Electronics for Analog Signal Processing - II

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Lecture - 5
h & g Negative Feedback

In the last class, we saw how z and y feedback could be applied to obtain voltage control current source and current control voltage source, respectively. Then, we also discussed how h and g can result in voltage control voltage source, that is common collector; and current control current source, that is common base structures. Same thing can be done with field effect transistors, single field effect transistor, resulting in common drain and common gate configurations.

We are now discussing how h and g feedback can be applied using a pair of transistors, cascaded amplifiers. That is, a transistor amplifier, let us say a bipolar or field effect, A C picture only is given, cascaded to another transistor amplifier. So, we have T 1 and T 2 with respective loads R c 1 and R c 2. So, one amplifier is cascaded to another amplifier.

When such a pair as shown here is used, what are the possible negative feedback configurations? I have told you earlier that with a single transistor and additional passive network, you can only get negative feedback structures, which are z and y. Without any passive network, you can get h and g; with a pair of transistors like this, you will get negative feedback only for h and g feedback.

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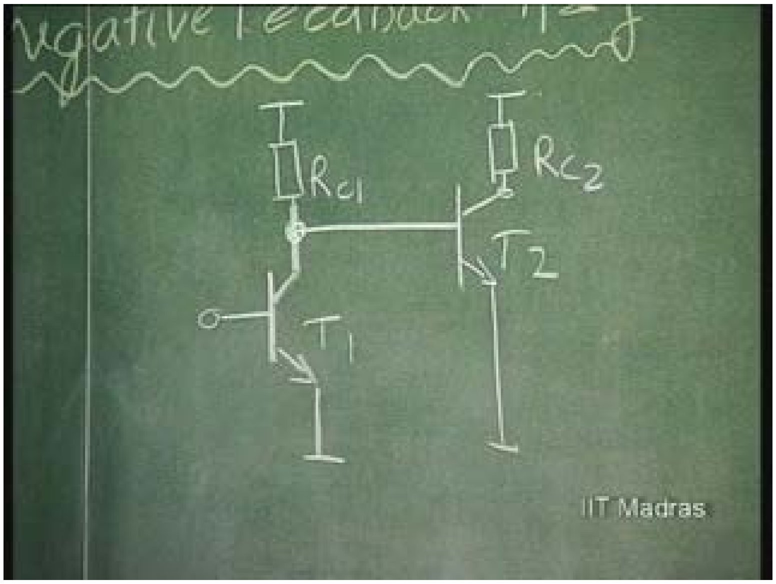

What is h? It is series at the input and shunt at the output. g feedback is shunt at the input and series at the output. h feedback is adopted in order to obtain a voltage control voltage source. So, h feedback is adopted for an idealization towards voltage control voltage source. g feedback for an idealization towards current control current source.

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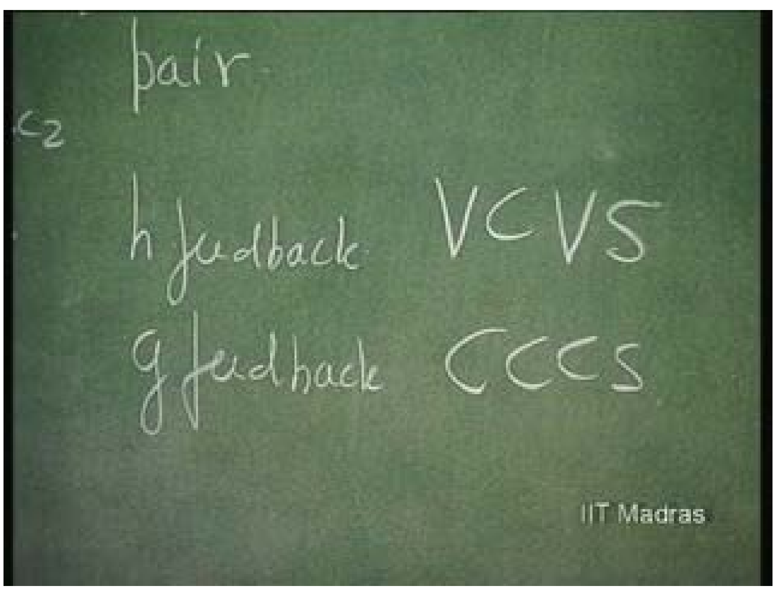

So, how are we therefore to implement this h feedback? It is shunt at the output and series at the input. That means, I take a feedback network. This is the passive feedback network. I develop…this is, let us say, R 1 and this is R 2. This is the passive feedback network. The output voltage is sampled here - V naught; and V naught into R 1 by R 1 plus R 2. V naught into R 1 by R 1 plus R 2. That is the amount of fedback voltage that is going to be put in series with the original input. The original input of the amplifier is this. This is the feedback voltage.

So, we are going to lift this and put it in series. From here to here, the phase shift is 180 degrees. From here to here, again, the phase shift is 180 degrees and therefore, from here to here, the output and input voltages are in phase. Therefore, this voltage and this voltage, they are in phase.

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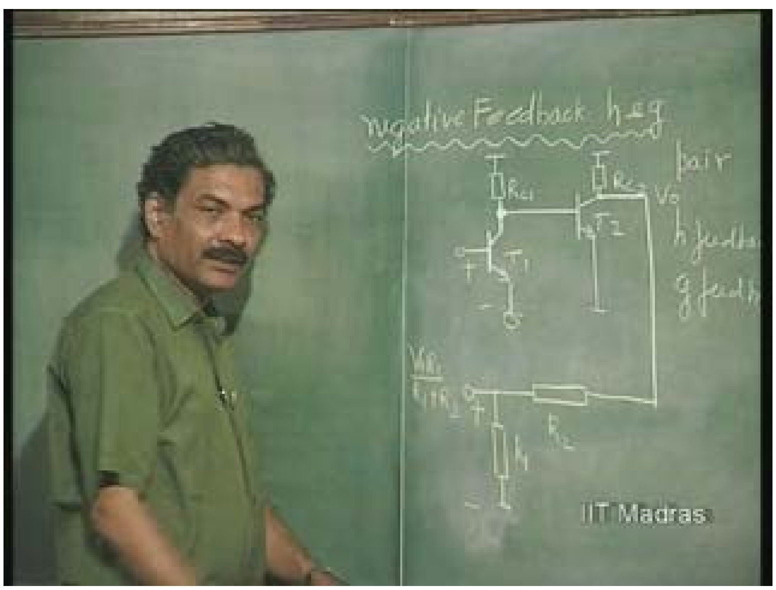

That is why, if I now apply this in series with this for the new input, these two will be coming in series and this fedback voltage will be opposing the input voltage. That is why, it is negative feedback.

So, this is the h feedback and obviously, h parameter is most suited for analyzing this. Therefore, we will write the composite h parameters for this.

This is the method we have been adopting throughout. Composite parameters, we will determine for this whole network. How do we determine composite h parameter? So, h i of this network…This is v i now. h i of the network is going to be h i of the amplifier plus h i of the feedback network when the output is shorted, because it is a short circuit parameter.

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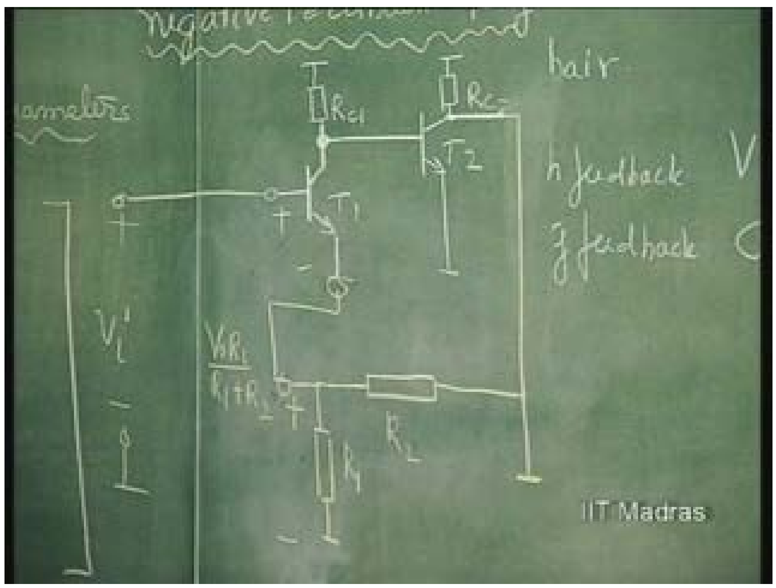

Now you can see. When the output is shorted, the feedback comes out of this amplifier. These two now get separated and R 1 will come in parallel with R 2 here at the input. So, R 1 comes in parallel with R 2 at the input of this amplifier T 1; and therefore, the input impedance of this network is going to be r e of this plus R 1 parallel R 2. r e 1 plus R 1 parallel R 2 into Beta plus 1. It is because we are looking at the base. The current here is Beta plus 1.

