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

Lecture – 22
One-Stage OpAmp Slew Rate

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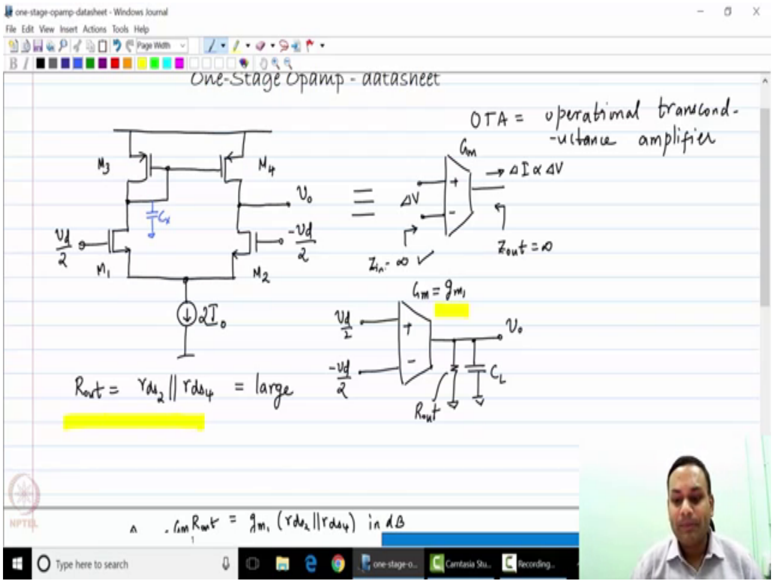

In this lecture, we are going to summarize the one-stage opamp and finally, build its datasheet with all the parameters that we have calculated for it so far. So, if you were to take the one-stage opamp shown here, and you had to represent it by a block diagram, it turns out it is best represented by a block called an operational transconductance amplifier or an OTA. Why do I say this? So, the if you take a transconductance amplifier it turns out that its properties are that if you were to apply a delta V at its input, you would get a current delta I which is proportional to delta V with the proportionality constant being some G m.

And more importantly the OTA has a very specific property that its input impedance is infinite and because it acts like an ideal current source at the output Z out is also infinity. It turns out that for R opamp. So, the one-stage opamp that we have built R out is r d s 2 parallel r d s 4 which is quite large. So, remember that one of the properties we desired originally from the opamp was that the output impedance should be very small. Normally, most CMOS opamps do not necessarily have this property. The reason why this property is not needed is because many opamps end up driving capacitive loads, where the low output resistance does not matter too much.

Now, let us look at the non-idealities of this opamp of this OTA. Now, it turns out that z in is equal to infinity is valid at low frequencies, because the input of the opamp that we have built is capacitor. Z out is not infinity, but it is quite large relatively large compared to the other impedances in the circuit. Now, if you were to draw the non-idealities, you could represent the opamp in the following manner. So, this is the positive input and this is the negative input, and it turns out that the transconductance of the opamp is small g m 1; in other words the g m of M 1 and M 2.

And if it were driving a capacitive load at the output it would also have its own output resistance that can be represented by R out. So, this is the representation of the one-stage opamp with ideal idealized components. So, you have a transconductor representing the g m of the opamp, and you have a output resistance R out, and you have the load capacitance at the output node which is C L.

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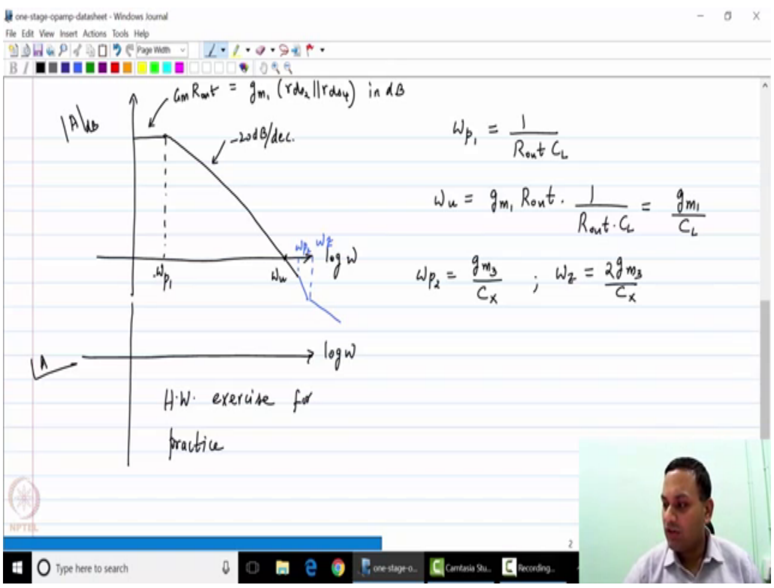

