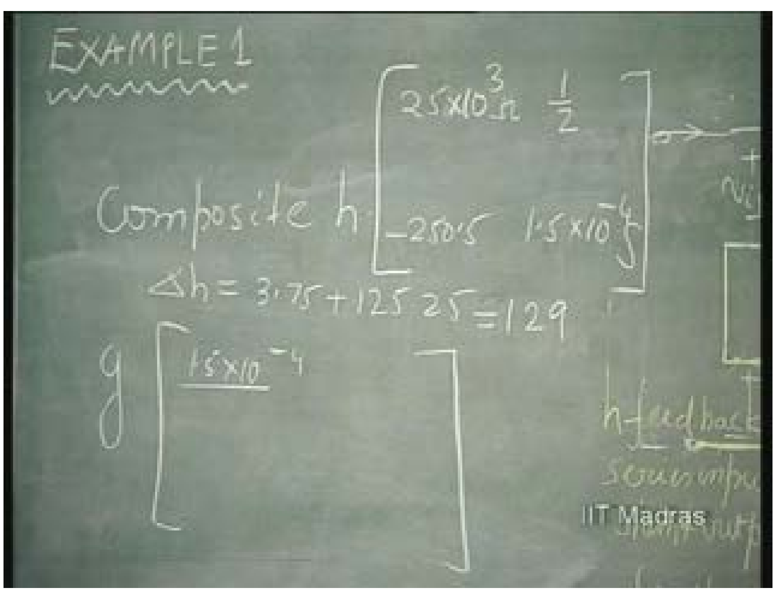

This is 3 point 75 plus 125 point 25. So, 129. So, divide by 129, throughout. So, point 5, minus point 5 by 129. Then, what else here? This factor was plus 250 point 5 by 29 and this is 25 into 10 to power 3 by 29. Pardon. 129. All these things are 129.

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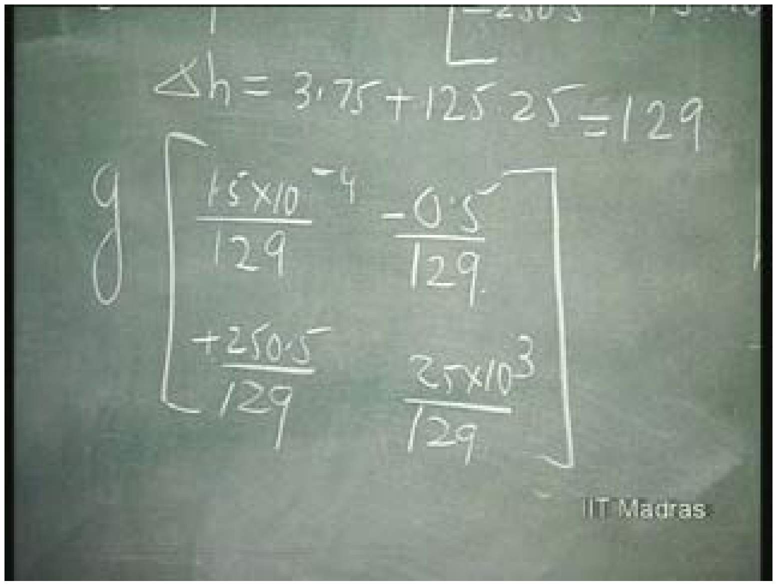

So, let us now see what is happening? The parameters, for example; we are not interested in this itself. What happens to the input impedance now? 129 by 1 point 5. How much is it? 129 by 1 point 5 into 10 to power 4 ohms is the input impedance with feedback; 1 over this. This is input conductance; so, input impedance is 1 over this; 129 by 1 point 5. How much is it? Pardon? 860 Kilo ohms. See, we started with an amplifier which was having only about 20 Kilo ohms. Now, it has got boosted up to 860 Kilo ohms. Fine.

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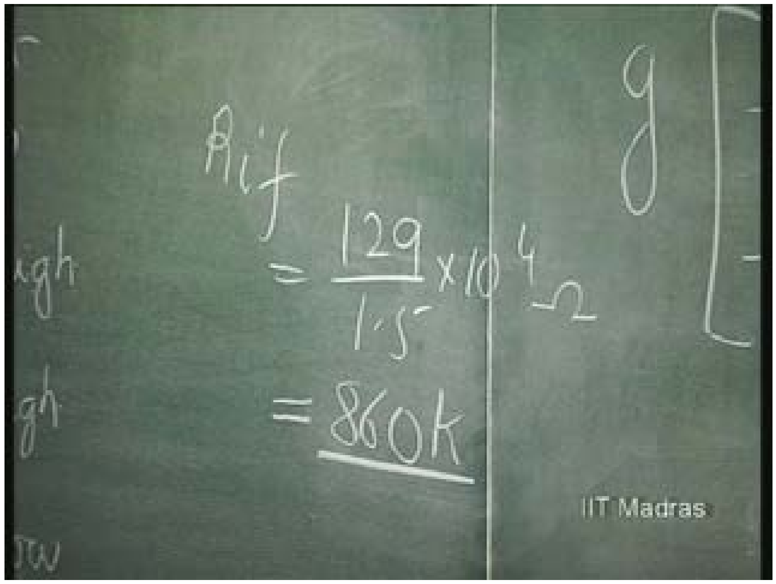