So, any impedance coming in series, that is r e 1 in series with R 1 parallel R 2 is what comes; that into Beta plus 1 is now h i of the composite amplifier. You can say, that of the amplifier is r e 1 into Beta plus 1; that due to the feedback network is R 1 parallel R 2. Since it is coming in series with the emitter, not in series with the base, we have this Beta plus 1 factor coming into picture.

So, we will see that the h parameters add. Next, we can simultaneously determine h f of the composite structure, which is again h f of the amplifier plus h f of the feedback network. Then, what is h f? I short the output and find out the current gain from input to output. When I have an input current I i, this current at this point is going to be Beta times I i.

This Beta times I i is going to split between this resistance and the impedance seen from here. Impedance seen from here. So the current gain is…one value is Beta straight away; from here to here, there is a gain of Beta. Then the current is going to split between this resistance and the resistance seen from here. The resistance seen from here is R e 2 of this into Beta plus 1.

So, it is going to get reduced by R c 1 by R c 1 plus R e 2 into Beta plus 1. That is the current that is going to be pumped into this, in this direction. This is the current now. That is again going to be Beta multiplied here. Beta times that is the current here. So, we get Beta square. This current we have come through and this current is going to be totally going into this, because this is short. So, this will be totally going into this, in this direction.

So, when this is going like this, this current is coming like this. This will come like this and therefore this will go like this. And therefore, the current gain is negative. Now, look at this current here. If I i is here, the current in this is Beta plus 1 times I i out of which, portion of the current gets added to this. So, the direction is in the same manner.

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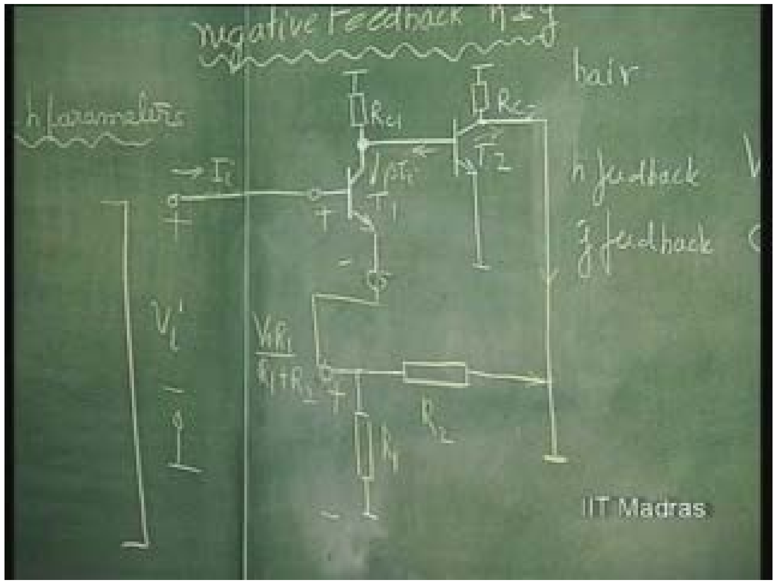

So, minus R 1 by R 1 plus R 2 times Beta plus 1 times I i. So, this contribution is due to the feedback network. This contribution is due to the amplifier. It is dominant. You can see Beta squared appearing here. So, this may be negligible, because there is an attenuation and just only Beta plus 1 here.

Now, that part is over. h i amplifier h f, that is, h i composite, h f composite, these are evaluated. Now we to have to evaluate the other two parameters.

For that, we make this open circuit and apply a voltage here V naught. So, V naught when you apply here, that... there is no current in this; and therefore, the voltage here is going to be V naught R 1 by R 1 plus R 2. So, there is no current here. So, this voltage is going to appear as the open circuit voltage here.

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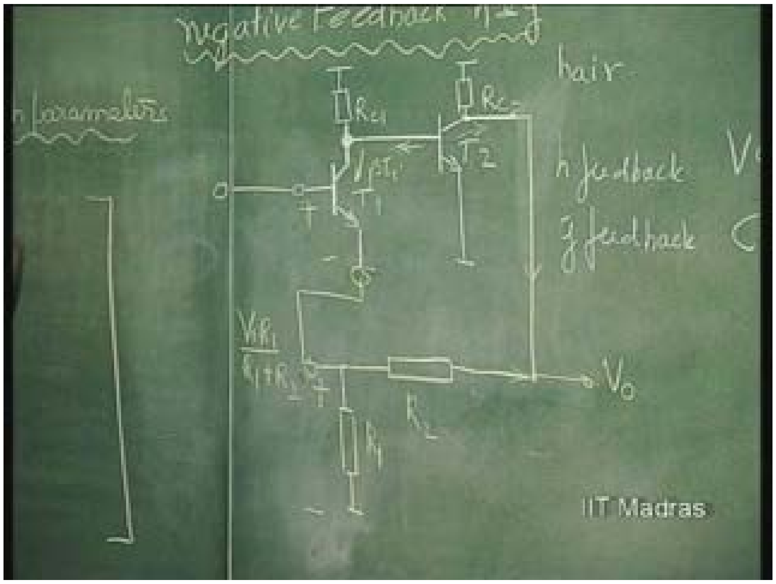

So, this is h r. The fedback voltage from output to input when the input is open is simply R 1 by R 1 plus R 2 times… So, this is h r. Very simple. Then, the output impedance is V naught by I naught here. So, there is R c 2 shunting this. Nothing is happening. This is zero, this is zero. So, these things are ineffective.

So, R c 2 is shunting R 1 plus R 2. So, 1 over R c 2 plus 1 over R 1 plus R 2. So, that is essentially the essentially the output conductance. So, the composite h parameter is very simply evaluated just by looking at the circuit.

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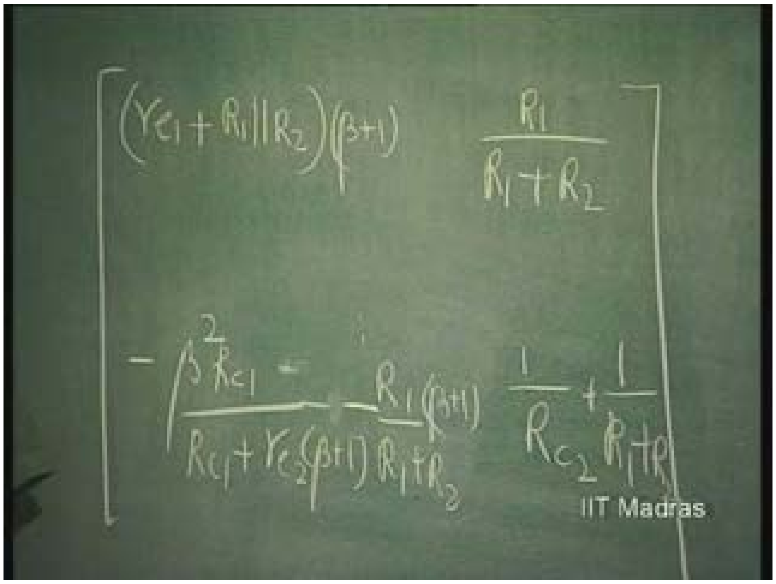

These are the open circuit parameters; these are the short circuit parameters. And, you can see that amplifier does not contribute to the feedback. Only the passive network contributes to the feedback. Here, this is the output conductance of the amplifier. This is the conductance of the feedback network.

So, the loop gain. Since this is Beta square here, this factor we are going to ignore. Let us say, this is neglected. Very small. Neglected because this is Beta square. Here, all can be comparable except r e 1 here, which is very small compared to R 1 parallel R 2, normally. So, we have simplified these parameters now. These parameters will establish the loop gain as negative here. So, this is negative feedback. This into this divided by this into this is the loop gain.

