Analog Integrated Circuits
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Lecture – 28
Telescopic OpAmp – 4

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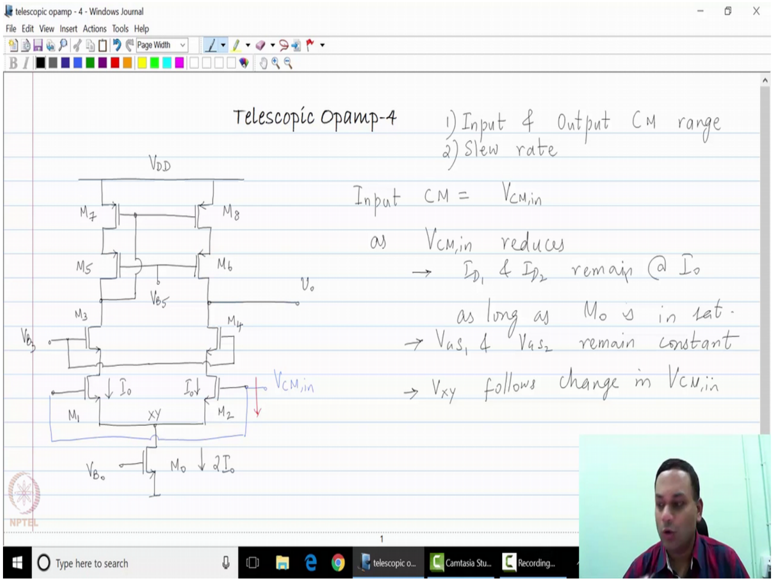

Telescopic Opamp-4

1) Input & Output CM range
2) Slew rate

Input CM = $V_{CM,in}$

as $V_{CM,in}$ reduces

→ I_{D_1} & I_{D_2} remain @ I_0 as long as M_0 is in sat.

→ V_{GS_1} & V_{GS_2} remain constant

→ V_{xy} follows change in $V_{CM,in}$

We are now going to look at the input and output common mode ranges of the telescopic op amp as well as its slew rate. So, let us look at the input common mode range. So, let us assume that the input common mode is equal to the VCM in and we want to find out the minimum and maximum values of VCM in. So, of course, to when you apply an input common mode, you connect the 2 inputs together and apply VCM in.

Now, suppose you started reducing VCM in. So, because the total current in M naught remains 2, i naught till M naught goes into triode the 2 transistors M 1 and M 2 will continue to have a current i naught each and therefore, VGS one and VGS 2 will remain will remain constant. So, therefore, the voltage that at xy reduces. So, as VCM in reduces. So, the points we will make id one and id 2 remain at i naught as long as M naught is in saturation this means that VGS 1 and VGS 2 remain constant.

Finally this means that v x y follows the change in VCM in. So, as VCM; VCM in as reduced v x y also reduces till M 0 goes to the edge of triode region.

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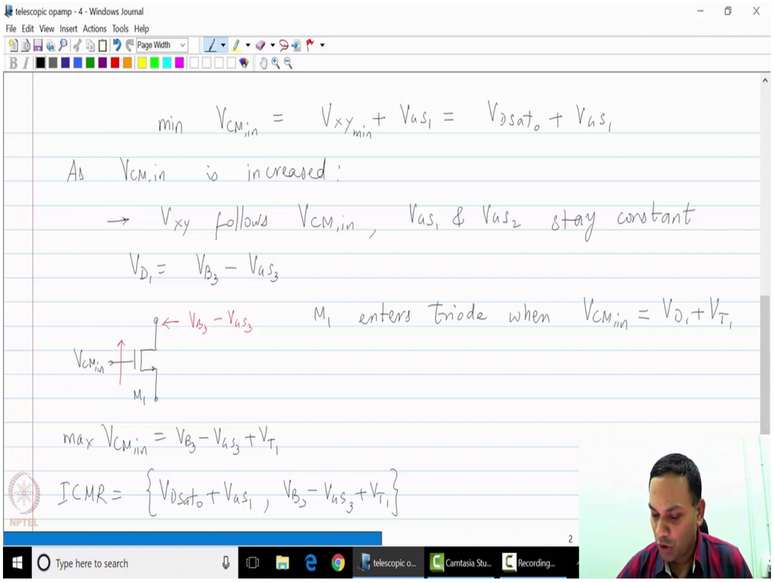

$$\min V_{CM_{in}} = V_{xy_{min}} + V_{GS_1} = V_{Dsat_0} + V_{GS_1}$$

As $V_{CM,in}$ is increased:

→ V_{xy} follows $V_{CM,in}$, V_{GS_1} & V_{GS_2} stay constant

$V_{D_1} = V_{B_3} - V_{GS_3}$

M_1 enters triode when $V_{CM_{in}} = V_{D_1} + V_{T_1}$

$$\max V_{CM_{in}} = V_{B_3} - V_{GS_3} + V_{T_1}$$

$$ICMR = \{V_{Dsat_0} + V_{GS_1},\ V_{B_3} - V_{GS_3} + V_{T_1}\}$$

Therefore minimum VCM is reached when the transistor M naught is just at the edge of the triode region at that point the voltage of that at x y is V D sat 0 and. So, this is nothing, but V D sat 0 plus VGS one just remember VD sat 0 is calculated at a current 2 i naught VGS one is calculated at a current of.

Now, next we will see what happens as you start increasing the value of value of VCM in. So, now, suppose we start increasing the value of VCM in as you can see you can follow the same set of arguments. So, as VCM in is increased you can say that v x y follows VCM in and therefore, M 0 is actually moving further away from triode there is no problem and VGS 1 and VGS 2 stay constant and both of them carry a current now as please note that the voltage at the drain of M 1 which we shall call V D 1 is biased V D 1is actually at a voltage equal to VB 3 minus VGS 3.

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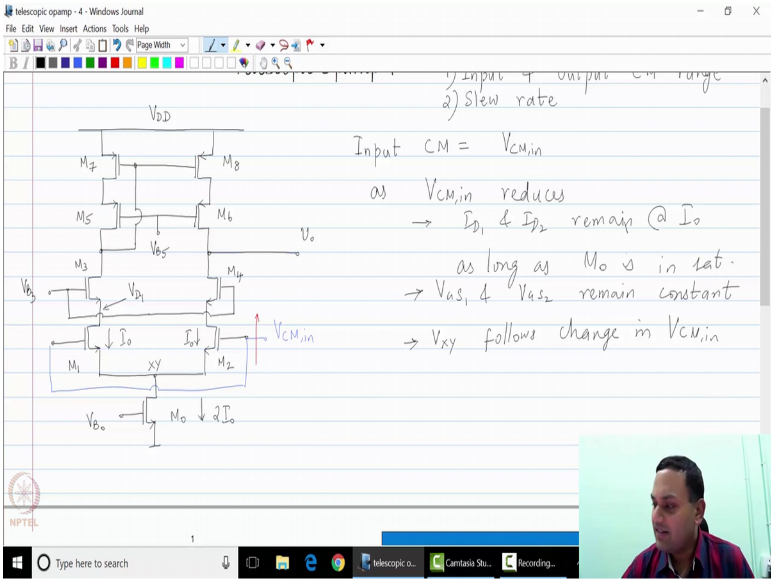

1) Input & output CM range
2) Slew rate

Input CM = $V_{CM,in}$

as $V_{CM,in}$ reduces
→ I_{D1} & I_{D2} remain @ I_0
as long as M_0 is in sat.
→ V_{GS1} & V_{GS2} remain constant
→ V_{xy} follows change in $V_{CM,in}$

Therefore one equals VB 3 minus VGS 3 where VGS 3 is calculated at a current i naught please note that because the current stays constant VGS 3 also stays constant now please note that for M 1 VCM in. So, the gate voltage is increasing whereas, this is constant at VB 3 minus VGS 3. So, M 1 enters triode when VCM in is one threshold voltage larger than v t. So, in other words. So, the maximum value of VCM in is VB 3 minus VGS 3 plus VT1. So, so the input common mode range. So, the input common mode is V D sat 0 plus VGS one comma VB 3 minus minus VGS 3 plus VT 1.

So, please note that the input common mode range is slightly different from the from that for the one stage opamp; now what about the output common mode range so.

