Electronics for Analog Signal Processing - II
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Lecture - 7
Operational Amplifier in Negative Feedback Structures

We had started discussing about negative feedback structures in op amp. First, we gave full output feedback, negative feedback; and then we got V naught equal to V i. V naught equal to A by 1 plus A, A being very large; V naught is very nearly... V naught over V i, this is V naught over V i; very nearly equal to 1. Buffer, it is called; unity gain amplifier.

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Another one where we sampled V naught; this was V naught into R 1 by R 1 plus R 2, where Beta was R 1 by R 1 plus R 2, definition. So, Beta times V naught was fed back. Therefore, ultimately, according to us, V i should be equal to Beta times A naught. This voltage should be zero, if it is working at finite output situation. So, we saw that according to equation A V i 1 plus A Beta was V naught; this was very nearly equal to 1 over Beta. This was equal to 1 plus R 1 by R 2. Therefore we can design a non-inverting amplifier of gain 1 plus R 2 over R 1 which is 1 over Beta.

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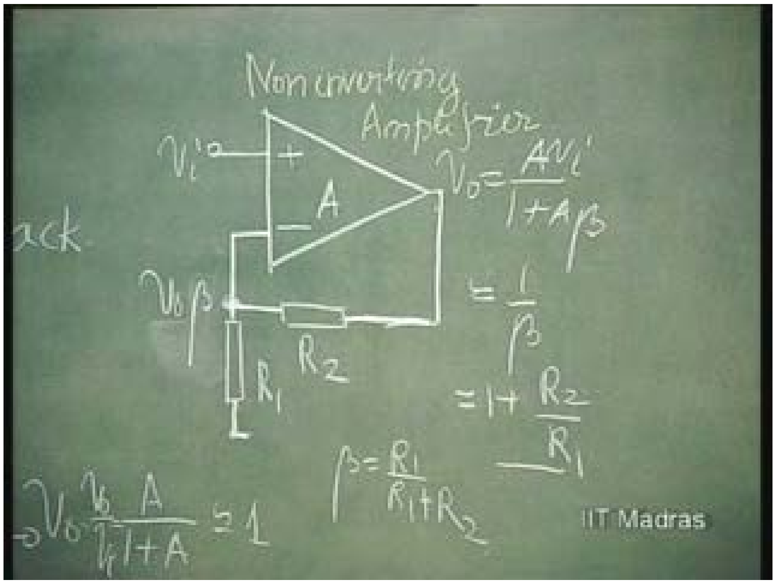

So, this is done by applying h feedback. So now, we will go into the two port parameter technique that we have used. Now, we will introduce all the non-idealities associated with op amp.

First we said, op amp is a structure with forward transfer parameter very high. So, A was tending towards infinity in the g matrix of this. The other three parameters were zero. But now, the other three parameters are not zero. They are finite. That means finite input impedance, finite output impedance and finite non-infinite gain. So, when we consider such an op amp, that means, such an op amp equivalent we can get for any configuration of cascaded amplifier. This we know how to obtain.

Once you obtain this and then give a h feedback using a passive network R 1 and R 2, this R 1 R 2 passive network, samples the output, feeds back Beta times V naught or R 1 by R 1 plus R 2 times V naught at this point, as the feedback voltage. Now, under that situation, what happens, in an actual situation?

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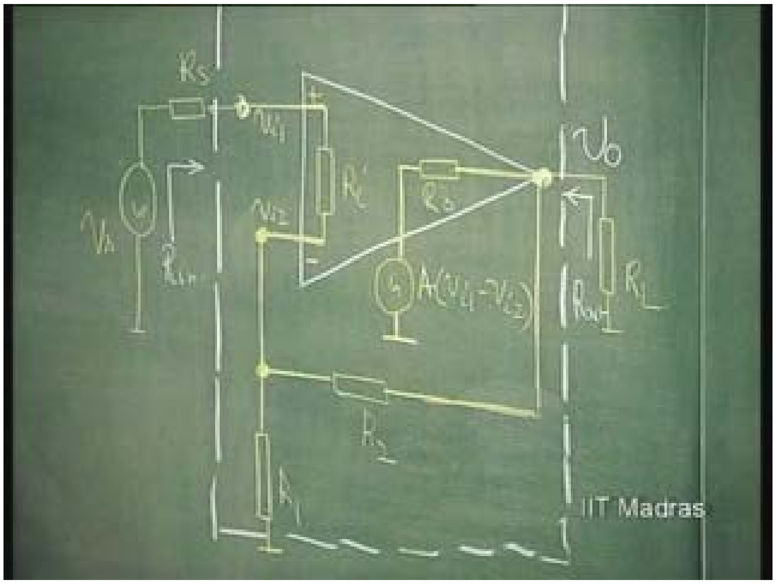

So, we would like to apply now, h parameter. Or a voltage control voltage source analysis with h feedback, we would like to use h parameter. So, composite h parameter we will write. So, h i and h f we get by short circuiting the output. So, we short circuit the output. Then you can see that the feedback comes out of it and the feedback is in series at the input. You can see, this is the amplifier input; this is the feedback network. So, these two are coming in series with the actual input. So, it is shunt at the output and series at the input. So, the h parameter of the composite network is nothing but R i.

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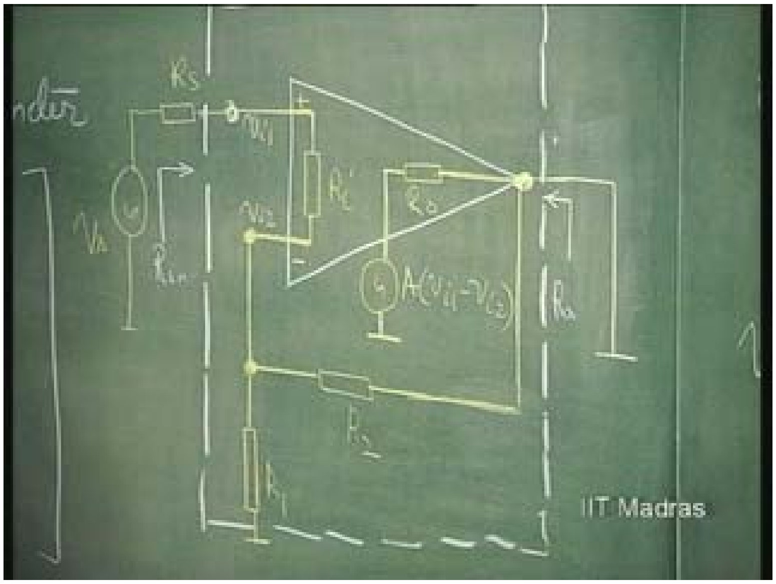

The input current flows through R i and parallel combination of R 1 and R 2, because R 2 is grounded. So, R i plus R 1 parallel R 2; that is, h i. Once again, h i is nothing but the input impedance of the composite structure which is R i of that amplifier and then R 1 parallel R 2, that of the feedback network. These things simply add. So, it is very simple to evaluate this.

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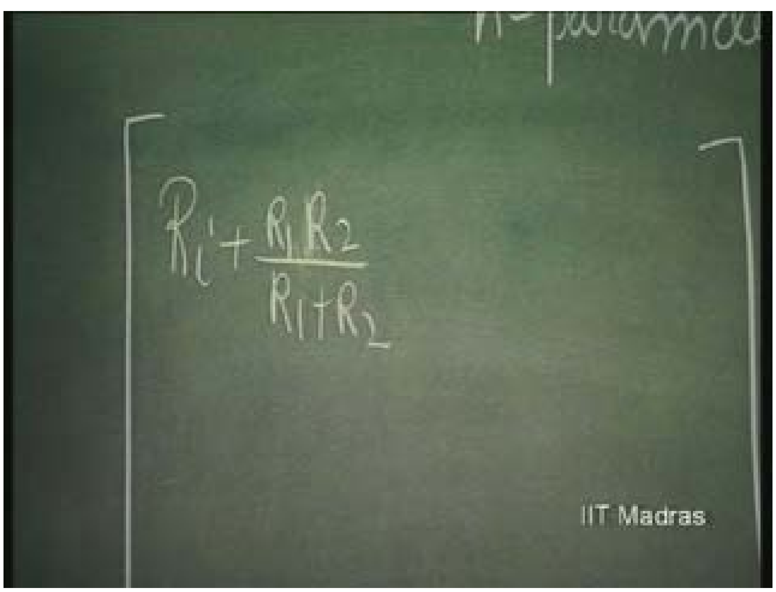

Next, let us evaluate the h f which is the short circuit current gain. When the output is shorted, what is the current gain?

So, the current output I naught divided by I i... I i is the input current. So, I naught by I i is what is defined now, under the situation of output being shorted. So, if I i is the input current, this I i will flow through R i and develop a voltage V i 1 minus V i 2 as I i into R i. So, this voltage is I i into R i because the current I i is flowing through it. That means this is I i into R i; V i 1 minus V i 2 is I i into R i.

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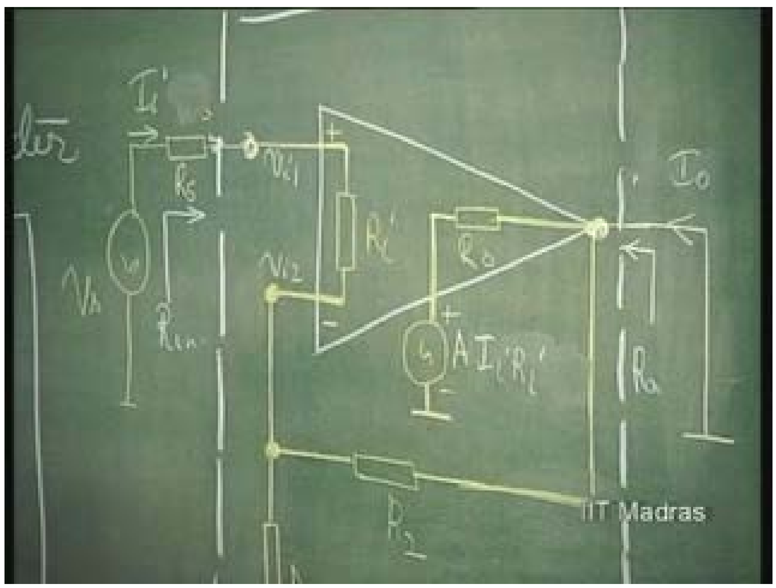

Next, if this is the voltage, what will be the current through the short circuit? A I i R i divided by R naught, but flowing in the opposite direction that we have assumed. So, negative sign indicating that it is actually flowing this way. So, A times R i divided by R naught; this into I i, divided by I i is the current gain. That is the output current. This is not the only current. I naught has this current as well as... you can see. This input current comes like this and portion of the input current... What portion? R 1 by R 1 plus R 2 of the input current is also going out. That means minus R 1 by R 1 plus R 2 divided by I i. So, that is the current gain.