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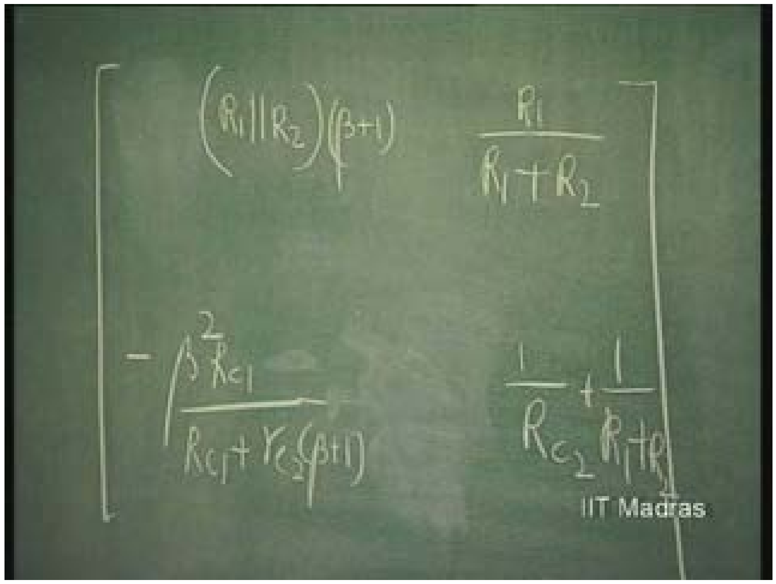

So, minus Beta square into R 1 by R 1 plus R 2 into R c 1 by R c 1 plus r e 2 Beta plus 1. That divided by R 1 parallel R 2 into Beta plus 1. This into 1 over R c 2; 1 over R 1 plus R 2. As long as this is much greater than 1, there is good negative feedback here; and therefore, it is a good negative feedback structure. And therefore, it will result in a good voltage control voltage source.

Now, we can once again establish after feedback, what the input impedance, output impedance and forward transfer voltage gain is going to be for this. Now obviously, the parameter of interest will be the g parameter of the structure.

And, in the g parameter, we can establish that the forward transfer voltage gain has to be determined by only the passive network. The feedback factor is R 1 by R 1 plus R 2; and gain has to be 1 over the feedback factor; that is what we have established, if the loop gain is very high compared to 1. So, the gain of this structure has to become g f; it is going to be very close to 1 plus R 2 over R 1 - just the inverse of this feedback factor; 1 over R 1 by R 1 plus R 2. Or, 1 plus R 2 over R 1 should be the thing. And these two, that is g i and g naught should go towards zero. g i, g r, g naught, all the other three should go towards zero.

That we can very clearly establish. The g f is nothing but plus this factor divided by the matrix here. This into this plus this into this. We will do this for a numerical example and show that g f will go towards always 1 plus R 2 over R 1. If this loop gain is, magnitude of loop gain, it is negative for negative feedback; and magnitude of loop gain, if it is much greater than 1, and this go towards this and it reaches an idealized voltage controlled voltage source.

So, the output impedance should, output impedance should go towards zero because it is a voltage source. Input impedance should go towards infinity or input conductance also should go towards zero. So, g i and g naught and g r, all these things will be going towards zero. So, you can establish that this g parameter in fact becomes extremely small, if this loop gain is very high.

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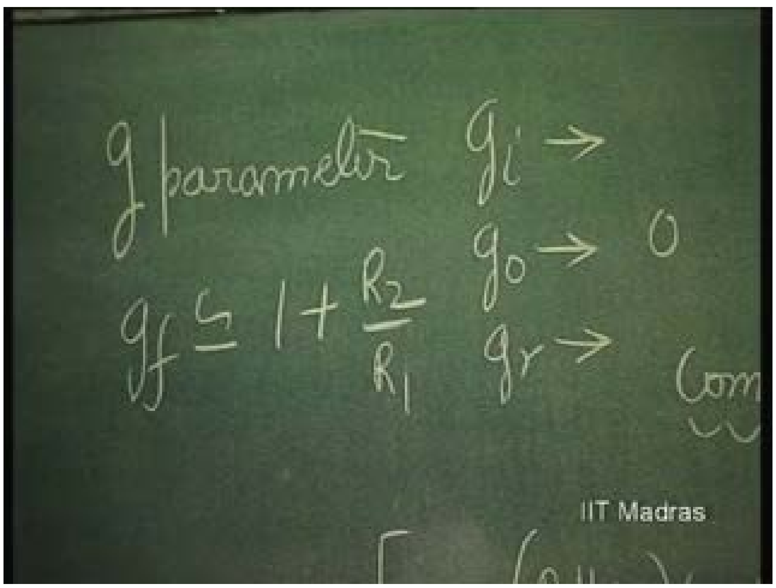

So, let us now consider an example in this h feedback. Example 3. This is the feedback amplifier.

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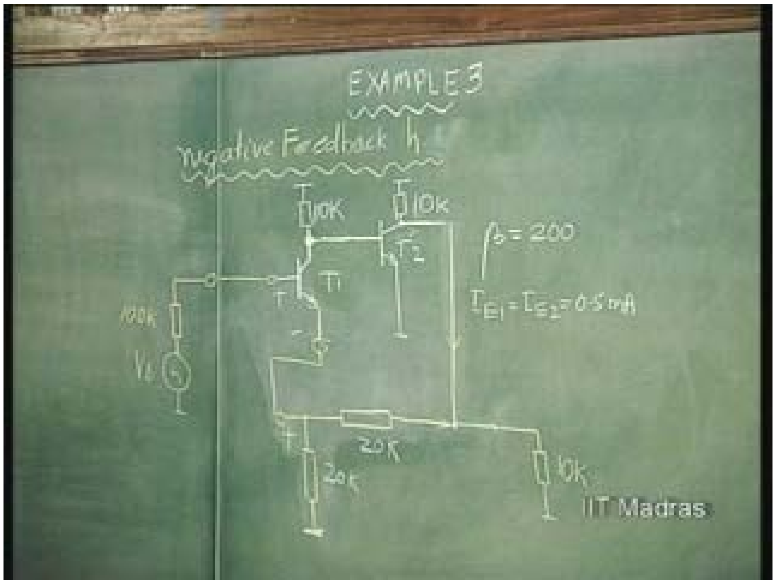

Now we have a source with 100 K, source impedance, and a load of 10 K. So, this is the practical situation. This circuit is the A C picture of the feedback amplifier network. Beta of the transistor equal to 200; and these two transistors are made to operate at a current of point 5 milliampere with the resultant effect r e 1 equal to r e 2 equally, to roughly equal to, 50 ohms. That is, 25 divided by point 5 ohms. So, 50 ohms…

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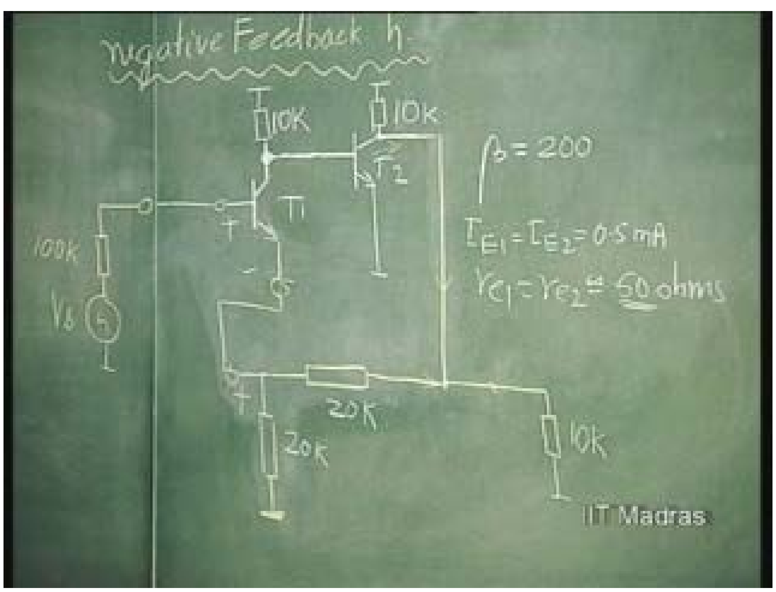

So, the input impedance of both these will be 50 into... r e into Beta plus 1. We will estimate as about 200 itself; which is about 10 K. So, this is offering 10 K. Here also, r e into Beta plus 1 is roughly equal to 10 K. For ease of calculation, these have been adjusted to be so, because the load resistance also is 10 K. Now, let us write down the composite h parameter straightaway.

Once again this will illustrate clearly how to go about writing down the composite h parameter, just by observation. Once again, we short circuit this. So, the composite h parameter of this network now has to take into account both source and the load impedance.

So, we have at the input, a 100 K source impedance plus, obviously, the 10 K which is r e 1 into Beta plus 1; roughly equal to 10 K plus… Then, this is shorted. We have 20 K parallel 20 K which is again going to be two 10 K. So, once again, we have the source resistance coming in series with this impedance. 100 K into… plus r e 1 into Beta plus 1 plus R 1 parallel R 2 into Beta plus 1.