Now, if you were to draw the gain of this opamp as a function of frequency when driving this capacitive load it would look like this. So, I am going to draw only the magnitude plot, I encourage you to draw the phase plot as a home work exercise. So, if I were to plot the magnitude of the gain of the opamp. So, at very low frequencies, the gain of the opamp is clearly G m times R out which of course, is g m 1 into r d s 2 parallel r d s 4 because R out is r d s 2 parallel r d s 4 and G m is equal to g m 1.

Now, it turns out that because you have a resistance R out and a capacitance C L, this particular opamp is going to have a pole. And the pole frequency I will call that omega p 1 is going to occur at one over R o times C L. Since R out is very large, this would be the dominant pole of the system and would be quite small. Once you hit this pole frequency, the gain starts to fall at the rate of minus 20 d b per decade. Please note that everything is being plotted in db. Now, the unit again frequency of the opamp that I will denote by omega u is clearly related to the dc gain and omega p 1. So, this is nothing but g m 1 times R out into 1 over R out C L this is clearly g m 1 over C L.

So, please note that if you have a transconductor driving an R c kind of load, the unity gain frequency of the system is the transconductance over the capacitance. So, it is g m 1 over C L. Now, it turns out that this opamp has a couple of more non-idealities. So, it turns out that as we have studied before there is some parasitic capacitance here which we will call C x, it turns out that this particular opamp also has a second pole at minus. So, since we are plotting only for positive frequencies, I will just show the positive value it happens to be a left half plain pole, but I will only show the magnitude. It has a second pole at g m 3 over C x we have calculated this in a previous lecture. And it also happens to have a zero at 2 g m 3 over C x. So, if you were to show this with blue color, the opamp should have been designed such that omega p 2 occurs after omega u. So, that it is a till it hits a gain of 1, it looks like a single pole system, so that it starts going down faster until it hits omega z and then it starts going down at 20 db per decade again. So, this would be the magnitude plot of the system. I encourage you to draw the phase plot of the system as a homework exercise.

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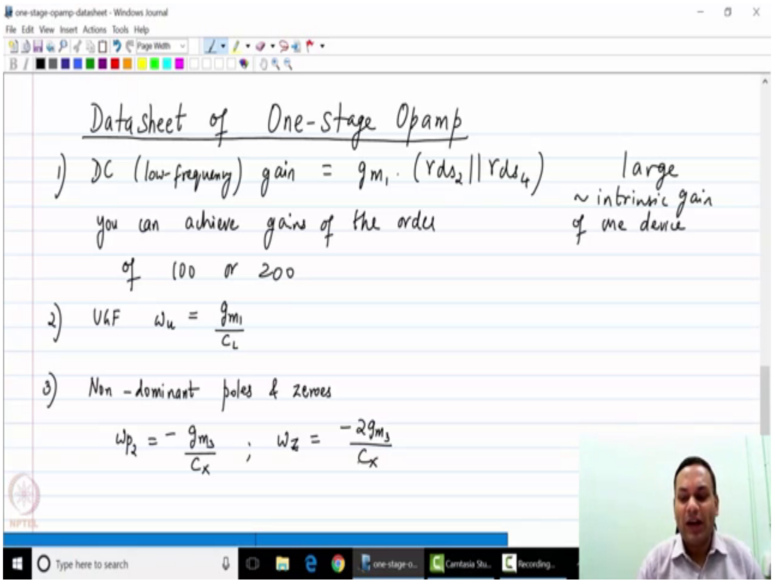

Now, we are now in a position to start writing down the datasheet of the opamp, which is going to consist of around eight parameters. So, this is the datasheet of the one-stage opamp this will just summarize the various parameters that we have studied so far about the one-stage opamp. So, the first important parameter of the opamp is going to be its d c gain when I say dc gain I do not necessarily mean dc signals applied I mean low frequency gain. So, the dc or low frequency gain of the opamp is nothing but g m 1 into r d s 2 parallel r d s 4.

Now, please note that this gain is quite large, and you would expect that this would be of the order of the intrinsic gain of the opamp, intrinsic gain of a transistor. Therefore, you would expect to achieve gains of the order of 100 or 200. So, you should with a single stage opamp, you should expect to get a g in of about 100 or so. Now, if you were to, if you wanted more gain, it turns out you will have to go for a different kind of opamp that we will discuss in future lectures.