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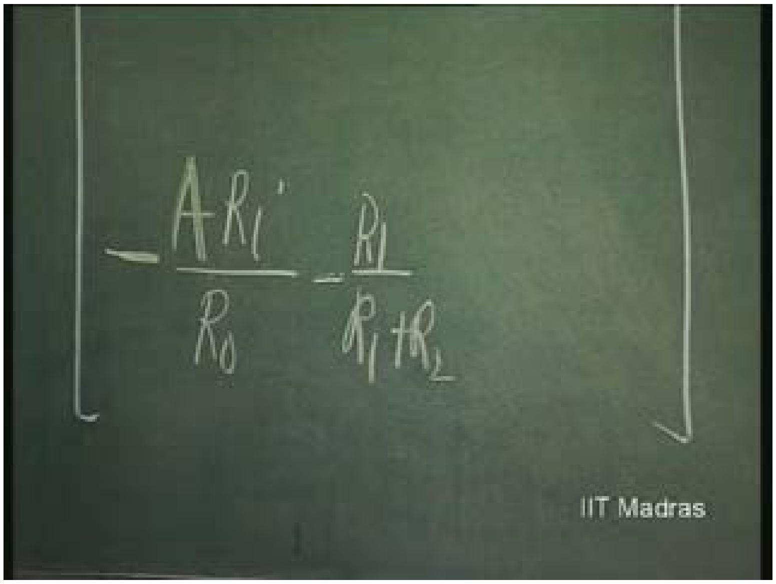

Once again, let us see. Going through the amplifier, this voltage is I i into R i; and therefore, A times I i into R i is the voltage here and that will drive the current A times I i into R i by R naught in the opposite direction. So, minus... So, A i A into R i into I i divided by R naught divided by I i. Here, I i also has a part of the current going in the forward path here. I i into R 1 by R 1 plus R 2, flowing this way. So, these two are the parameters h i and h f.

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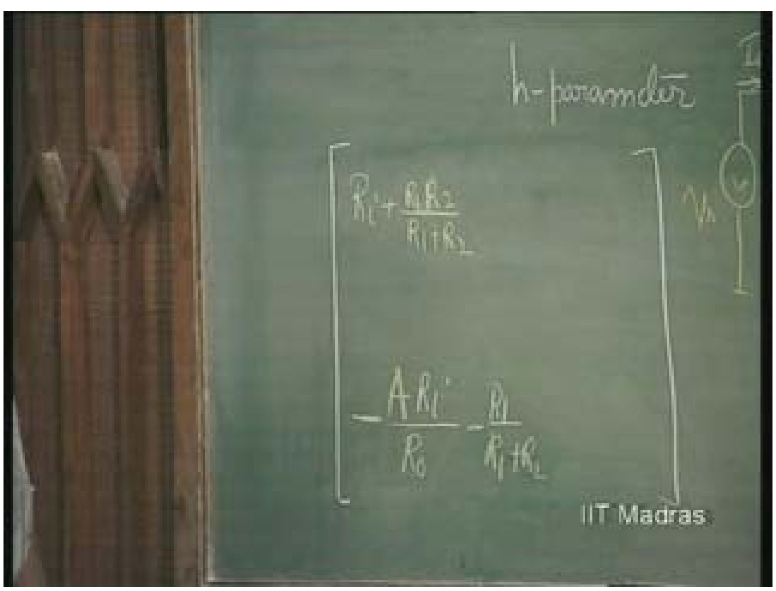

Next, we have to evaluate open circuit input. Input is open. Input is open. So, this source is removed. So, what happens? There is no current in this. That means this in inactive. So, there is V i 1 minus V i 2 equal to zero. So, this is not... So, R naught is shunting this. Apart from that, R 2 plus R 1 is shunting that.

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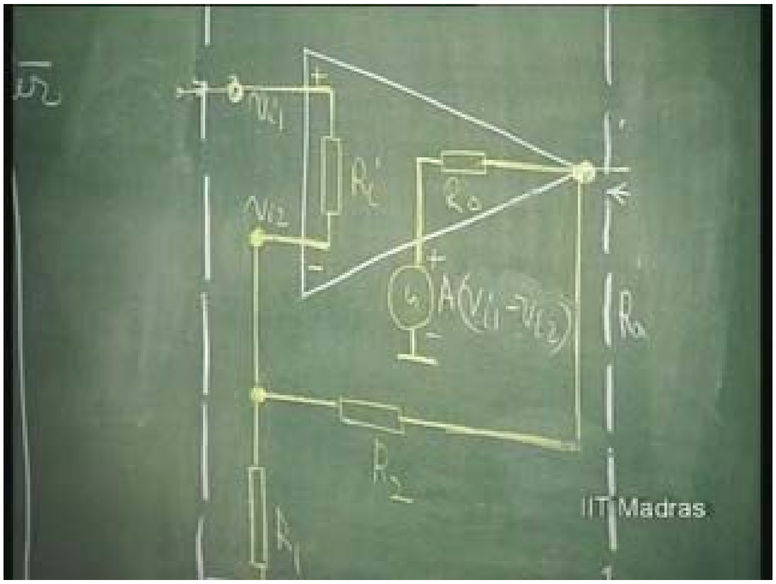

So, this h naught is 1 over R naught plus 1 over R 1 plus R 2. This is that of the amplifier output conductance. This is the feedback network output conductance.

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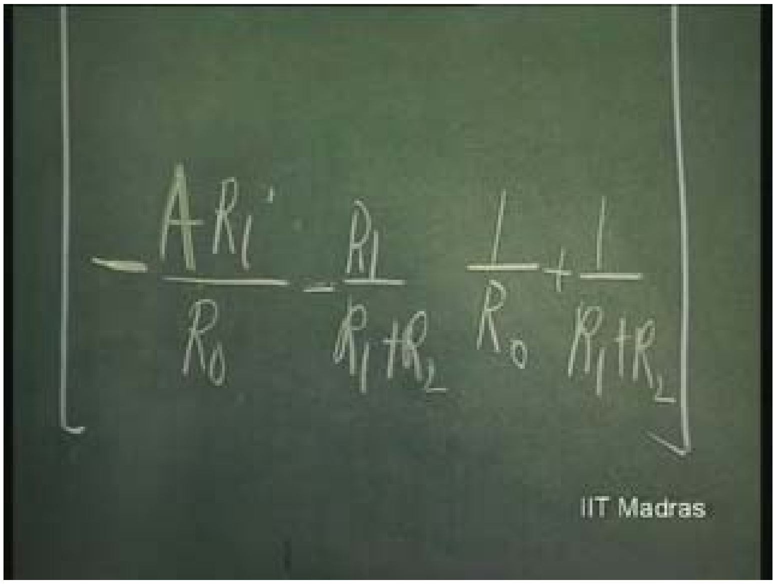

As far as feedback voltage is concerned, if I apply V naught here, the only voltage that applies here, comes here, is R 1 by R 1 plus R 2 times V naught. So, R 1 by R 1 plus R 2 times V naught. That is h r; that is positive. So, we have simply written the composite h parameter of this fairly complex feedback network, where nothing is neglected.

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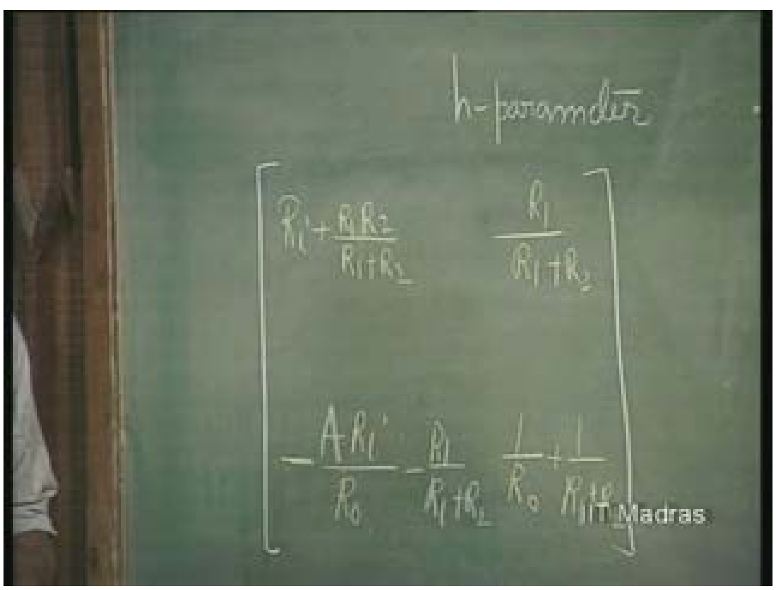

Now, if you include the source impedance here, this is the situation. Source impedance is coming in series with R i and the load impedance in the case of h parameter always comes in shunt with the output impedance.

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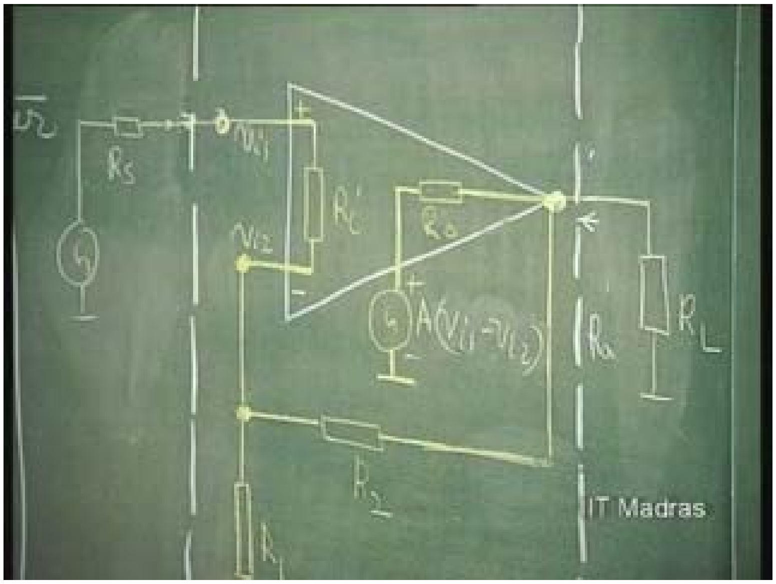

So, this is the total situation where we are now considering also load impedances and source impedances. So, this is giving you the complete picture of a negative feedback situation with operational amplifier. Nothing is neglected. Now, of course, there is no point in keeping things which are things which can be neglected.

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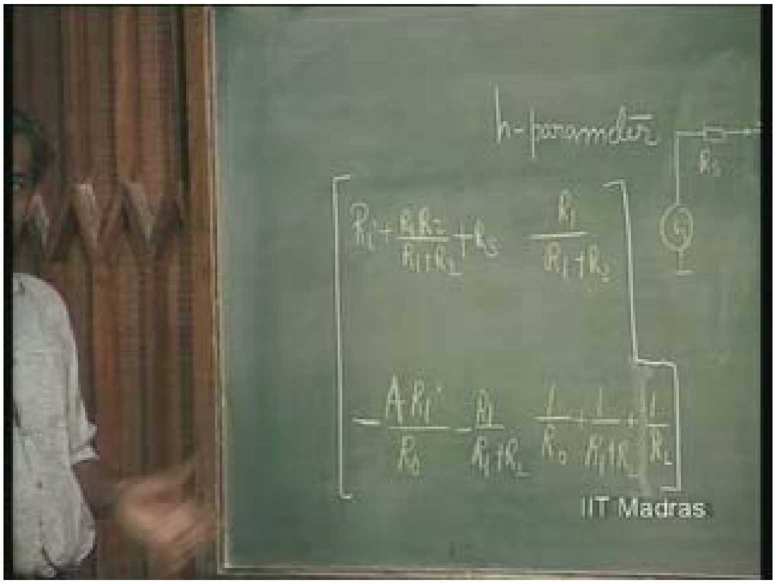

Now, I would like you to come out with some definitions, practical definitions. See, what did we say about the forward transfer parameter here? Or, this is A which should have been infinity; R i which should have been infinity; 1 over R naught which should have been infinity. So, if any... actually, A is infinity itself. That is sufficient to make this infinity; but we can see that the other parameters will make this a very huge value. So, having R naught equal to zero and R i equal to infinity and A equal to infinity means, this is, really speaking, infinity cube kind of thing. That is a high value; a third or a high value here.

So, this therefore is very huge in a practical op amp itself wherein A is any way high. R i is going to be also high. R naught is going to be very low. So, there is no point in retaining this, which is always a fraction. So, this can be ignored, compared to this, always.

