Analog ICs

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Audio Power Amplifier and Norton's Amplifier

Lecture - 18

So in the last class we discussed about different instrumentation amplifier strategies. Continuing our discussion about amplifiers, in today's class we will discuss something about some other special purpose amplifiers like audio power amplifier and another general purpose amplifier called Norton's amplifier. These are the two topics that are going to be discussed today. So let us see the strategy adopted in all these amplifiers. We will see some kind of similarity between this and whatever we have done so far.

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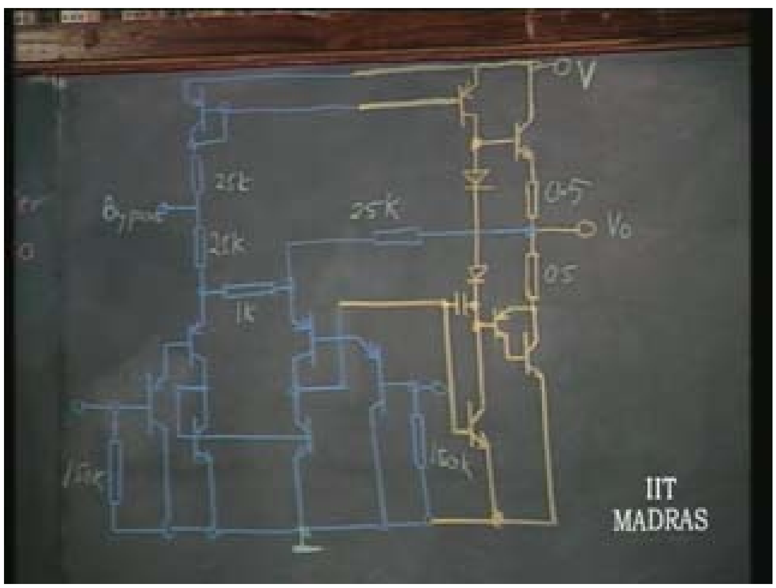

This is supposed to be a voltage amplifier. And obviously the input stage is again the good old differential stage and since it is going to be designed for a specific gain namely the feedback amplifier. It is true that this is a differential amplifier input stage with negative feedback. We have to only identify the various blocks which we have earlier recognized in various amplifiers.

Let us now identify the differential amplifier input stage. This operates with single supply and self biased. So single supply self biased audio power amplifier is what we are going to discuss now. This is the active input stage, you can see the buffer stage here, these two will be acting as the buffer and the primary pair is here and this particular thing is nothing but the active load and you can see the diode here getting reflected. So this is similar to the input stage we have earlier discussed except for a small difference here.

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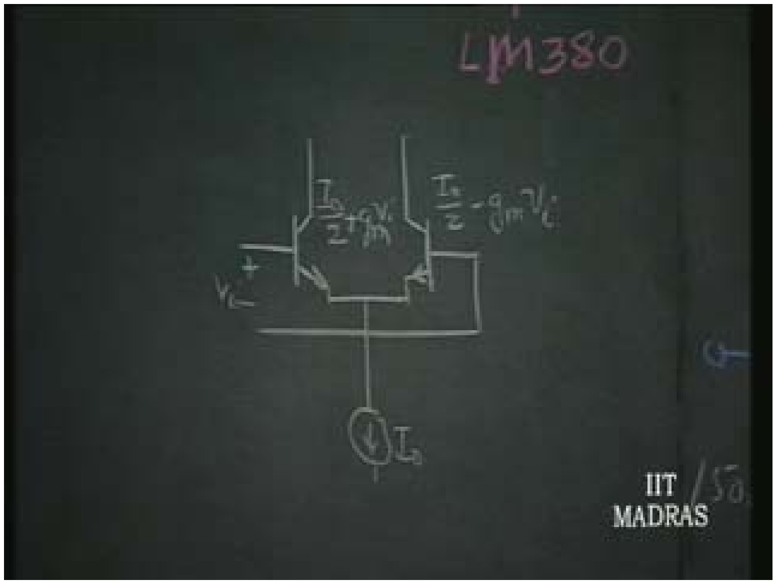

Earlier we have been discussing about differential amplifiers like this. There will be a current source here I_0. The idea is when you apply a voltage V_i this will carry I_0 by 2 plus gm times V_i this will be I_0 by 2 minus gmV_i. This aspect we had already discussed.

