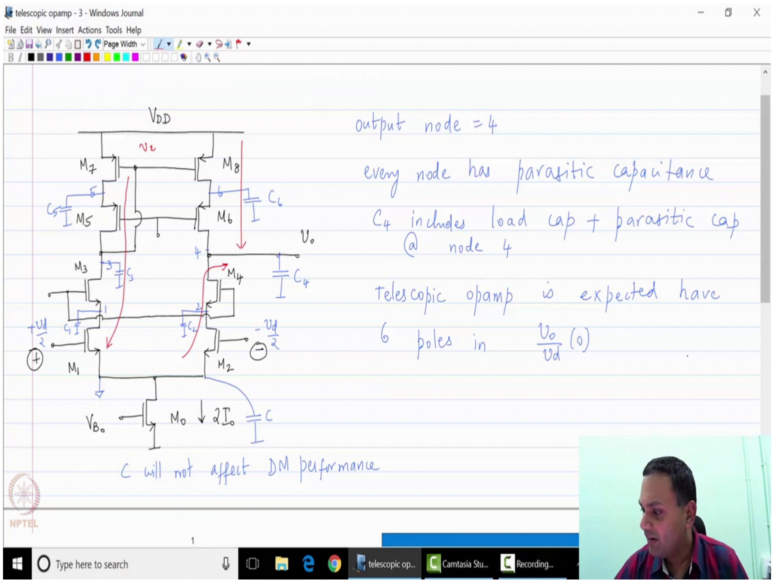
Analog Integrated Circuits
Prof. S. Aniruddhan
Department of Electrical Engineering
Indian Institute of Technology, Madras

Lecture – 27
Telescopic OpAmp – 3

(Refer Slide Time: 00:17)



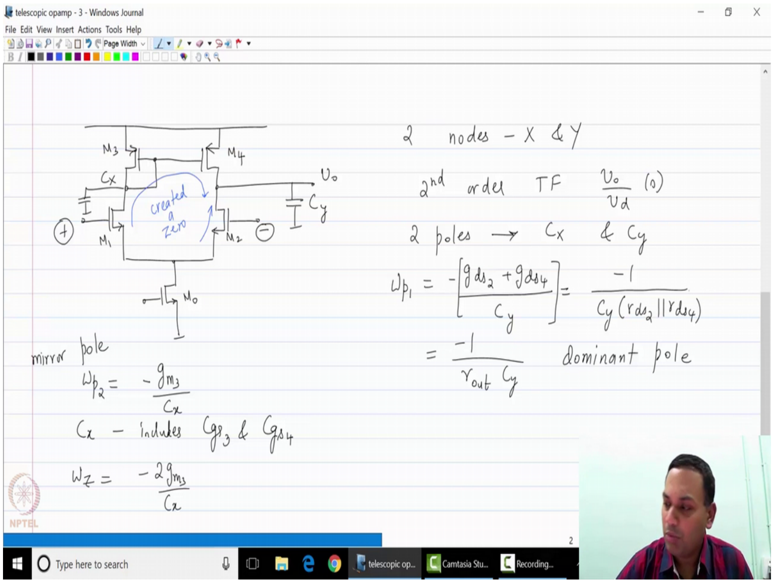
In this lecture, we are going to look at the frequency response of this telescopic opamp. So, let us now start naming the nodes as you can see the telescopic opamp has a much larger number of nodes compared to the 2 stage opamp. So, let us first point out that any capacitance at the common source node capacitance will not affect C will not affect the differential mode performance because it happens to be at a common mode node, you should note. So, we can ignore the capacitance there because the common source node happens to be a virtual ground.

Now, let us start naming the other nodes. So, let us now name this node 1, node 2, node 3, node 4, node 5 and node 6. So, as you can see including the output node which is 4 the cascade; opamp has 6 nodes compared to only 2 nodes including the output node for the simple one stage opamp. So, as you might imagine every node has parasitic capacitance due to transistors being connected to those nodes apart from this you will also have some load capacitance C l. So, everything put together we will call this total capacitance C 4.