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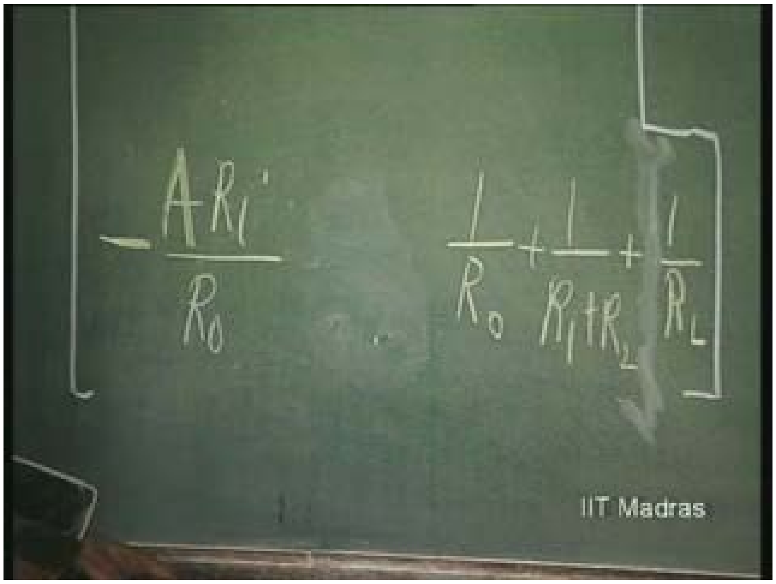

That means, the forward transmission parameter contribution due to passive device can be ignored. Here, the active device has not contributed to any reverse transmission at all. That is something that you have to remember. Only the passive device has contributed to the reverse transmission. So now, you can find out the loop gain. It is an important thing. This should be much greater than 1 and this should be negative for negative feedback; that you can verify. This is negative and this is positive. So, the loop gain is negative. This A into R i by R naught into, let us call this Beta; because we have defined this R 1 by R 1 plus R 2 as Beta.

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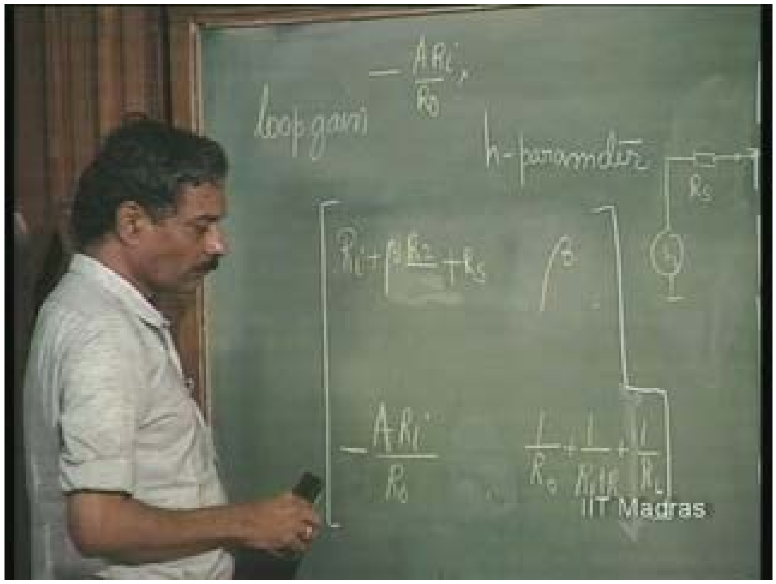

So, A R i R naught into Beta divided by... Now you can consider this. This into this; R i. Now R i is normally very huge compared to Beta R 2 plus R S. R S is anyway going to be source resistance. Normally, R i is going to be very high compared to Beta R 2 and R S; but then, we cannot... R i plus R S Beta R 2. Here, normally, R naught is very low compared to R 1 plus R 2 and R L.

So normally, this factor alone becomes significant. See here, this factor alone becomes significant. So, that is the actual loop gain.

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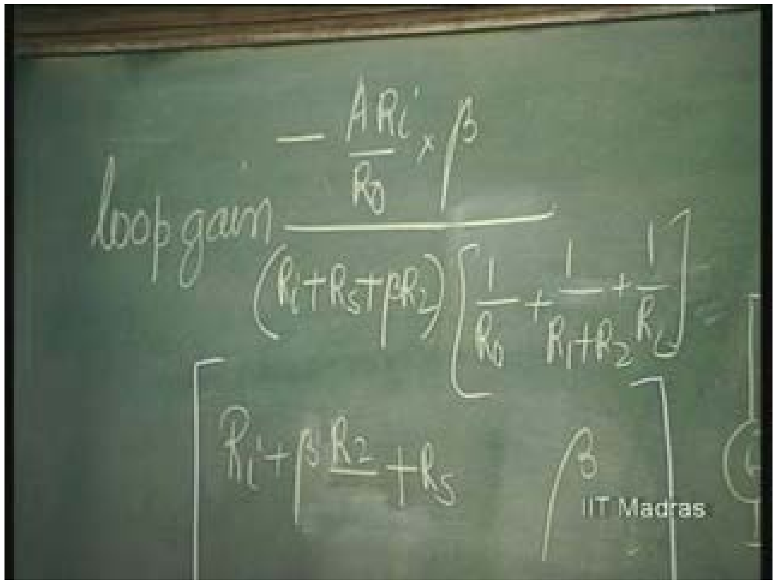

I will rub it off. So you can see here... A, one thing that is supposed to be high; R i which is very high, R naught very low. That means this is infinity to the power 3 here. R i which is high, R naught which is low; this is infinity square. So, loop gain is still very high.

So generally, this loop gain is going to remain very high and this R i by R naught will get cancelled with this R i by R naught; and it is really A into Beta which we had earlier defined as the loop gain, there. A into Beta. So, you can see here. I will therefore take this R i and take this R naught, retain the actual loop gain as minus A Beta; and how is it different from that? Divide R i by R i here; and here, multiply by R naught. So, you can see that it is the normal loop gain minus A Beta, under the situation, R i is infinity and R naught is zero. You can put R i equal to infinity here. This will go to zero. R naught – zero; this will go.

So, if this is minus A Beta, under the situation, R i is equal to infinity and R naught equal to zero, the loop gain is equal to minus A Beta for R i equal to zero, R naught equal to... R i equal to infinity and R naught equal to zero.

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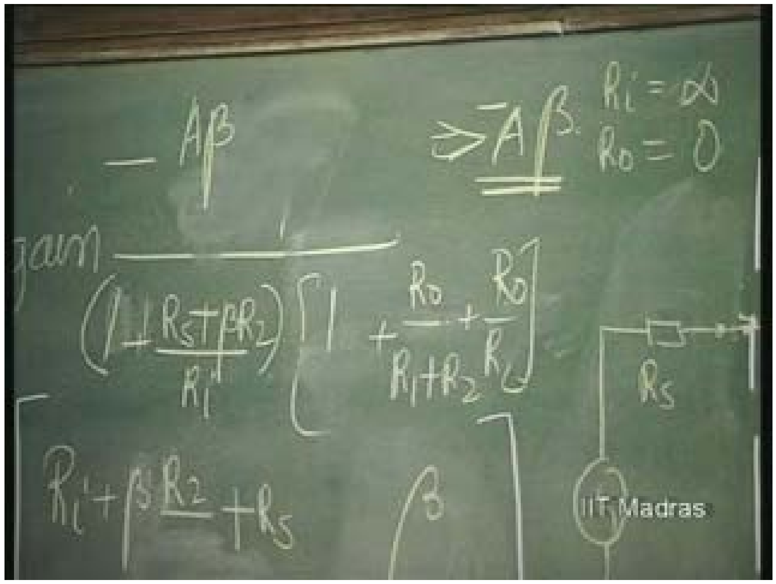

Otherwise, it is going to be dependent upon this R S by R i ratio in relation to 1. Similarly, R naught by R 1 plus R 2 ratio in relation to 1. So now, what is the input impedance? What is the forward transfer parameter? All these things, we can now define. First, let us find out the input impedance. See, input impedance is going to increase over and above what? - the original input impedance. The original input impedance is R i plus Beta R 2 plus R S.

And the present input impedance will be 1 plus loop gain times the original impedance. This can be also found out by taking the matrix Delta h as this into this plus this into this. Find out Delta h and divide this by Delta h. That is the input conductance. Instead, I have also told you that original input impedance gets modified by a factor of 1 plus loop gain. So, this is the original input impedance; R i plus Beta R 2 plus R S. So, that is getting multiplied by 1 plus loop gain.

So, actual loop... input impedance R in is R i plus R S plus Beta R 2 into 1 plus A Beta divided by that factor. That is actually the input impedance. So, you can see that it is increasing very much. Input impedance seen from this side which is going to include R S... So, if you remove R S, it will be input impedance without R S.

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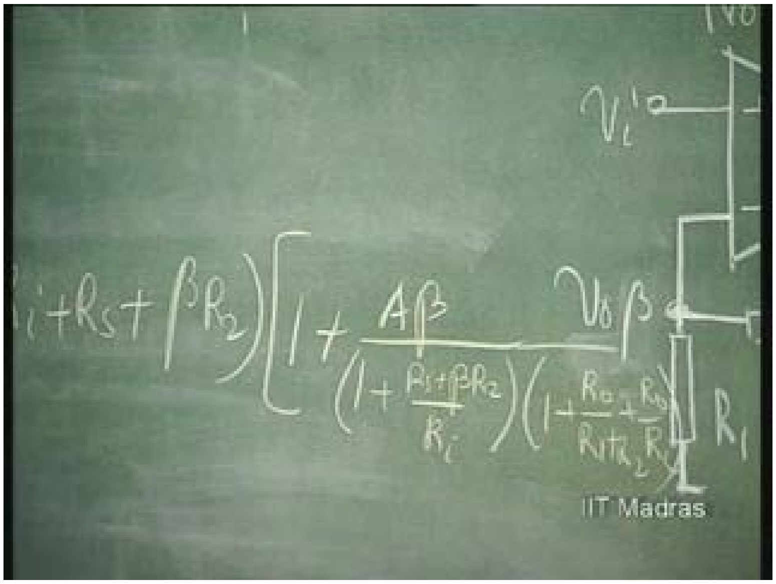

From this, you subtract R S. That is the actual input impedance. So, R in of the amplifier, really speaking, is this. So, this is including R S.

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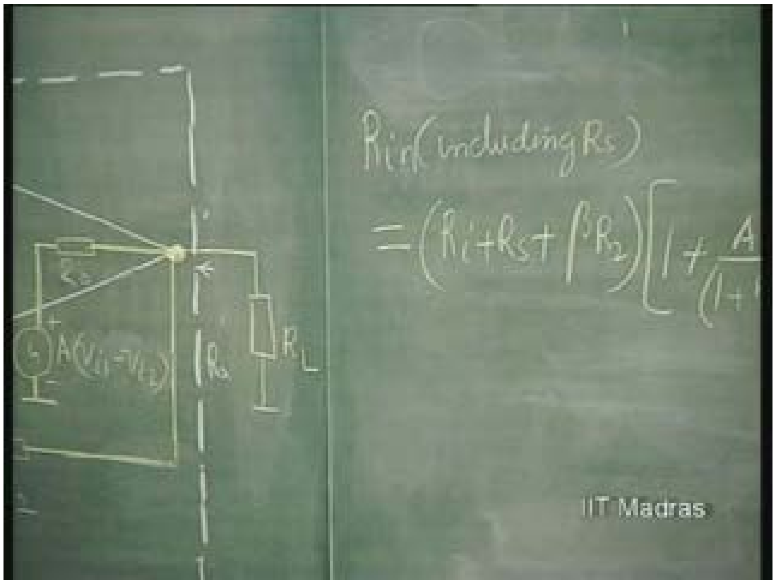

Now, output impedance. Once again, you can do it by this method. This one is to be divided by Delta h, the matrix of this. That is the output impedance; or, original output impedance is this. That is, output conductance is this.