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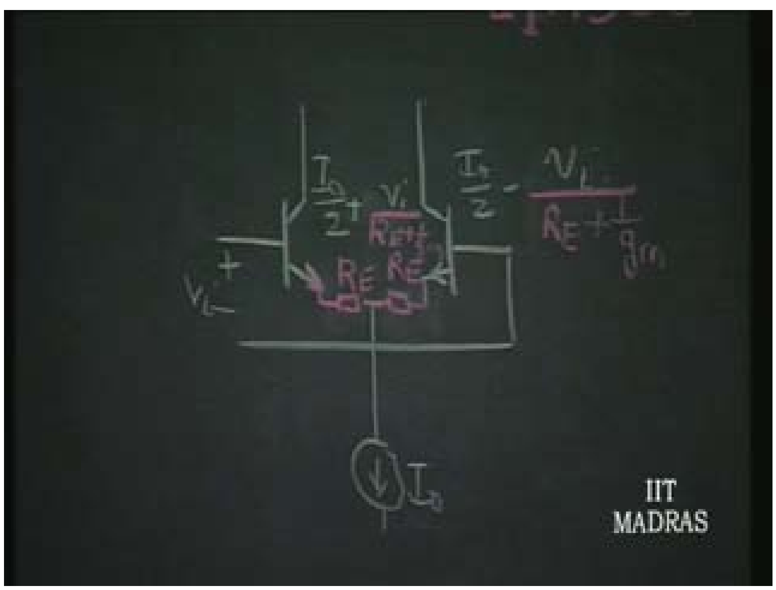

Obviously if we want this gm to be independent of the active device then we can put in series with these physical resistances called emitter degeneration resistance. That means it becomes a feedback structure R_E. So what happens is, this gm now gets transformed to V_i by R_Es plus R_E 1 by gm so it gets modified as this.

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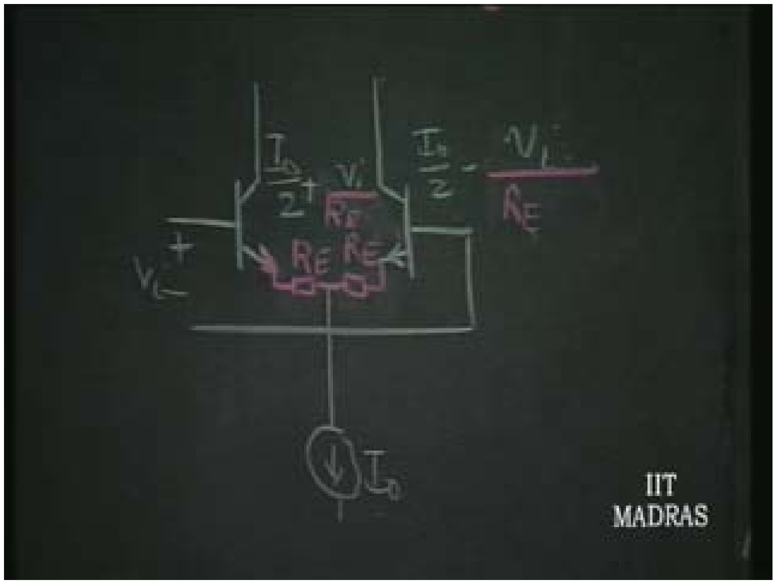

Therefore we can design in such a manner that this becomes negligibly small. So we are able to produce from a differential input voltage a differential current output with the common mode current equal to I_0. So here it is I_0 by 2 plus V_i by R_E and I_0 by 2 minus V_i by R_E so this is nothing but a transconductor stage whose conductance value is going to be pretty stable and is going to be equal to 1 by R_E. So you can say this is transconductor amplifier. The differential input voltage and differential output current is obtained by feedback here. Now it is important that these R_Es must be the same in order to produce a common mode DC current.

So how do you do it in an IC?
This can be done easily instead of relying upon matching of resistors relying upon matching of currents this way. The same thing can be affected by removing this arrangement.