C 4 includes load cap plus unwanted parasitic cap at node four. So, C 4 is the sum of the load capacitance C l and whatever parasitic capacitance exist at that node apart from this. So, you will have other capacitances C 1; C 1, C 2, C 3, C 5 and C 6. So, as you might imagine the telescopic opamp will probably have. So, is expected to have 6 poles in its transfer function because you will have single current flowing through every one of these capacitances at high frequencies.

So, if we draw a parallel with the 2 stage opamp just a quick reminder.

(Refer Slide Time: 03:56)



In the case of the 2 stage opamp, let us quickly draw out the picture to draw to understand the analogies. So, if you look at the analogies between the 2 stage opamp and the one stage opamp. So, the one stage opamp have 2 nodes x and y and therefore, it had a second order transfer function. So, its gain had 2 poles. So, 2 poles corresponding to C 2 nodes x and y, they depended on cx and cy they also depend at on the impedance at those nodes.

So, just a quick reminder, the dominant pole omega p one was gds 2 plus gds 4 over C y which was the same as one over C y into rds 2 parallel rds 4 in other words. So, it has one over r out times cy. So, the dominant pole and was the dominant pole because r out was extremely large and it will also assume that the load capacitance is large enough. So, that the combination of these 2 make as the dominant pole apart from this you also had second pole which was called the mirror pole because it came from the current mirror consisting of m 3 and 4.

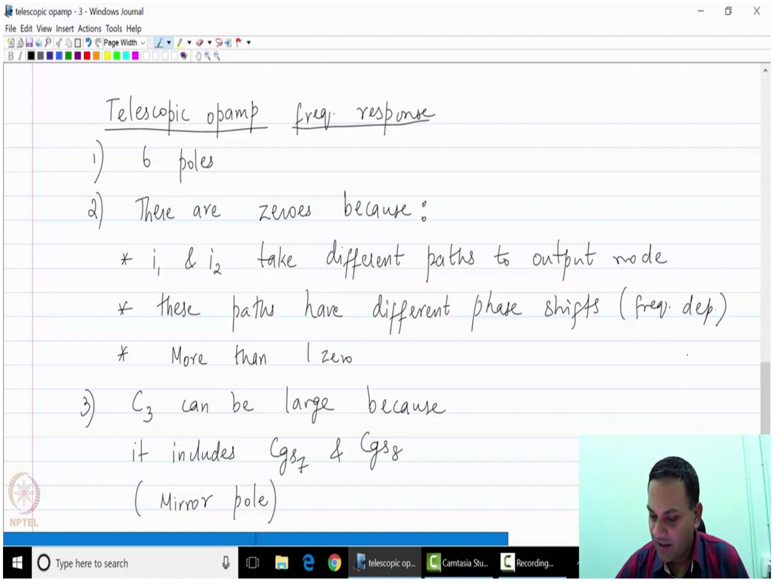
So, this was given by gm 3 over C x and this was because 1 over gm 3 was the impedance at node x and the total capacitance as node x was C x and as we pointed out C x is the could be important because C x includes an C g s 3 and C g s 4 because these 2 gate source capacitances can be quite large C x can be significant enough to affect the phase margin of the opamp and close load.

Now apart from this we also got a 0 which whose magnitude was 2 gm 3 over C x just a reminder that in reality all of these where left half plane poles and zeros. So, I will correspondingly even though; I was drawing writing the magnitude all this while I will now add the sign to indicate that they are l h left half plane poles. So, this particular 0 arose because the signal took 2 parts one through m 1 m 3 m 4 and the other through m 2 alone. So, this created a 0 because you had 2 paths each with frequency dependent phase shifts that were different which added up at the output to create destructive interference at a particular frequency.