So, that has to be reduced by a factor of this. So, the conductance is increased by a factor of 1 plus loop gain. So, original output impedance - 1 over R out is going to be this... This is the original output conductance into the same factor in which you have to remove the effect of 1 over R L.

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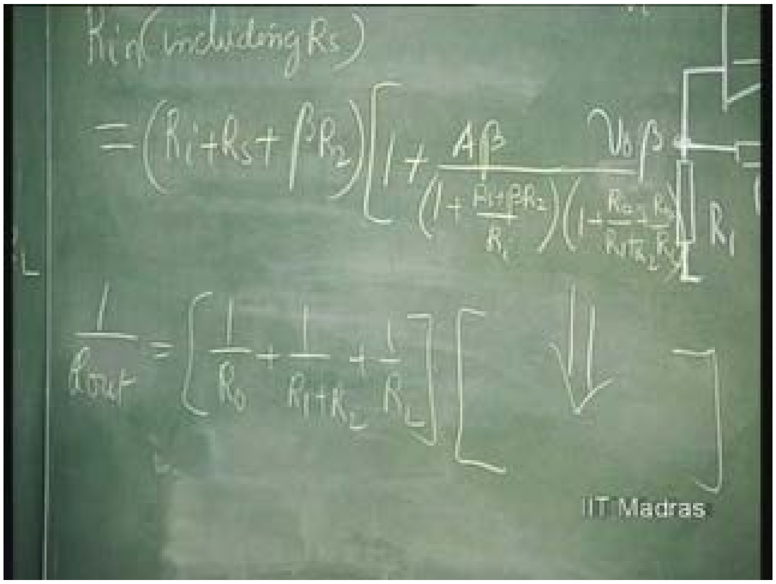

This 1 over R L that is coming here so that actual output impedance... so, this is including shunting effect of R L.

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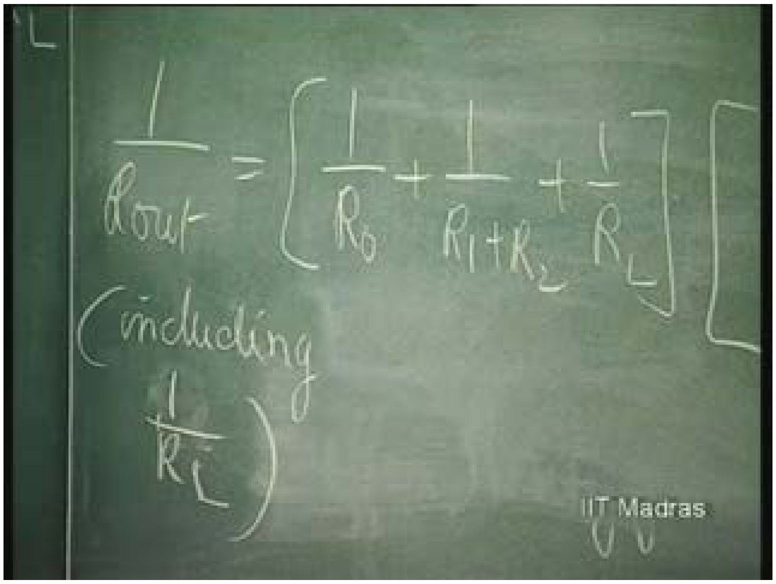

So, you subtract from this - 1 over R L. Then, you will get the actual output impedance. So, you see this, this conductance increases enormously. That means output impedance is brought down considerably. Now finally, the gain. This divided by the loop gain.

So, as far as this is concerned, this divided by Delta h. Delta h, you will see is nothing but this into this. That is going to cause only infinity square; but this into this is going to get added to it. So, Delta h has major part of it as A R i by R naught into Beta. This is infinite cube. This plus this factor into 1 over R naught plus 1 over R 1 plus R 2 plus 1 over R L. This is actually the... this is with plus. So, this is the forward transfer parameter out of which this factor is much less than this. So, this can be ignored. So, what do you see?

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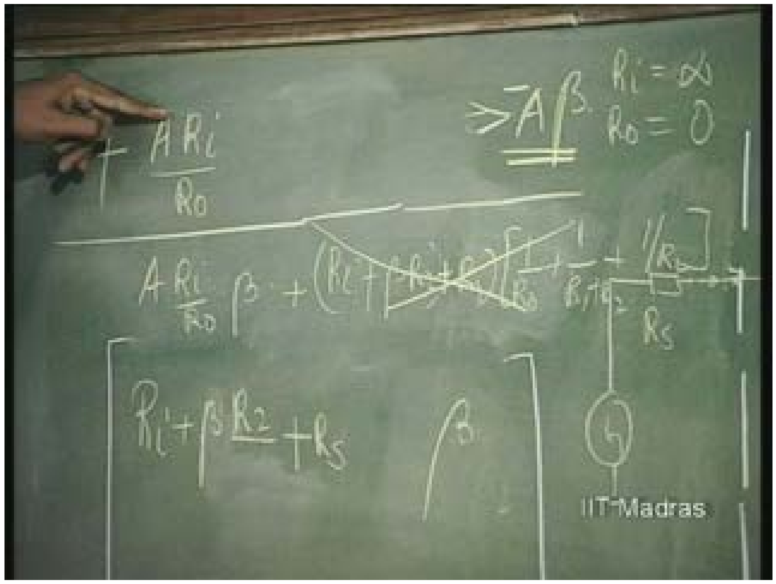

This is simply becoming one over Beta. So, this factor really gets cancelled here. So, this becomes... this is nothing but V naught over V s. Please remember. This is nothing but V naught over V s.

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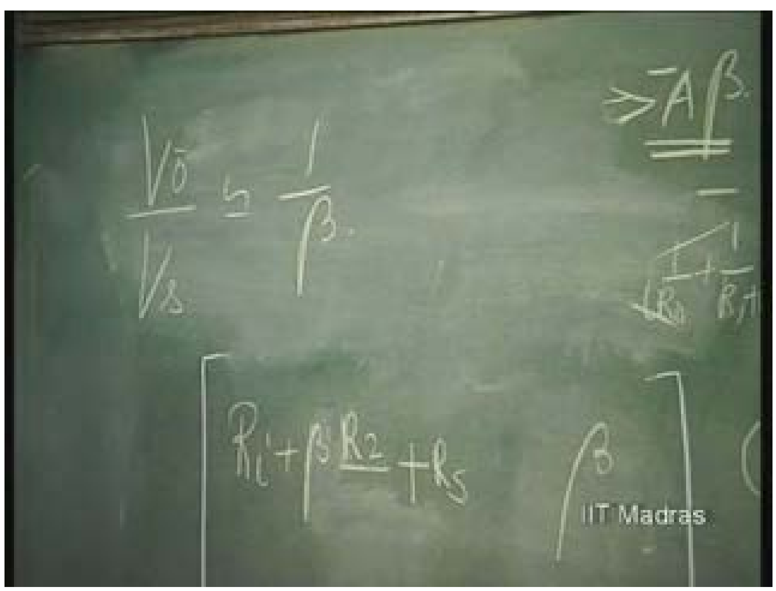

This is... Loop gain, V naught over V s. So finally, we can say that, as far as the gain is concerned, it is very nearly equal to 1 over Beta; and input impedance is equal to this. Output impedance is given by this. So, these are the exact values of the... actually g matrix; one is g i. That is really g i. This is g naught. This is g f.

So, these actually gives a very good idea as to how to select the value of R 1 and R 2 so that this approximation becomes valid. You can see that if R i is known to you, then you can select this R S and Beta R 2 such that this is predominantly determined by R i. Here also, you can... if R naught is known to you, R 1 plus R 2 and R L can be so selected that this becomes negligible compared to 1 over R naught.

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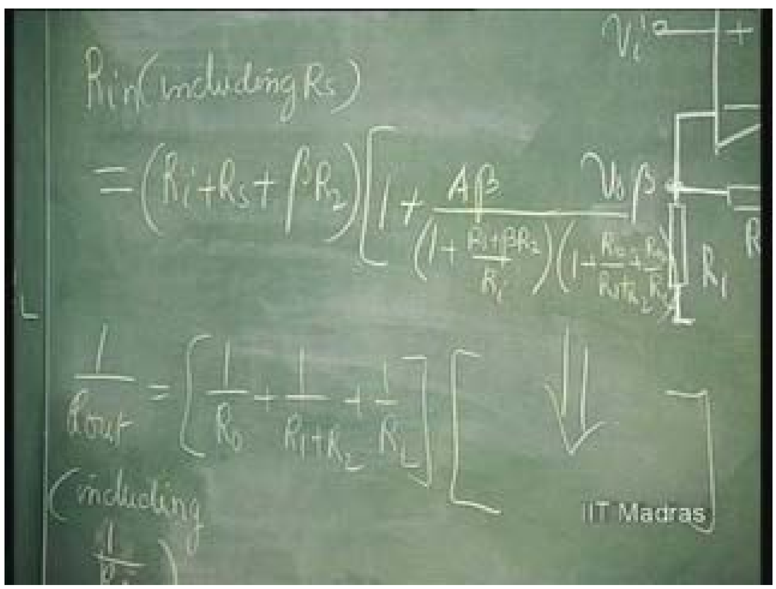

So basically, R i gets multiplied by 1 plus A Beta; R naught gets divided by 1 plus A Beta; and A gets divided by 1 plus A Beta, if R i and R naught were to be made respectively infinity and zero.

So, this concludes the discussion about h feedback. The next circuit that we have discussed, as far as this is concerned, is the Y feedback which is the only other negative feedback possible with operational voltage amplifiers.

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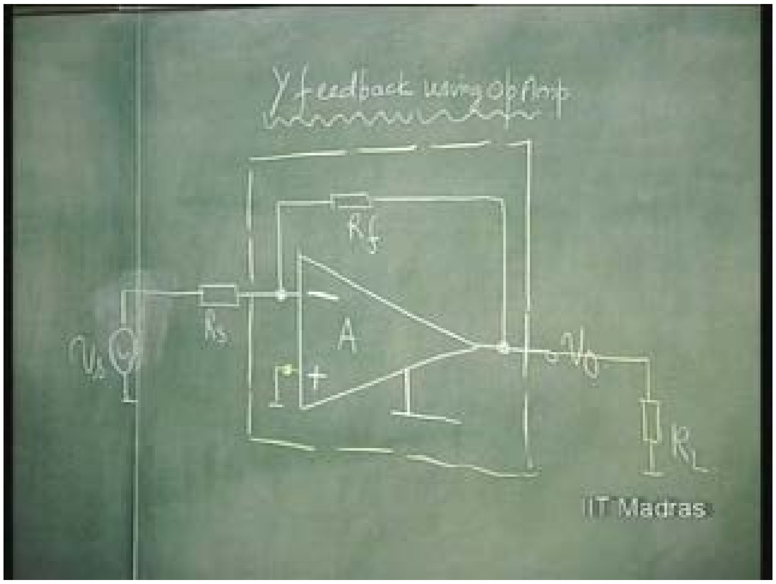

Now, let us consider Y feedback as applied to the operational amplifier, negative feedback. So, we have this op amp. The feedback is from the output; shunt at the output. That means output voltage is common to both amplifier as well as the feedback network. Shunt at the input; again, the input is...voltage is common to both the amplifier as well as the feedback network.

So, the feedback network is R f, a single resistor, from... connected from output to input. Output - it is coming in shunt; input - it is coming in shunt. So, this is shunt, shunt feedback or called Y feedback. Now, simple way of analyzing this is... As I told you, if A were to be infinity, if A is infinity, we know that this is grounded; and this is a nullor. We have introduced this equivalent earlier also. So, this voltage is zero. Why? Because, if this is finite, V naught by A is this voltage; A is infinity. So, this voltage is pulled down to zero. This therefore is called virtual ground.

