Analog Circuits
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Module - 03
Lecture – 03

Now, we will look at the effect of the small signal output conductance g d s of the MOS transistor on the common source amplifier. This is the common source amplifier structure we had. We have source resistance of 100 kilo ohms in our previous example. I am taking exactly the same values that I had earlier. And we had this bias resistance, which are made to be much more than R s, so that there is no voltage division between R s and these bias resistors. All of this V s appears across the gate and source. And on the drain side for biasing, we need R D; and we have used 100 kilo ohm load resistance so that 20 volts is dropped across it from a 23 volts supply and 3 volts are left across the MOS transistor. And the load resistance also is specified to be 100 kilo ohm.

So, we know that the operating point in this case, this is already been worked out earlier. If you have forgot on the details, please go back to that lesson and work it out again, it will just be additional practice. So, the operating point is V G S of three volts, V D S of three volts corresponds to a drain current of 200 microamperes. And at this operating point, the small signal trans conductance g m is 200 micro Siemens, this is what we had calculated. So, now the question is what is the effect of the channel length modulation or the extra factor of 1 plus lambda V D S that appears in the drain current expression in the saturation region. Now, as was discussed earlier, the fact that we had channel length modulation means that the operating point current also changes right, because here we get V G S of three volts that does not change at all, because the gate current is still zero.

But for a gate voltage of three volts, instead of the current being two hundred microamperes, it will be dependent on V D S as well and you can calculate it. But like I mentioned usually we do operating point calculations without taking into account the effect of lambda V D S. So, we will assume that I D will remains at 200 microamperes and therefore, V D S will remain at 3 volts and so on; and similarly, g m will remain at 200 micro Siemens. So, we ignore the changes in operating point, because of this.

But, we have this small signal picture of the same amplifier here, and if C 1 and C 2 are sufficiently large, now we do know how to calculate them to be sufficiently large. They do behave the shorts at the signal frequency. So, now if they behave as shorts and if R 2 and R 1 are very large compared to R s, so let me write those things down. C 1, C 2 very large, I would not specify the value, but we do know how to calculate that. And similarly, R 1 and R 2 are much more than R s. In this case, we know that the small signal gain V naught by V s is minus g m R D parallel R L according to our previous calculation.

Now, what is the effect of channel length modulation across the drain and source of the MOS transistor, we have a small signal conductance g d s. So, we have this additional conductance g d s. And again, we know that g d s is basically lambda I D, and if I take lambda to be point zero five volts inverse, this g d s turns out to be ten micro Siemens or the reciprocal of 100 kilo ohms. So, the resistance that appears across drain source is 100 kilo ohms. Now, what is the effect of this, it is very easy to see; it simply appears in parallel with R D and R L. We have R D across the drain and source, R L across the drain and source in the small signal incremental picture. Now, this r d s or g d s also appears across drain and source. By the way the notation g d s is used with the conductance and r d s is used with the resistance, so r d s is 100 kilo ohms and it is basically the reciprocal of g d s.

So, what happens, all these three resistors are in parallel, the current g m times V G S goes into the parallel combination of these resistors. So, the output voltage would be minus g m because of the polarity of the current times R D S parallel R D parallel R L times V G S or the gain V naught by V G S would be minus g m R D S parallel R D parallel R L. Now, remember this will only reduce the gain, because we have an additional resistance in parallel with R D and R L. If you remember the sequence of the events, we started off trying to make a gain of minus g m R L. And for the values of g m being 200 micro Siemens and R L being 100 kilo ohms, we will have this value to be 20. And what we really get is minus g m R D parallel R L, because R D is inevitable and we can try to make R D higher and higher, but that will need a larger and larger supply voltage. If we choose R D to be 100 kilo ohms, the same as R L then the gain will become half of what it was before, so we get only minus 10.

And finally, what we get is not even that we have r d s also in parallel and in this case coincidentally, r d s is also 100 kilo ohms, so minus g m r d s parallel R D parallel R L will turn out to be minus six point seven, six point six seven. So, the effect of r d s is to reduce the gain of the common source amplifier and in general any amplifier. One thing you notice is r d s appears in parallel with these, so even if you set R L to infinity and R D to infinity, somehow you find some way of biasing and there is no load resistance at all, the maximum value of gain magnitude would be g m r d s.

Because, this gain V naught by V s which is minus g m R D parallel R L parallel r d s. If I consider only its magnitude becomes plus, and we know that this is going to be less than g m r d s. So, this g m r d s both are just parameters of the transistor. Once you have a transistor, and you decide its operating point this number is fixed. And this tells you that there is a maximum limit to how much gain you can get from a single transistor that gain number can be large or small, but there is a limit, depending on the value of lambda and the operating point current you choose, you could have larger or smaller number for this limit, but there is going to be a limit. So, even if you find magical ways of biasing where R D is tending to infinity, you do not have any load resistance at all, you still cannot get infinity gain from a single transistor. And this is anyway obvious if you look at the small signal picture of the MOS transistor including the output conductance g d s, or output resistance r d s.

Now, this is g m V G S, gate, source and drain. And let say that somehow we are able to establish the correct operating point in the MOS transistor without any extra component appearing anywhere. So, this is all the circuit we will have in the small signal. Let’s not worry about how to do it, but if we do it like that this is the circuit we have so the current here is g m V G S, all of it goes into the conductance g d s. So, this voltage will be minus g m by g d s times V G S, which is the same as minus g m r d s times V G S, and this is the gain that we are going to get at most. So, this g m r d s number is the significant number and it is the inherent gain limit of a transistor. It is not a fixed number, it also depends on the operating point, and like I mentioned in the lesson where we introduced channel length modulation, the coefficient lambda itself depends on the length of the transistor. But whatever it is there is some upper limit to the gain that you can achieve. So, I hope this part is clear.

So, for completeness, in a MOS transistor small signal model, you have to include the output conductance. Now, because calculations are very cumbersome, we do not include it in operating point, and we do not include it for the calculation of g m and so on. Al though, we could do it with some extra effort, so unless otherwise mentioned for operating point calculations and for g m calculations, omit the effect of lambda, but the lambda will cause the MOS transistor to have an output conductance g d s. And that you have to include into the small signal picture of the MOSFET in any circuit that you have and of course, like g m, g d s also depends on the operating point.