Analog Integrated Circuits
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Lecture – 25
Telescopic OpAmp – I

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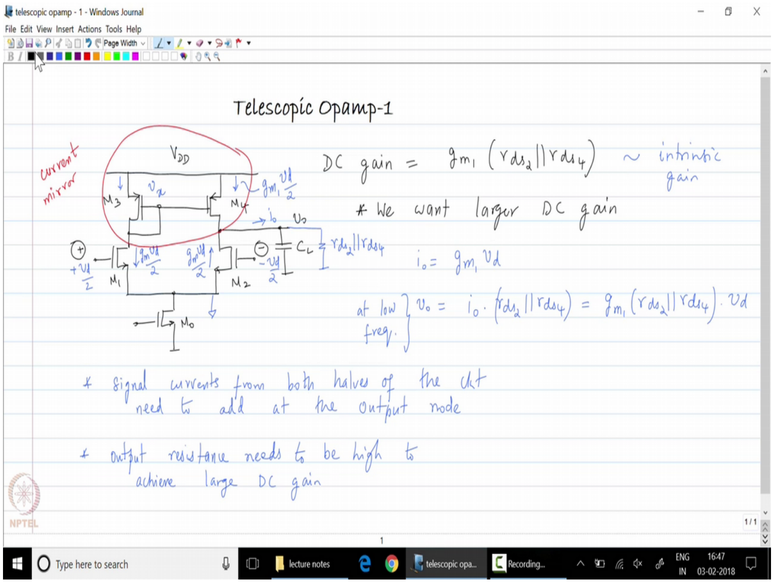

In this lecture, we will look at another type of one stage opamp called the telescopic opamp now let us first start with the original one stage opamp and see how we can improve upon it even further . So, this is the one stage opamp regular one stage opamp that we have been studying. So, far now of course, the dc gain of this opamp which is a low frequency gain is gm 1 into rds 2 parallel rds 4 and the output node is the node which has the dominant capacitance which is normally the load capacitance C L.

Now, let us assume that I want to increase the gain of this opamp. So, I want even larger DC gain that is the goal. So, now, as you can see this is of the order of the dc gain as we have it now is of the order of the intrinsic gain of a device. So, clearly you will have to make a circuit change to get even more gain because you have now reached the limits of the gain that every device can offer and from a single stage, it is not easy or its not from single device it is not easy to get any more gain.

Now, of course, there are circuit techniques that we know now before we go there we will now understand the or quickly review the progression of the signal through the circuit. So, let us say that the inputs are Vd by 2 and minus Vd by 2 we first need to understand the progression or review the progression of the currents through the circuit so that we can see how to improve the circuit. So, as we pointed out the common source node is a virtual ground and each transistor now has a current g m Vd by 2 in the directions shown and in a parallel with C L, I will also explicitly show the output resistance which is rds 2 parallel rds 4.

So, that we understand where they current is flowing now the current through m 1 creates a small signal voltage at node x and this also causes a current to flow through m four. So, you need to understand that this portion of the circuit this portion of the circuit comprises a current mirror and it is an active load you do not have any resistors you have a pmos load and it comprises a current mirror now the current through m three is the same as the current through m 1 which is gm Vd by 2 and that current gets mirrored into m four.

So, the current through m 4 is also gm 1 Vd by 2 and therefore, the total output current i o is gm 1 times v d. So, as you can see the function of the active load the function of the current mirror is to take the current from the left hand side and pump it back into the right hand side in a constructive manner. So, that you get even more signal current flowing into the load the second thing to note is that the output voltage is generated by passing this current through the load.

Now, let us assume we are looking at the output at low frequencies at low frequencies the capacitance presents an open circuit and the output resistance that the output voltage is nothing, but i o times rds 2 parallel rds 4. So, this tells us that the output current flows through the parallel impedance of m 2 and m 4 to create the output voltage. So, this is gm 1 into rd s 2 parallel r d s 4 times Vd now this shows us where the gain is coming from the signal currents need to be additive at the output node. So, so that is important from both halves of the circuit need to add at the output node. So, that is an important requirement and number 2 the output resistance needs to be high needs to be high to achieve large gain large DC gain.

So, what this means is that if you want to increase the dc gain of the opamp, you only have 2 options you have to either increase gm or you have to increase r d s now we are now very close to the intrinsic gain of the device. So, we need to find out ways to improve the r d s of the device the gm of the device it is much harder to increase we will not try to increase the output resistance of the opamp.