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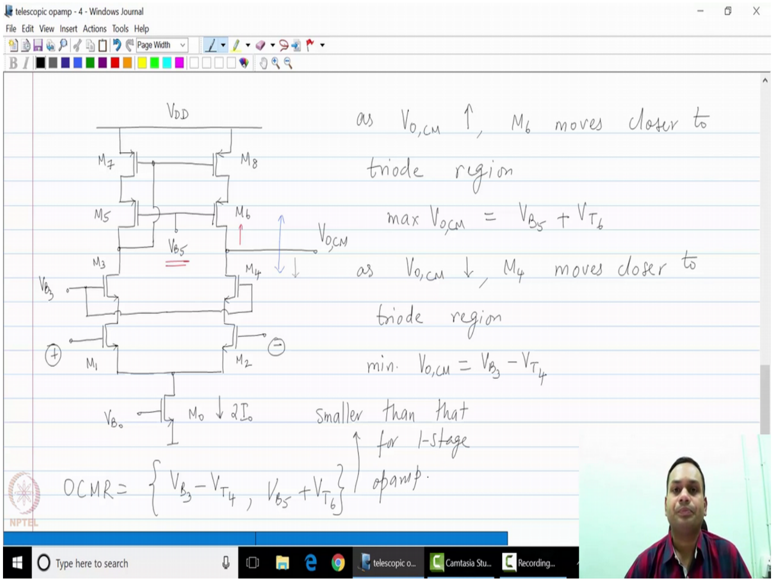

as $V_{O,CM} \uparrow$, M_6 moves closer to triode region

max $V_{OCM} = V_{B5} + V_{T6}$

as $V_{O,CM} \downarrow$, M_4 moves closer to triode region

min. $V_{O,CM} = V_{B3} - V_{T4}$

$OCMR = \{V_{B3} - V_{T4}, V_{B5} + V_{T6}\}$ $\uparrow$ Smaller than that for 1-stage opamp.

Let us again take the same opamp, but now we are now going to see what happens you know what is the maximum voltage at the output versus the minimum voltage at the output. So, of course, as let us call the output common mode as the OCM. So, as V OCM increases you will find that M 6 has a constant gate voltage VB 5 whereas, its drain voltage is increasing M 6 moves closer and closer to the triode region and therefore, the maximum value of V OCM is nothing, but VB 5 plus VT 6.

Similarly, as V OCM decreases you will find that the gate of M 4 is constant and M 4 moves closer to triode region this means that the minimum value of the o c M is nothing, but VB 3 minus VT 4 therefore, the output common mode range is VB 3 minus VT 4 comma VB 5 plus VT 6 as you can see this depends on VB 3 and VB 5 numbers, but in general you will find that the output common mode range of the telescopic op amp is smaller than that for the one stage opamp.

Naturally because you now have large number of transistors and you cannot support a large enough common mode range or spin at the output node.

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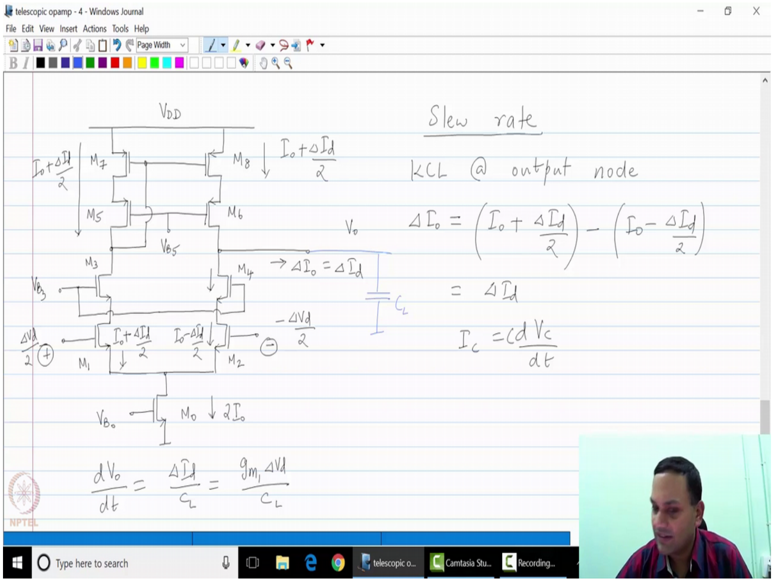

Slew rate

KCL @ output node

$$\Delta I_0 = \left(I_0 + \frac{\Delta I_d}{2}\right) - \left(I_0 - \frac{\Delta I_d}{2}\right)$$

$$= \Delta I_d$$

$$I_c = C\frac{dV_c}{dt}$$

$$\frac{dV_0}{dt} = \frac{\Delta I_d}{C_L} = \frac{g_{m_1}\Delta V_d}{C_L}$$

Finally we will look at the slew rate of the telescopic op amp. So, we are now interested in slew rate. So, to find out the slew rate. So, we will now apply increments of delta V D by 2 and minus delta V D by 2 at the inputs as you might imagine the currents are now i naught plus delta ID by 2 and downwards and i naught minus delta i d by 2 from downwards to M 2 and these are the incremental currents delta i d by 2 and minus delta i d by 2 are the incremented currents through M one and M 2.