Now, let us go back to the telescopic opamp and see if all of these things are possible. So, if you look at the telescopic opamp you will find that many of these things are definitely possible even in the telescopic opamp. So, the first thing we have identified that there are 6 poles and the transfer function let us find out that there are zeros as you can see the path to the output from the signal current from m 1 takes the following paths. So, the current flows the signal current that flows through m 1 also flows through m 3 m 5 and m seven and that creates a small signal voltage v x and that causes signal current to flow into m 4 from m 8 and m 6.

Similarly, the path from m 2 flows through the signal current through m 2 flows through m 2 and m 4 as you can clearly see they see the signal in the 2 halves.

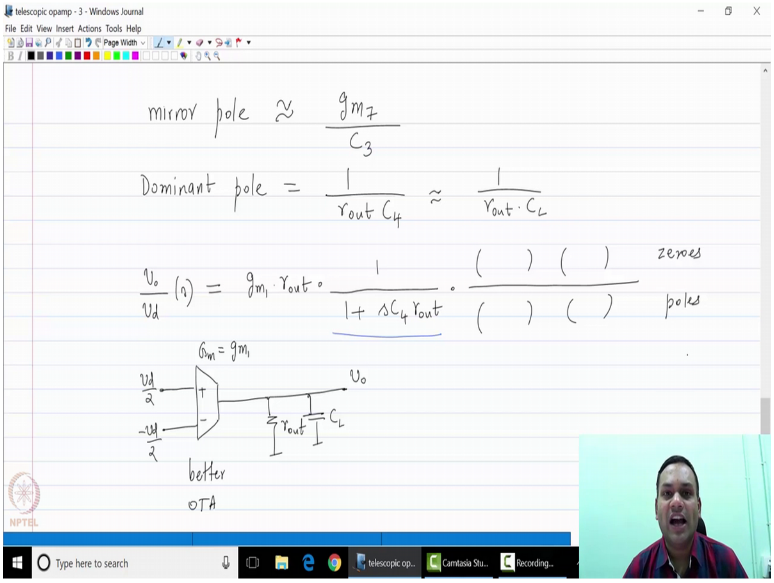
(Refer Slide Time: 09:30)



So, in the telescopic opamp in the telescopic opamp frequency response we note that there are 6 poles and there are zeros because i 1 and i 2 take different paths to the output node and more importantly these paths have different phase shifts that are frequency dependative.

So, this is enough to create a 0 and you will find that there because these 2 paths have multiple transistors and multiple capacitances the telescopic opamp will have more than 1 0. Now number 3 will go back to the main circuit we noted that there are 6 poles; we noted that there are zeros the third thing we will note is that the capacitance or rather the capacitance C 3 C 3 because it includes C 3 can be large because it includes the gate source capacitance of m 7 and m 8; this is the mirror pole.

(Refer Slide Time: 11:56)



Please note that the mirror pole will be approximately at a frequency that is the impedance at that node or rather the conductance at that node which happens to be one over g m seven we have calculated that in a different lecture. So, the mirror pole will be approximately gm seven over C 3 and this would be one of the important non dominant poles of the system.

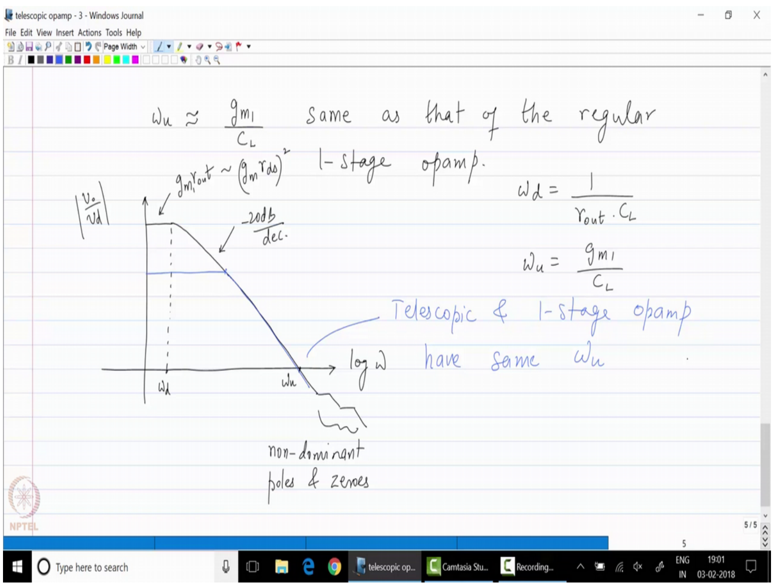
Now what about the other capacitances it turns out that the other capacitances C 5 C 6 and C 1 includes some gate source capacitances, but also some drain bulk capacitances. So, therefore, we will and their impedance levels at those points are also you know either very low because they are connected to some sources or they are low enough to cause the non dominant pole to be somewhat further somewhat high compared to the dominant poles.