This is an important concept. If I ground the amplifier and if the amplifier gain is made infinity and if the output is finite and output is connected to input through negative feedback, then it is always this potential that becomes virtual ground. Potential here is the same as that of the ground potential, virtual; which means, the current in this is V s divided by R s and this current cannot go into a nullor. So, it can only go into R f and develop a potential which is V s by R S into R f, with this end positive and that end negative.

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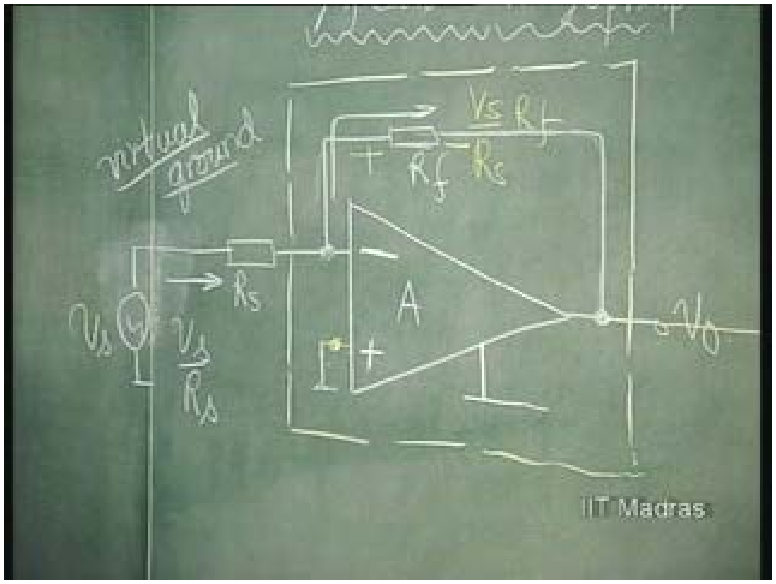

So, this is at ground potential and therefore output potential V naught is nothing but the potential across R f because this is at ground potential, virtual ground. So, this is minus, because this is plus and that is minus; V s into R f divided by R s, independent of R L.

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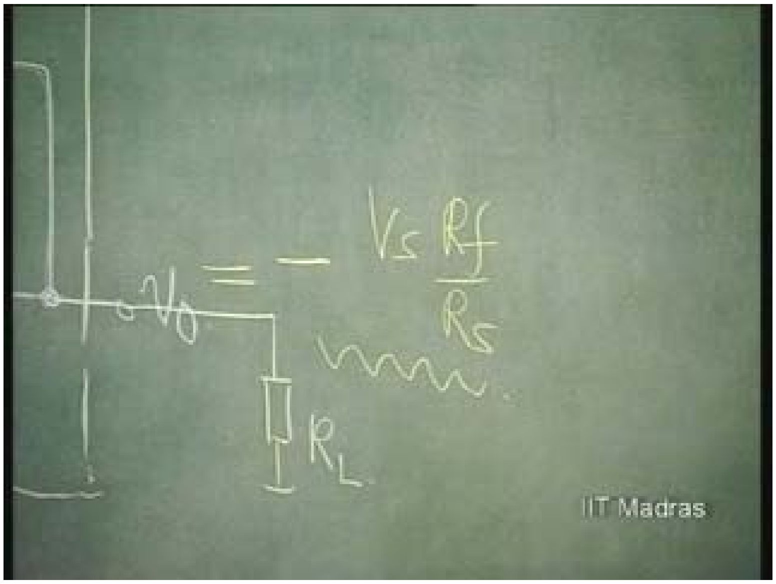

Because this is virtual ground, the current pumped into this is V s by R s and the same current is forced to go into this feedback network, R f; develops a potential, V s by R s into R f. Therefore, V naught is... This is therefore called an inverting amplifier. Why inverting? There is a phase shift of 180 degree here. If the input amplitude is increasing, here it will be decreasing.

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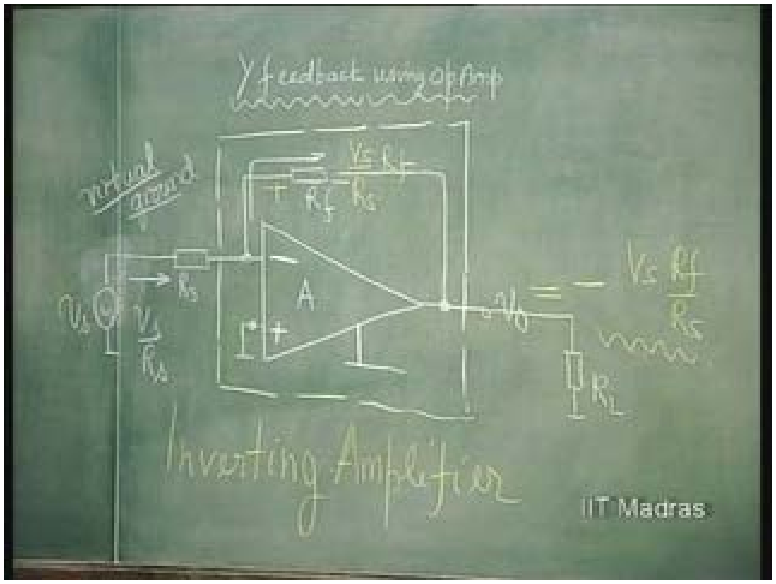

So, there is a phase inversion, inverting amplifier; and the gain is R f by R s. So, there is a concept here that is to be highlighted is that, this point is always at virtual ground. That means this is a current summation point.

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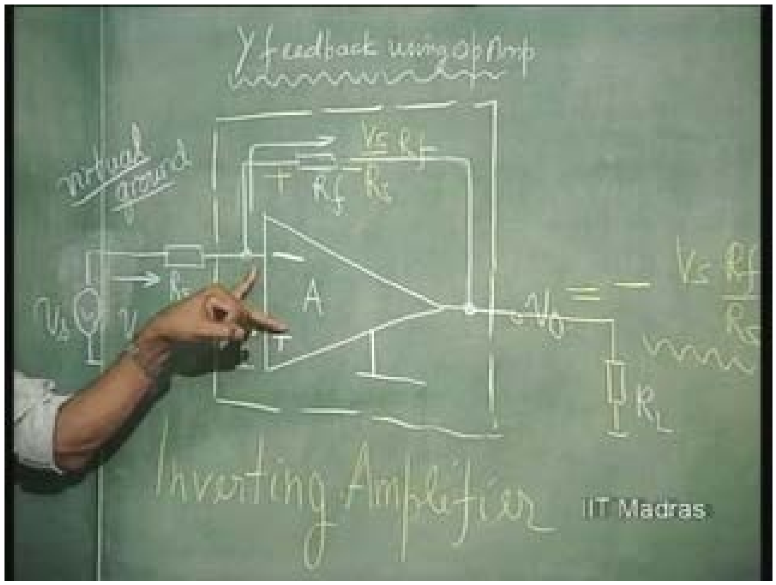

Any number of currents can be added here; and all those currents will be pumped into the feedback network. So, this concept is very useful in a variety of applications of converting current into voltage. We will see this later.

But now, suppose this is not infinity. Then what happens to this? We therefore will modify this. If this is not infinity, this potential is minus V naught divided by A. It is not zero because this is V naught. So, this is minus A. So, this potential is minus V naught by A; and therefore, this current is not V s by R s; but it is V s minus V naught by A. That is, V s plus V naught by A by R s; and it is this current that will be going into the R f.

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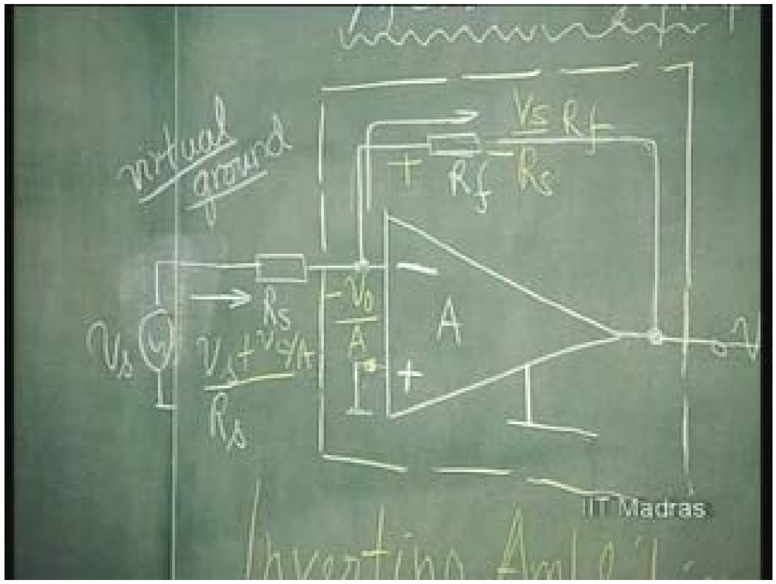

Therefore, the potential is going to be V s plus V naught by A divided by R s into R f. Instead of... here we...V s into R f by R s. Therefore, V naught is going to be not zero; because this potential is not zero. So, it is minus... V naught is going to be minus V naught by A, this potential, minus V s plus V naught by A into R f by R S.

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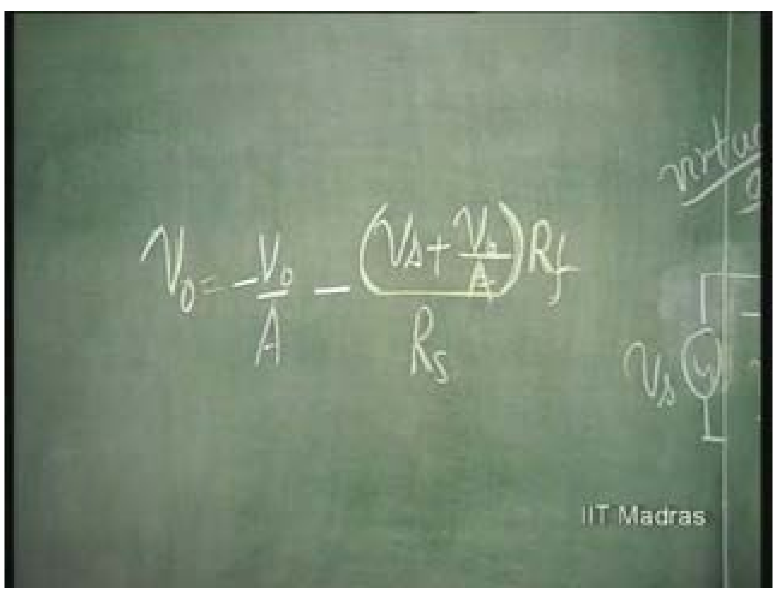

So, if A is infinity, you can just look at it. This will go to zero; this will go to zero; and we will get back what we had earlier. That is minus V s into R f by R s. Therefore, V naught into 1 plus... you have 1 over A plus R f by R s over A from this; and this is equal to... This factor, these two factors, have been taken into account and minus V s into R f by R s.