What is the output impedance of the amplifier? That is straight away 25 K by 129; or, it is less than about... Pardon? 194 ohms is it? No. This is 129. So, if you take it as 120, this will be 194 ohms. Is this correct? So, 194 ohms. We started with an amplifier with an output impedance of 10 K and we have now gone towards an amplifier whose impedance is only 194 ohms. See how things have improved? So, these two things have drastically improved.

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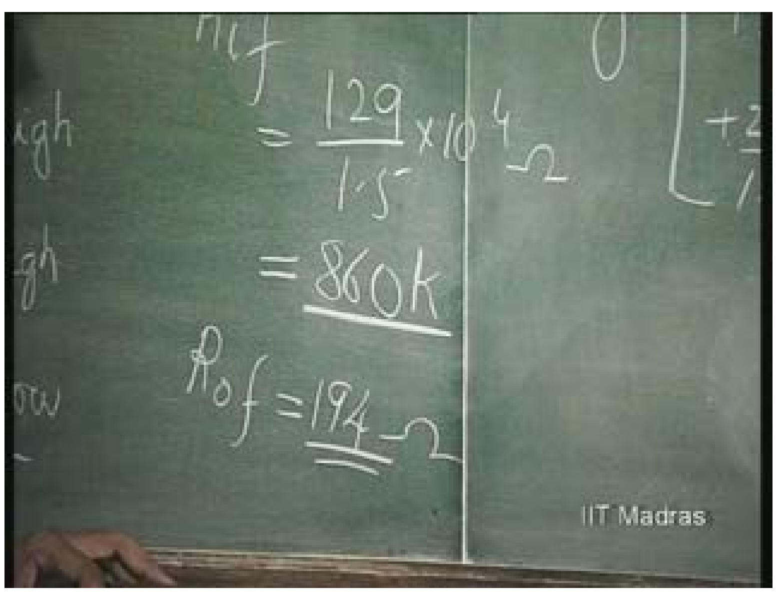

Of course, this is less then point 5. Basically, this point 5 comes about because of the passive network; not because of the amplifier. This point 5 is also getting reduced by a factor of 129. So, it is also going towards zero. Now, this is of interest to us. What is this? This is the gain; this is g f. 250 point 5 by 129. 1 point 94. It is pretty close to the factor which we wanted. What was it that we wanted? We wanted a gain of 2. It is pretty close to that value.

That means, it is not going to be much influenced by the varmint...variation of the active parameters; like the gain 100, etcetera, it can vary. But, this is going to be close to 2. So, we have stabilized the gain. We have improved the input impedance as well as the output impedance; and this amplifier has become a near ideal voltage controlled voltage source. So, this illustrates very clearly how we can exploit these concepts, basic concepts, in designing whatever amplifier we want.

Let us now consider practical negative feedback circuits, using transistor. I am just as an illustration, taking a BJT. You can as well replace it by a MOSFET. Whatever we discussed will be equally, well valid for the circuit with MOSFET as well.

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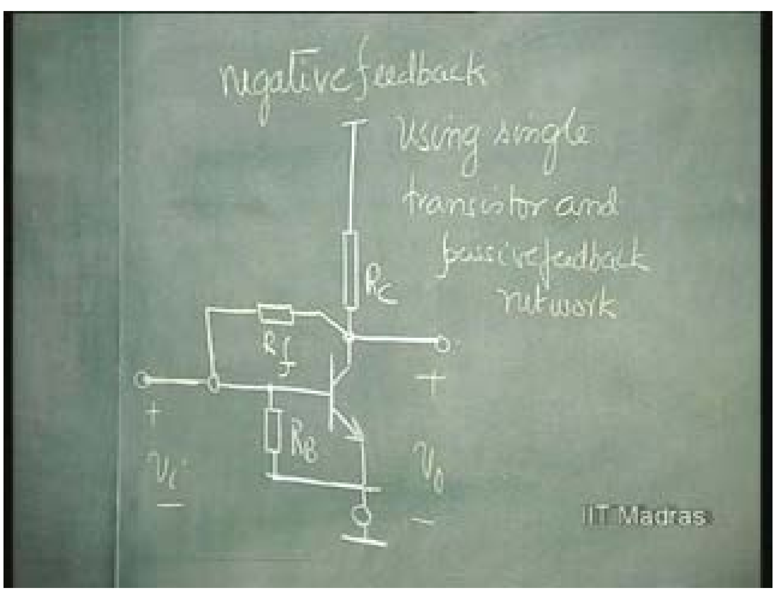