So, this 10 K into Beta plus 1, which is again, 201 or ... So, this is the input impedance of the network; r e 1 into Beta plus 1. This into Beta plus 1. So, we have here now, again, current gain equal to Beta 200; another Beta here 200 square; and this being short circuited, it will go there. Here, there is a current division. This is 10 K and this is 10 K. So, current division is by half. The current here which is, Beta times I i is going to split between this and this equally because the input resistance is 10 K. So, these two parameters are easily evaluated.

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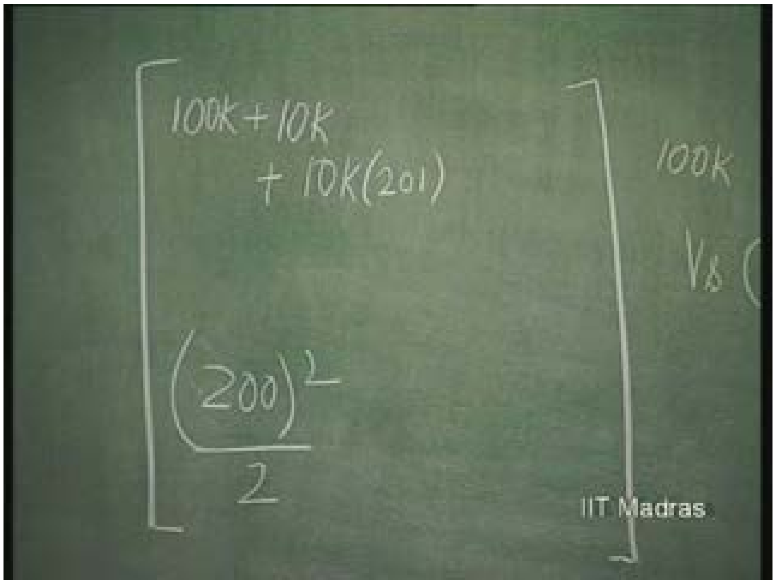

Then, open circuit this and find out the output parameters. When you open circuit and apply V naught here, the feedback factor is half 20 K by 20 plus 20 K, which is half; and the impedance here is 1 over 10 K. This shunted by 40 K plus, of course, this load resistance, which is 1 over 10 K.

So, total admittance at this node: this 10 K, 1 over 10 K, this 1 over 40 K, this 1 over 10 K - total admittance. Here it is total impedance; here it is total admittance. So, that is how… This is the composite h parameter.

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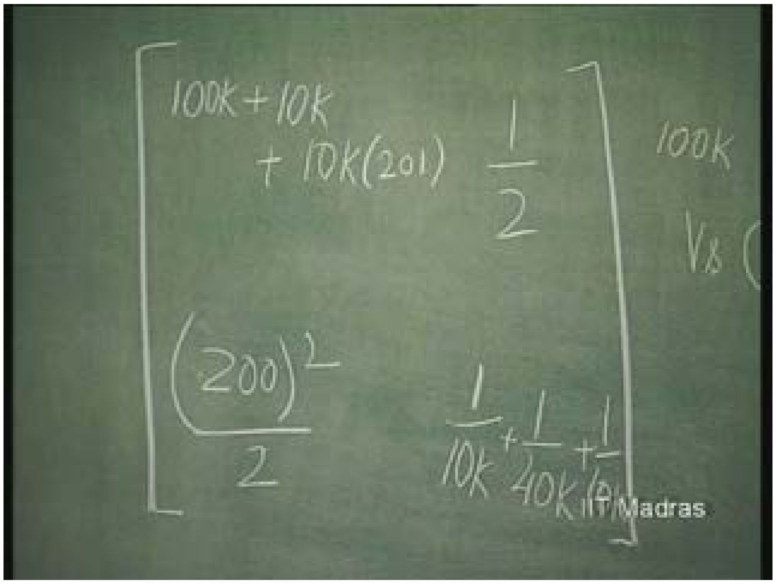

So basically, let us evaluate this. This is going to be 10. This is going to be 20. 20, 10 K. So, 2020, 2120 K. So, this is pretty high. You can see, already. Then, we have this as point 5; this is 4 into 10 to the power 4 by 2. So, 2 into 10 to the power 4. The other factor due to this, which is, Beta plus 1 into half is going to be ignored here. This is going to be added to this. 2 into 10 to the power 4 plus this, with this negative sign; minus 200 by 2, 100; a factor of 100, we are ignoring here.

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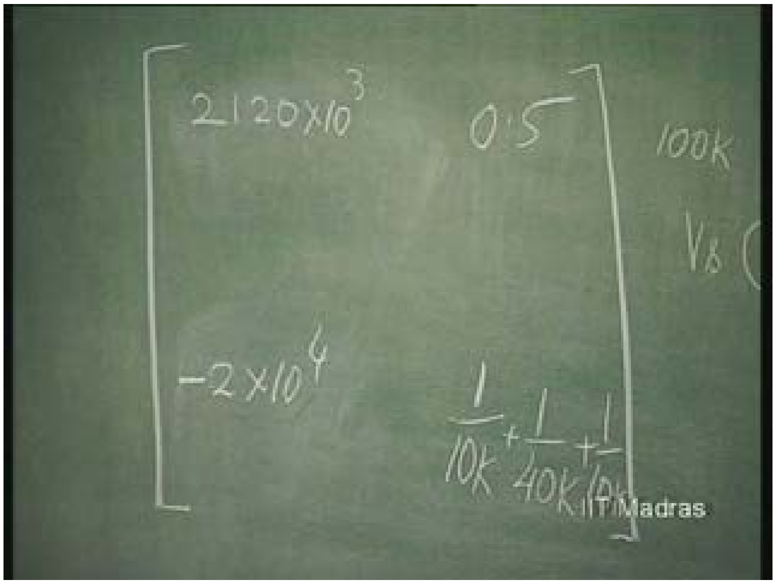

So now, the loop gain is minus 2 into 10 to power 4 into point 5 by 2120 K. So, into 10 to power 3. This is going to give you, 10 to power minus 3. So, that gets cancelled into 1 over 10 plus 1 over 40 plus 1 over 10.

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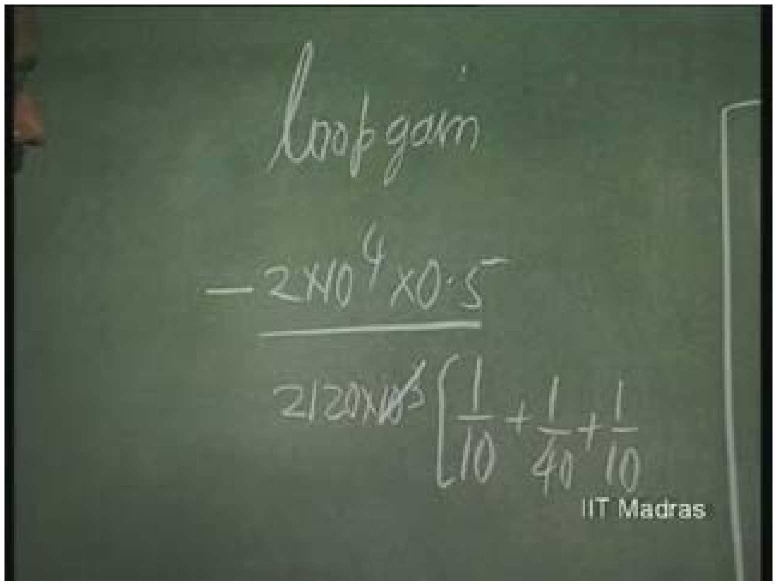

Strictly speaking therefore, it is 2 over 10 or 8 over 40. So, 9 over 40. 2 over 10, or 8 over 40; 8 plus 1, 9 over 40; K getting cancelled with this K. So, this is strictly into 10 to power minus 3. So, we see here, this is getting cancelled with this. This is cancelled with this; and therefore, we have this as 4 into 10 to power 4 by… So, 1908; about 2000. So, this is really equal to, roughly 2000. So, approximately equal to minus 2 into zero. 20 much greater than 1; so the loop gain is much greater than 1. No problem.

