Course name- Analog VLSI Design (108104193)
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Week- 10
Lecture- 29, Module-1

Welcome back, this is lecture 29. So, in the previous lecture, we were trying to see how to make a voltage controlled voltage control source with a gain of more than 1 with certain characteristics like for example, it should be again should be invariant of invariant to changes in process voltage and temperature also naturally if it is a voltage control voltage source, we would want the gain to be kind of independent of the load resistance that it is driving. Then with based on the arguments, we came up with this following architecture and this is based on negative feedback. Right. Okay. Then we said that I mean what type of amplifier do we know which gives us large gain because ultimately we saw that in order to make this negative feedback loop work properly the gain the gain state had to be of infinite value right ideally infinite, but in principle it has to be quite large and what is the only gain stage that we know of till now it is a common source amplifier right.

So, what I would like to do is we can then say that let us put in the common source amplifier and then see what happens correct. So, let us put in the common source amplifier. What is the common source amplifier? The incremental model of a common source amplifier is the following that we have been doing for a long time. So, this is Ve, this is gm times Ve because remember in a common source amplifier the source is rounded.

So, it is not gm dgs it is gm Ve right and this kind of goes here right. So, this becomes this becomes a V0 ok fine. But then do you see a problem and we saw that there is a problem if we connect it like this and the problem is that of sense of feedback. So, how do I figure out the sense of feedback? Anywhere in the loop I give a hypothetical excitation and see if the action of the loop is to is to increase the excitation or reduce the excitation right. So, we can do that.

So, let us let me choose the excitation point here if this goes up what happens this goes down this goes down there is another inversion that is taking place because of this negative sign so this goes up. So, clearly this is a positive feedback which means this is not going to this is not going to work. However, we also we also saw that if the sense of the loop is negative or if the sense of the loop goes towards the positive feedback we can change some polarity somewhere right. So, in this case we have this ideal summer where we have a plus and minus we have mark. So, we can simply argue that if this had be a common source amplifier all we need to do is to change the signs of this summation block right.

$$g_{m1}(V_i - V_x) + g_{m2}(V_f - V_x) = 0$$

$$\Rightarrow (g_{m1}V_i + g_{m2}V_f) = (g_{m1} + g_{m2})V_x$$

$$\Rightarrow \boxed{V_x = \frac{g_{m1}V_i + g_{m2}V_f}{g_{m1} + g_{m2}}}$$

If we change the sign of the summation block what happens to the loop? Note that Vi is relevant, Vi I can as well round while trying to find out the sense of the loop right. So, let us see again if this goes up this goes down this goes down now it goes through a positive sign so this goes down correct. So, in a sense the excitation any excitation in the loop that I am trying to insert the loop is trying to negate it right. The loop is trying to suppress the excitation which means that this loop is in negative feedback ok fine so far so good. So, now we want to make this thing with transistors so what should we do? So what is Ve? So, if I call this voltage Vf right what is Ve? Ve becomes Vf minus Vi ok.

$$i = g_{m1}(V_i - V_x)$$

$$= g_{m1}\left(V_i - \frac{g_{m1}V_i + g_{m2}V_f}{g_{m1} + g_{m2}}\right)$$

$$= g_{m1}\frac{g_{m2}(V_i - V_f)}{g_{m1} + g_{m2}}$$

$$\Rightarrow i = \frac{g_{m1}g_{m2}}{g_{m1} + g_{m2}}(V_i - V_f)$$

So, if Ve is Vf minus Vi what is this current what is gm Ve? And gm Ve becomes gm Vf minus Vi correct. So in a sense the current through this incremental what I am essentially saying that this is Ve this is rounded. So, the current that is flowing out is gm times Vf minus gm Ve which is gm times Vf minus Vi because this is gm Ve because Ve is equal to Vf minus Vi correct. Now if we pause here for a second and think given that we have a single transistor right. So, this is the incremental picture of a transistor given that we have a single transistor can we manipulate the transistor or can we manipulate the terminals of the transistor in such a way that we get gm times Vf minus Vi directly and get rid of that get rid of this summer at the at the input.