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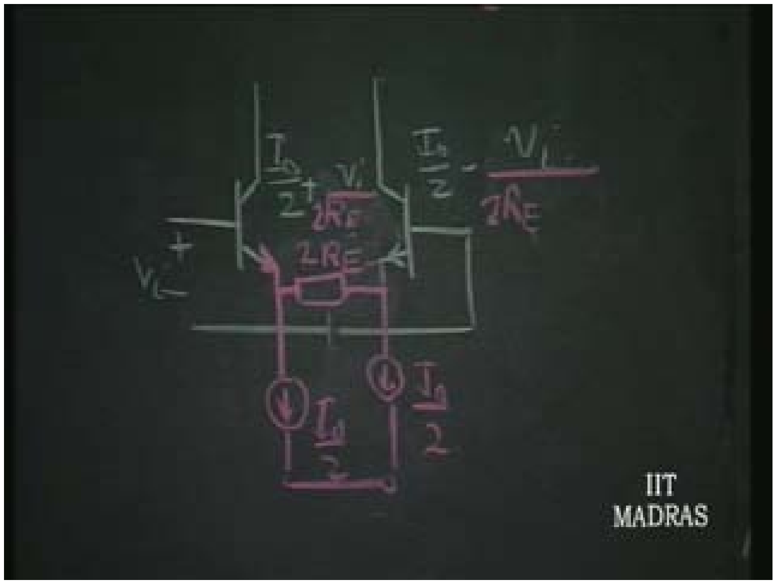

This can be now removed and we will replace this region by a resistance which is $2R_E$, R_E is removed and then we put here this current which is I_0 by 2 and this current here also equal to I_0 by 2.

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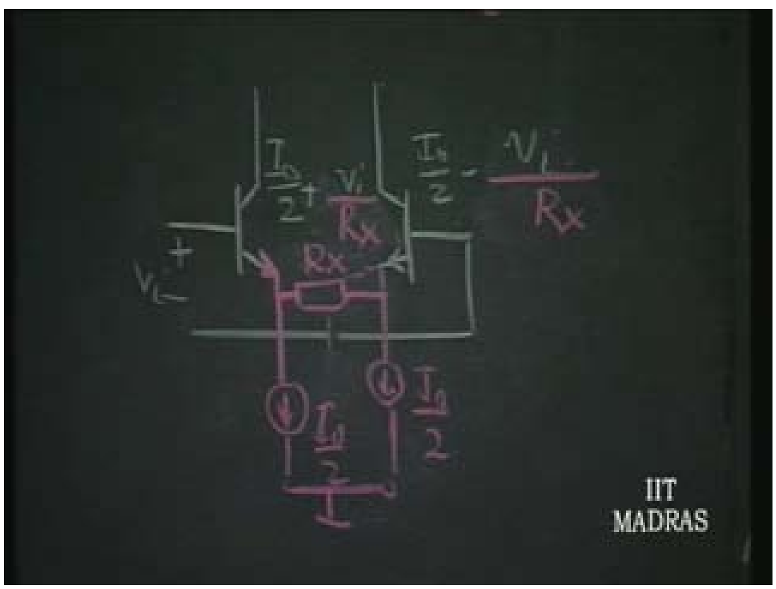

Earlier this thing should have been $2R_E$ so V_i by $2R_E$ plus 2 into 1 by gm. You simply replace this by $2R_E$. Or actually speaking it is a single resistance because there is nothing like two resistances separately here. Now this is V_i by R_x. So this is again a differential arrangement where whatever differential voltages applied here corresponding to that only the signal current will be coming. So you have common mode voltage here and there will be no signal current here.

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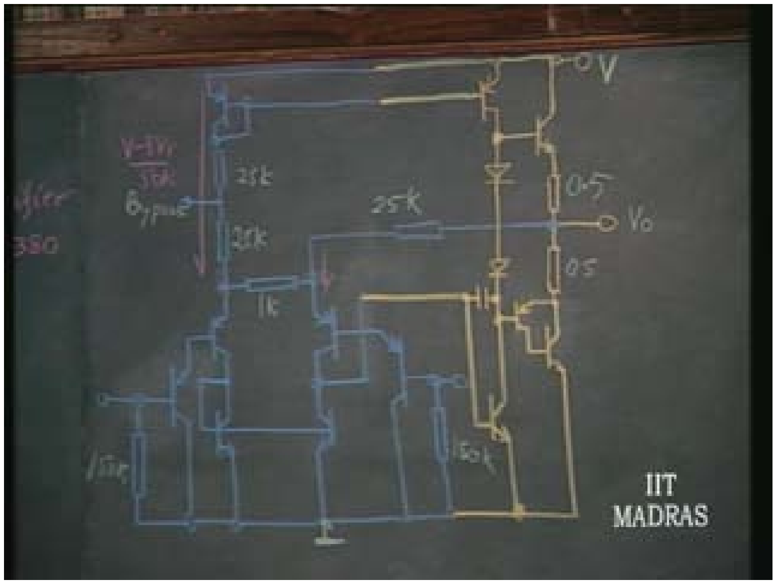

So this is the strategy adopted. You have equal current sources and now this can be used for negative feedback mode of operation etc. This is nothing but a differential amplifier which is perfectly symmetric, imagine this is 25k, 25k with diode to the ground then there is 25k and something else like that. So this is the place where the negative feedback is effective to the input stage.