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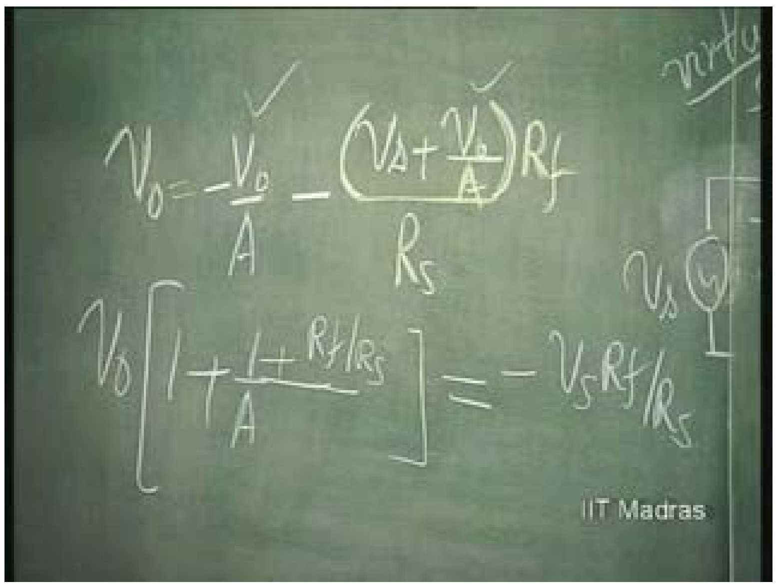

So, V naught by V s, which is the transfer function now becomes modified at minus V s into R f by R s divided by 1 plus 1 plus R f by R s by A.

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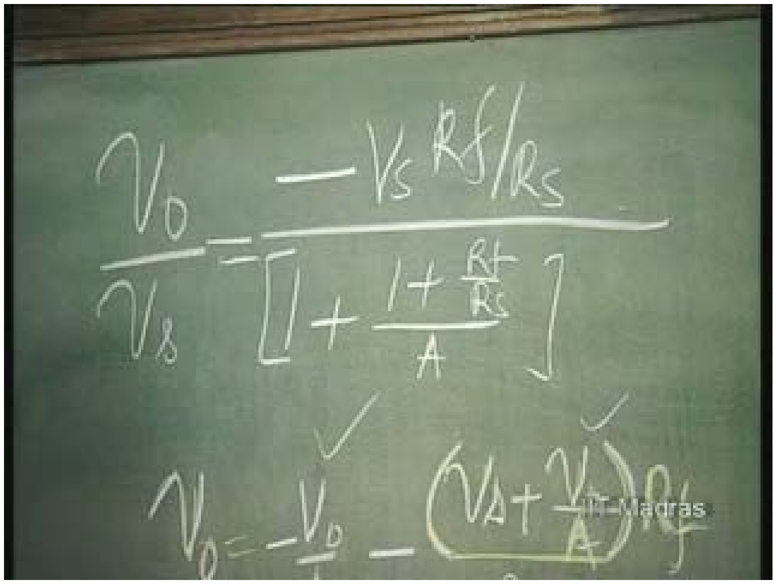

So, you can see... if A were to tend to infinity, this is what it was. With A finite, we have that getting modified by gain. This is the loop gain. 1 plus loop gain. This is the loop gain. If you look at this, A into R s divided by R f is the loop. You short circuit this. A into R s by R s plus R f is the loop gain here. If you break the loop here... So, that is what it is. A into 1 plus 1 over loop gain. So, I will write this. So, if the loop gain is very high compared to 1, this goes towards zero. So, 1 plus 1 over loop gain.

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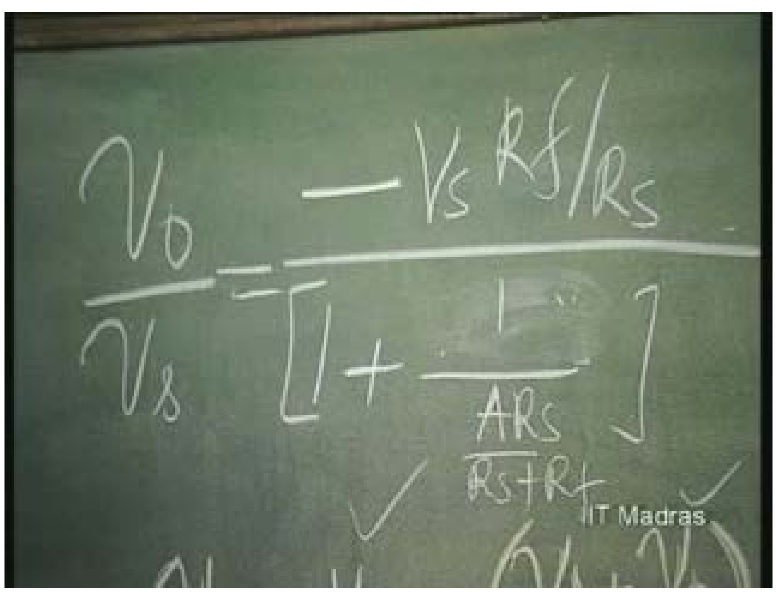

So, let us now investigate this using proper parameters. What I mean is, just as I did in the case of h parameter, we investigate the feedback with R i, R naught, etcetera, also taken into account. So, instead of making this approximation, we will retain this just like this. Now we will consider the same circuit without neglecting R i and R naught.

So, that means here instead of it being an open circuit, we have R i, same thing; and here, the output R naught and... if this is, let us say, V i here, this is V i; A times V i there. If this is positive and this is negative, this is A times V i. So, this is the equivalent circuit now, of the op amp. Then, how does it work?

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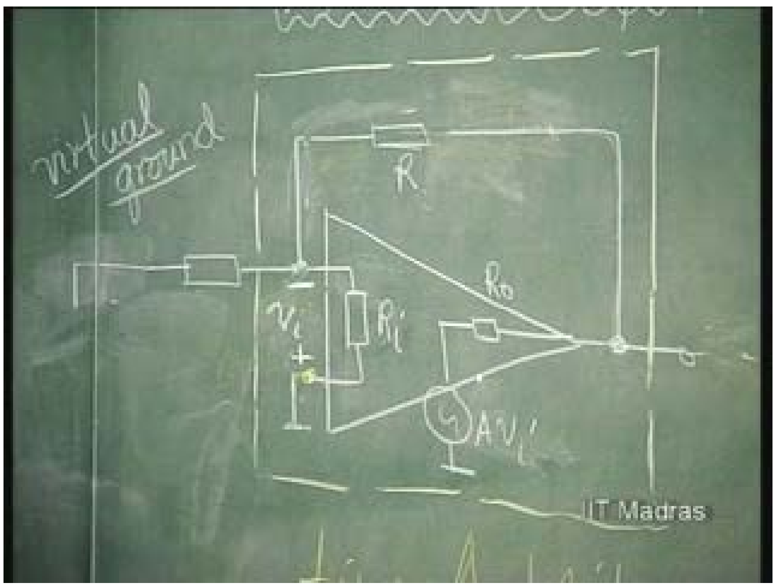

So, once again...Now we will consider Y feedback. This is Y feedback. So, composite Y parameter must be determined. What is composite Y parameter? I short circuit the input and find out Y i and Y f. Short circuit the output; short circuit the output, find out Y i and Y f. Short circuit the input; find out Y r and Y o. So, let us do that. So, short circuit the output. So, we have here 1 over R i. When I short the output, 1 over R i comes in shunt with 1 over R f; 1 over R i comes in shunt with 1 over R f.

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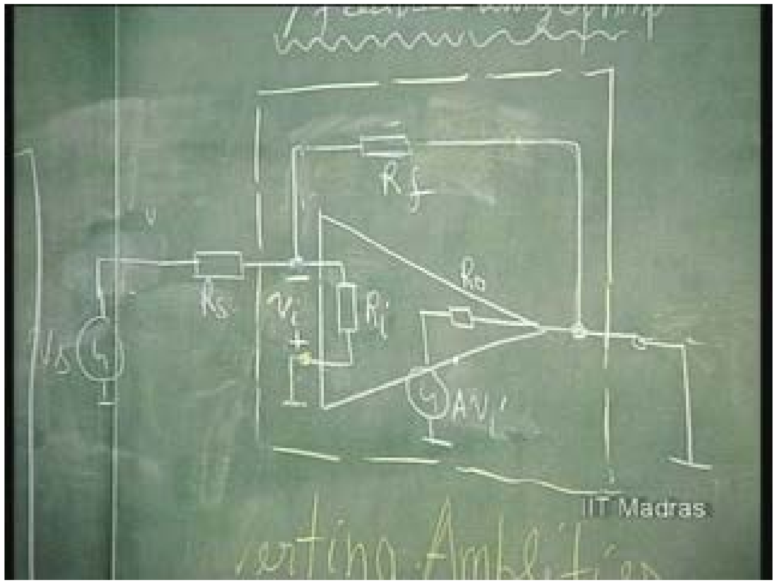

This is that of the amplifier; this is that of the feedback network. As far as the forward transfer parameter is concerned, if the voltage is V i here, this way, this way, A times V i is the voltage there and the current is A V i by R naught, that way. But, actual input is positive here and negative here. So, let us put it that way. Clearly understand. If this is V i, then I should put here minus and plus indicating that there is an inversion.

So, if this is V i, there is an inversion; A times V i here... this applied to the inverting terminal. So, the current is going to be pumped in. If this is plus and minus, it will be pumped out. So now, pumped in... that means for an input current like this, this will be having a current, this way.

So, A times V i by R naught is the output current. Output current divided by input voltage, this parameter. So, A times V i by R naught divided by V i. So, A by R naught is the Y f of the amplifier alone. What about the feedback network? If we apply V i here, the current V i by R f will be going out. So, minus 1 over R f. So, you can see A by R naught is due to the amplifier; minus 1 over R f is due to the feedback network. Simple.

Next, I short circuit the input and apply voltage at the output, the feedback parameter Y f. When I apply voltage V naught, if I short this, V naught by R f will be going out. So, minus 1 over R f is Y r. For the amplifier, there is no feedback. So, only the passive network has feedback. As far as output conductance is concerned, this is zero. V i is zero. So, this is zero. So, 1 over R naught plus 1 over R f.

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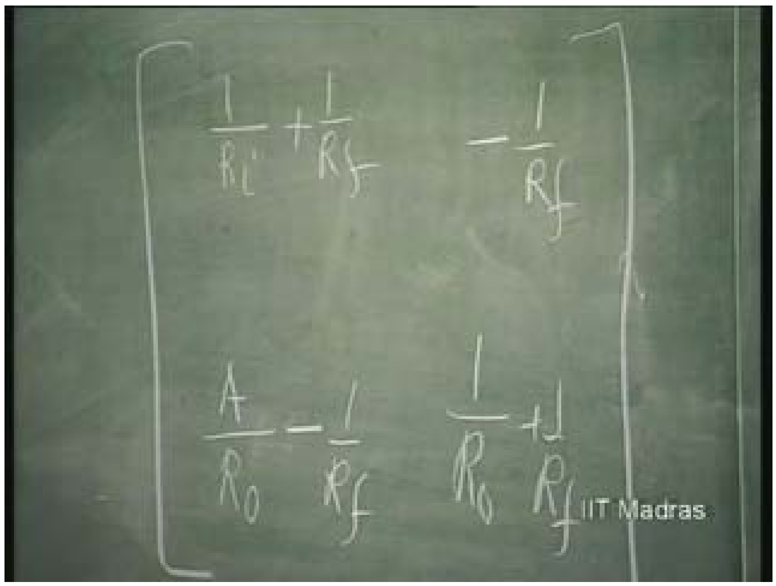

These are the short circuit parameters very simply obtained by definition. Then, as far as the input is concerned, the source admittance is added in shunt. 1 over R s. As far as the output is concerned, you can add 1 over R L, so that, effectively you have, strictly speaking, the source that you have to use here should be compatible to that of the Y parameter. That means, instead of Thevenin source, you use Norton source, which means you put a shunt resistance of R s and a current source of I s, instead of using Thevenin source.