And as you would as you must have noticed by now that what is a transistor current? A transistor current in principle in principle the transistor current is gm Vg minus Vs correct. So, in principle this is what our transistor current is. Now as it turns out in common source amplifier we have rounded the source. So, the current becomes gm Vg in this case in this case in this case we have also rounded the source and applied the difference voltage at the gate. But we could have as well if we could apply if we could as well apply Vf at the gate right we could have as well applied.

So, like instead of rewriting over writing over it. So, this is Vf minus Vi right the round. So, we could have as well said that we will do this. We could have as well said we will do this we will put Vf here at the gate and we will put Vi at the source if that is the case what would have been the current this would have been gm Vf minus Vf minus Vi correct. So, why are we doing this? We are doing this because if we can get this difference of difference current from the transistor itself then we can get rid of this then we can get rid of this sum correct.

So, what I am essentially saying is this. So, let us go back and re sketch our plot. So, if we can replace this guy in such a way that this is Vf and this is Vi. Then we are all good right in the sense that this can be connected here because this becomes Vf this K minus 1 R this is R and this current will be this is gm times Vf minus Vi and this becomes a V0 right. Note that the picture on the left and the picture on the right are essentially identical as far as the transfer function between V0 and Vi is concerned right ok.

So, if I I mean this that the drawing here look looks a bit messy. So, let me redraw it. So, instead of instead of putting the gate on the left hand side what I will do I will put the gate on the right hand side. So, that I do not have to I do not have to get this long line from one side of one side of the register stack to the other. So, let me redraw this.

So, this has to be gm Vf minus Vi right. So, let me sketch the gate here. So, this becomes Vf this K minus 1 R this is R and this becomes Vi right. So, and this becomes my transistor this is the transistor where this is the drain this is the gate this is the gate and this is source ok. Make sense? Note that we have not done any magic here we just have simply argued in plain English and an arrange the arrange the incremental model in order to realize a negative feedback loop.

This negative feedback loop is exactly the same negative feedback loop that we started off with in terms of I mean as far as the relationship between V0 and Vi is concerned ok. But do you see an issue? Some of you might have already seen the issue and the issue is this Vi that we have will not be an ideal voltage source right. So Vi whenever we say Vi we assume that it is some Vi with some intrinsic resistance Rs I mean that is what we have been assuming all along. So, there is no point for us to remove that assumption right. So, we will have this.

Now what is the problem? If we have this, if we have this then naturally this voltage here is not equal to Vi right. Why? Because the looking in impedance of this structure is what looking in we have done this before the looking in impedance and the source of a MOSFET this is the MOSFET if you look into the source if we neglect channel and modulation the looking in impedance is 1 over gm right. Looking in impedance is 1 over gm which means that there will be a you will be drawing some current through Vi which means that the source voltage will not be will not be Vi ok. So, that is a problem. So, what should we do? So, among all the circuits that we have learned what do you think we should do in order to rectify this problem? What is the problem? The problem is connecting input directly to the source of a transistor loads the loads the input correct.

So, what should we do? We should prevent loading, we should prevent current getting sucked out of the source whereas, we still want to have to get Vi at the source right. So, what is the solution? The solution is apply use a use a voltage buffer to feed or rather to isolate the S isolate the source from the input. So, what type of what type of voltage buffer that we are aware of the only voltage buffer we are aware of till now is a common drain amplifier right or a source follower architecture right. So, let us do that. So, if we do that what will what will we get? So, this is Vf.

So, what do we what do we want now? We want a source follower architecture or a common drain amplifier and we have done common drain amplifier before. So, we will just pull out that architecture and this is what the common drain amplifier look like right and now that we have seems like we have two MOSFETs let us mark one as gm2 and this as gm1 and what is the what should we do? We should connect this common drain amp because we are buffering Vi we are trying to buffer Vi into the source of gm2. So, what we would like to do is to simply connect correct and let us call this common node dx right which is a source of both this transistors. I am calling transistors, but these are in essence are incremental model of a transistor ok ok. So, if we do this what is essentially is happening? So, this voltage is Vi we are not drawing any current from Vi right.

So, then we need to find out what is this what is the current that is actually now flowing right. So, what is this what is the current through the left contraption the current to the left contraption is gm1 times Vi minus Vx correct. What is the current through the right contraption? The current to the right contraption looking down. So, this current is going downwards right this current is going downwards. Similarly this current going downwards is gm2 Va minus Vx right ok.