If you are applying an input at one point and to the other point you can give the feedback so the actual input to the amplifier is the current input minus the fed back voltage. Therefore the current input minus the fed back voltage can be effective. That is how you can adopt a strategy like this using emitter degeneration resistance. It is no different from the differential amplifier except that a physical resistance occurs coupling the two emitters. Therefore there is negative DC feedback also from this. So operating point of the whole structure is going to be determined by negative DC feedback here. Assuming that these two voltages are the same so the differential input voltage is 0 then these two potentials are going to be the same and therefore there should be not be any input voltage. Therefore these two currents will be the same.

These two voltages are same and there is no current in this so these two currents are the same. If these two currents are the same what will be this current? It is V 1 diode 2 diode 3 diode so V minus $3V_{gamma}$ by 50k is the current here. It is V minus $3V_{gamma}$ neglecting the dropping, assuming that the beta of the transistors are high, V minus $3V_{gamma}$ by 50k is the current.

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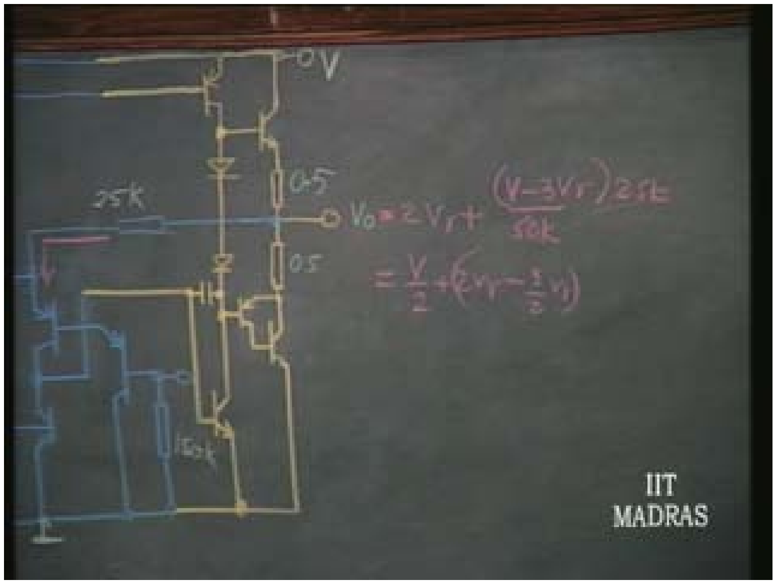

Therefore what is the current in this?
The current in this is the same. So what will the voltage V_0? It is going to be $2V_{gamma}$ plus the drop in this which is nothing but V minus $3V_{gamma}$ by 50k into 25k which is nothing but V by 2 plus $2V_{gamma}$ minus 3 by $2V_{gamma}$ almost negligibly small, $0.5V_{gamma}$. So, essentially this is a strategy of biasing the output at almost half the supply voltage. Irrespective of supply voltage the bias point is going to be at half the supply voltage so that the output swing is the maximum possible.

This is the audio output stage here. So it should operate for the maximum possible output swing. So you are now capable of getting the maximum possible output swing by locating yourself at half way between these two as far as the operating point is concerned. And as far as the negative feedback for the signal is concerned once again we will adopt the same strategy we adopted earlier. That is, for signal operation we can consider that the midpoint of this can be grounded.

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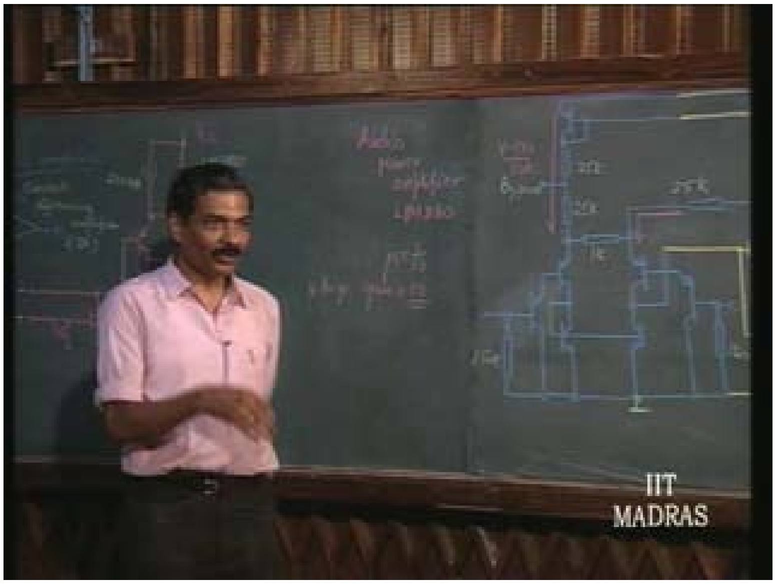

