Analog Electronic Circuits
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Lecture - 79
Miller Compensated OTA Schematic

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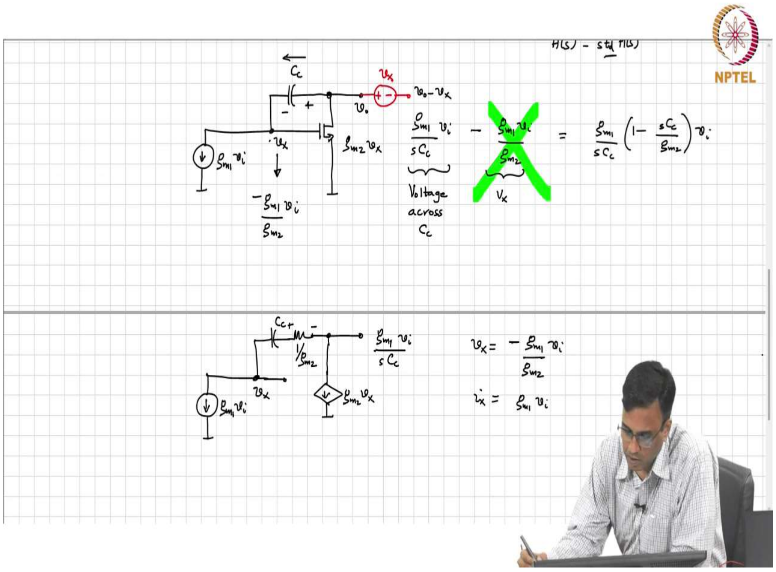

So, this is so, now let us get back to ok, this is the principle. So, now let us get back to how one can implement the 0 cancelling resistor in practice.

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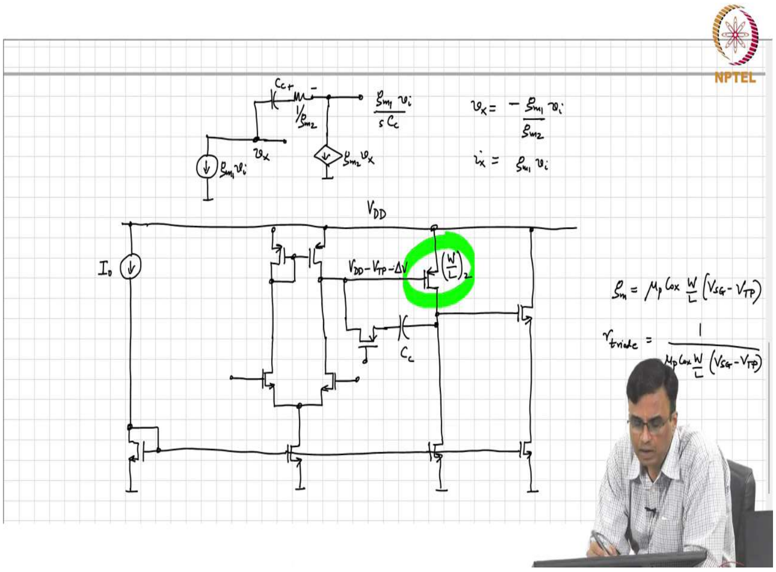

So, this is the first stage to let me draw the full Op-Amp. So, this is the master bias, right. And right and this is the Miller compensating capacitor. We need a resistor, right. And this resistor here mind you must be its resistance must be exactly equal to the trans conductance of that transistor, correct.

So, do you have any ideas on how we can implement that? One of course, to choose a resistor, find a resistor and then make it equal to $1/g_{m2}$, right. But how do you ah, but then you know obviously, when threshold voltage changes the g_{m2} may change, correct. And you know this g_{m2} and that g_m this $1/g_{m2}$ will not track the g_{m2} of the transistor, correct. So, what do you think we can do?

So, remember one thing: what comment can be made about the transconductance of a transistor operating in saturation and its resistance when it is operated in the triode region? What if you take a transistor and operate in saturation ? The transconductance g_m is nothing but A μ_p C_{ox} W/L(V_{SG} -V_{TP}). If the same transistor is operated in the triode region, what is the resistance?

The R triode is nothing but μ_p C_{ox} W/L(V_{SG} -V_T). So, what is the moral of the story? If you take the same size transistor operated in the triode region with a source, gate voltage, which is same as the transistor operating in saturation then you will have the resistance of that device be the same as the trans conductance of the device when operated in saturation, correct.