So, negative feedback using single transistor and passive feedback network; whatever has been earlier put in white chalk, is the circuit necessary for biasing, etcetera; and this is giving only the A C picture. What I mean is I have collector resistance normally connected to the supply. So, this is connected to the ground. As far as signal picture is concerned, emitter is grounded because it is a common emitter amplifier. There might have been a resistor in the emitter which is bypassed; or, it might be a differential amplifier stage, whatever it be.

So, we have emitter, signal wise connected to ground and R B is the biasing resistance which might have been used for obtaining V bias, V B B, for this transistor from a common supply. So, these are all the non-idealities. R B is coming here, taking away certain amount of current and R C is the load. There might be additional loads resistance also connected. So, you might have this as this also. So, without that, we have evaluated the gain of this amplifier stage. What is it going to be?

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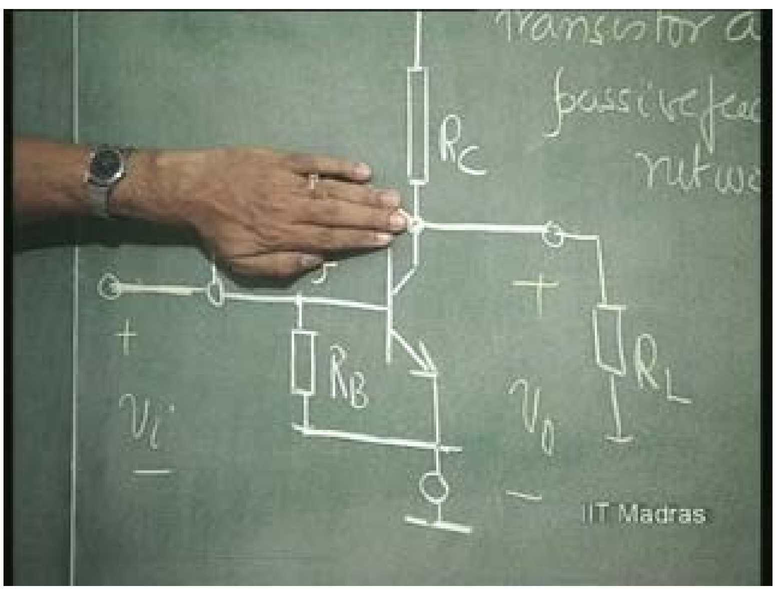

If you have v i here, v i by R B is the current taken away; but v i divided by r e, small r e, into Beta plus 1 is the current taken from this. The input impedance of this structure, amplifier, without this feedback network, for the amplifier network alone, is going to be... input impedance of the amplifier is going to be R B shunted by r e into Beta plus 1.

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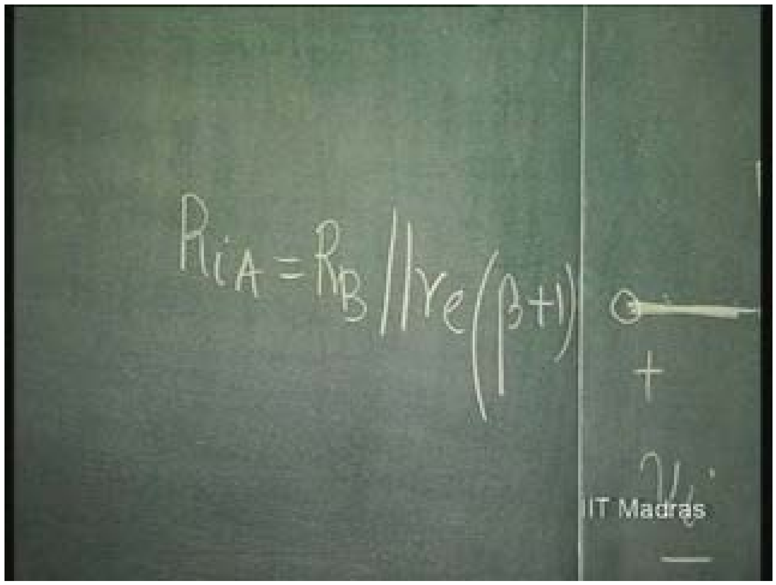

This we have established earlier itself for the common emitter amplifier. The output impedance of the amplifier is nothing but R C shunted by R c e. R c e has not been given. So, it is R C; and the gain of this stage which is nothing but V naught over what? v i. If you do not have this, let us therefore not put this. Gain of this stage, if you have only R C parallel R L as the load...This is v i. v i divided by R e is the emitter current. That into Alpha is the collective current. That into R C parallel R L is the output voltage, with the negative sign. So, the gain, voltage gain is going to be V naught over v i minus g m into what is it? R C parallel R L.

