Analog ICs

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

Lecture - 08

IC Negative Feedback Wide Band Amplifiers (Single stage)

In the last class we discussed about wide band amplifiers which used pairs without any feedback. And we came out with a very important configuration called cascode configuration for the wide band. We had other configurations like common collector cascaded to common base, common collector cascaded to common emitter and things like that. So, in this series of lectures we will discuss about negative feedback and its use in wide band. Therefore ultimately we will go to negative feedback wide band integrated circuit amplifiers.

Let us now just revise our knowledge about negative feedback. We had seen earlier that negative feedback has to be given cautiously. In case negative feedback is likely to turn itself into a positive feedback and result in oscillation it is a dangerous thing because we have to cut down the oscillation by introducing dominant pole and that will cut down the bandwidth further. If at all we in use negative feedback the negative feedback amplifier should not need any frequency compensation. That is the condition of negative feedback that we must utilize in wide banding.

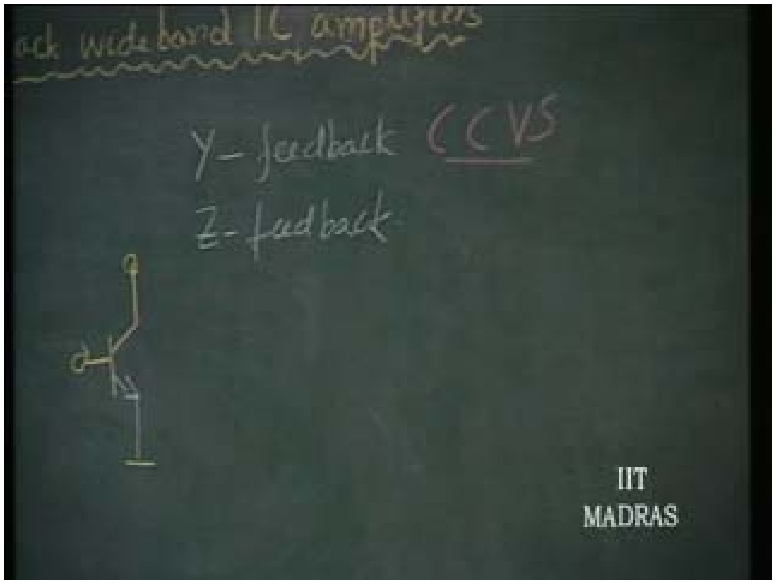
We have seen that any negative feedback system which has three or more dominant time constants will invariably result in serious problem of oscillation. Only systems which are less than third order that means only first order and second order systems will not oscillate when used under negative feedback. So the best system therefore is the one that is simplest first order system. But we know that a single stage amplifier for example, a common emitter amplifier has two time constants namely the input time constant and output time constant. So the minimum order of a single stage itself is going to be 2. So, if we cascade more number of stages we are landing ourselves in more problems because the order of the system will increase above 2 it will become 3 or more.

Further the loop gain is also going to increase. The consequent need for frequency compensation becomes more serious. Therefore the best negative feedback configuration for wide banding is a single stage. Now, how do we have the negative feedback arrangement for a single stage, let us consider. If it is a single stage transistor we know that only two types of negative feedback will be valid. What are those? Out of h y z g type of feedback what are those which are possible in a single stage which will result in negative feedback?

It is y and z type of feedback. So we know that only y feedback and z feedback are the allowed types of feedback if it is to become negative. What is the purpose of this type of feedback, the y feedback? What happens to the input admittance and output admittance?

Input admittance is increased. That means input admittance is made to go towards a higher value as possible. The output admittance is going to be increased. That means it is leading you towards idealization of current control voltage source, this type of amplifier. So this is going to lead you towards current control voltage source.

(Refer Slide Time: 06:32)