So, therefore, what should we do if we call this W/L_2 right, standing for the second stage? What we will do is, we will take a PMOS transistor here, ok. It does not matter which side you put the arrow because anyway the transistor is operating in triode, it can be on the left side, it can be on the right side.

So, if this is V_{DD}, what is this potential? Basically if you assume that the overdrive of the transistor is Δ V this voltage is nothing but V_{DD} - V_{TP} - ΔV, ok. And so, this transistor here and this transistor must have the same. If you want the resistance of the transistor the 0 cancelling resistor to exactly track $1/g_m$ of that transistor in the second stage, what must be I mean as per our discussion just now, the source gate voltage of the both the transistor must be the same, but the source of this transistor is at V_{DD} - V_{TP} -ΔV. So, what should I put it as, what should be its gate potential?

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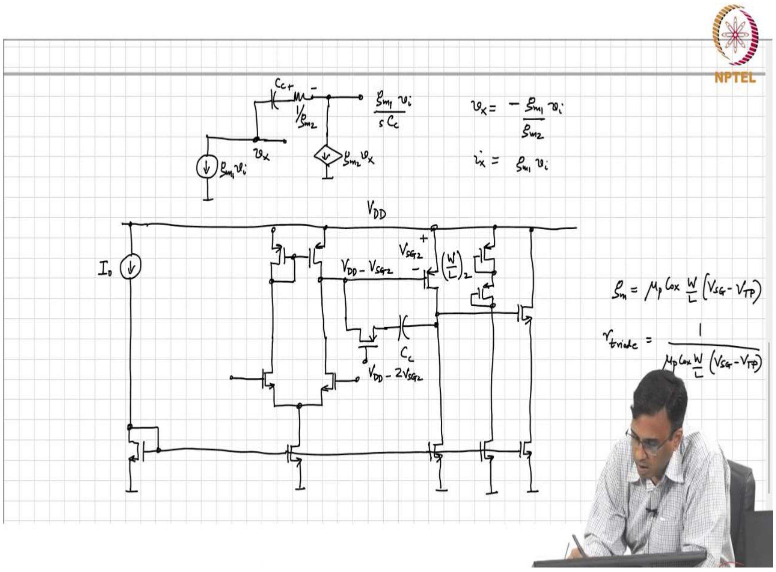

So, basically the source voltage is at V_{DD} - V_{TP} -ΔV or let me just call that V_{SG2}. So, this voltage is V_{DD} - V_{SG2}. So, what should this voltage be V_S ? V_{DD} -2 V_{SG2}. And how will you realize that V_{DD} -2 V_{SG2}? 2 diode connected devices in series.

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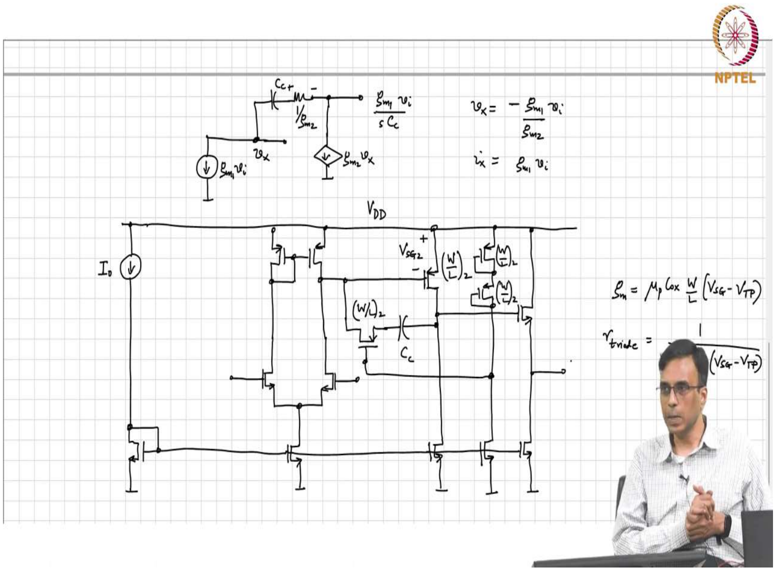

So, basically this is also going to be W/L_2, W/L_2, W/L_2 and I go and tie this, does it make sense? So, as you can see you know all of a sudden you know you have 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 transistors, right, ok. So, this is a great way of impressing your friend's right, but as you know there is really as you can see there is nothing really much to the whole thing, ok.

