Analog Electr$_{on}$ic Circuits
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Lecture - 52
Large signal Behaviour of The Differential Pair

I just want to spend a few minutes talking about the large signal properties.

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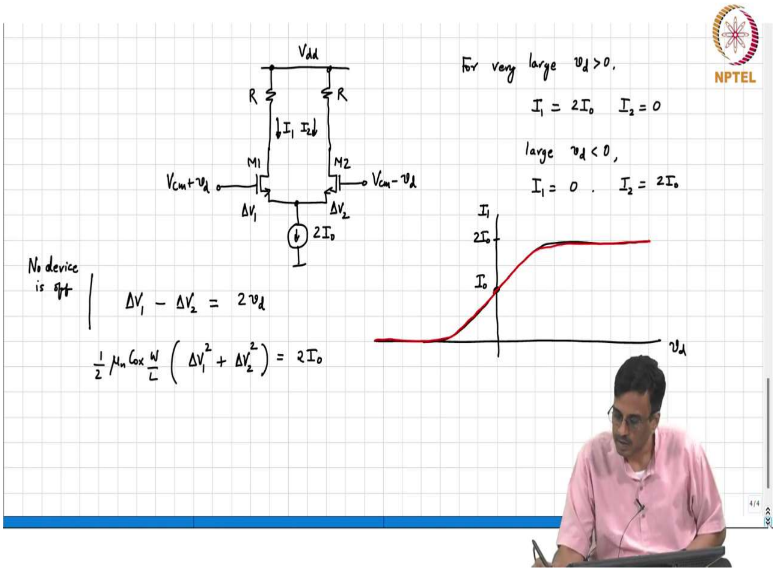

And again, I am not going to do it with the active load, I will do it with the resistive load and then where $\lambda_n = \lambda_p = 0$ and leave it at that. This is V_{dd}, this is R, this is R. So, this is $V_{cm} + v_d$, this is V_{cm} - v_d, the question is what happens to the currents I_1 and I_2 when v_d is not small.

Before we get into algebra let us basically get our intuition straight. So, for very large v_d, positive v_d, what comment can you make about this current which transistor M1 or M2, which of them will have. So, basically if you go on increasing the gate of M1, M once M1 will steal more and more current of more and more of that 2 I_o. So, $I_1 > I_2$ is ok, but if you go on increasing what is the maximum I_1 can be? So, if you go on increasing M1 what will happen, it will steal more and more current. So, M2, M2 will get cut off. So, I_1 will be equal to 2 I_o, I_2 is equal to 0 and likewise for large $v_d < 0$ what comment can we make?

Student: (Refer Time: 02:33).

Well, I_1 becomes 0, now and I_2 M2 steals all the current, alright. So, basically if you plot for instance I_1, for $v_d = 0$ what should we get?

So, if you plot I_1 you basically get, for $v_d = 0$ what should we get, I_o, right and then for large positive v_d it should do something like this, right and for large negative v_d do something like that, I am going to use a different color. Now the question is you know we should go and be able to calculate what that, and what the actual characteristic is, alright.

So, let us quickly get through the algebra. So, what are the constraints? Let us assume that the overdrive of this transistor is ΔV_1, the overdrive of M2 is ΔV_2 so, ΔV_1 - ΔV_2 is nothing but 2 v_d and that is regardless of I mean you know even if v_d becomes large. I guess that is, as long as the transistors are not cut off you know this is fine, right, assuming, why am I saying no devices off? Otherwise they are not, they will not be any Δ, straight forward, ok and what is in another constraint?

We want, I mean what do we want to find actually? Yeah, if you want to find current you have to find ΔV as the overdrives equivalently. So, we have two overdrives to find, we need two equations, one equation is here, what is the other equation?

$I_1 + I_2$ is $2I_o$. So, basically it is ½ μ_n C_{ox} W/L $(\Delta V_1^2 + \Delta V_2^{\,2})$=2 I_o, ok. So, now, the question is how do you find it?