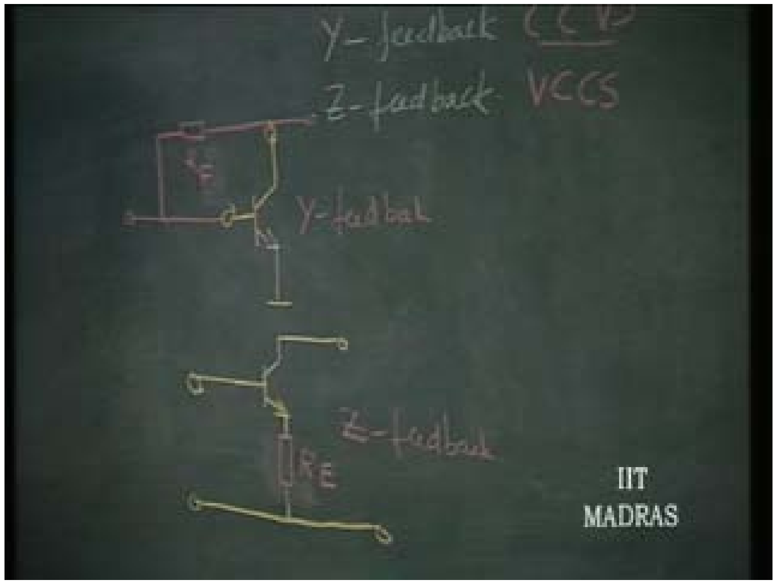


The dual of that is voltage control current source. That is nothing but z feedback. Voltage control current source is the dual of that. That means if I put z feedback input impedance is going to increase and the output impedance is also going to increase and therefore it is going towards an idealization towards voltage control current source. Now this is important.

What is idealization?
The forward transfer parameter corresponding to that type of source is going to become desensitized with respect to active parameter. If it is y feedback the type of feedback structure is going to be this. This is y feedback. About z feedback you have the same configuration like this but it will come in series at the input and series at the output. Therefore what we have here is nothing but the feedback element, the z feedback. You will call this R_F.

Now what will be the transfer parameter that is going to be desensitized in this particular case?
It is the relationship between current and voltage so it is the forward transfer resistance because I_i is the input current let us see and this I_i is going to flow through R_F totally and result in a voltage which is Ii times R_F with ground terminal being positive and output terminal being negative that means there is an inversion.

(Refer Slide Time: 08:43)



Therefore V_0 is going to be I_i minus I_i times R_F. This I_i will be going through this totally, a very small current is going to flow through the transistor amplifier and most of it will flow through R_F due to Miller effect where R_F is going to appear as R_F by 1 plus AV where AV is the voltage gain of the stage that means it is going to act like a short circuit. If AV is very high most of the current will be pumped into rs. So this current will flow through this and develop a voltage which is minus I_i into R_F and therefore forward transfer resistance is nothing but minus R_F.

So it is an input current control voltage source developing a voltage which is equal to minus I_i times R_F. So we have desensitized the forward transfer parameter by this kind of feedback which is nothing but trans-resistance in this case by using y type of feedback. That is known to you. What must be emphasized here is, if you now take the y parameters of the transistor and the feedback network everything put together and evaluate its bandwidth, the bandwidth of forward transfer impedance in this case and then that will also get modified by loop gain. That means this bandwidth also is going to improve by a factor of looping. Everything improves by a factor of loop gain. In a feedback network always we can take for granted that improvement is always by loop gain so the bandwidth also improves by a factor of loop gain.

Therefore this particular amplifier should be used only for obtaining trans-resistance type of amplifier, this type of negative feedback and it will improve the bandwidth of transimpedance. The dual of that is nothing but the trans-admittance that is nothing but the z type of feedback. So that is going to realize an idealized version of voltage controlled current source. In this case you must remember that it is the trans-admittance which is going to have wide banding. Therefore you must know to give the correct feedback to improve the bandwidth of transfer parameter. If you are interested in transfer parameter as admittance then the type of feedback to be given is in turn the z type of feedback and not the y type of feedback.

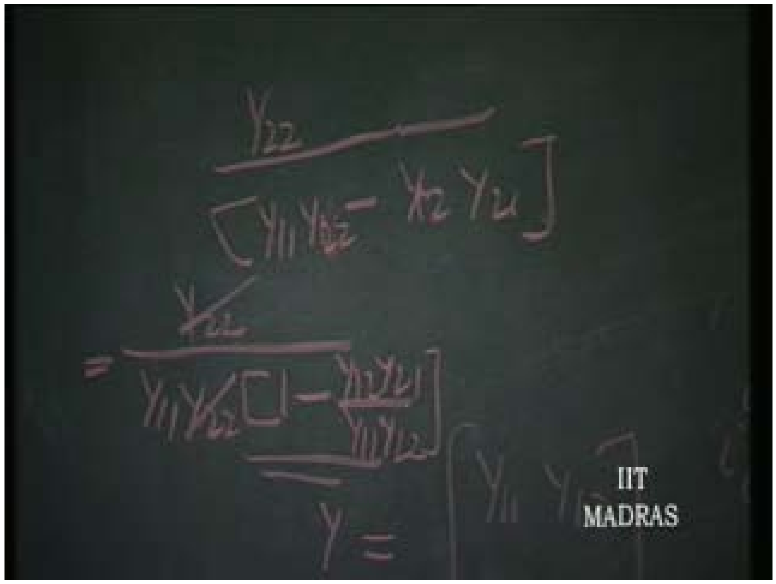
In the case of y type of feedback it is only trans-resistance that will have wide banding effect. In the case of any feedback you are going towards idealization.