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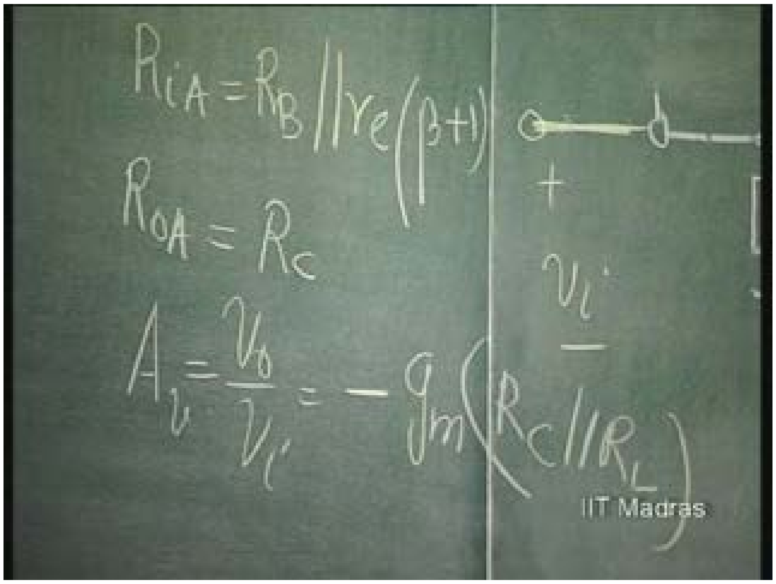

And g m being equal to Alpha by r e. For the bipolar junction transistor, we know the value of g m; Alpha by r e.

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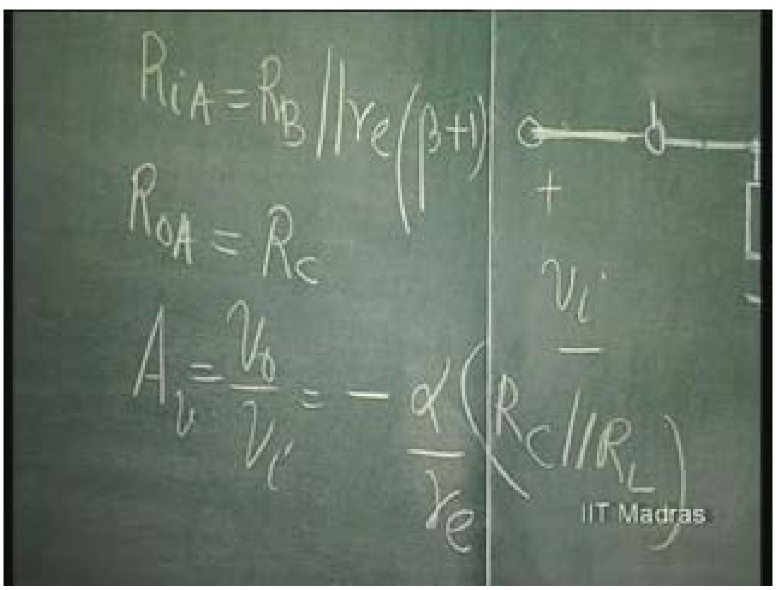

So, we also know now all the parameters associated with the amplifier, without feedback.