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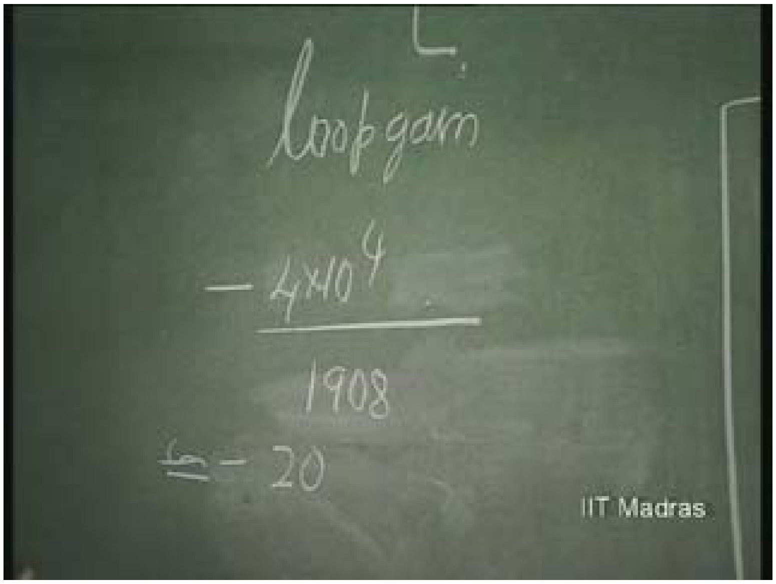

Therefore, we can go ahead with evaluation of g parameter now.

So, we establish that this is resulting in a very good voltage control voltage source. For us to obtain the g parameter, it is… let us find out Delta h here, which is, this into this; which is, 2120 into 9 over 40. That is that factor; plus 10 to power 4. So this, we have once again... So, 10 to power 4 plus ...something like that. So, 10,000 plus 500. 477. So essentially, 10 to power 4 dominates.

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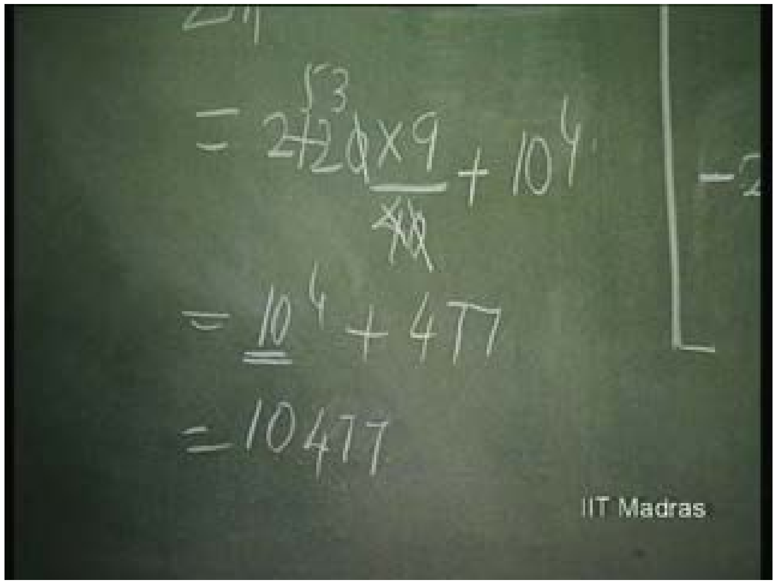

We therefore now establish the g parameter simply by… here g f is 2 into 10 to power of 4 by this 10477, which is very nearly equal to 2. So, this is very nearly equal to 2, slightly less than 2. You can see that. That is what has happened. We had feedback factor of point 5; 1 over point 5 is what is going to appear as g f. 1 over point 5 - 2. That is purely determined by these two passive resistances: 20 K and 20 K. Nice.

Now, let us find out g i. g i is this factor divided by this. Let us say, we will approximate this as 10 to power 4 already. So, this factor which is 9 by 40 into 10 to power minus 3 divided by 10 to power 4.

So, 10 to power minus 7. See, see it goes towards zero. What is it actually? It is nothing but input impedance which is 40 by 9 into 10 to power 7 ohms or 400 by 9 megaohms. This is the kind of input impedance that this feedback amplifier has given you. 400 by 9 megaohms. So, it has become almost an open circuit.

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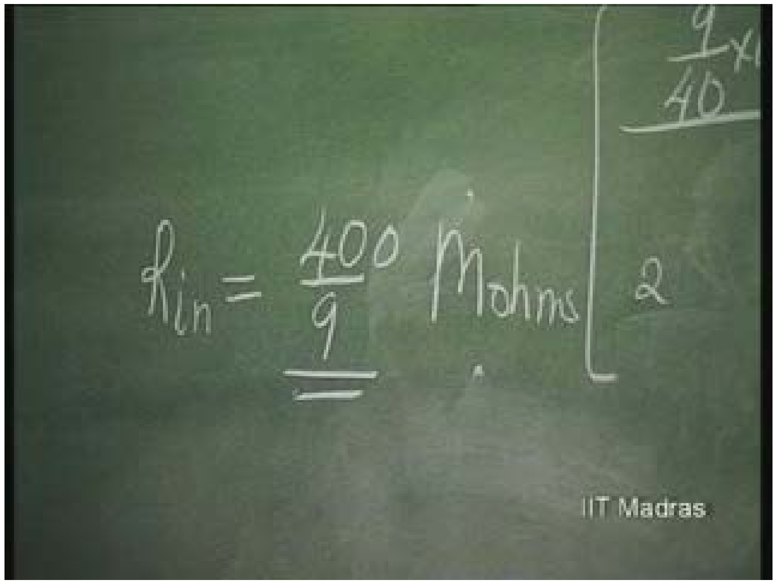

Next, let us see what is the output impedance? That is going to be given by g naught, which is, this divided by 10 to power 4, which is going to be 212 ohms. So, even though we have had an amplifier which uses 10 K and parallel with 40 K and 10 K, etcetera, we have now got an output impedance which is of the order of 212 ohms, pretty low.

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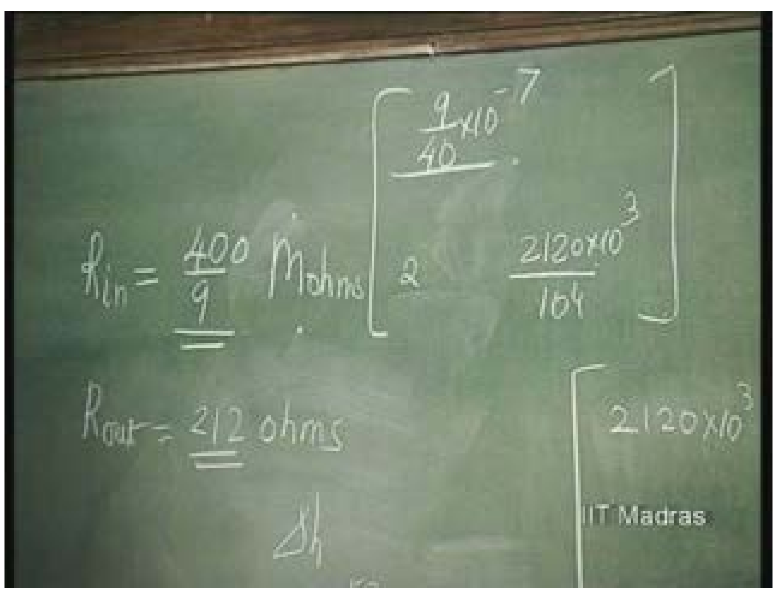

So, the output impedance is going towards zero; input impedance is going towards infinity; or, input conductance is also going towards zero; and this factor, obviously, is minus point 5 divided by 10 to power 4. So, that also has gone towards zero. Point 5 into 10 to power minus 4; or, 5 into 10 to power minus 5. So, all these factors are going towards zero.

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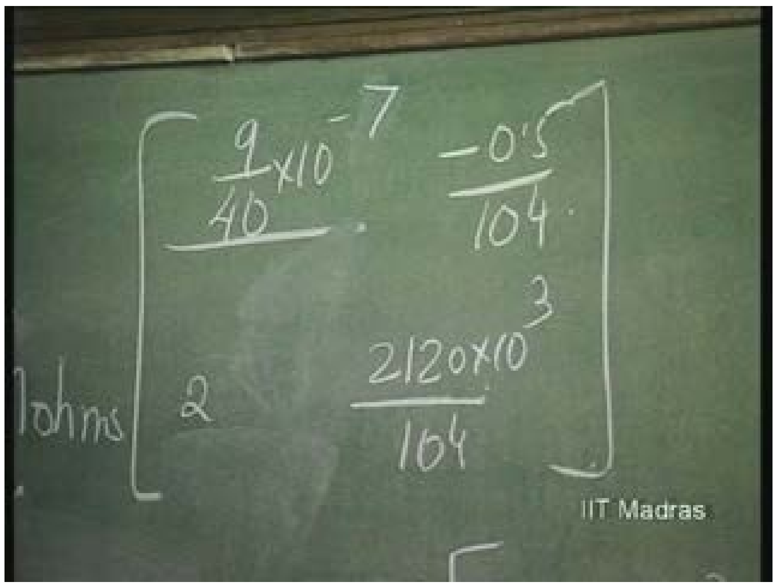

So, this is the important conclusion that we are arriving at when we design a practical voltage controlled voltage source. Now, this input impedance involves this 100 K source resistance. So, if you want input impedance of the amplifier without source resistance, you have to take away 100 K from this. So, that is very simple.