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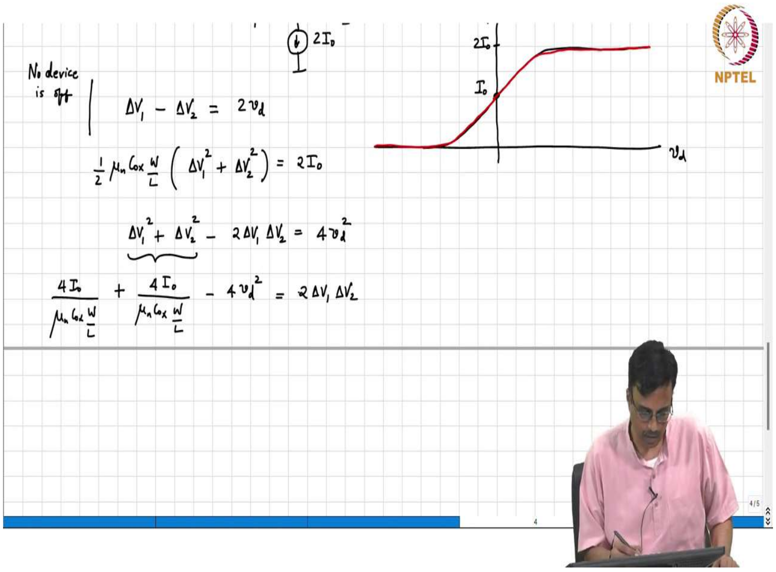

So, ΔV_1^2 from the first equation, I mean this is now just algebra, there is no major insight here, - 2 ΔV_1, ΔV_2 is 4 v_d^2, right, but this guy is equal to 4 $I_o/(\mu_n C_{ox} W/L)$, right. So, this - 4 $v_d^{\ 2}$ therefore this is equal to 2 $\Delta V_1 \Delta V_2$, ok. So, now we can add this to the second equation. So, if I add 4 $I_o/\mu_n C_{ox} W/L$ to this equation, what will I get?

Student: $(\Delta V_1 + \Delta V_2)^2$

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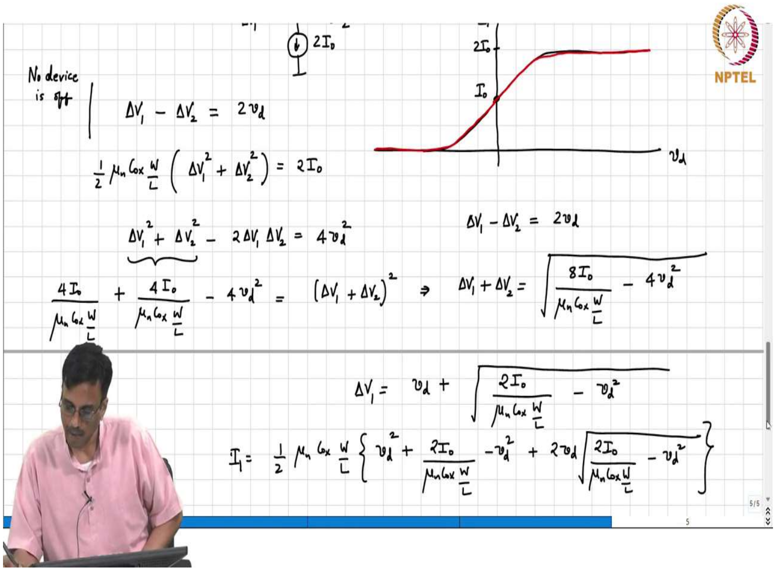

Therefore, that is nothing but $\Delta V_1 + \Delta V_2$ therefore, is nothing but $\sqrt{\frac{8I_0}{\mu_n C_{ox}\frac{W}{L}} - 4v_d^{\ 2}}$.

$\Delta V_1 - \Delta V_2 = 2\ v_d$. So, ΔV_1 therefore, is nothing but,

$$\Delta V_1 = v_d + \sqrt{\frac{2I_0}{\mu_n C_{ox}\frac{W}{L}} - v_d^{\ 2}}$$

Sanity check, v_d is 0, what should we expect the overdrive to be Chaudhary? v_d is 0, what is the equation telling us and what do we expect? So, is it agree or not, our formulas ok or no?

Student: Ok.