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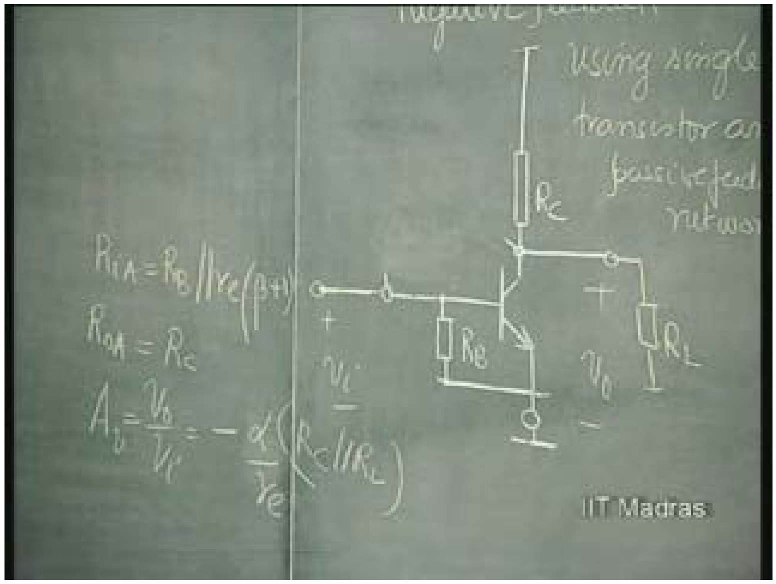

Just as in the earlier case, I gave you earlier the input impedance, the output impedance and open circuit voltage gain. Here also, I am giving you input impedance, output impedance and open circuit voltage gain. Only, the difference between the Example 1 and this is, here it is having inversion and earlier example, the gain was without inversion.

So now, what kind of feedback can be applied? We will now connect a simple resistance as the feedback, r f. When I have an amplifier like this... So, I will convert this. Now you can see it here. This can be put in shunt with this. So, your amplifier is going to be just this. Let us be very clear about it, chalk wise. So, that is the amplifier. Now, simply we will ground this and this is the feedback network and that is the load.

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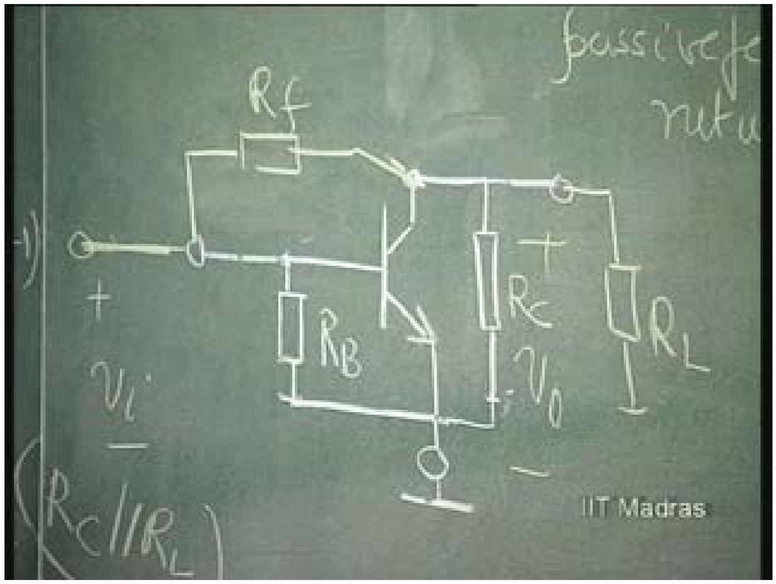

So, how is it at the input? How is it at the output? This is to be understood. I have not disturbed the earlier input voltage. I have not disturbed the earlier output voltage. So, I have connected the output to the input. That means, it can only be in shunt at the input and in shunt at the output.

So, this is definitely shunt at the input and shunt at the output. How do you know that it is shunt at the input, because I have not disturbed the earlier input voltage in any manner. It remains... it still remains the same. Similarly, output, I have not disturbed the output voltage point. So, both are going to be in shunt; input as well as the output. The feedback network comes at the...in shunt at the input and shunt at the output; or, what kind of feedback is it? Just look at your table. It is Y feedback.

Let us now conclude. If it is negative feedback, the input impedance should what? Come down. Output impedance should come down; and it should become what? What is the ideal control source it will approach? Current control voltage source. It has therefore become current control voltage source, ideal.

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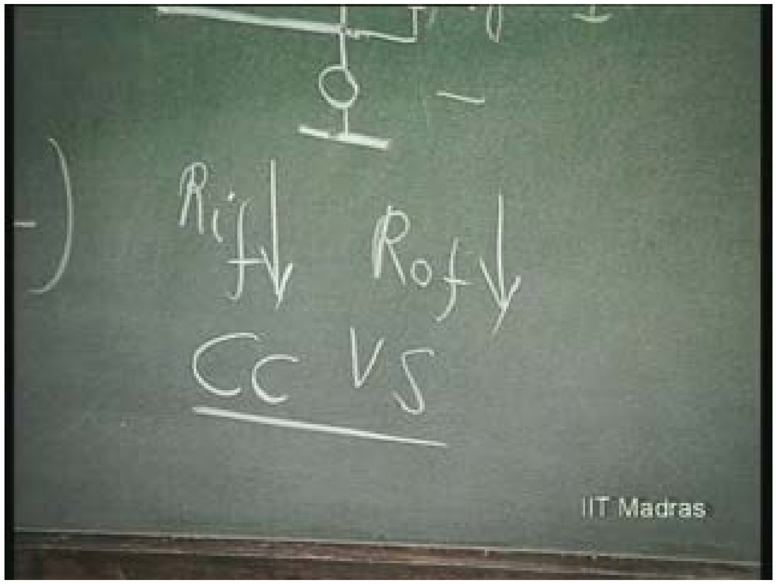