This is of the order of megaohms. Taking away 100 K is not going to influence this much. Similarly, if you want the two output impedances, you have to take away the shunting effect of the load resistance 10 K from this. So, that is also very simple. 212 is the output resistance and 10 K is not going to cause much of a difference in the output, even if you take away. So, it is nearly going to remain as the same value.

So, we have now seen how we can design a good voltage control voltage source with stable gain with high input impedance and low output impedance.

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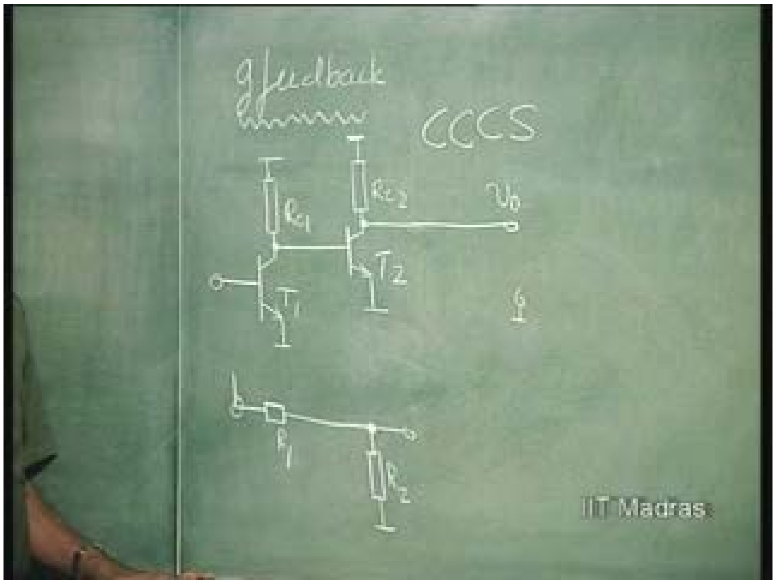

We just saw how h feedback results in idealized voltage control voltage source. Now, the dual of that is g feedback. That should result in current control current source. Now, we once again take the cascaded amplifier T 1; Amplifier T 1 with collector load of R c 1 is cascaded to amplifier T 2 with collector load of R c 2; and then we say, it is current control. That means input impedance should come down; current source output impedance should go up; things should be in shunt at the output.

So, this is the feedback network. It is in shunt at the output, common. Voltage is common to both and in series at the input. That means, I lift this and connect it together; lift it and connect it together in series. So, the output current is common to both; right here, for the feedback network and all. So, the feedback network remains the same; R 2 and R 1. The current here is going to be taken and is going to get divided based on this kind of relationship here between R 1 and R 2.

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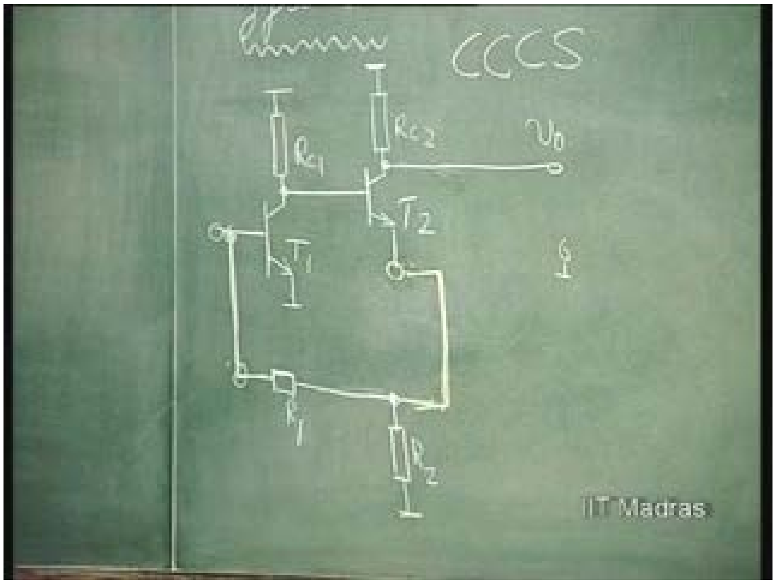

So, g parameters have to be chosen; which means, you open circuit the input and open circuit the output and short circuit the input for obtaining the respective g parameters and evaluate g i composite g parameters have to be determined. You open the output, measure the input conductance, which is due to the amplifier as well as the feedback network and then short the input and measure the feedback factor here. If you short, the output current is going to be split between R 2 and R 1; and therefore, the feedback factor is, once again is, going to be divided by R 2 by R 2 plus R 1.

So, there is going to be feedback factor only determined by the passive network and output conductance also can be evaluated here. Ultimately, you must have, since the feedback factor here is R 2 by R 2 plus R 1, that current at the output is going to be divided between this resistance. This is already shorted here. So, R 2 by R 2 plus R 1 is what is fed back as the current. So, this is the feedback factor and therefore 1 over this is the current gain. So, you have to obtain the composite h parameter or h f from the composite g. So, then it will be 1 over this, as the gain. 1 plus R 1 over... That will be the current gain, from here to here.

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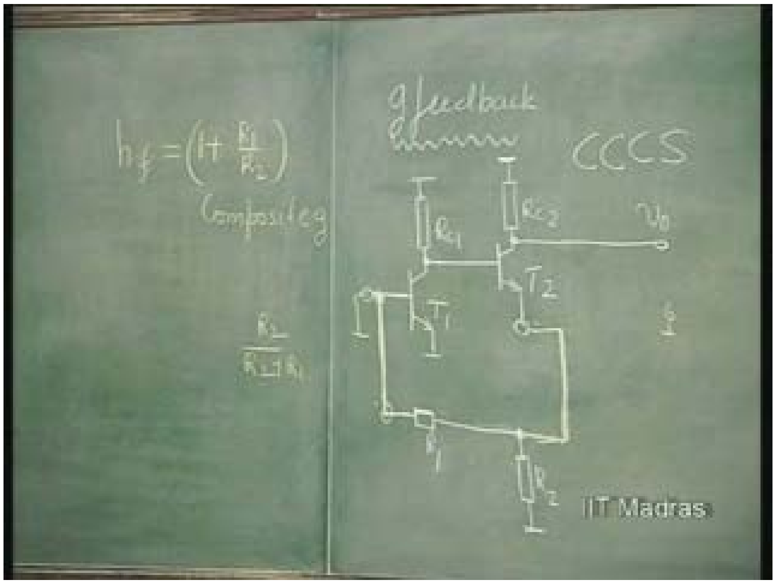

And what happens to the input impedance? It comes down. Output impedance should go up. Or, in the h parameter, h i, h r and h o, all these three things should go towards zero. Only h f should get stabilized at a value of 1 plus R 1 over R 2.

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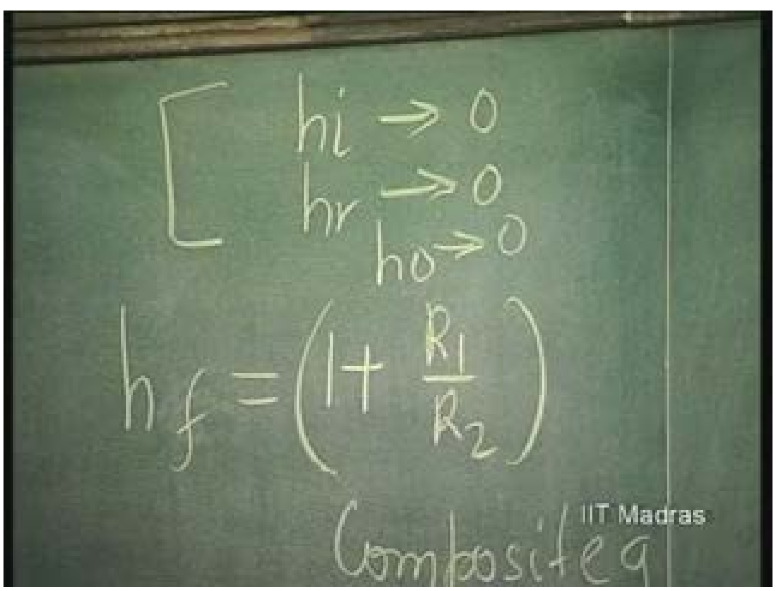

I am going to leave this as an exercise for you. Just as we did in the case of h parameter, please find out the composite g parameter here. In the h feedback, we found out the composite h parameter and then converted into h. Here, find out the composite g and then convert it into h; and establish that the current gain is 1 plus R 1 over R 2. Now, this completes, essentially, realization of all the idealized sources.