What is idealization?
If it is y feedback it is going to become current controlled voltage source. That means the modified thing is the z parameter. If it is y feedback the modified thing is z parameter. In z parameter all the other parameters will go towards zero and only the forward transfer parameter will go towards a smaller value than originally by the extent of loop gain. Going towards the zero of the other parameter is also by the extent of loop gain. In terms of parameters if you remember you will never commit mistakes as to what gets modified and how by what extent. All these depend upon your proper identification of the feedback and what is it that gets modified?

When you give y feedback it is the z matrix that gets modified automatically. All the y parameters will simply add and it is the z parameter that will get modified. Those y parameters will be divided by l_y which will involve the loop gain. Therefore the z parameters will get modified and all the z parameters like z_{11}, z_{12} and z_{22} will go towards 0 and z_{21} will go towards the stabilized value desensitized value and how will this get desensitized? It is because of the loop gain coming into picture and the desensitized value is primarily going to depend upon the feedback component. It is not going to depend upon active device. These are y parameters y_{11}, y_{12}, y_{21} and y_{22} and this is the composite y of the amplifier. Therefore the z parameter is going to be y_{22} by Δy, y_{11} by Δy and minus y_{12} by Δy and minus y_{21} by Δy. This is the inversion of the matrix, the plain mathematics.

Let us take this: y_{22} by Δy? What is Δy?
It is y_{11} y_{22} minus y_{12} y_{21}. If you take this out then it is 1 by y_{11} y_{22} [1 minus y_{12} y_{21} by y_{11} y_{22}]. Therefore y_{22} will get cancelled with y_{22}. And 1 by y_{11} is the original z parameter. It is the short circuit impedance. That is getting modified by a factor of 1 minus y_{12} y_{21} by y_{11} y_{22} which is by definition nothing but the loop gain.

(Refer Slide Time: 17:34)



If you consider this as a voltage amplifier it will be nothing but a by 1 plus a beta factor. This a and beta factor business is all applicable only for voltage whereas in this case it is a general parameter. In terms of any parameter you can say that the parameter that is getting modified is by a factor of 1 minus p_{12} p_{21} by p_{11} into p_{22} where p is called immittance matrix immaterial of what the parameter is. The 1 minus loop gain is defined in terms of immittance matrix immaterial of what the parameter is. It is this loop gain which is going to modify all the factors. If the gain is getting reduced it will also get reduced by the same factor. Similarly this is nothing but z_{11}, now let us do that for z_{21}. Similar things can be done for other parameters.

What is z_{21}?
z_{21} is equal to minus y_{21} by y_{11} y_{22} into 1 minus the loop gain. If the loop gain is very high that 1 can be neglected. So, if the loop gain is very high this 1 can be neglected and it is nothing but minus g_l and what is it?
It is nothing but into minus y_{12} y_{21} by y_{11} y_{22} so you will get this as plus 1 by y_{12} which is nothing but the total feedback factor and no frequency component comes here because y_{12} is nothing but y_{12} of the amplifier which is negligibly small plus y_{12} of the feedback structure which is nothing but 1 by R_F. Since y_{12} of the amplifier has gone very close to 0 or it is very small even with very high frequency the improvement factor comes simply because of that because of desensitization itself.

And if you do this similar thing here, if the loop gain is very high you will note that it is the loop gain which makes this go towards 0 because here also these things will get cancelled with that and it is y_{12} y_{21} product which will make it go towards 0 which is not getting cancelled there, y_{21} is still a large factor assuming that you are using a good amplifier with good forward transfer parameter. In all the other factors this forward transfer parameter will be the one responsible for making it go towards 0. In order to

understand more clearly you have to work out a specific problem and see how these parameters will have the wide banding effect, what will have the wide banding effect?
The forward transfer parameter will have the wide banding effect. In this particular case of our example it is the z parameter the z_{21} which is going to have wide banding effect.