That means the feedback factor is 500 ohms and 25k which is going to give a gain because beta of 1 by 50 or a voltage gain of 50 assuming that the open loop gain is very high. Now, for the entire state as you know the component value, assuming beta is equal to 200 evaluate the open loop gain as well as loop gain of the structure and show that the gain is very nearly equal to 50.

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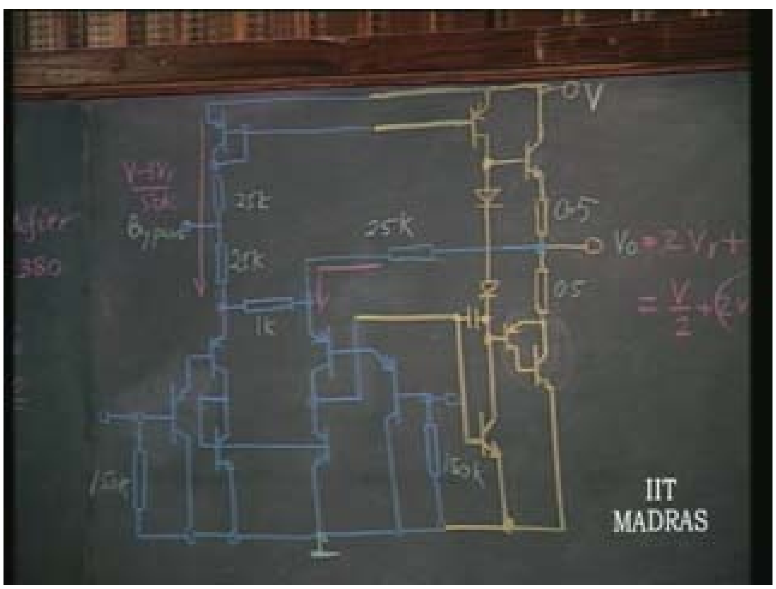

Once again you can find out the input impedance etc from the same strategy. It is going to be effectively, what is the input impedance? It is the effective emitter resistance here. Essentially emitter resistance is made up of only 1k and beta beta so it is beta power 2 and of course 150k will be shunting that, the V_1 V_2 here. So it is this 150k and this 150k. Now, as far as the output is concerned, once again we have the same push pull stage. The intermediate is again the same common emitter stage. So you have a differential input stage, intermediate common emitter stage and an output stage which is biased to class ab mode of operation. So the topology is similar to that of the operational amplifier topology but it is used for a specific feedback application. So you have a compensating capacitor here once again between the output and input of the intermediate stage for compensating frequency instabilities.

Then here this is another strategy which is commonly adopted, this is the NPN stage and we should have a PNP here which is a bad PNP that is available. So, in order to make it good you are now adopting the Darlington pair that is possible connecting PNP to NPN. Effectively the gain of this is controlled by the NPN beta the current gain rather than the PNP. So this is commonly adopted in most of the output stages pairing a bad PNP with a good NPN so as to make the current drive capability of this as well as that almost identical. So we have the provision for some amount of short circuit protection there for current sensing because this has to operate for higher power here so this can tolerate higher current leakage.

This is typically one of the most useful audio power amplifiers using single supply and also you can see here, the voltage level required to drive this input is going to be very small. And the voltage level can go both positive and negative because it is going to be very small. The voltage drive can go slightly negative also in spite of using single supply. This is a very nice advantage associated with this single supply stage where the operation is such that we can go both positive as well as negative slightly by about almost 1 diode drop negative and that much is sufficient in order to give large output swing.

This is LM380 commercial audio power amplifier which is available. Here in order to make it appear symmetric for the AC purpose you are grounding the midpoint of this 25k AC wise. So if you ground here AC wise this is going to be symmetric as far as AC operation is concerned. Therefore the bypass point is brought out here so the capacitor is connected externally.