So, what is the so if I solve for KCL at Vx what should I get solving for KCL at Vx I should get gm1 Vi minus Vx plus gm2 Vi minus Vx sorry gm2 Vf minus Vx is equal to 0 right. So, what is Vx? Vx becomes so gm1 Vi plus gm2 Vf becomes gm1 plus gm2 times Vx. So, what is Vx? This becomes gm1 Vi plus gm2 Vf by gm1 plus gm2 right ok. If this is the case then what is the incremental current? What is the incremental current that is flowing? Which is essentially gm1 times Vi minus Vx or I can as well say minus gm2 times Vf minus Vx. So, let us pick any because both will be same.

So, the incremental current let us say this current let us say I say this is the direction of the current I this current is gm1 Vi minus Vx. So, I becomes gm1 Vi minus Vx which is equal to gm1 gm1 Vi. So, let us do this, this becomes Vi minus gm1 Vi plus gm2 Vf by gm1 plus gm2. So, we get gm1 plus gm2 in the denominator. So, the denominator is gm1 here.

So, in the top we get gm2 Vi minus Vf right by gm1 over gm2 correct which in essence means that the current I becomes gm1 gm2 by gm1 plus gm2 times Vi minus Vi correct ok. So, this is a crucial outcome and let us ponder over this for a moment right. So, what is this telling us? This is essentially telling us that this contraption that we have just designed, this is Vf, this is Vi right and this is grounded and something is connected at the load side of the second transistor and this is gm1, this is gm2. So, the short circuit current or the current that I am drawing from this is equivalent to the difference between the two voltages Vi and Vf multiplied by some factor which is some equivalent transconductance. So, this is equivalent to, this guy is equivalent to, maybe I should go to the next page.

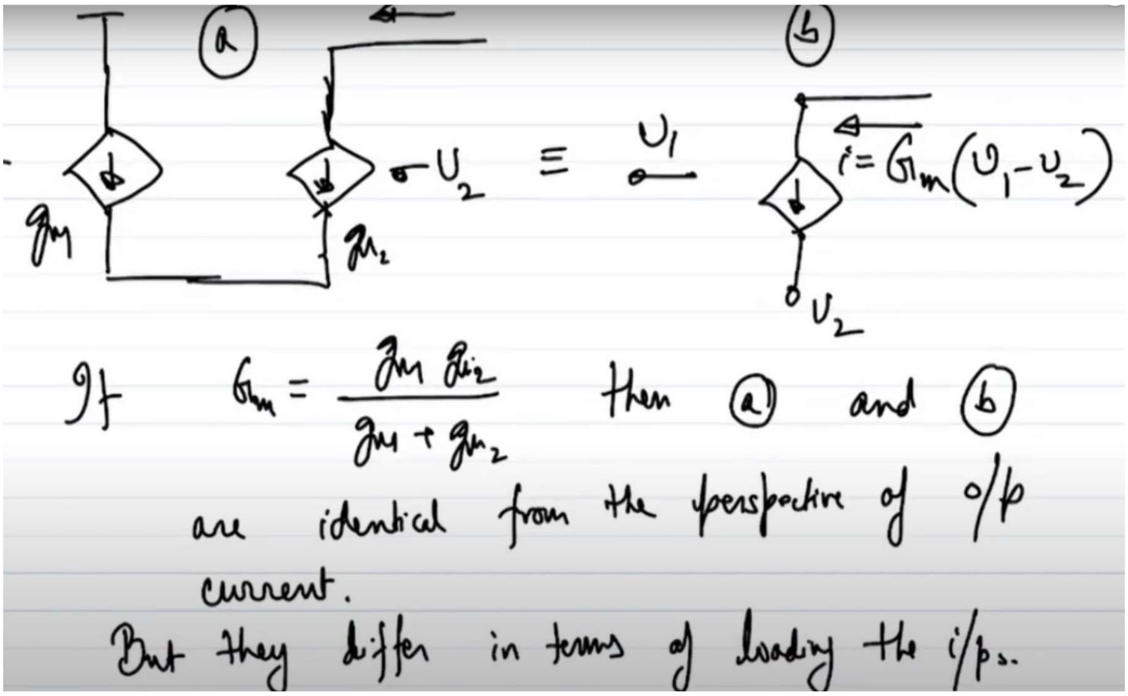
So, this is Vf, this is gm1, gm2. So let us say I am interested in the current that I am drawing out, this guy is equivalent to a case where I have a single transistor circuit where at the gate I applied Vi sorry yeah at the gate I applied a Vi and at the source I applied a Vf and the current that I am getting is equal to some gm times Vi minus Vf. As far as if I say that this is equal to I right then the equivalence of the output current the only and not that I am only trying to draw an equivalence of the output current nothing else. The equivalence of if these two networks are identical as long as gm becomes equal to gm1 gm2 by gm1 plus gm2 right. If this becomes, if we satisfy this relationship then it seems like if these are true then figure A and let me call it figure B, the figure A and B are identical from the perspective of output current right. However, they are not identical but they differ by but they differ in terms of loading the inputs.