Seems to be ok, alright, ok. So, what is now, what is ours, what is our, what is the current therefore? I_1 therefore, is nothing but,

$$I_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left\{v_d^{\ 2} + \frac{2I_0}{\mu_n C_{ox}\frac{W}{L}} - v_d^{\ 2} + 2v_d\sqrt{\frac{2I_0}{\mu_n C_{ox}\frac{W}{L}} - v_d^{\ 2}}\right\}$$

So, as you can see this is not the most fun thing to be doing on a Friday evening, right, or doing things like this builds character, let us do it, ok. So, this goes away.

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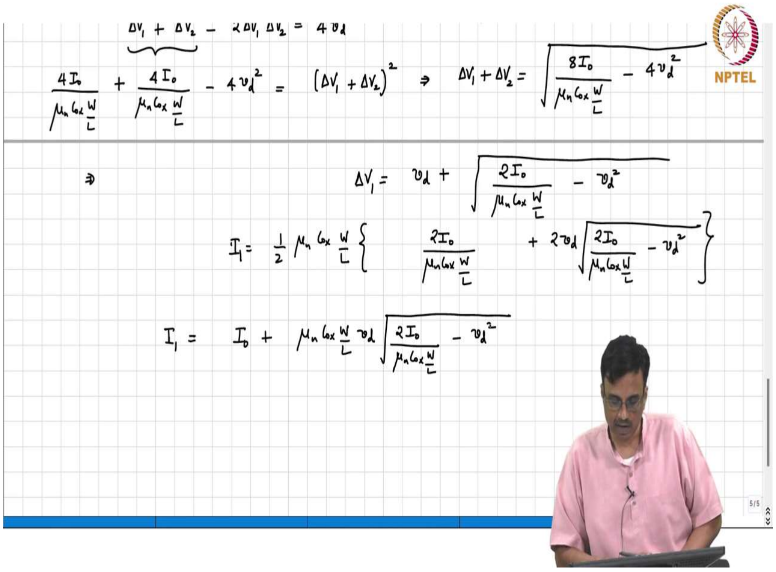

So, what do we get? therefore I_1 is,

$$I_1 = I_0 + \frac{1}{2}\mu_n C_{ox}\frac{W}{L}v_d\sqrt{\frac{2I_0}{\mu_n C_{ox}\frac{W}{L}} - v_d^{\ 2}}$$

Now this can be simplified by pushing this one here.

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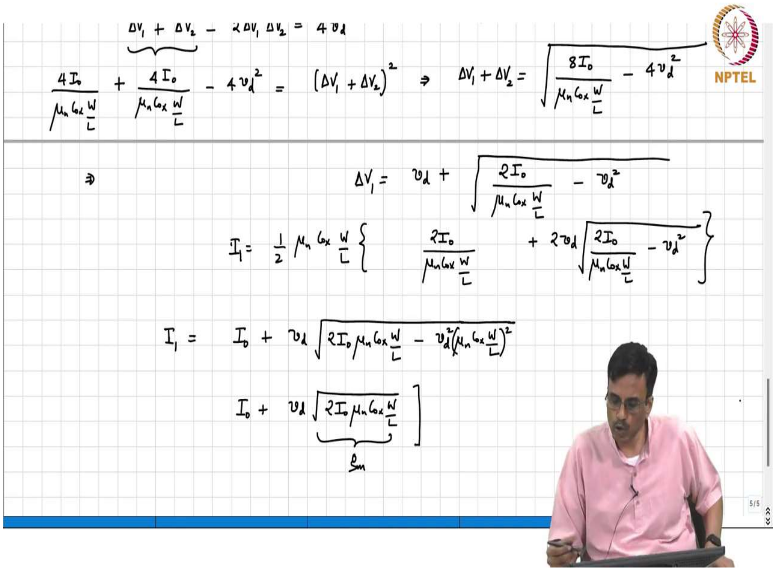

So, you basically will get,

$$I_1 = I_0 + v_d\sqrt{2I_0\mu_n C_{ox}\frac{W}{L}}$$

Or equivalently you could have pulled that I_o out and then written it differently, ok. So, sanity check v_d equal to 0.

Student: $I_o = I_o$.

What else can we do for v_d what term can you neglect here?

Student: v_d^2.