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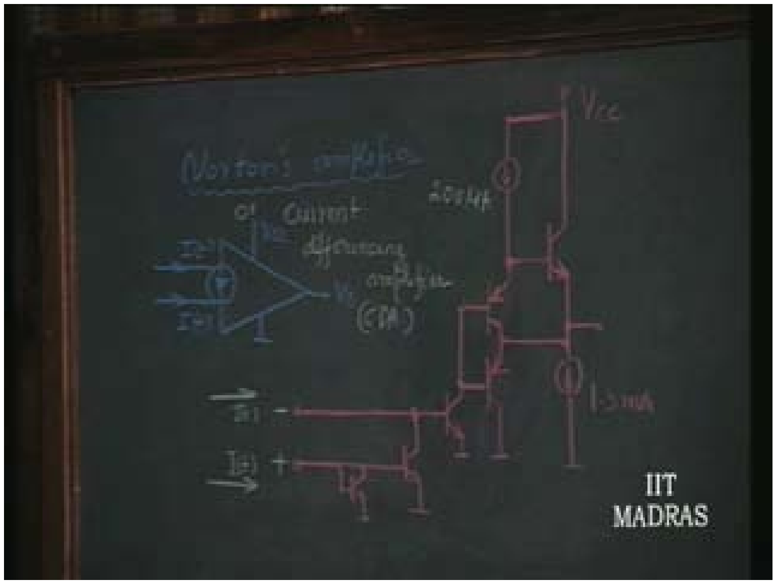

Now let us discuss about a very interesting general purpose amplifier called Norton's amplifier or Current Differencing Amplifier CDA. The amplifiers we earlier dealt with were primarily dealing with voltage difference V_1 V_2 being the two voltages applied to the two terminals then V_1 minus V_2 was intended to be amplified, that is the difference amplifier we had discussed and almost in every stage we thought of we had used that concept.

Here it is the dual of this, why use V_1 minus V_2 as the difference input signal instead we will use the dual which is I_1 minus I_2 or I minus I plus or I plus minus I minus the current differencing. The difference between two currents I_1 and I_2 I_a and I_b is the one which is amplified and fed as input to transistor in case which is automatically amplified by beta times gain beta times may be another transistor stage etc and appears as an output voltage. So this is called Norton's amplifier or Current Differencing Amplifier CDA and this particular thing is manufactured by National Semiconductors LM3900 and Motorola also manufactures this particular Norton's amplifier current differencing amplifier. But anyway the strategy employed is totally different.

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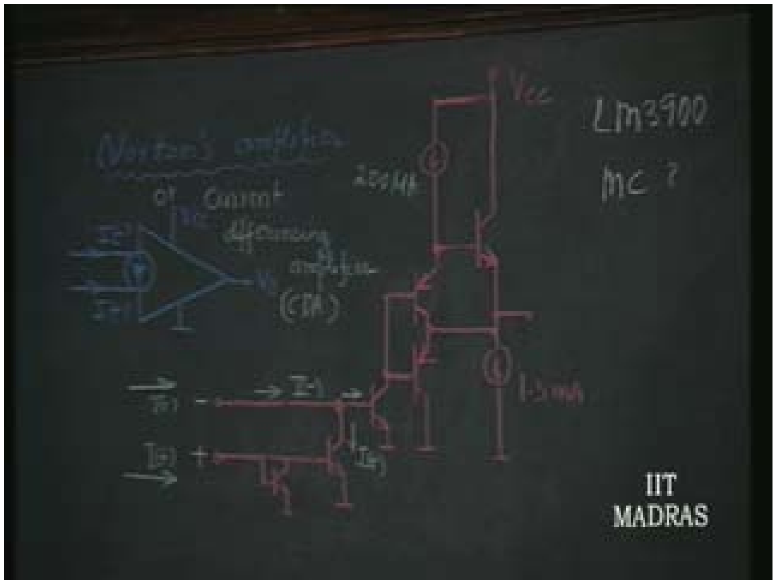

Again it is the current mirror input stage which is responsible for achieving this kind of current difference as coming as input. We have a current mirror at this point which is going to get I plus as its input current, this is the diode and therefore the current here is going to be always equal to, because of this diode since it is sensing I plus this current will be always I plus and since the other terminal gets automatically current of I minus the input current into this direction is going to be I minus I plus or current drawn out from this is I plus, I minus. So this is the essential feature of the current differencing.

Obviously the voltage between these two points is very nearly 0 because this is a diode and this is another diode so the voltage is going to be maintained very nearly 0. Whereas in the earlier situation the current input to this stage was 0. When we had V_1 minus V_2 as the input signal it was drawing a very little input current. Here when we are pumping two currents I plus and I minus, it is taking across it a very small voltage difference. So this current difference is going to be beta times multiplied here and further amplified by further transistor amplifiers and appears at the output, this is the output stage here making it appear as an output voltage.