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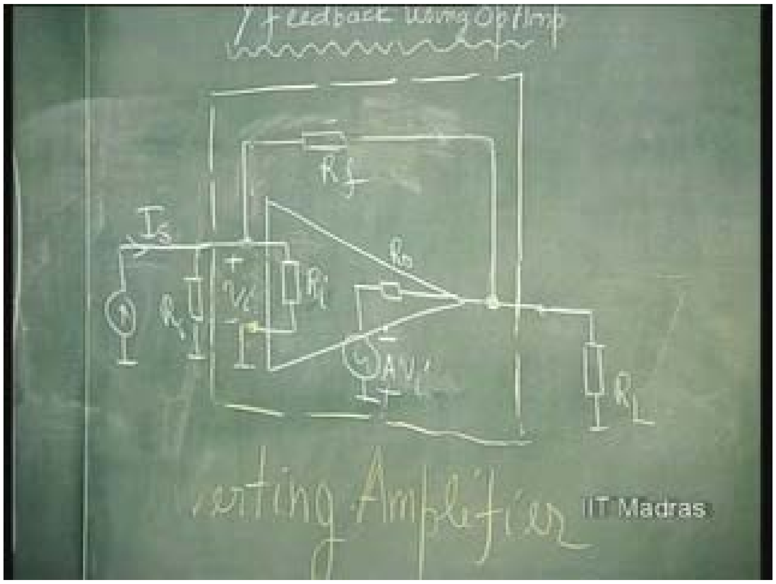

Now, this is the composite Y parameter of this fairly complex Y feedback network. We can now find out the loop gain. Once again, you can see. Because A is coming here, R naught is coming here. So, this is infinity square. So, this can be neglected.

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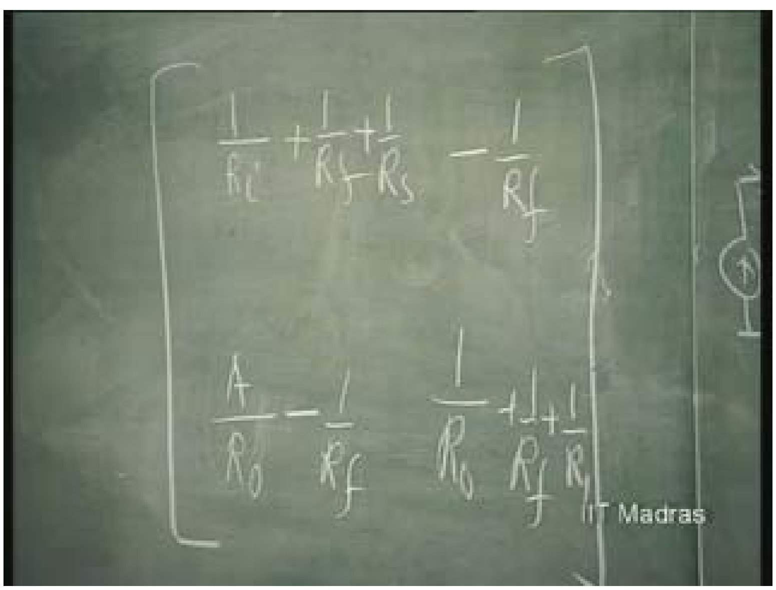

And loop gain is A by R naught into minus 1 over R f divided by 1 over R i 1 over R f plus 1 over R s into 1 over R naught 1 over R f 1 over R L. This is the loop gain.

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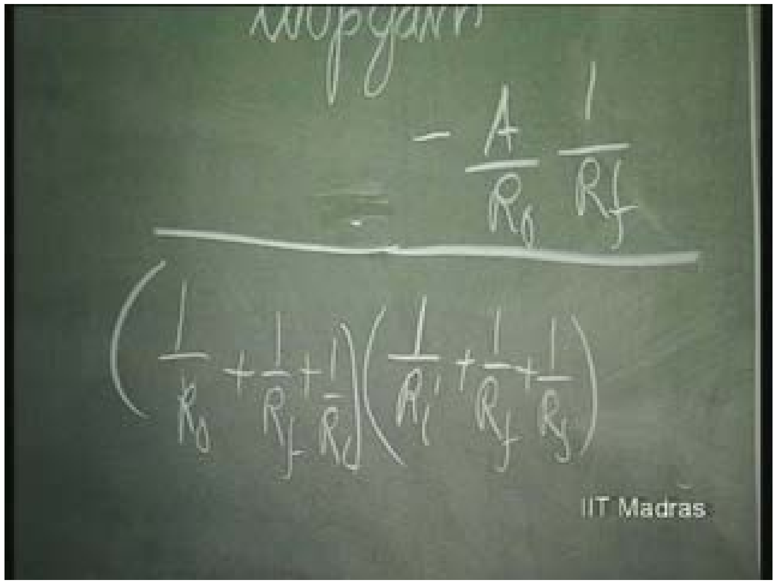

So, you can again make the approximation. R naught can be taken inside. 1 R naught, R naught. So, I will rewrite it. 1 plus R naught by R f plus R naught by R L. Once again, R f can be taken inside this. So, 1 plus R f by R i, R f by R s.

So, you can see. Basically, the loop gain is minus A; basically the loop gain is minus A; or, if you... if you were to really make R naught equal to zero, R naught equal to zero and R i equal to infinity, then the loop gain is minus A into 1 plus... minus A into R f plus R f by R s. That is what we have got. This will go to zero; this will go to zero; this will go to zero. So, it will become minus A into R s by R s plus R f. Now, strictly speaking, R s should be made equal to infinity also because it should be driven ideally by a current source. It is a current control thing.

So, R s also... if it is made equal to infinity, then actual loop gain is minus A, if it is strictly a current feedback. So, you can see that this is the loop gain and everything decreases by loop gain. 1 plus loop gain.

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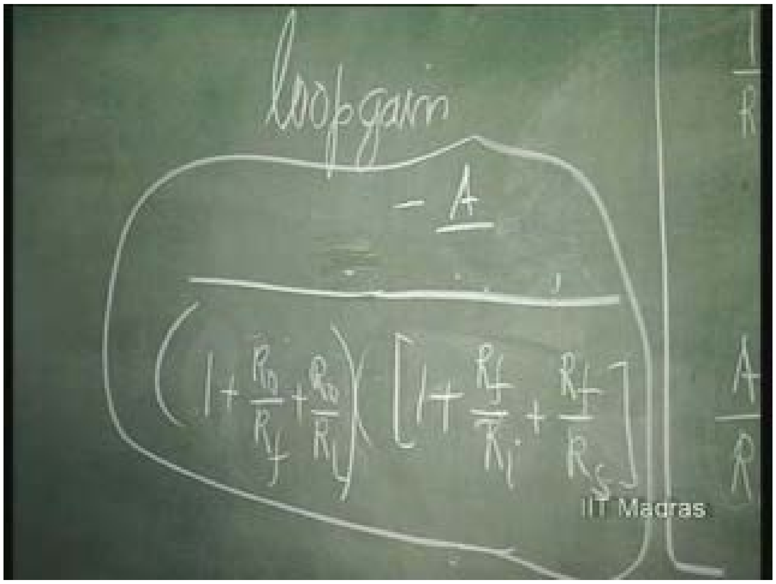

That means R i becomes R i divided by this factor. The original input impedance, input conductance, is this. This conductance is going to be multiplied by 1 plus loop gain. This conductance is 1 over R naught plus 1 over R f plus 1 over R L. So, this again decreases; output impedance decreases. Or, output conductance increases by 1 plus loop gain. So, we will see how this gets now modified. As far as this parameter is concerned, it will become minus A divided by R naught. This is the Y feedback. So, we have to convert it into Z parameter. So, what is the Z parameter? minus A by R naught divided by this into this plus this into this. In this, A by R naught into 1 over R f is dominant factor plus you have that factor which is 1 over R i plus 1 over R f plus 1 over R s into 1 over R naught plus 1 over R f plus one over R L.

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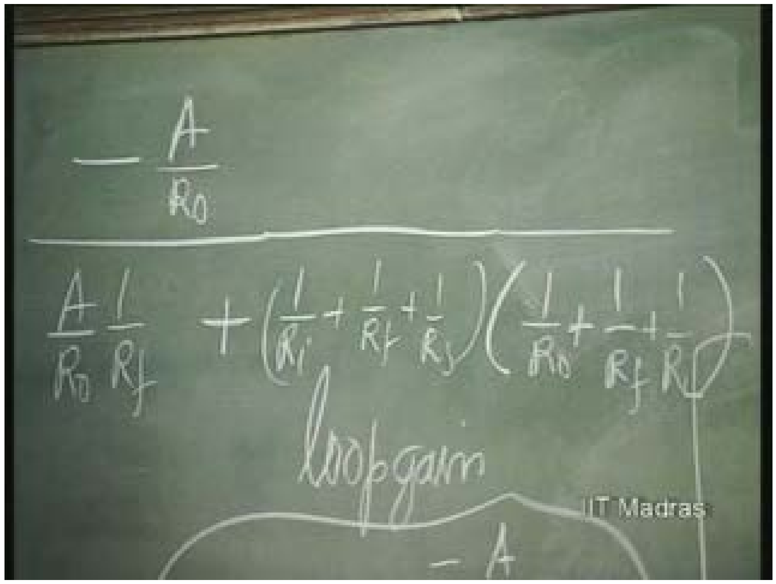

This factor is negligible compared to this because you have A going towards very high value - 1 over R naught going very high. Strictly speaking, therefore, this will converge towards minus 1 over R f; sorry, that is 1... 1 by minus 1 over R f; or, this is going to be equal to minus R f, here. A by R naught will get cancelled by A by R naught. So, this will be 1...minus 1 by 1 over R f; or minus R f.

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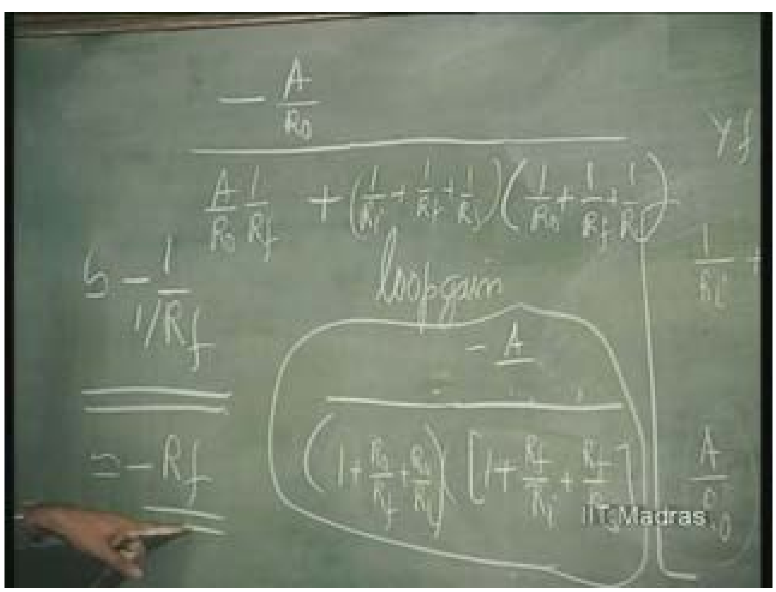

So, the Z parameter, Z f is going to be minus R f. Now, all these parameters... Z i is going towards zero; Z naught is going towards zero, by a factor which is 1 plus loop gain, from the original value. So, please see this. This becomes insensitive to operational amplifier gain. It is simply the impedance connected between output and the input.

So, if I apply I s here, what it means is this I s will almost totally go across this. This is virtual ground and the output will be minus I s into R f. So, now we have seen y feedback and h feedback as applied to the operational amplifier. As I told you, these are the two negative feedback structures available to us.

I would like to, at this juncture, also discuss what happens if we give positive feedback. So, I want to now, in the light of the op amp being made available to us... we have understood negative feedback and we have seen that negative feedback improves the performance of the amplifier enormously; brings about linearity; brings about insensitivity; and also reduces effect of noise, etcetera. Now, let us see what happens if we give positive feedback.