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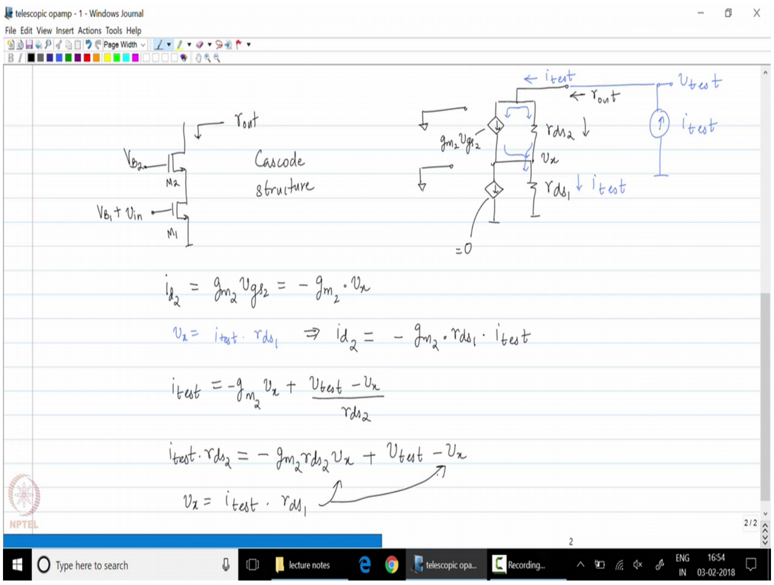

So, the first structure that we look at is one that we have seen before. So, if you take a common source transistor which is m 1 and include a common gate transistor m 2 in series with it; it turns out it behaves in such a manner as to increase the output resistance this is of course, the small signal output resistance.

So, again let us quickly review this. So, let us say at the gate of m 1 I have v b 1 plus v in and at the gate of m 2, I only have v b 2, I want to analyze the structure to find out the output resistance of this structure. So, let us draw the small signal equivalent circuit this particular structure is called the cascode structure. So, this will be a quick review for us because we are going to use this to increase the output resistance of our opamp. So, we want to find out the output resistance of our particular structure. So, just want to point out that v in will be set to 0. So, this current source is equal to zero this is rds 1; this is r d s 2 and this is g m 2 times v g s 2.

Now, let us denote this node voltage by d x therefore, ib 2 is g m 2 times vgs 2; this is clearly nothing, but minus g m 2 times v x. Now we want to find out the overall output resistance of the structure now let us say we excited with a test current source i test. So, the total current flowing into the circuit is i test and therefore, the value of the x of course, is also equal to i test times r d s 1 this is because the current i test flows into this node into the output node it splits between these 2 devices these 2 components and combines back up to flow through r d s 1.

So, the current through r d s 1 is also i test therefore, v x is equal to i test times r d s 1. Now, therefore, the value of the drain current through m 2 is minus gm 2 into r d s 1 into i test therefore, the output test voltage that is generated denoted by v test can be written the voltage v test can be determined by applying kcl at the output node in the following way.

So, the sum of all currents at the output node has to be equal to zero. So, i test is the current flowing into the input node. So, i test splits as minus gm 2 v x plus v test minus v x by r d s two. So, the 2 currents you have minus gm 2 v x and the test minus v x by r d s 2 flowing through the resistance r d s 2. So, this means that i test times r d s 2 is minus gm into r d s 2 v x plus test minus v x and now we can also write i test in terms of v x yes since v x is equal to i test times r d s 1 we will substitute this back into these 2 points.

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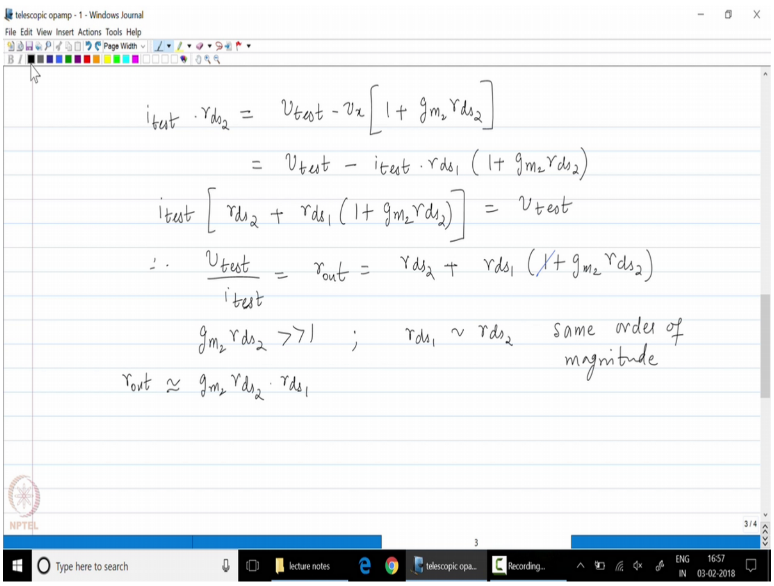

So, i test times r d s 2 was v test minus v x into 1 plus g into r d s 2 this is v test minus i test into r d s 1 into 1 plus g m 2 r d s 2 therefore, i test into r d s 2 plus r d s 1 into 1 plus g m 2 r d s 2 is equal to v test therefore, v test by i test is r out this is nothing, but r d s 2 plus r d s 1 into 1 plus gm 2 r d s 2 now we can make some approximations we can say that 1 plus. So, we can say that g m 2 r d s 2 is much-much larger than 1 and we can also say that r d s 1 and r d s 2 are of the same order of magnitude.