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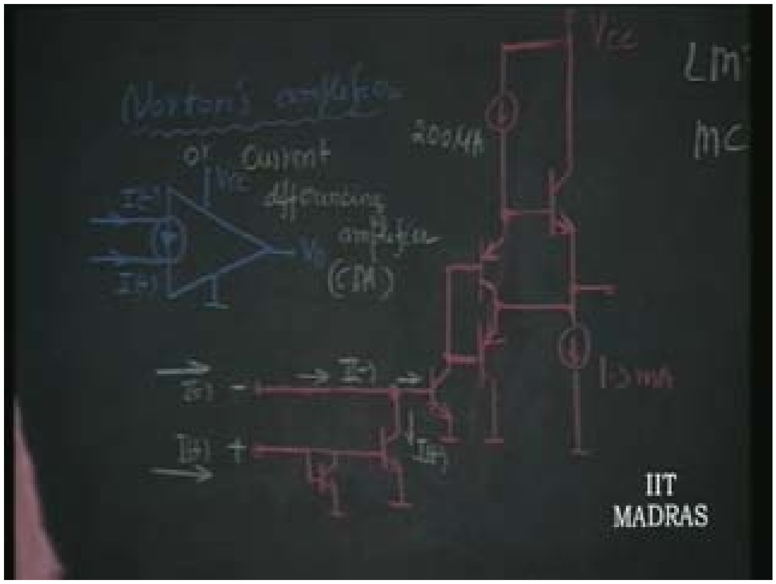

These are the operating currents of these stages. This is the output stage operating current and this is the intermediate stage operating current. So this also has a current differencing input stage, intermediate stage and an output stage. So you can see the three stages again appearing in this operational amplifier.

The advantage of this over 741 is this, both these, the Motorola and National Semiconductor op amps have this advantage because it is the current gain you are ultimately looking for, this performance of this open loop gain etc is going to be independent of power supply. And the power supply can range from pretty low values may be 5 to 6V to 20 to 24V range. For the entire range you can use this without its parameter changing much and it uses single supply. Therefore this is the cheapest amplifier available for most of the single power supply applications.
It has become quite popular.

The only thing is, you have to look at it slightly differently when compared to what you were doing earlier, what is this difference? How were we looking at an op amp? The op amp was used in a negative feedback situation and when it is used in a negative feedback situation if the op amp gain the open loop gain is very high, then we said the input voltage V_1 minus V_2 becomes equal to 0, it becomes a nullater, nuller, 0, the input voltage becomes 0.

Now, in this particular case the dual of that should happen. What should happen? The input current difference should become equal to 0. In a negative feedback situation the two input current should become equal to one another. If it is used in a negative feedback situation in the voltage differencing amplifier the two voltages would have become equal if the open loop gain goes towards infinity. Here if the open loop gain goes towards infinity the two currents will become equal. And also, you know that at what DC potential this is going to be. Strategically you can find out that this DC potential is going to be always one diode drop above the ground potential at the input.

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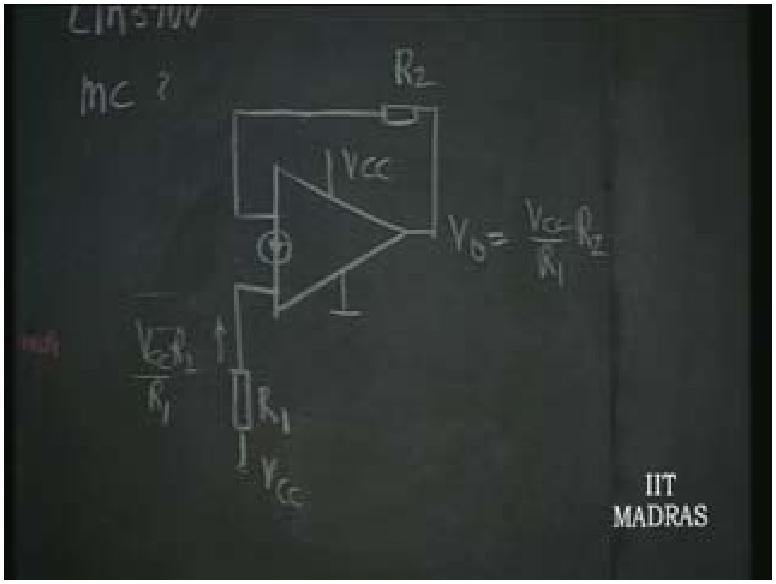

So it is very easy for normal design of this circuit in a negative feedback interval. Now what V_0 becomes equal to? The current here is going to be V_{cc} by R_1 it is V_{cc} minus V gamma by R_1 whatever it is, so V_{cc} by R_1 and this current should be same as that and that into R_2 is the output voltage. This is one way of biasing it DC wise. So you can make the bias point at any point you want. And this to be the quiescent point, if you want it to be half you can accordingly select this.