What is the parameter by which it can be represented? Since it is Y feedback, it can be represented by z parameter and what is the parameter that is going to become stabilized? Z f is going to be stabilized and Z f in this case is going to become equal to minus R f because Z f should become equal to some resistance which is coming as the feedback resistance. The only resistance that is coming back as feedback resistance is R f. So, Z f should ideally become R f.

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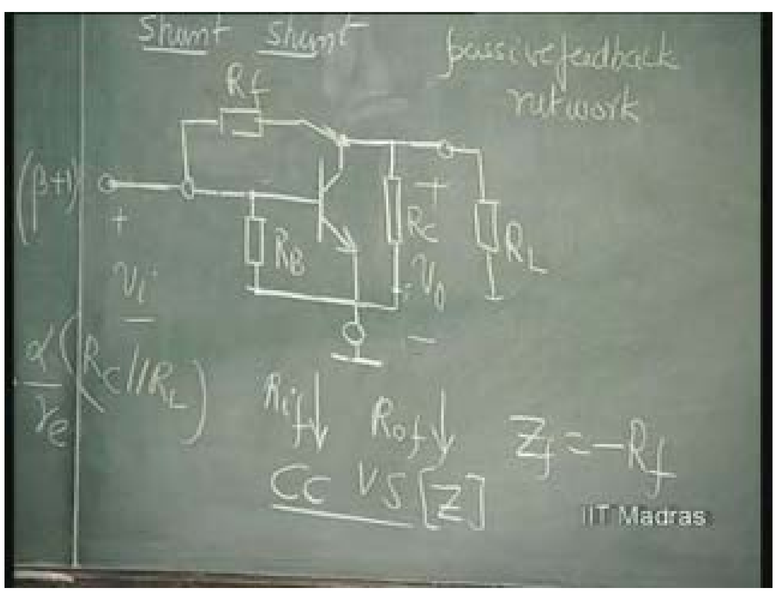

So, let us therefore see how it is going to become this. How do we therefore represent the feedback amplifier, composite amplifier, in terms of the composite Y parameter?

That is the easiest because it says Y feedback. So, Y parameter is the easiest. For this R f, what will be the Y parameter? This is the ground. This is the input, input; this is the output. So, what will be the Y parameter? Y parameter is known as a short circuit parameter; both input and output will be shorted and Y parameter will be measured.

So obviously, Y parameter of this is simply 1 over R f because you short this. Input impedance is 1 over R f; current is, if I apply a current here, the...if I apply a voltage here, the current in this is going to be v i by R f. It will be going out. So, if I short this, if I apply voltage here, current will be v i by R f going out. That means, actually speaking, this is also minus 1 over R f. Since this is a symmetric network, Y i is same as Y naught; Y r is same as Y f. This is perfectly symmetric; i and o can be interchanged. So, minus 1 over R f, plus 1 over R f.

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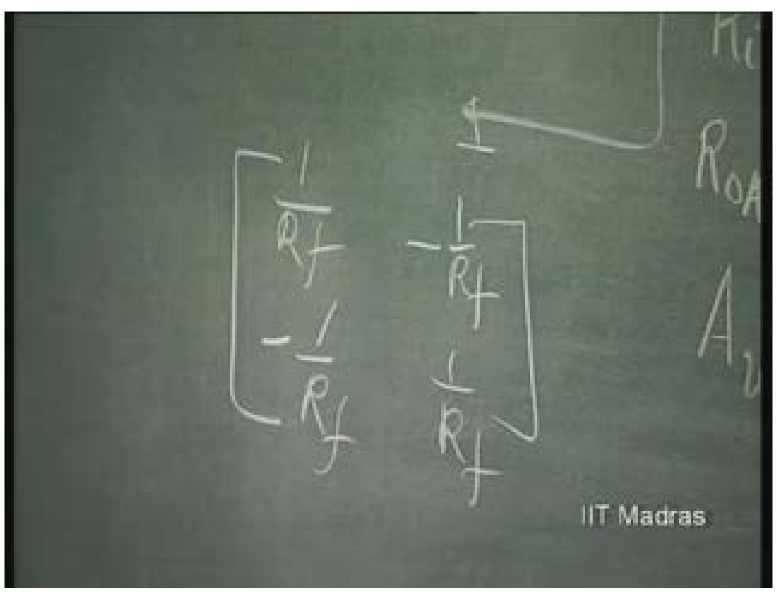