Now, there is another way of obtaining voltage control voltage source and current control current source. These are not really basic sources, as I had mentioned about this in the first part of my lecture. You can obtain voltage control voltage source and current control current source by cascading... Voltage control current source cascaded with current control voltage source will give you voltage control voltage source. Current control current is... that is, current control voltage source cascaded with voltage control current source will give you current control current source. So, this results in voltage control voltage source. This results in current control current source.

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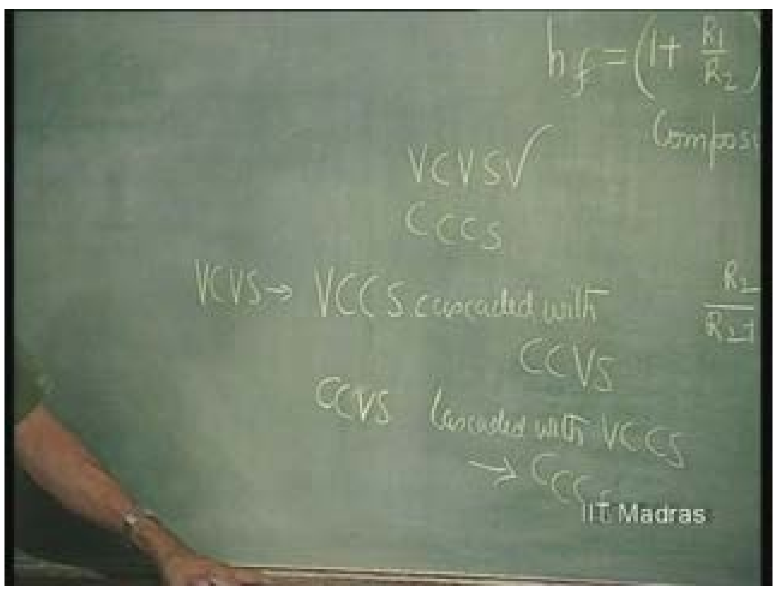

So, if you are able to develop good voltage control current source and good current control current voltage source, that is sufficient. You can realize all the idealized sources. That is, voltage control voltage source, current control current source, current control voltage source, voltage control current source; whereas, if you realize good voltage control voltage source and current control current source, you cannot realize the other two sources by simple cascading. So, these are basic sources; current control voltage source and voltage control current source; these are basic sources. If you realize this, then by cascading, you can realize this.

So, we know that, for example, by giving z feedback - this is z feedback - we are able to realize voltage control current source. This, we had discussed in the last class. By giving y feedback, we are realizing current control voltage source. And now, if I cascade these...at the input it is voltage control; at the output, it is a voltage source. So, I am going to realize this, cascaded together. This is going to realize a voltage control voltage source of gain, now, let us see.

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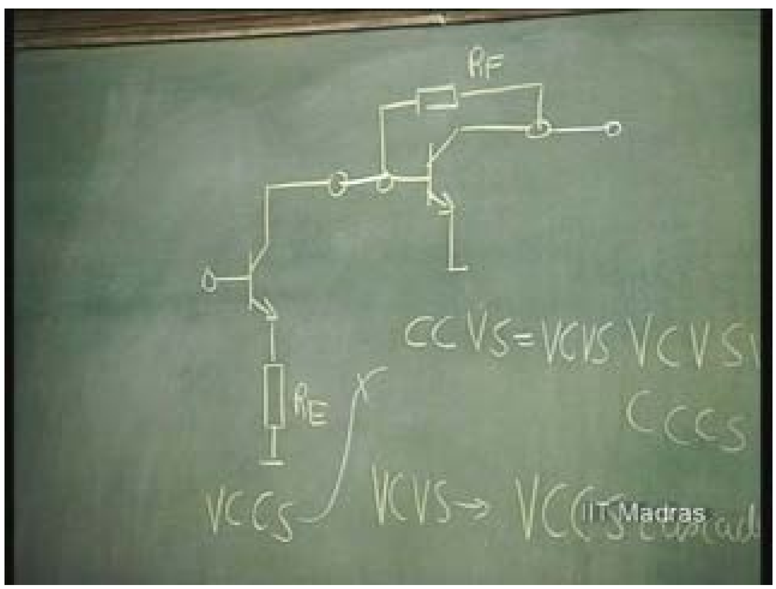

If I apply v i, this v i is going to result in a current of v i by R E, approximately, because this small r e is going to drop very little bit. So, this current is going to be emitter current. This current is going to be collector current; almost nearly Alpha times that. So, this is also v i by R E. So, if this is v i by R E here, we have seen in our earlier this thing that this whole of this current is going to flow through R f only and result in a potential here, plus minus of V naught is equal to R F into v i by R E. So, we get a voltage gain of R F over R E.

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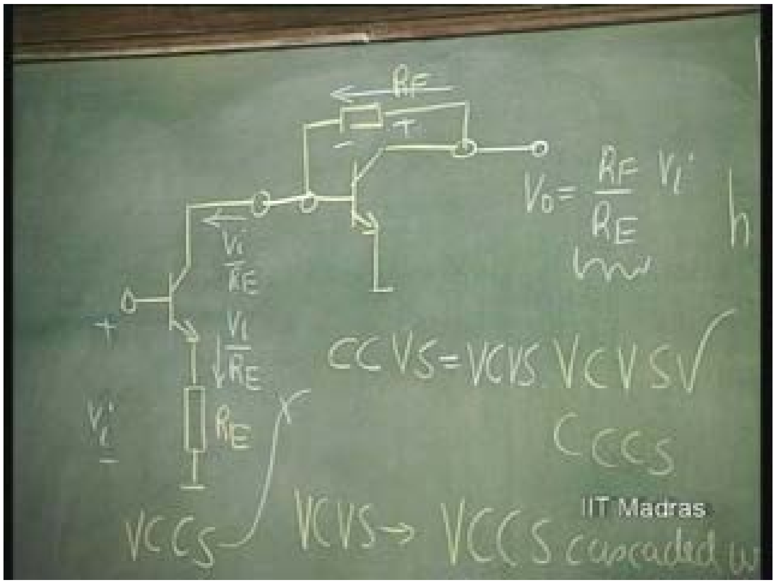

So suppose R f is 10 K and R E is 1 K. You are now designing a nice voltage control voltage source of gain equal to 10 without taking request to the h feedback with the pair that we had earlier discussed. Similarly, you say, I want a current control current source; not this. Then, what you do is simply put this first. R F. So, put this first. Current control voltage source put first and then you put this later.

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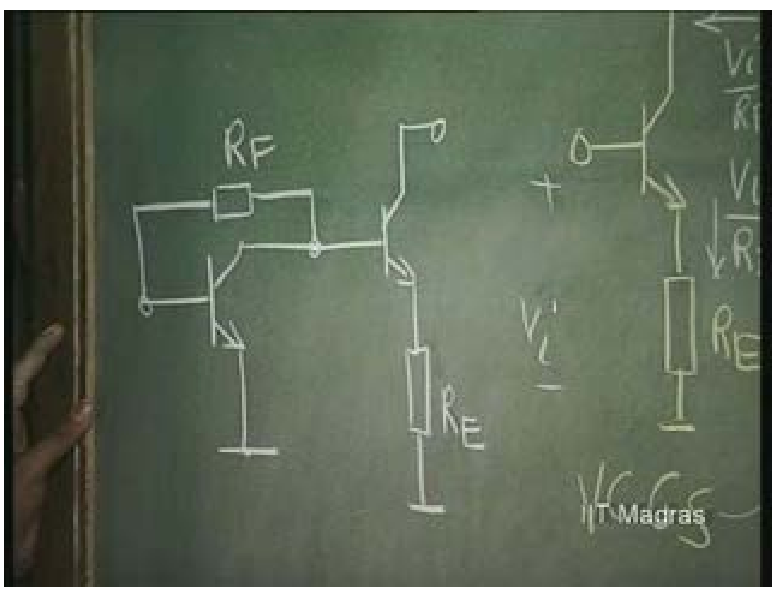

Now, once again, if this is I i, the voltage that is developed here, all this current will go through this as I i into R f. So, the voltage is I i into R f, this way. This is minus and this is plus; this voltage is then nearly zero. So, the output voltage is I i into R f; and this is going to result in... this is plus and that is minus. So, a current in this direction of I i R f divided by R E. So, the current will come out. I i R f divided by R E. So, output current is going to be I i R f by R E. Once again, if I pump a current here, this is going to establish the potential here, plus minus this way. Minus here, plus here. This will force a current in this, in that direction. This voltage which is I i R f divide by R e and therefore output current I naught is going to be I i R f by R E.