Therefore the dominant pole of the system is actually one over r out time C 4 C 4 and ill say this is approximately one over r out times C l where C l is the load capacitance, I will assume this is large enough to dominate the frequency response at that particular node. So, this is the frequency response of the amplifier. So, if I were to write it as a function of the dominant pole. So, the frequency response, v o by v d of s would consist of several parts the first part should be the a DC gain of the system. So, that is nothing, but g m 1 times r out. So, that is the dc gain of the system I know that I am going to have at least one pole which is 1 plus s C 4 r out and that to have a bunch of zeros and a bunch of other poles.

So, these are the poles and these are the zeros and since this is the dominant pole of the system I would expect that the unity gain frequency of the opamp of the telescopic opamp is dominated by this particular number if you were to have an idealized telescopic opamp the telescoping opamp should actually be replaced with a ota and because the output resistance of a telescopic opamp is larger than that of a one stage opamp this is a better ota compared to a one stage opamp and its transconductance is the transconductance of the input pair and if you just show the dominant dominant impedances that would just be the output resistance in parallel with the output capacitor C l.

And now since we know the dominant pole as well as the output resistance output capacitance and the trans-conductance we should now be able to write the unity gain frequency of the system assuming that all the undesired poles and zeros are much further away than the unity gain frequency.

(Refer Slide Time: 16:00)



So, you can say that omega u should be equal to in an ideal case should be equal to gm one over CL as you can see the r out of the system does not figure into the unity gain frequency of the loop because the DC gain is also decided by r out and. So, is the dominant pole frequency?

Now, as you can see this unity gain frequency is same as that of the one stage regular one stage opamp in that sense a telescopic opamp from a frequency response point of view is not that different you do have a whole number of extra poles and zeros undesired poles and zeros, but at the end of the day the transconductance is similar the unity gain frequency is similar and most importantly the telescopic opamp simply looks like a better operational trans-conductance amplifier because it has a larger r out.

Now, let us just draw the magnitude response. So, that we get an idea of what this would look like if you were to draw the magnitude response of the telescopic opamp. So, at low frequencies the telescopic opamp has a gain gm r out that is of the order of gm rds the whole square now because r out is extremely large the dominant pole omega d is extremely small. So, omega d is one over r out times C l and at this point the opamp has a minus twenty db per decade roll off until it hits omega u and as you can clearly see omega u now does not depend on r out it only depends on C gm and C l.

Now, beyond this you could of course, have several poles and zeros. So, ill show them somewhat of this manner. So, I will say these are the non dominant poles and zeros now if you were to overlay this plot on top of the original one stage opamp; I now show that in blue now the original one stage opamp had a dc gain of only of the order of gm times rds. So, I will show that this, but please remember the r out of a one stage opamp was only of the order of rds by 2 and not the gm rds square and therefore, the dominant pole of the one stage opamp will be higher than that of a corresponding telescopic opamp.

Now, I will assume that these 2 have the same gm and the same load capacitance and therefore, you will find that what you have achieved with the telescopic opamp is simply larger dc gain. So, the telescopic and one stage opamps both the telescopic and the one stage opamp have the same for the given and a given CL, this is important to note because omega u represents the true speed of the opamp when placed in C pack therefore, the telescopic opamp has given us larger dc gain, but it will not help in making the opamp faster.