So, it is very simple to write the Y parameter of this network. So, this is the Y parameter. What is the Y parameter of the amplifier? This is for the feedback network. What is the Y parameter of the amplifier? Let us see. 1 over input impedance is the input admittance. So, 1 over R B plus 1 over r e into Beta plus 1; that is the input admittance. We are assuming that Y f is zero. If that is true, then what is y naught? Nothing but 1 over R C. Is this clear?

And what is Y f? Now, what is Y f? I am applying a voltage and finding out the short circuit output current. So, if I apply a voltage here, v i, I short this. Output current is going to be nothing but g m times v i, by definition. So, this is nothing but g m, which is flowing in which direction? If I apply v i, the output current will be flowing in this direction. So, it is positive. Currents entering will be always positive. So, this is going to be plus g m or Alpha divided by r e. Is this clear? So, this is the composite y parameter of the amplifier.

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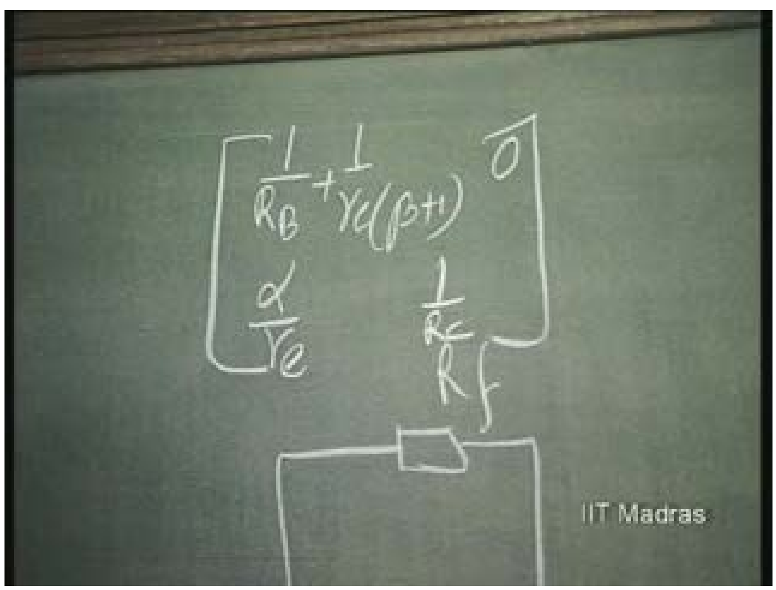

What is the composite y parameter? y parameter of the... What is the composite parameter of the plus feedback network? This plus this.

So, the composite y parameter is going to be 1 over R B plus 1 over r e into Beta plus 1 plus 1 over R f minus 1 over R f is the other part because this plus this, here it is Alpha over r e, minus 1 over R f. Then we have 1 over R c plus 1 over R f. Now, if you want the effect of load also to be taken into account, that can be added as an admittance, 1 over R L. That is all.

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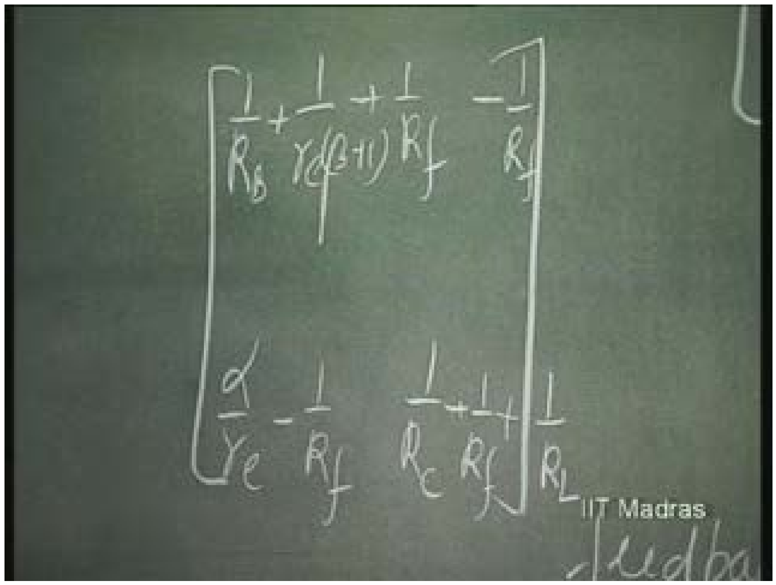

Here, if there is any other effect of source impedance coming into picture, that also can be added as 1 over R S. It is similar to R B here. R L is similar to R C there. So, this is the composite y parameter of this feedback amplifier. Now, what should you do? We have obtained the composite Y parameter. What should you do? It is enough now if I convert this into... This is composite Y. I have to convert this into Z.