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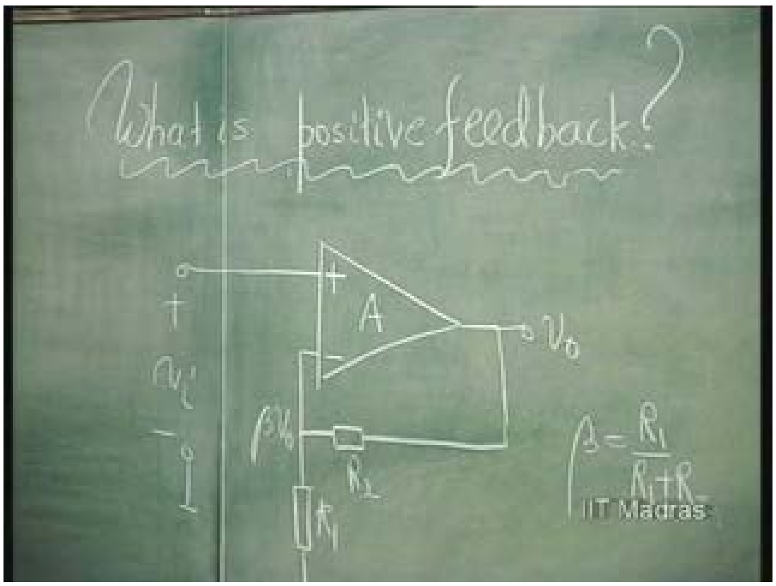

So far, we have been concentrating on negative feedback and its virtues. Let us now consider what is positive feedback. Whether it is going to be useful at all is one point we would like to see; and how far positive feedback can be given. This is the negative feedback circuit illustrating voltage, negative feedback output voltage is sent. Beta times V naught is fed back to the input which is the inverting input.

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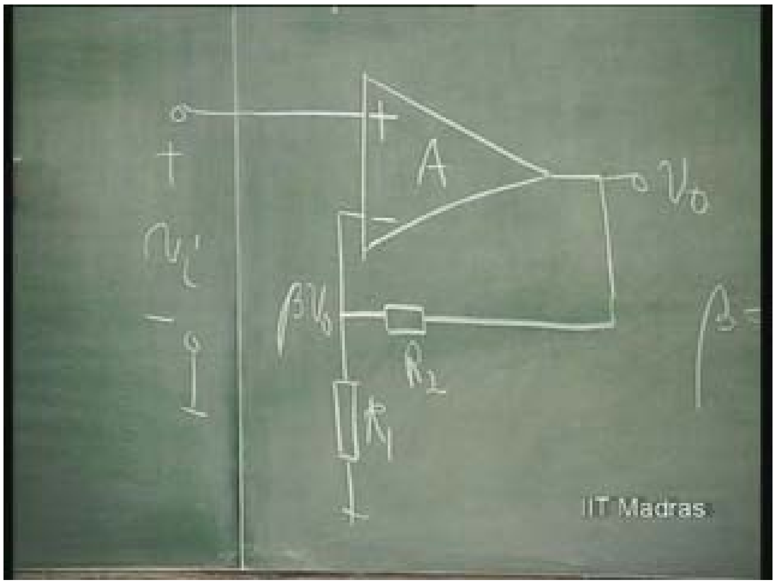

This is plus. So, V i... V i is the actual input. Minus Beta V naught. V i minus...this is important... Beta V naught, is what the amplifier takes at the different signal. V i.... That means output voltage is fed back. V naught is going to be in phase with V i because it is applied to plus. So, Beta V naught is in phase with V i. If Beta V naught is in phase with V i, V i, Beta V naught, they are both in phase voltages.

So, V i minus Beta V naught means this Beta V naught is opposing the original input; opposing... the fed back voltage is opposing the input and that is the resultant voltage that is applied to the amplifier. So, V... V i minus Beta V naught; that times A is equal to V naught and from this we have got V naught over V i as A by 1 plus A Beta. This we had discussed earlier.

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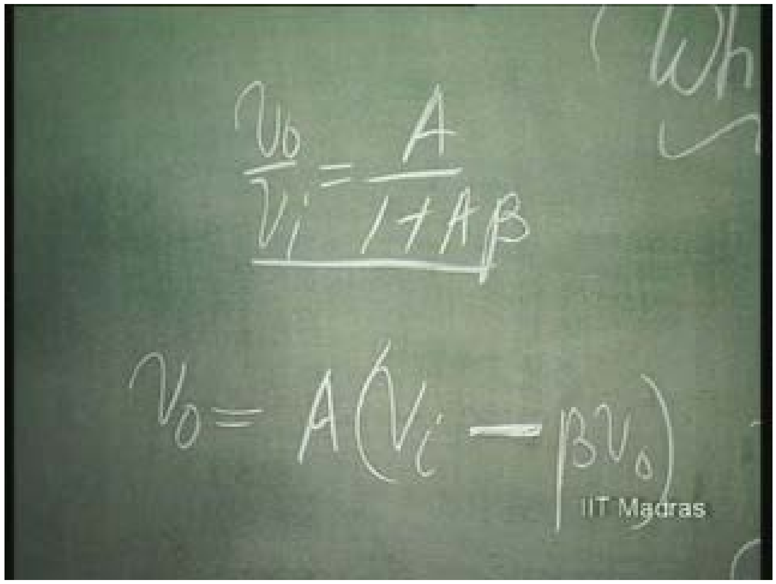

Now I am going to make it different. This is going to be minus and this is going to be plus. So, V naught and V i are out of phase; and this Beta V naught is going to be coming in series with V i. So, what happens here? Now earlier, V i minus Beta V naught was getting multiplied by A. But now, V i minus Beta V naught is getting multiplied by minus A. That is the thing. Wherever A was there, put minus A and you will get the equation because earlier V i minus Beta V naught was multiplied by A.

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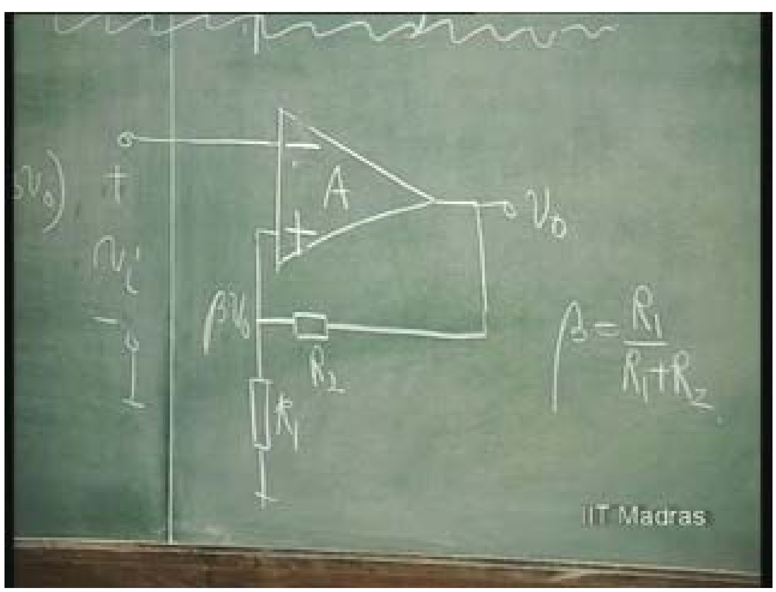

So now, V i minus Beta V naught is going to be multiplied by minus A, because of the inversion. So, this becomes minus and this becomes minus. So, this is what happens with positive feedback. This is called positive feedback.

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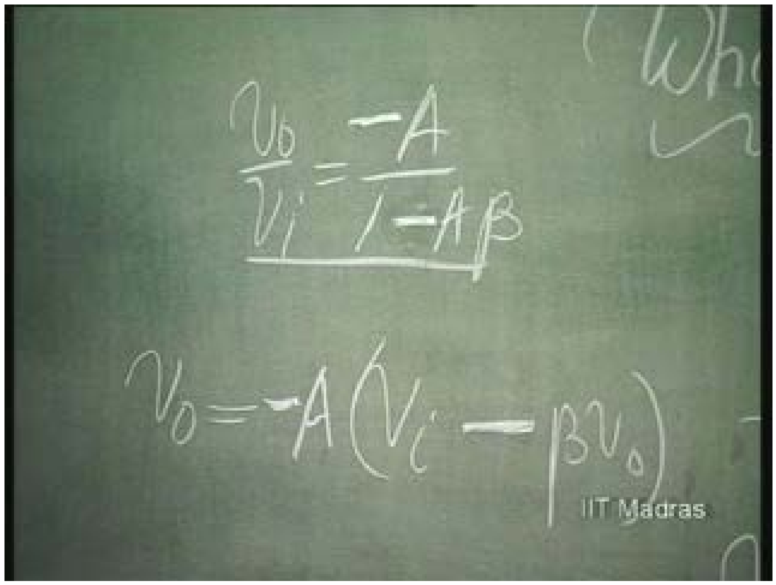

You consider... Ground this. This is A. This is Beta times V naught. That means if I have V i here, A times Beta times V i will appear here. The loop gain is positive. Now, this is V i. This will be A times V i and A times Beta. So, loop gain is positive now. So, you get minus A by 1 minus A Beta as the gain.

So, if A Beta is less than 1, whereas Beta is zero, no feedback situation; V naught over V i is going to be minus A. If Beta is finite, but A Beta is less than 1, then the gain is going to be greater than A, because A is 10, let us say. A Beta is point 9. This is 10 divided by 1 minus point 9 which is 100. So, from an amplifier of gain 10, I can get an amplifier of 100. So, using positive feedback, you can increase the gain.

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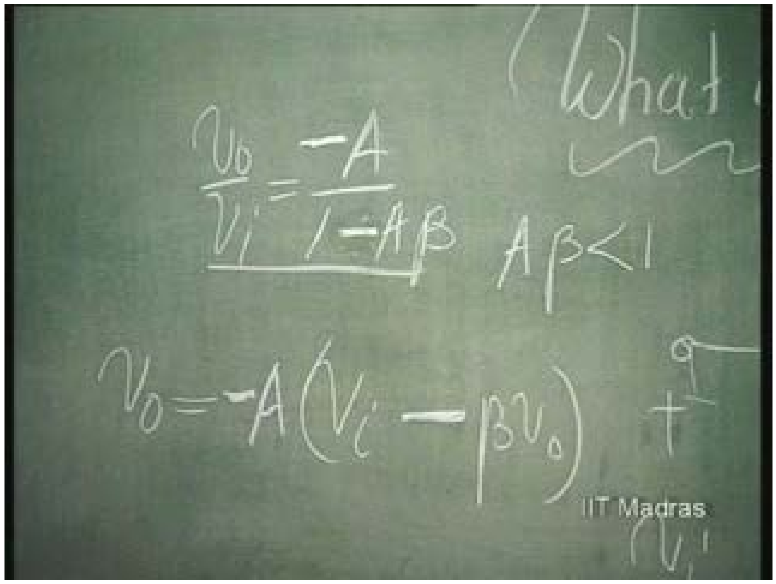

This is an advantage; but then, it is very sensitive to that. If A Beta becomes point 99, then it will go to 1000. If it is point 999, it will go to 10,000. So, a small variation in A Beta will boost up this gain enormously. If A Beta becomes equal to 1, this goes to infinity; a practical way of obtaining infinite gain amplifier is this.

Now question is what happens if A Beta becomes greater than 1? We will discuss this in the next class. That is called regenerative positive feedback. Until A Beta equal to 1...is less than 1, this can be still used as an amplifier. Beyond A Beta equal to 1... Beyond A Beta greater than or equal to 1, this is not possible to be used as an amplifier.

That is called regenerative positive feedback which is finding also application in a large number of circuits. We will discuss this later. The positive feedback of A Beta between zero and 1 is also used in what are called comparators. We will discuss this in the next class. So, positive feedback after all may be quite useful in certain other applications, other than amplifiers.