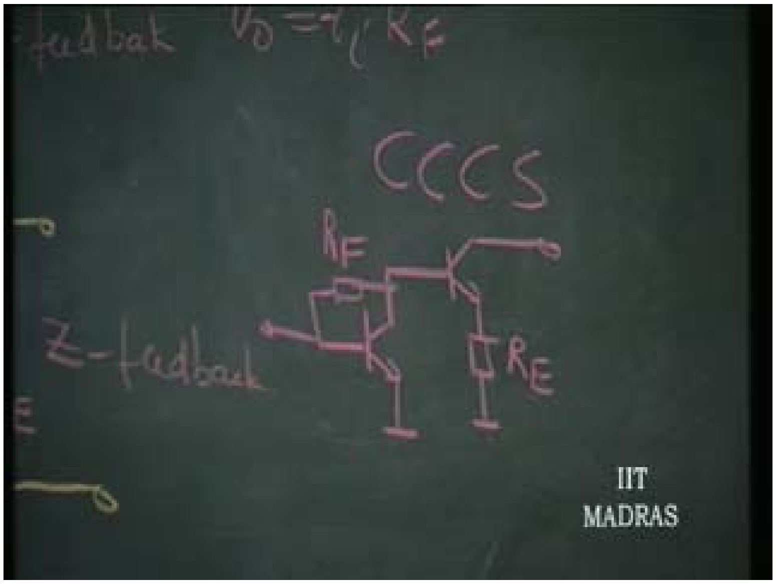
Now the basic things in negative feedback that we should be aware of is, if that is the case the reason we have used a single stage is because it is only in the single stage we do not have more than two time constants and single stage feedback amplifier never becomes unstable. It does not need any frequency compensation. Whatever be the negative feedback it is never going to become unstable because it is at most a second order system. A system is likely to become unstable when it is of the third order or higher, when the loop gain is higher. So in wide band amplifiers we always select a single stage and not multiple stages. Multiple stages will result in serious problems.

A single transistor cascade, cascode is not a single stage, cascode is a pair, a single stage cascaded to another stage, a single stage meaning an active device which may even be a Darlington pair but it is a composite device with three terminals. So that kind of stage is only this for y feedback and therefore the other two do not exist, h and g using a single stage cannot result in negative feedback, it will result always in positive feedback. So h and g feedback do not exist. Then how do I obtain other sources, which are the other sources? The other sources are the voltage controlled voltage source and current controlled current source, how do I obtain?
I obtain them by simply cascading because if I cascade a current controlled voltage source with a voltage controlled current source there is ideal mismatch because this is a voltage source and this is voltage control. There is ideal impedance mismatch, a gross mismatch.

Voltage control means it is an open circuit and voltage source means it is a source impedance of zero magnitude. Therefore there is gross mismatch of impedances. Therefore it is retaining the wide band nature. Now I can cascade these two together and result in current controlled current source, how do I do it?
I put y feedback first then I cascade z feedback. This is the near ideal what current controlled current source of gain equal to, here gain also is retaining its property.

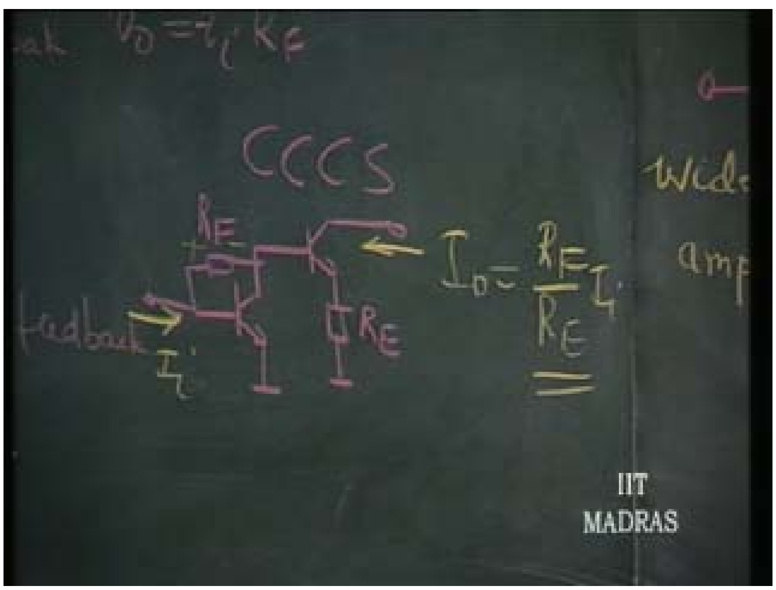
How does it happen?
If I apply a current here the voltage will be input current times R_F and this is going to be directly coming here as I_i into R_F by R_E which is the current, the output current.