In the circuit in the right right in figure B in figure B whatever is connected here will get will get loaded I mean I may as well not save Vi and Vf I may as I may instead of Vi and Vf I can say this is V1 and V2 right. So, this is as this is V1 this is V2. So, this will become V1 gm V1 minus V2 right. So, the again the network in the left and the network in the right are identical from the standpoint of the incremental current that it they are producing. So, essentially if we are interested in only evaluating incremental current we can as well say that the network on the left is a is almost like a common source amplifier whose whose transconductance is gm1 times gm2 by gm1 plus gm2 right.

However, from the standpoint of loading the input clearly this network on the left does not load because you are not drawing any current through the through either of the inputs V1 and V2. However, in the network on the right you are drawing current through one of the inputs in the network on the right you are drawing current through V2. So, if we use if we use the common source amplifier in our case right if we had used common source amplifier in our case in order to get that difference right we are trying to amplify the difference note that we are trying to amplify the difference of Ve right. We are trying to amplify the difference and in a common source amplifier that difference can be got by applying one of the inputs to the gate other inputs to the source. However, the input to the the input that you are applying to the gate is not getting loaded but the input that you are applying to the source is getting loaded.

So, what is the solution? The solution that we came up with was to instead of directly applying this buffer it if we buffer it we get an we get an interesting contraption and this contraption uses uses two transistors right looks like one is a common source other is a common gate right or in other words one is a common source other is a voltage buffer. But when you put the two contraptions together it is impossible to say which one is the common source and which one is the common gate it essentially they are identical and on top of that if we say that gm1 is equal to gm2 right if we make gm1 to be equal to gm2 then there is absolutely no way you can figure out which one is driving what ok. So, essentially both sides are driving each other and this contraption is often called a differential amplifier right. So, this contraption is often called not I mean I have not really shown the output side right, but this essentially is a is a is a first step towards making a differential amplifier because we are amplifying the difference of two voltages.

How are you planning to amplify? We are planning to amplify by putting some resistance here right if we put some resistance here then the voltage that you will achieve here will be will be what gm times V1 minus V2 times R right.



So, the voltage across that R will be voltage across that R will be an amplified version of the differences of V1 and V2 right. The same would have been true for a common source amplifier one might argue the common source amplifier is also a differential amplifier because it amplifies the it senses the difference between the gate and the source voltages and produces a current proportional to the difference of the gate of the source difference between the gate and the source right. So, however the key difference is what is the key difference? The key difference is the source terminal will load one of the inputs ok fine. So, now that we have a new configuration it is time to it is time to look into what this new configuration entails and that is what we like we are going to look into in this class and few more classes right. So, note that what is the genesis that again the genesis is we would like to put everything in negative feedback right.

So, we would like to put this guy in negative feedback right. So, before we put this negative feedback network back what we would like to understand is how does this part of the circuit works in isolation. We will assume that I have an input of Vi in one terminal and I have an input of Vf in the other terminal and we would like to establish we would like to understand the nuances of this configuration before we proceed and put the feedback back right. We will eventually put everything together, but since we this seems to be a new beast right. So, let us invest some time and figure out what this will what new things that this contraption brings to that table ok. .