Analog Circuits
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Module - 02
Lecture – 11

We now know the small signal picture of an amplifier using a two port. We have to bias the MOS transistor at the correct operating point, and come up with the circuit which in its small signal form in its incremental form will be the two port amplifier. And throughout this discussion, I will continue to use the MOS transistor whose parameters are given here, these two together mean that current factor is 100 micro amperes per volt square and threshold voltage will be 1 volt. So, now, I said that two port amplifier using MOS transistor will have this incremental picture, where this is V G S. By the way, I will assume that all of you understand the meaning of this ground, all of these are connected together. It is very common to show point like this because lots of terminal will be connected to this common point, and the schematic diagram will look very messy if we draw lines connecting everything.

So, just keep the diagram neat; this is shown this means that connected to this, and load is connected to this one and so on. This is of course, gate and drain source, and this is the MOS in saturation region. Now this is very simple nothing much here, all of this V s appears as V G S and the output voltage across the R L is minus g m R L times V s, this is the gain. For the sake of illustration, let us assume that this input source as R s which is hundred kilo ohm and the load R L also hundred kilo ohm. Now let us also say that the gain magnitude, we required is twenty and because gain of this circuit is negative, the gain will be minus 20, and it will be equal to minus g m R L. And from this compute the desired value gm, g m will be minus 20 divided by minus 100 kilo ohms which gives you 200 micro Siemens.

Now, we know that the gm of the MOS transistor in saturation is given by mu n C ox W by L V G S minus V T; putting these two putting together we see that we have to bias the transistor with V G S minus V T of 2 volts, because this part is 100 micro ampere volt square, if this is 2 volts you will get the gm of 200 micro Siemens. And we know that V T is one volt, so V G S has to 3 volts. Also its useful to what the current flowing in the MOS transistor, we have to use the saturation region current equation because that is where we will be operating, and if you substitute V G S minus V T equal to 2 volts and this current factor to be 100 micro ampere per volt square you will get 200 microamperes. So, these two give you the operating point of the MOS transistor V G S has to be 3 volts and I D has to be 200 micro amperes. So now let see how to get the operation point in the MOS transistor.

This is the MOS transistor, whose threshold voltage is 1 volt; and whose current factor is 100 microampere per volt square. Now, we saw that we had to have a V G S of 3 volts and V D S, I am showing a voltage source here I will call it V D S 0, the V D S at the operating point. What should that be, we know that transistor has to be in saturation, so V D S 0 has to greater than or equal to V G S minus V T and this number is 2 volts. So, whatever this is this has to be greater than 2 volts.

And let me assume just for the sake of illustration that this is 3 volts also. This is an example it can be anything more than two volts, we will take three volts. So, this sets the operating point correctly. So, we will have 200 microamperes flowing through the MOS transistor if we set up this circuit, but this is not the circuit we want, what is the circuit we want circuit, the circuit we want is such that its incremental equivalent; its small signal equivalent should be like that, so that means that we have to connect the input and the load to the circuit appropriately.

Now, this is one circuit start becoming apparently more complex and difficult, there is no difficulty here. The point is there are many ways to do these things, we have to setup certain operating point for transistor and we have to make sure that the overall circuit conforms to some small signal picture, that is, it performs some function. They are many ways of setting the operating points and many ways of getting the function. So, the number of circuits that you see this I alluded to in the introductory lecture also is very large because you can take a whole bunch of operating point setups, whole bunch of functionalities and combine them together. So, the important thing is to understand the logic behind each of these things.

So, now let us go port by port, this is the V G S of the transistor. For the operating point we need this to be 3 volts, and in the incremental picture, we need it to be V s that is the source has to be connected. So, if I sum these two, and 3 volts will be the operating point when the incremental source is zero; and when the incremental source is applied then V s will appear as the increment across V G S. So, somehow I have to make V G S to be equal to this.

And that does not appear to be very difficult, because I have a voltage source to get 3 volts and I have another voltage source for V s. Of course, this V s always come with this R s, but adding two voltage sources is easy in principle. All we have to do is put them in series. So, what we do, I have 3 volts and I have V s and R s which is 100 kilo ohms in series. Now if I connected to the gate of the transistor and the source is grounded, it is very clear, what appears here as the gate source voltage, this will be equal to three volts when V s zero; when the signal is zero, this is exactly what you want when the signal is zero is when we have the operating point.