(Refer Slide Time: 26:00)



Therefore the current gain is, if this is the input current Ii this current will go into this I_i into R_F and that will be divided by this which means current will be going into this stage and it is going to be I_0 is equal to R_F by R_E into I_i.

(Refer Slide Time: 26:32)



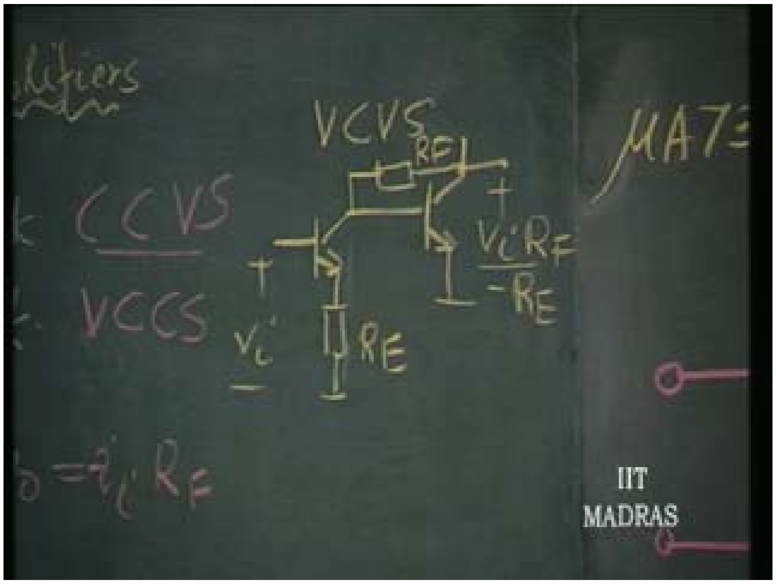
The current is going to be in the other direction or this is going to be minus and the actual voltage is this. So this is a wide band current amplifier of gain equal to minus R_F by R_E.

Now what is the dual of this?

In order to get a voltage controlled voltage source I cascade with, so what happens when I apply V_i here?

The current in this is V_i by R_E and that current will go directly into R_F so output voltage will be V_i by R_E into R_F.

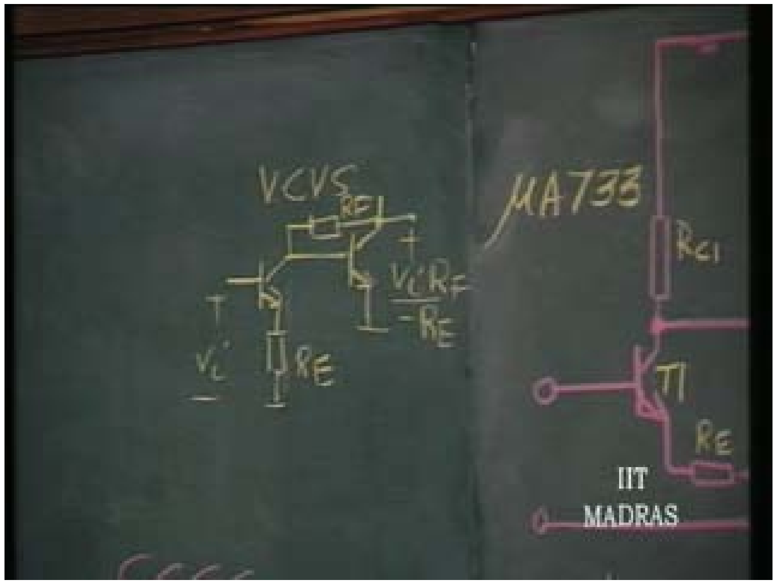
(Refer Slide Time: 27:40)



Again it is a wide band structure. And this is what is utilized in one of the most popular wide band structures called [ ] this wide band amplifier which is called muA733. If I have to convert this into a differential configuration path bias purpose what should I do? If I have to convert this into IC so that biasing is taken care of automatically without the need for bypass capacitors and coupling capacitors then what should I do to this?

