Analog Circuits
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Module - 02
Lecture – 15

We now have our amplifier complete with biasing arrangements that is arrangements to set the operating point correctly and so on. And the circuit is what you see over here, but of course, this looks somewhat different from what we started with. In particular, originally, what we wanted was, a MOS transistor across the gate source we should have three volts plus V s or whatever operating point voltage we want plus V s. And R L should get connected across drain and source. And the input source of course, is given by this V s and R s. Of course, we expect to have some battery power in this; in our case, it is V D D of 23 volts, but we do have some extra stuff we have this R 1 here, R 2 there and this is R D. We need all these things to bias the transistor correctly and add the input signal to the gate to the appropriate bias value. And also this R D is required so that we establish the correct drain source voltage to maintain the transistor in saturation region and so on.

So, this circuit is somewhat different from what we started with. We have some extra components. We need to analyze this and see whether it behaves exactly the way we wanted or there are some deviations. In fact, we can kind of now assume that somebody gave us this circuit and we have to analyze it. In the way we do it is first we analyze the operating point then we analyze the incremental picture. This is what you would do if you came across an unfamiliar circuit, so this exercise is kind of a practice in that direction as well. So, first let us look at the operating point of this particular circuit.

In our case, operating point means dc operating point so this means that the signal sources which are what introduced increments into our circuit. Remember, operating point is some point for which you find the solution. In our case, we think of our amplifier as being quiescent or being ideal when you apply no signal and that is where we calculate the operating point. And then when we apply the signal, we treat the signal as an increment. Signal sources set to zero, so in our case we have a just single signal source, so this V s must be zero, so this voltage source should become a short circuit. If we had a current source as the signal source, it would become an open circuit. And also, because it is dc, capacitors are open circuited and inductors are short circuited. Now, our case, we are not use any inductors, but you could. If you do for dc operating point, they will become short circuits and capacitors will become open circuits.

So, if you do that for this particular circuit what happens this C 1 becomes an open circuit, C 2 becomes an open circuit. So, effectively this cuts off both the source and the load from this part of the circuit. Then what do you do, you do the operating point analysis. We have a 23 volts across this voltage divider, so here we will get twenty three volts times some ratio R 2 by R 1 plus R 2. By design we made this entire thing become equal to three volts. So, across the gate and source, we have three volts. Again, when you do the analysis, you do not know whether this transistor is in saturation or in triode region. By the way let me put the values I had before; R D we took it to be hundred kilo ohms.

Now, if you want to analyze this, you have to leave room for both possibilities; this could be in triode or saturation region. And test both and see whichever comes up consistently. So, let me assume that this is in saturation region. Again given the constants of the transistor, the current factor being hundred microamperes per volt square, and the threshold voltage being one volt, the current in this if it is in saturation would be 200 microamperes. And if this 200 microamperes is really flowing, it will flow through this R D and across it, it will give you drop of 200 microamperes times 100 kilo ohms which is 20 volts. Now, you check for consistency, we have 23 volts here, 20 volts across R D. So, across this MOS transistor, we have 3 volts.

Now, just check whether it is in saturation or in triode region. So, this is V D S, V D S is three volts, it should be greater than V G S which is also 3 volts minus V T, which is one volt. So, clearly this is satisfied, so the transistor is in saturation and everything is fine. While designing this amplifier, I had made sure that it is in saturation, but like I said if you come across an unfamiliar circuit you have to check for the possibilities, so that is all that is there to operating point calculations.

Next what we have to do is at this operating point, we have to evaluate the incremental circuit. So, what do you do when you want to go from the full circuit to the small signal incremental equivalent circuit, the only change is that all the fixed sources which are not incremented. For instance, this power supply V D D that will be set to zero. All the signal sources which provide the increments that will be non-zero that will be at whatever the value they have. And all the linear elements will remain as they are, because for a linear element it does not matter which one it is. The relationship between incremental voltages and currents is same as that between that total voltages and currents for a linear element. For non-linear elements, you replace the non-linear elements by its incremental equivalent circuit.

In our case, we have this complete circuit and in this, we have this fixed source. This will be reduced to zero, so it becomes a short circuit. If you have fixed current sources, they will become open circuits. And V s will be retained as it is, V s will be retained as it is, and this transistor which is the only non-linear element we have will be replaced by its incremental equivalent; this is V G S, and we have g m V G S. This is all we have in our small signal model now. Initially if you are getting confused, you just mark the terminals of the non-linear elements, write down the incremental equivalent of the non-linear element and then connect it to the appropriate terminals.

So, in summary, the incremental equivalent circuit, these are the constant voltage sources and constant current sources you have used in this circuit. And one thing that will always be present is the voltage source used for the power supply. And replace non-linear elements by their small signal equivalents. And of course, linear elements do not change. So, this is all that we do. And I will redraw the circuit in terms of the small signal equivalent of the MOS transistor. One thing is now this is short circuited at ground in the incremental equivalent circuit, so this is also ground. Normally we draw circuits with the ground as the bottom rail and that is what I am going to do for this as well.

So, let me redraw this. We have R 2 and from this point to ground; and R 1 goes to V D D in the incremental picture, it will go to ground then we have the MOS transistor. This is V G S between this point and ground, and we have an incremental source g m V G S from there to ground. And R D which goes to V D D is also connected to ground. And we have the capacitor C 2, and we have R L also. So, this is the small signal incremental equivalent circuit. Now, notice that the capacitors are still in place. What I want to emphasize is that this is the small signal incremental equivalent circuit, and all linear elements including capacitors remain exactly as they are. Now, the reason I am emphasizing this is that sometimes there is confusion between incremental equivalent circuits and ac equivalent circuits. The two refer to different things, incremental equivalent you deal with only the increments and you also replace all the non-linear elements by their small signal linear equivalents, and ac equivalent circuit refers to something else.

If we know that the signal frequency is some omega naught or the smallest signal frequency is omega naught and if the capacitors happens to have a very small reactance, then you can treat them as short circuits. In fact, that is how we want them to behave in this circuit, but that is a different step all together. So, do not get confused between ac equivalent circuit and incremental equivalent circuit, they are for completely different context. In a small signal incremental equivalent circuit, it is not that the every capacitor becomes a short. We will see the detail criteria when to treat the capacitors as short, but if the impedance of the capacitor, if the reactance of the capacitor is very small, it can be treated as a short.

So, if we assume that C 1 and C 2 are very large, and sometimes I will say tending infinity, in that case, you do not have to worry about what the frequency is you can treat them as short circuits. Effectively, what is really meant is that if the signal frequency is omega naught one by omega naught C 1 is much smaller than something. And one by omega naught C 2 is much smaller than something. We will see what those things are later. We have already evaluated them roughly, but we will see that in detail. So, if you assume these conditions, if you assume that C 1 and C 2 are tending to infinity or that the frequency is large enough for you to treat the capacitance as short circuits these can be replaced by short circuits. And if I do that as well, this is the circuit I get and here it is not just the small signal circuit, the capacitors are also assumed to be large.