Now, the second important characteristic of the opamp is going to be the unity gain frequency of the opamp or omega u. And as we have just studied omega u is g m 1 over C L. And as you can see the unity gain frequency of the opamp depends only on its transconductance and the load capacitance that it is meant to drive. If you need a larger unity gain frequency for a fixed load capacitance, you have to increase the transconductance of the opamp.

The third parameter of interest for us is again related to the frequency response. So, we are now interested in the non-dominant poles and zeros and as we have seen you have one non-dominant pole and one non-dominant zero due to the non-idealities of the opamp of the single stage opamp. So, you have omega p 2 which is minus g m 3 over C x; and you have a 0 which is minus 2 g m 3 over C x, you happen to have one non-dominant pole and one non-dominant zero.

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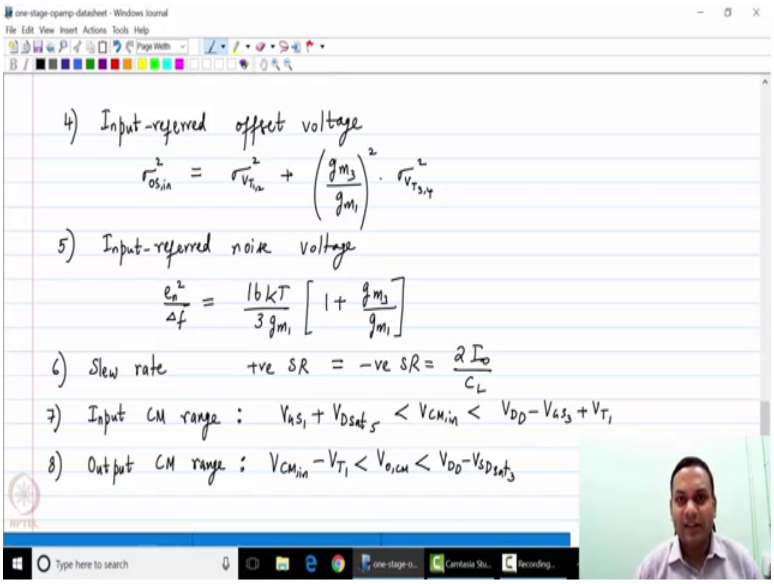

The fourth parameter of interest is going to be the input referred offset of the opamp which we will represent as sigma squared os in. And as we have seen this consists of two portions, the first portion is the offset voltage of the input differential pair M 1 and M 2 that appears directly at the input. And a second portion which is scaled by g m 3 over g m 1 squared, the second term is the V T mismatch of transistors M 3 and M 4. So, this is the expression for the input referred offset voltage. As we have seen before if you were to minimize the offset contribution of M 3 and M 4, you have to decrease g m 3 relative to g m 1.

The fifth term that we are interested in is the input referred noise. In this case, because the opamp has an infinite input resistance, we only have an input referred noise voltage and e n squared by delta f is nothing but 16 K T by 3 g m 1 into 1 plus g m 3 by g m 1. Again as we have seen before you to minimize the input referred noise voltage; in other words, to built a low noise opamp, you will need to maximize g m 1 as well as minimize g m 3 relative to g m 1.

The next important parameter is the slew rate of the opamp. For this particular opamp, the positive slew rate is equal to the negative slew rate which is equal to 2 I naught over C L, where 2 I naught is the total bias current of the opamp. Another important parameter metric of the one-stage opamp of any opamp is the input common mode range. And as we have studied for this opamp, we can write down the input common mode range as follows. So, V GS 1 is the gate source voltage of the input transistors if the common mode voltage keeps going down the current source goes into the triode region. And at the edge of the triode region, if the current source were to have a V D sat which is V D sat 5 the minimum input common mode permissible is V GS 1 plus V D sat 5. And the maximum permissible voltage happens as we have seen when the input transistor goes into triode and that happens at V DD minus V SG 3 plus V T 1.

Finally, the other the last parameter of interest for us is the output common mode range, it turns out that for this opamp, the output common mode range is also related to the input common mode range. As you keep reducing the output common mode, the minimum voltage that it can achieve is related to the input common mode as V CM in minus V T 1; and the maximum common mode voltage is nothing but V DD minus V SD sat 3. So, this completes the datasheet of the one-stage opamp. As you can see, there are eight important parameters that we have listed out, and summarized for the opamp.