Now, apply an AC signal and capacitively couple it at this point so that you can inject whatever current you want into it. Then summation of all those currents will flow through this and appear as signal current at the output. You can extract it again by decoupling it by means of a capacitor. So the strategy adopted is exactly similar to the voltage amplifier except in making it operate at a quiescent point which of interest to you depending upon the signal swing you would like to have at the output.

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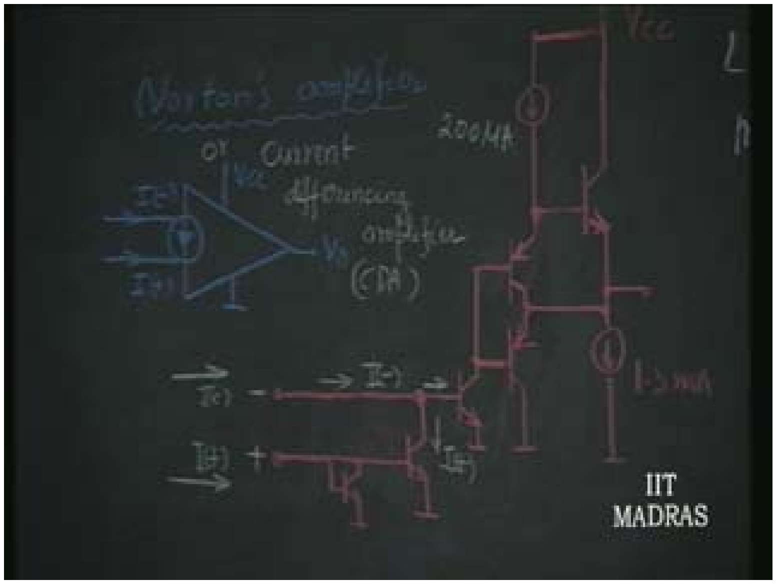

You can use it in almost all the applications where in you can use the conventional general purpose operational voltage amplifier. The symbol for the Norton's amplifier is like this, this is indicating that it is a current source; this is the current source kind of a thing. It is the current difference that is fed as the input and the current difference between these two input pairs. The other amplifier which we already touched upon is making use of the principle we enunciated in the introductory lecture on translinear principle. That is, you can take a differential input current as the input and keep on amplifying it by using what is called Gilberts gain cell. And these cells can be put one over the other.

The advantage of this strategy is once again, you can keep on amplifying the signal in terms of current alone having retaining the signal swing very small. It will be only of the order of difference in two diode drops. Maintaining the signal swing very small you can keep on amplifying the current difference and when you reach the required power level of current you can pump it on to the load that you decide upon.

This is another strategy. The advantage of this is, it is useful for wide band applications because you are dealing only with current swing here and voltage swing is maintained very low that means capacitors need not be charged. So, in wide band amplifier application where you want the gain of the amplifier to be stabilized without negative feedback, in all these cases you saw that voltage gain becomes stabilized only with negative feedback. Whereas there in the current amplifiers using Gilberts gain cell you saw that the current gain is stabilized already in the open loop only in terms of ratio of the operating currents. Therefore that is another strategy adopted in amplifier design. You can design such amplifiers as wide band current amplifiers.

We have so far discussed input current difference as the input to a Gilberts gain cell. If you want voltage difference to be converted into current difference you can adopt the same transconductor using emitter degeneration. That will convert a differential voltage into differential current and there after you can keep on amplifying it. So, transconductor is first used converted into differential current and then the Gilberts gain cell is used which is successfully operating at higher and higher currents. And then when you require the highest current difference then again that is made to go through two resistors and converted into voltage.

These are the varieties of amplifiers available in the market. It is not exhaustive but it is only representative of the different types that can be made possible. In the next class we will discuss something about the other active elements necessary for filters, integrators, differentiators etc. It is not the operational amplifiers but basic active elements themselves can be straight away used, how we can make them become relatively independent of earlier parameters which are sensitive to temperature etc and how we can use those active parameters themselves in a variety of application will be discussed next.