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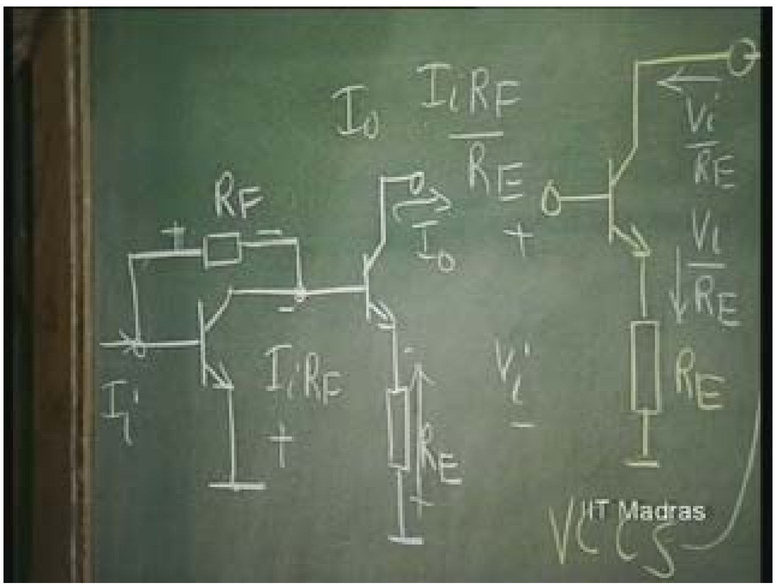

So, you have now have established a current controlled current source here with a gain of R f over R E. So, you see, these two networks are not networks with overall feedback. Here, this current control current source has overall feedback. Two transistor amplifiers are cascaded first; and then, the output current is fed back to the input using this network. Here, it is not done that way. These have local feedback; two local feedback structures are coupled together. So, that is the difference between this structure and this structure. This local feedback and overall feedback have their own advantages and disadvantages.

Obviously, the first advantage here, which is very clear, is that since you are cascading two amplifiers, the loop gain is always going to increase, compared to one amplifier. So, the loop gain of more number of stages will always be higher than the loop gain of less number of stages; that is obvious.

So, the sensitivity to pair active parameters is going to be less in overall feedback structure compared to local feedback structures, where the loop gain is just that of the individual stage. So, the sensitivity to active parameter is going to be more here; but we will later see that there is a great advantage in local feedback in terms of trouble free operations at high frequencies because, as you increase the number of stages, we get into the problem of oscillations.

Negative feedback turns itself into positive feedback beyond a certain frequency; and the circuit, instead of amplifying, is going to oscillate. This, we will later on discuss. So, it is not always advantageous to simply cascade amplifiers and then give overall negative feedback. As a cascade amplifier, the individual time constants will cause a delay in the whole structure and what you are considering as negative feedback will turn. The phase shift will change in such a manner that what you consider negative feedback at a certain frequency will turn itself into positive feedback; and that is a danger.

The positive feedback with loop gain greater than 1 will cause what is called as instability in amplifiers or oscillations. So, this kind of configuration for more than two pairs is definitely dangerous.

This pair gives you problems if the loop gain is pretty high; but, if you add one more stage of amplifier, it will make it a triple instead of a pair. Then definitely, it is rare that such a circuit straightaway works without, what is called, frequency compensation. We will discuss these effects of high frequency and effect of delay in individual stages at a later point. That is also very important.

So, we always restrict our operation, if possible, to two stages. When we go to three stages, we encounter several problems in the operation of the amplifier satisfactorily. So, overall feedback is mainly restricted to two stages; and a rare cases, one can go to three stages; but then there is bound to be problem.

Now therefore, we have discussed almost all negative feedback structures using transistors. Same thing can be discussed using field... instead of bipolar junction transistors, we can replace them with FETs. The same analysis is valid; same conclusions will also be valid. So, we are not going to do this except that may be at a later stage, we will work out certain problems with FETs being used. I would like to, at this juncture, bring in the operational amplifier that we have already ((... Refer Slide Time: 48:05)) to construct.

Operational amplifier is nothing but controlled source with power transfer parameter being very high. It could be voltage controlled voltage source, current controlled current source, voltage controlled current source or current controlled voltage source. So, any of these four categories can become operational amplifiers.

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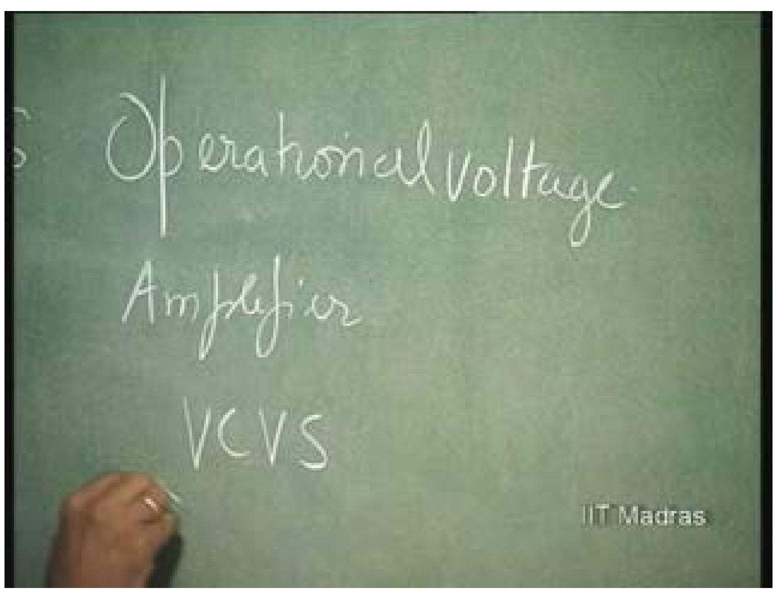

The conventional operational amplifier, which is very popular like that of 741 or 747, is a voltage operational voltage amplifier. That means, it is a voltage control voltage source, with what kind of parameters we are talking of? h parameter. Ideally, this is zero, this is zero, this is zero. Sorry. This...this is a voltage control voltage source, g parameter. g i is zero, g r is zero. g naught is zero. g f is going towards infinity.

If it is a current control current source or a current operational amplifier, then you have h parameter of concern. This is zero. This is zero. This is zero; and h f goes towards infinity.

If it is a transconductor type of amplifier, then the y parameters are the ones that have been taken, which is zero, zero, zero; and y f goes towards infinity.

If it is transresistor type of amplifier, that is, the z parameter is what is talked about; and here this is zero, this is zero and this is zero; and it is z f which goes towards infinity.

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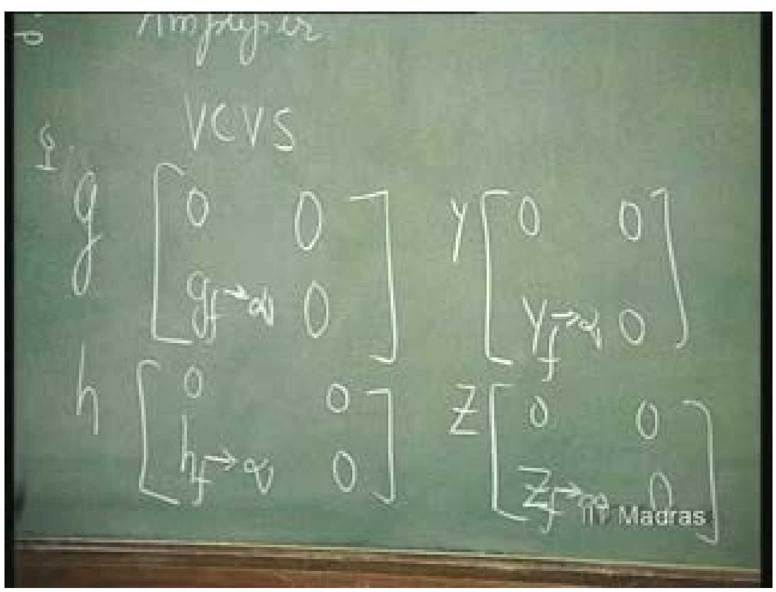

So, these are the four types of op amps which can be made available. This is the popular one. These are becoming popular now; and therefore, it is necessary to know that one could use any one of these four and still come up with applications of the same type. So, we will discuss this in the next class; how to design negative feedback configurations using operational voltage amplifiers - that will be the topic of the next class.