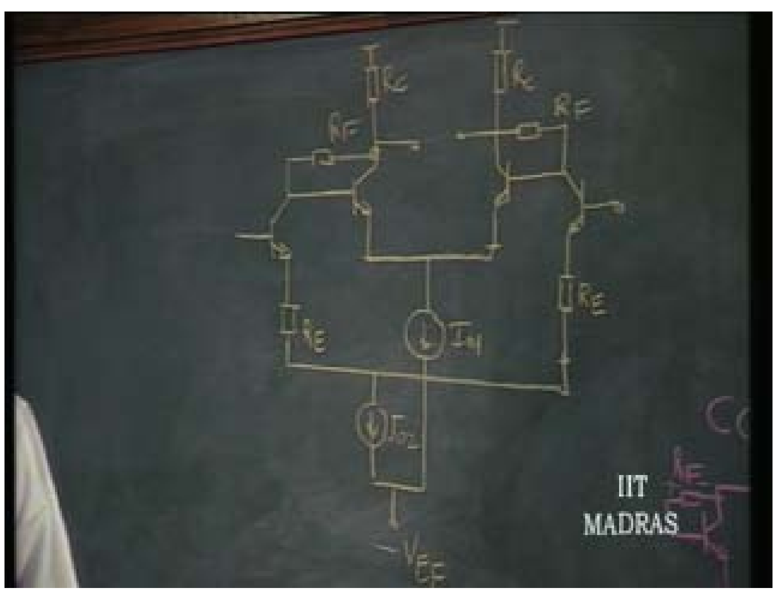
The standard technique for converting this single stage structure into differential structure is to convert it into differential structure from single stage to differential then it can become an IC. Let us see how this can be converted into a differential structure for application in integrated circuit. Now see how we can convert this structure, this is a configuration which has been now chosen based on our basics about negative feedback. Now we want to convert it into an integrated circuit. This is a good exercise for us to convert this particular structure into an integrated circuit.

(Refer Slide Time: 29:25)



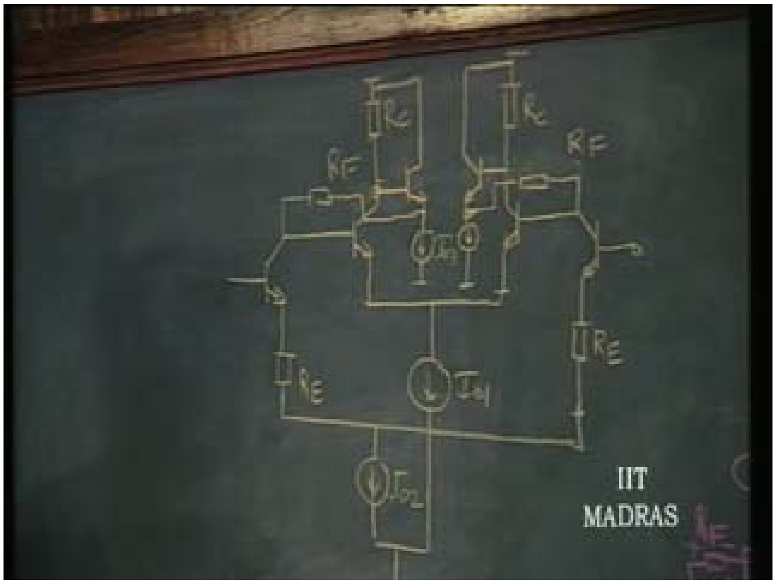
Any single stage structure can be converted into an IC by simply making it differential. This is a single stage. As already pointed out this is the output and there is a load or R_C whatever it is so that load exists, this may be the next stage. Then I will make another structure here which is exactly identical to this. Now I have to convert it into differential. Whenever I convert it into differential I make this into a current source. And again there is grounding of these two and that will also become a current source.