And if you look at the incremental picture, this three volt goes away, we will be considering only the increments this V s will be the increment. So, I hope you are all convinced that this gives you an operating point V G S of three volts and incrementally it resembles the bottom picture on the input side because this 3 volt is fixed, so its increment is zero. So, it becomes a short circuit, you will have V s and R s between the gate and source. And if you are not completely convinced, you can simply evaluate V G S, no current is flowing into it. You can see that the voltage is appeared here is simply three volts plus V s. So, this arrangement provides an operating point of three volts and an increment of V s between V G S, so that part is ok.

Now what we do for the other side, the second port or the drain side. Remember what we need is 3 volts or some voltage V D S 0 across drain and source in the operating point so that it remains in saturation. And also in the incremental picture, we need to have R L between drain and source.

So, how do we do this or you can consider many ways of doing it; usually when I asked students to do this they suggest putting R L between here and there and so on, clearly that would not work. Let me show that particular alternative. If I have three volts here, and also I connect R L here, what happens in incremental picture, this is the operating point voltage; in the incremental picture, this is the short. I hope you understand why it is a short, because this source is not incremented this is a fixed source this is a 3 volt source it is not incremented. So, it will be a short. So, in the incremental picture, what we get will be, instead of R L, R L will also be there, but it is not relevant, because we will have a short between drain and source. The incremental current source from this simply goes into the short circuit and there will no voltage at all across R L, so this is not useful.

So, with a little bit of reasoning, you can see that the correct way to this is the following You should have your voltage source that you originally had and in the incremental picture this point will be grounded. And we want the resistor R L between the drain and ground which is this, which is also this in the incremental picture. So, what do we do, we just connect this R L in series. So, again I hope it is clear what happens in the incremental picture this three volts becomes ground and the R L appears between drain and source. So, this is topologically correct, that is, if you look at the incremental picture, we will have, I am showing the MOSFET here, it is quite common to do this what is understood is that this is the incremental picture you have to replace the MOS transistor with its increment equivalent circuit which is the g m and g d s and so on.

Whatever is in the MOS transistor. For convenience, many times you do not show the two port picture, but you simply show a MOSFET, but if it is the incremental picture, it should be the incremental equivalent of the MOSFET. So, this is what happens in the incremental picture. Now this still has a problem, remember what was the current flowing here, it was, let me call it I D naught operating point current that is 200 micro amperes. So, if I do connect in series with R L like this I will have I D naught times R L, and R L is 100 kilo ohms. So, I D naught times R L will be 20 volts, it appears like a very large voltage and it is for present day integrated circuits, but do not worry about it right now we are just looking at basic principles of amplifiers.

Now, clearly see that there is some inconsistency here, if you apply three volts here, you are not going to get 3 volts here. You will get 3 volt minus the drop across R L, and you can consider the circuit and see that if you do actually make a circuit like this, this transistor will get pushed into the triode region. Originally, this voltage source will directly across the drain and source. So, this is equal to whatever V D S you need. Now this voltage should not be three volts, but it is equal to whatever V D S you need plus whatever drop you have across the load resistor. So, if you have a twenty volt drop across the load resistor and you want 3 volts here this should be equal to 23 volts.

So, finally, the picture of our basic amplifier looks like this. We have the input source and that is connected in series with a voltage source which provides the operating point for the gate source voltage and we connect it to the gate source of the MOS transistor. On the other side, you connect the R L in series with the drain, and to provide the correct operating point voltage V D S whatever that is, let us call it V D S 0 then this voltage will have to be equal to V D S 0 plus the operating point drain current, the operating point drain current also flows through R L. So, operating point drain current I D 0 times R L. So, what happens in the operating point case, I will show that in blue. In the operating point case, this V s will be zero and V G S will be V G S 0 and V D S will be V D S 0.

And there will be a voltage drop I D 0 R L across this and the incremental picture which I will show in red. The increment, there is only one incremental source here which is V s. So, this will be V s this will be zero which means it becomes a short circuit and this is also zero it becomes a short circuit. So, the incremental picture reduces to what we want and again I will show the MOS transistor here, it means that for incremental calculations, you have to substitute the small signal or incremental equivalent of the MOS transistor. So, this is our basic amplifier, it works, but it has a lot of issues which we will deal with in the coming lessons, but please convince yourself that the logical arguments leading to this amplifier are correct. As I said these logical arguments combining different circuits are extremely important, and that is how you can understand different circuits and also come up with circuits on your own. Please understand all of those things carefully.