Now what happens to these incremental currents. So, these currents flow through the other transistors. So, i the current M 3 M 5 and M 7 is i naught plus delta i d by 2 and this gets mirrored through between M seven and M 8 to give you i naught plus delta id by through by 2 through M 8 and M 6. Now what happens to this current flowing through M 2 that current flowing through M 2 flows through M 4 also.

So, if you were to find out the total delta i o you do that by applying kcl at output node you find that delta io is the total current leaving the node should be the sum of the currents entering the node the sum of the current entering the node from M 6 is i naught plus delta i d by 2 and the current entering the node from M 4 is minus of i naught minus delta i d by 2.

So, this is nothing, but delta i d. So, the current delta i d flows through the output now where does this current flow of course, the output will have a load capacitance c l and therefore, this delta i d current charges the load capacitance . So, therefore, for the capacitance you write i c is DVC by d t times C; this means that the value of d v naught by d t is nothing, but delta i d over c and this of course, for small signals is nothing, but g M one delta V D by c l now if you start increasing the value of delta VD you will find that since M one carries i naught plus delta id by 2 the current through M 1 increases and the current through M 2 decreases.

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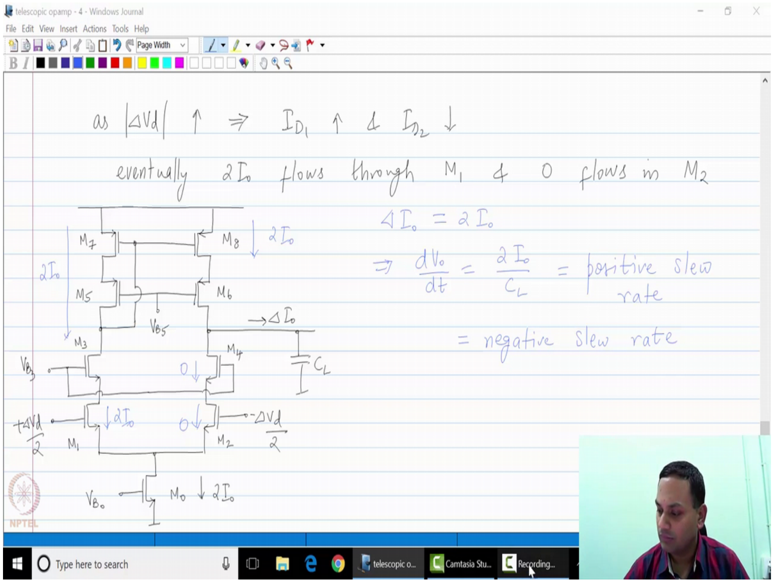

as $|\Delta V_d| \uparrow \Rightarrow I_{D_1} \uparrow$ & $I_{D_2} \downarrow$

eventually $2I_0$ flows through M_1 & 0 flows in M_2

$\Delta I_0 = 2I_0$

$\Rightarrow \frac{dV_0}{dt} = \frac{2I_0}{C_L}$ = positive slew rate

= negative slew rate

So, as the magnitude of delta V D increases. So, i d 1 increases and i d 2 decreases eventually 2 i naught current flows through M 1 and 0 current flows through M 2. So, all the current has shifted into transistor M one. So, in this case you will find that the in this case let us write down the expression for the total current flowing into the output node. So, that is delta i o. So, if you were to apply a really large step at the input. So, so you would find that you would have a current 2 i naught would have 0 current therefore, M 2 and M 4 would be cut off this current to i naught flows through M 3 M 5 and M 7 and this gets mirrored into M 8 and M 6.

Again if you apply kcl at the output node it is clear that delta i naught is equal to 2 i naught this means that V D o by d t is 2 i naught over a CL. Now if you were to increase the input step any further the output cannot rise any faster because the op amp can only source a maximum current of 2 i naught. So, this is turn the positive slew rate of the op amp now you can apply a negative slew rate you can apply a negative step to the op amp and in that case M 1 M 3 M 5 and M 7 are cut off and. So, are M 6 and M 8 and M 2 and

M 4 carry the full current of 2 i naught and discharge the load capacitance. So, it turns out that this is also equal to the negative slew rate. So, the positive slew rate is equal to the negative slew rate for the telescopic opamp also.