(Refer Slide Time: 31:48)



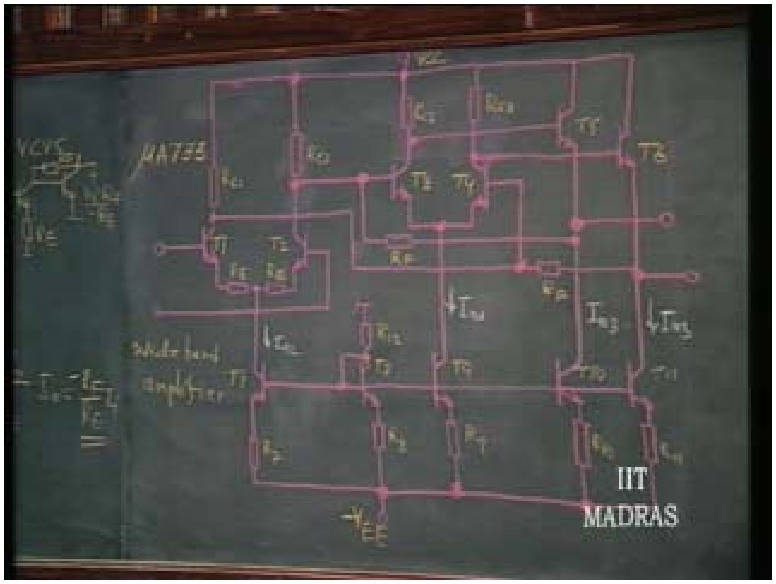
Therefore you have the differential integrated circuit version of the so called voltage controlled voltage source. The only thing is, if you want the gain as R_F by R_E you have to take the differential output. So it is a differential output to differential input whose voltage gain is now R_F by R_E. Other than that you can now independently fixed the biasing current as, let us consider this as I_{01} and this as I_{02}. These are going to fix up the biasing currents here. And if you want to still use a wide band configuration you can still cascade a common collector output stage. Now we are very liberal with transistors. So, instead of taking the output here I will just put a common collector stage here and then take the output here. Then this has to be biased so I will put a current source here. I am very liberal with current sources now because of designing the IC. Therefore I put I_{03}. Similarly I do it here, if you look at it this it is nothing but the structure as it is without any modification.

(Refer Slide Time: 32:54)



Let us identify the current sources and the respective transistors. The transistors are T_1 and T_2 and the current source that is I_{02} is this. That is obtained by a reference that is getting generated. This is a transistor connected as a diode so V_{EE} minus V gamma by R_{12} plus R_8 and you can accordingly fix the voltage here so that you obtain the desired current by adjusting R_7. So this is I_{02}.

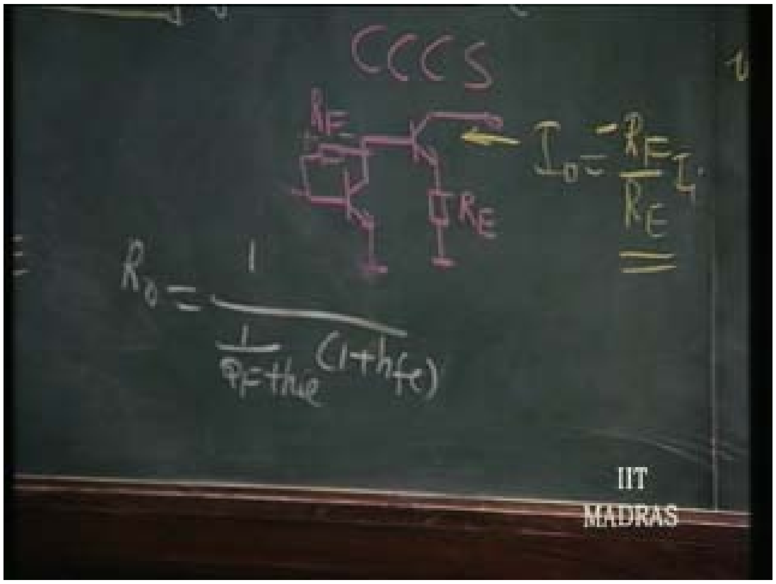
(Refer Slide Time: 34:34)



Next we have the second stage which is nothing but this structure. Here we have I_{01} which is…..and finally I_{03} is through the common collector stages and in the final output stages we have I_{03}. Try to do the analysis of the circuit not neglecting anything but considering all the non idealities into account that means beta is not infinity or alpha is not equal to 1 and then consider all the effects of other transistors in evaluating the gain or the loop gain etc.