And of course, if you want to look even brighter than you are you can add cascodes you know everywhere, right. And you know which you need anyway in practice because to get high output resistance slash good replication of current in the current mirrors and all that. And you know how to make current mirrors which are very accurate by adding more and more devices.

So, I mean you know you can easily add double the number of transistors and then you know make the thing look or you know awfully complicated. And you can impress your friends even more by simply saying looking at the picture and then you know given the first stage bias current. And the value of the compensating capacitor you can just basically say what the unity gain bandwidth of the Op-Amp. Op-Amps unity gain bandwidth is only dependent on g_{m1} and C_c, right, ok.

Alright, so, simply looking at it you can basically ah right give the entire unity gain bandwidth. And you know if you are a little good with numbers in your head then you know I gave the bias currents and you know μ and C_{ox} you can actually also do the phase margin you know pretty much by looking at the picture, ok. And you know that the DC gain is going to be high, right. Otherwise, you know nobody would have designed the Op-Amp in the first place, ok, alright.

So, this basically is pretty much the culmination of what we wanted to achieve in the first place, right. So, you know kind of doing a little bit of a rewind right, we started off you know ah without assuming any background, right. We started off saying we want gain and then we deduce the characteristics of the device, which will give that right, we figure out how to bias it. Then make a whole bunch of building blocks, basically the four the four control sources, right.

Then we said that to bias things to I mean the most important aspect of any circuit is negative feedback then ah and the key point in realizing a good negative feedback loop is having a contraption, which can subtract two voltages and gain that difference up that led us to the differential pair, correct. And to get more gain we said we are going to cascode stages that led us to the 2-stage Op-Amp and then we figured out that oops this thing is going to be unstable when you close the loop then we figured out how to stabilize it, right.

And with that you know all that I wanted to say about MOS transistors and MOS amplifiers is complete, right ah. So, for those of you who are ah interested you know you can sign up for analog IC design ah next semester where, you will go you know ah. And of course, we saw some fun applications of transistors like you know the band gap reference and fixed trans conductance bias circuits and ah what do you call cascode current mirrors and all this stuff, right.

But in the next semester I mean in the advanced course you will basically you know kind of all this seems pretty obvious when somebody explains it to you, right. When you start designing things yourself you know you have all sorts of ah doubts I will start to come, right. And the only way to learn design is to actually do it right, I mean just like how you cannot learn swimming by watching a YouTube video, right, ok. I mean the only way to learn design is to do it, right?

But then of course, it does not make sense to ah you know to take you and throw you into the deep end of a pool on day 1, correct. So, first you have to go to the shallow pool like you know, kick your legs, make sure you float, make sure you know to breathe and so on. And that is the equivalent of ah this course, right.

So, once I mean once you understand the basics now you can build on this to make more and more complicated circuits. And unfortunately you cannot make circuits ah make the real thing, but the simulator is close enough. And you know it provides you a way of learning things you know which you cannot do even with real transistors. Because now you can probe all sorts of things and plot all sorts of things and enhance your understanding, right.

So, that is all that I had to say with CMOS right, over the next tomorrow and on Friday we will go over the same thing all over again with bipolar transistors, right, ok. And now the same thing does not mean that you know it is like saying you know I know how to drive I do not know a Hero Honda now you know ah now you know I have a Yamaha bike now you know should I go and learn driving all over again. The answer is; obviously, no alright, you know.

Once you know about MOS transistors. It is the same volt, same volt, same volt, with bipolar stuff this is some small the bipolar transistor got some quirks, right ah. In many ways it is easier to do the math in terms of transconductance and all that, right.

It is just that as I promised you earlier the characteristics of the device look very similar, right. Except for the math governing I_D, I mean now you call the drain you call it the collector, the gate you call it the base and then the source you call it the emitter.

Right, then there is the equation relating the drain current to the gate source voltage right, is now the equation relating the collector current to the base emitter voltage that equation will change, ok. And therefore, the formula for trans conductance will all change. But otherwise, you know the same you know the same principles underlying principles hold.

So, this you know, obviously, it does not make sense for me to spend another 40 hours lecturing about bipolar transistor circuits. You will all get bored, right? So, we will just, you know, go through the bipolar transistor stuff in a couple of lectures where the key focus will be on highlighting the principal differences between MOSFET and bipolar.

The bipolar transistor also has another minor difference in the sense that the base current in the MOS transistor, the gate current, is 0. In the bipolar transistor ideally, it is supposed to be 0, but in practice it will be a small number right, a small fraction of the collector current. So, that introduces some quirks, ok.