Now, before I convert it into Z, I will have to tell you something. I have to find out that it is negative feedback. It is going to remain negative feedback, if this into this, that is loop gain... What is loop gain? It is nothing but Alpha by r e minus 1 by R f into minus 1 over R f divided by 1 over R B plus 1 over r e into Beta plus 1 plus 1 over R f into 1 over R c plus 1 over R f plus 1 over R L. So, this is negative.

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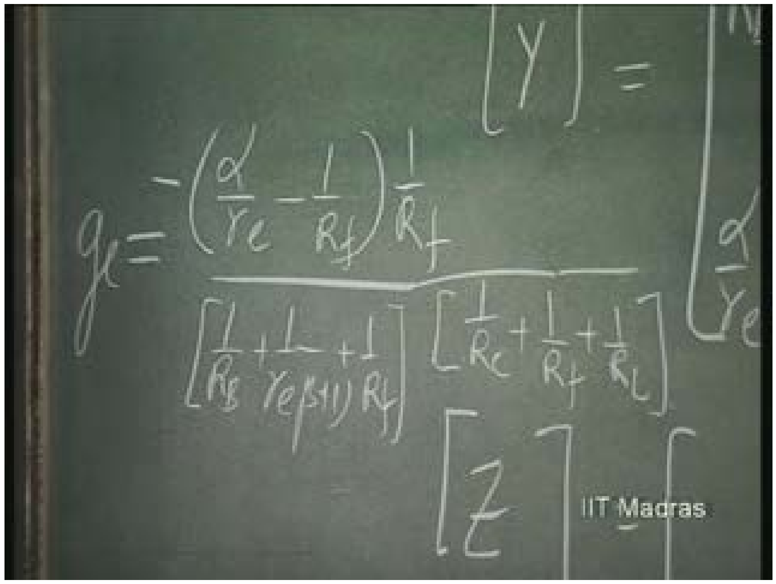

Now, there is no problem in this being negative as long as this whole quantity is remaining negative. That means Alpha over r e should be always greater than 1 over R f.

This is normally the case because r e is the of the order of tens of ohms. Alpha is 1 and R f is of the order of Kilo ohms. So normally, this is neglected in an actual design because we make sure that this is always going to remain what? - negative feedback. So, this factor always dominates. This is the loop gain.

I would like you to work out for this entire Z parameter, in terms of all these parameters. This is not very clearly indicating what is happening here because we have all these big expressions.

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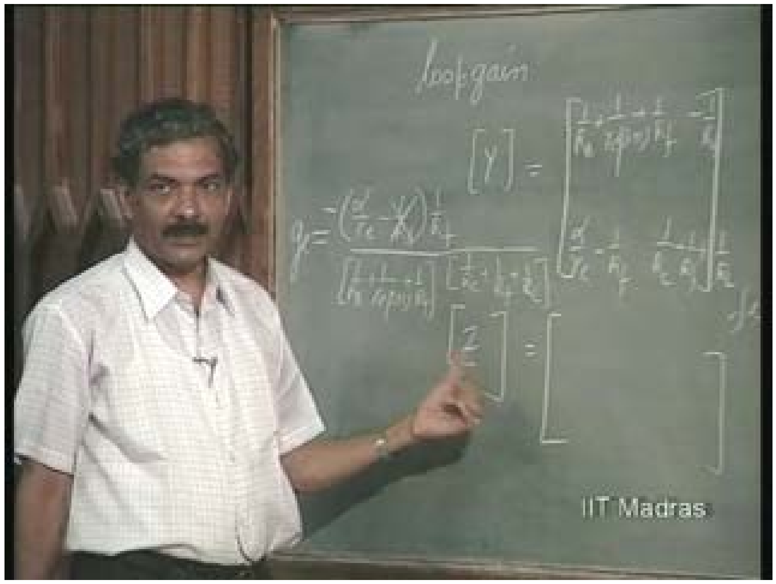

Therefore, in the next class, we will take up a numerical example based on this and see how these things are becoming what we are expecting them to become; how therefore the input impedance decreases; output impedance decreases and Z f becomes very close to minus R f, in the next class. However, I would like you to do this as an exercise and bring it to the class when you come next.