What is the differential input impedance of this structure? It is $2R_E$ into 1 plus hfe straight away. It is the voltage control because it is of high input impedance here plus input impedance is $2R_E$ into 1 plus hfe, what is the output impedance?
The input impedance is R_E into 1 plus beta and the output impedance of this is, if this is a current source then you apply voltage here V by R_F plus hie which is going to flow into the transistor resulting in hfe times that current through this. So the current is V by R_F plus hie plus V by R_F plus hie into hfe and this is the total current when I apply a voltage of V. This is the total current. That means V divided by this current is going to be nothing but the output resistance or impedance. Therefore it is nothing but 1 by 1 by R_F plus hie into 1 plus hfe or it is nothing but R_F plus hie by 1 plus hfe. So you can see that output impedance is going to be very low if the hfe of the transistor is high and that is why it is a voltage source.

(Refer Slide Time: 37:10)



Similarly, for the differential structure the output impedance depends upon R_F and the hfe of the transistor. Now we know the input impedance, we know the output impedance and we know the voltage gain. Therefore we know all the small signal parameters of this wide band amplifier. You must also analyze the voltage swing etc because this wide band amplifier may be ultimately amplifying large signals. So I would like you to evaluate the DC voltage at this particular point. It is very easy.

Please remember this is the wide band amplifier. That means it is a negative feedback amplifier even for DC. Therefore there is DC negative feedback here. So you can evaluate the operating point only by finding out the DC voltage first. It can be straight away found out and from that value you have to go back. You do not know the voltages of these two points as there is going to be current here drawn. Now what will be the current? It is simply I_{02} by 2 so the current drawn here is known. This voltage is V_{cc}. But please remember, there is a considerable amount of current pumped into R_F. It is not pumped into the transistor but since because there is y feedback as the next stage even there is going to be considerable amount of DC current flowing in R_L so you cannot neglect the current flowing in R_L, that is, this R_F and this R_F. So you have to evaluate this current in order to find out these voltages.

Here I_{01} is the current so what will be the current in these two? It will be I_{01} by 2 and I_{01} by 2 so what will be the voltage at this point? It is V_{cc} minus I_0 so you know that voltage that is fixed already. So these two voltages will be V_{cc} minus I_{02} by 2 into R_{c2} and that minus V gamma minus V gamma will be the voltages at these two points. Therefore the output voltages are already known. Now you know these two DC voltages, you know these two currents and you know this voltage so now you write down the Kirchoff's load equation at that particular node and evaluate the voltages at these two points. Therefore it is one equation and one unknown.

After working out this problem you will know how much these amplifiers can handle as output signal. And depending upon the bias voltage here their capability for handling signal is going to be determined. So I would like you to come out with the voltage swing capability of the stage. That means how much input swing it can handle, how much output swing it can handle as for as this wide band amplifier is concerned. Please determine that after determining the operating point of all the transistors. After giving this structure for some test I wanted to know the cohesent power dissipated in the IC. It is V_{cc} plus V_{EE} into current drawn.

Now there have been cases where people have evaluated the power dissipated in each one of these devices and then added. But you can evaluate the cohescent power dissipated simply by finding out the current drawn from the supplies. Unless there is a load resistance that is connected to ground you can easily determine by simply finding out the current drawn from V_{cc} and V_{EE}.

Now we have seen one such IC wherein we have cascaded a voltage controlled current source with current controlled voltage source. If you are desirous of obtaining current controlled current source of the same gain you have to just simply change the gain and cascade it or convert it into an IC in a similar fashion. So now you are aware of how an IC design is conceived of starting from a single stage structure up to the final IC without bothering about biasing. Biasing is becoming a trivial thing because we can use any number of current mirrors and convert the single stage into a differential stage. In the next class we will see why not go for two stages.

You just said single stage is the most preferred stage because the order of the system is going to be 2. If I go for two stages the order is definitely going to be 3 and it is likely to cause serious problems of oscillation when used. This is what happens. Even in IC amplifiers you have two stage amplifiers but they will require external frequency compensation in order to maintain them stable. Frequency stability is what we are talking of and we will see such structures in next class. When we use two stages you will automatically see that y and z will be positive feedback structures and h and g will be negative feedback structures. When we use three stages again y and z will become negative feedback stages and h and g will become positive.

Actually speaking people have gone only up to three stages as negative feedback wide band amplifiers but those amplifiers are not at all popular. The once which are most popular are these single stage structures and sometimes if we can afford to understand the working of a negative feedback amplifier you are advised to use the two stage structure otherwise you can simply languish in the luxury of using this low loop gain. These are all having low loop gain. If you use two stages loop gain is going to be boosted up and it is going to remote desensitized. But the price you are paying is in terms of trouble due to quick oscillations.

Thank you.