In such a case we can say that the output resistance is approximately equal to gm 2 r d s 2 times r d s 1. So, in other words we have neglected this term first and we have also said that this term is much-much larger than this term now we this is a circuit that we want where the output resistance has been increased using a circuit technic alone. So, now, let us go back and try to implement this in a opamp.

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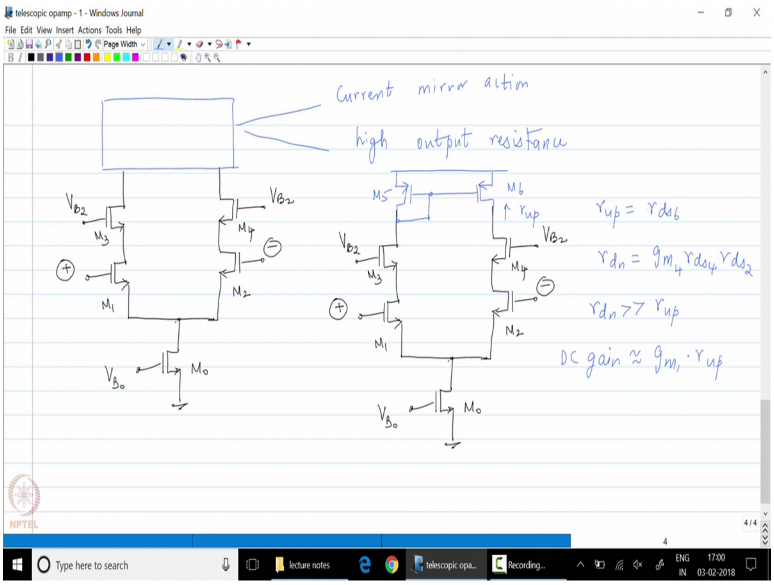

So, if I were to build an opamp; now I know that my input should now have a cascode because the impedance looking down nicely as largest bus. So, now, I am going to connect both these voltages to the same voltage and call that v b 2. So, this is the bottom portion of the circuit. So, I have now managed to increase the impedance looking down.

Now, I will now have something up here the block up here needs to perform 2 components. So, first of all it needs to build a current mirror action. So, this is something, I need from this particular block it also needs to have high output impedance this block also needs to have high output resistance and for example, if I were to take the circuit; let us take an example; if I were to take the circuit and connect a normal current mirror let us try that first.

So, I will draw that in blue. So, let us say I will do this if I were to do this. So, let me call this M 5 and M 6, I will clearly get the current mirror action that I have been looking for, but I have i problem the resistance looking up is r d s 6 whereas, the resistance looking down is gm 4 r d s 4 times r d s 2. So, r d n is much much larger than up this means that if I look at the gain of this opamp; this gain would be approximately gm 1 times r up.

So, I have not move that much I would get earlier it was half the intrinsic gain of the transistor. Now I would get approximately the intrinsic gain this is a difference of only around 60 db. So, this I want to increase the gain even further compare to this; now please note that what is left unsaid is that this particular cascode structure has the same gm. So, if I want to look at I have so far look only at the output resistance the output.

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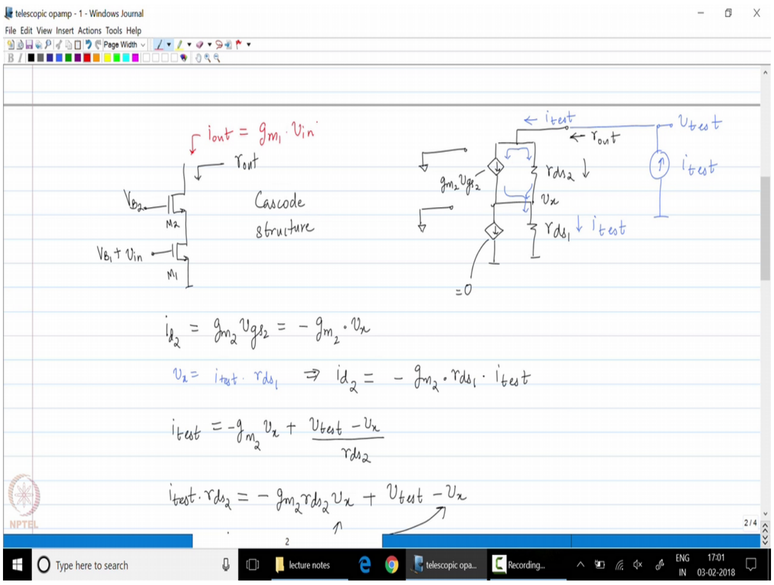

Current flowing into the circuit is gm 1. So, it is the gm of the lower transistor times V in.