You can neglect the v_d^2. So, we get v_d we should get I_o plus v_d, what we actually get is this μ_n, C_{ox} W/L and why does this make sense? This is nothing but g_m at the operating unit. This is just a sanity check, that is all I am saying, right, this makes sense, ok, now when you know what is the largest v_d that you can apply? So, basically what do you call, as v_d keeps increasing?

Have we made a mistake or what? A sign missing somewhere, we ok, yeah, we are ok, alright. So, you know you can go on as you go as the as v_d goes on increasing, right, basically the discriminant must become 0, I mean eventually the maximum v_d you can use is the one where the discriminant becomes 0, try at that point you will find that the current will be, the total current will be 2 I_o. Beyond that you know nothing will happen, I mean you know the current will remain 2 I_o and if I_2 it will be the complementary behaviour. So, this is I_1, this is a 2 I_o. The sum of the two anyway have to be equal to $2I_o$.

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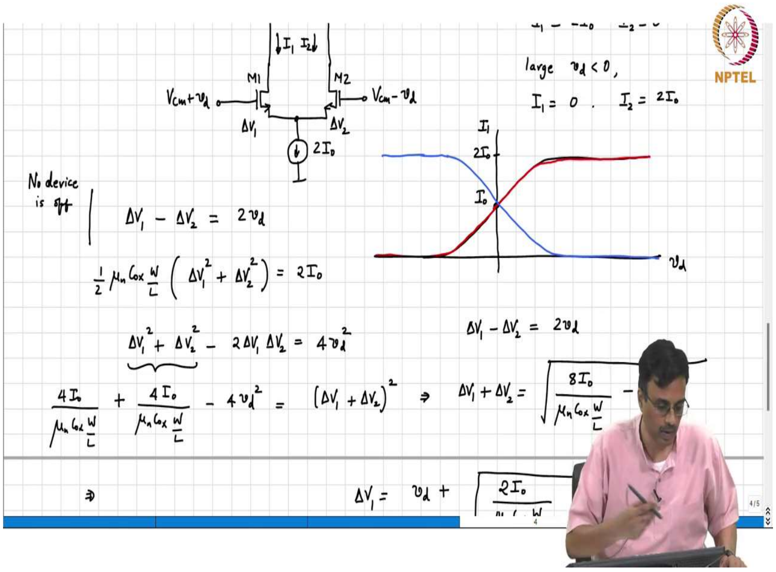

So, basically the other one must do something like this. So, you can see that this differential pair has got a nice natural limiting function, right and in the past when neural networks were the rage like some 40 years ago and people used these kinds of things to generate.

I do not know how many of you are familiar with some basic stuff about, everything so much talk about A_I going around, right and $neur_{on}$ is basically something which takes multiple inputs and then you know thresholds this is called a threshold function, right. And so a differential pair is one way of getting this stuff, ok, alright.

So, with this we have you know we have finished all that we needed to learn about the differential pair, small and large signal properties and the active load as well as you know the right way of deriving the gain of the active load and the wrong way of deriving, right, ok.

But the wrong way is useful in the sense that you know when you remember when you have to remember the formula you just basically assume that source is grounded and then that is the formula, but as you can see the analysis is actually quite, quite in one, ok.

And those of you who are brave can basically you know replace every transistor with its incremental equivalent and go through the algebra, right and it will be very messy, ok and you can convince yourselves and your friends that it is indeed close to 2 g_{mn} v_d (r_{on}//r_{op}), alright.

So, our next job is now, I mean so, we now we have now have a good handle on the first stage of the of an operational amplifier, but the gain is still only of the order of you know - g_m r_o, right, the (r_{on}//r_{op}) is roughly r_o/2, g_m 2 g_{mn} is basically that 2 and this 2 gets cancelled in roughly of the order of g_m r_o. g_m ro is typically maybe 40, 50 if you are if you are lucky otherwise 10, 15. So, you need more gain. So, how can you get more gain?

One way of getting it is the two fundamental ways of getting more gain, if you want to take something you make it more you actually add multiple copies or you multiply, right. So, multiplication is done easily by cascading stages. So, what is the next stage that we will take? We want more gain, which is the simplest transistor stage, which gives us a common source, so we have to cascade this differential pair with an active load with a common source, right? So, we will discuss this in the next class, ok.