So, please note this. So, therefore, since the dc gain is has not increased that much we need to come up with an even better circuit that will improve the DC gain even further.

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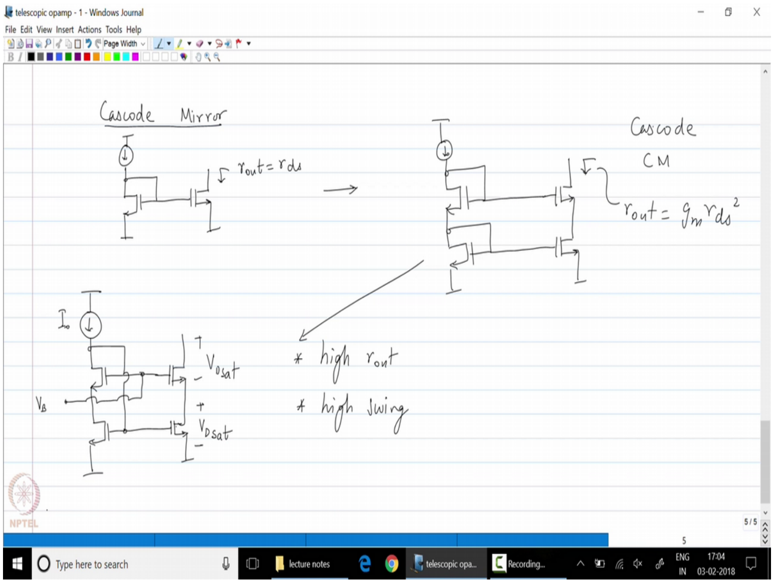

So, now let us look at the other circuit that we have seen before which is a cascode current. So, I start with a simple current mirror this has an output resistance of r d s and now I need to add a cascode device to improve the output resistance of the current mirror even further.

So, I move to a cascode current mirror which looks like this. So, this is the cascode current mirror. So, this has a very large output resistance of approximately gm rds square if I assume all of them are identical and finally, from the cascade current mirror; I move to the high swing cascade circuit the difference is that the feedback is taken from this particular node and in this particular case the gate of the upper transistors is tied to a bias voltage such that this is approximately 1 Vd sat this is approximately 1 Vd sat.

Therefore this particular circuit has high r out and high swing; this is called the high swing current mirror or the low voltage cascode current mirror.

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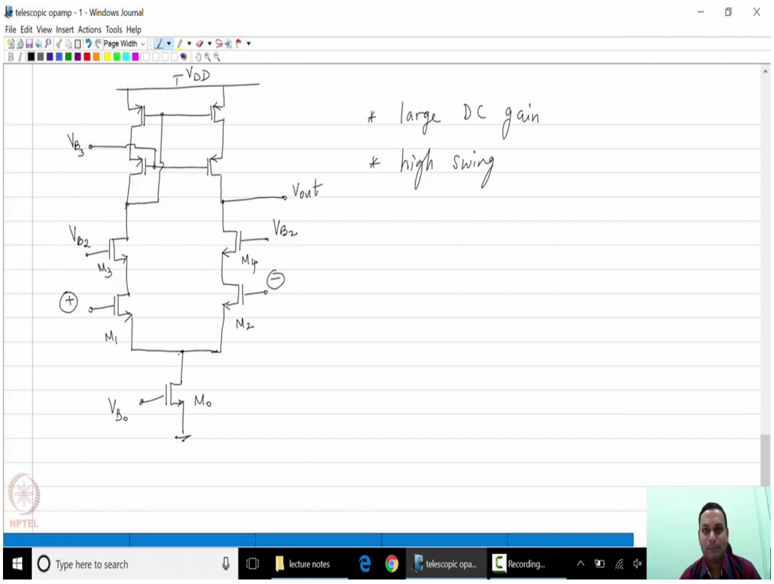

So, this is the circuit we are going to use except we are going to use the p mos version of this circuit. So, let us now build the cascode opamp by filling in the pmos current mirror this is V DD call this V B 3 and now we have an opamp that could potentially have large DC gain and proportionally high speed because we have used a high swing cascode now we are going to analyze this opamp with a small signal differential signal applied to the gates of m 1 and m 2 and we will really see if it has large dc gain we will really see if it has high swing.