Analog Circuits
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Module - 02
Lecture – 06

We have just introduced the MOS transistor which is the three terminal two port which has some of the characteristics desirable in a good amplifier device. In this lesson, we will look at a characteristic of the MOS transistor in some more detail. We have the gate, drain and source. And we have the two port voltages V G S - gate source voltage and V D S - drain source voltage; and the drain current – ID. The gate current I G is zero, which makes analysis and even design simple in many cases. Now I just crudely showed the current as the function of voltage, now I will show it in more detail, I also did not define any of the constants earlier, I will do that now.

So, it turns out that this I D, the drain current is zero if V G S is less than or equal to some constant called V T. I will later explain what all these constants are. I D is equal to some other constant mu n C ox W by L times V G S minus V T times V D S minus V D S square by two, and this is when V G S is more than V T, and the drain source voltage V D S is less than V G S minus V T. And there is a third region where the current is this constant mu n C ox by 2 times W by L which is some other constant of the transistor V G S minus V T square. And this happens when V G S is greater than V T, and V D S is greater than V G S minus V T.

Now, first let me define these constants. The electrical variables are just this V G S and this V D S, remaining terms are some constants of the transistor. This V T and please do not confuse it with the thermal voltage which is also denoted by V t; in my case, I always use the lowercase t for the subscript of the thermal voltage, and uppercase for the threshold voltage V T. This is known as the threshold voltage, and it is some constant of the transistor. Now, you can see why it is called the threshold voltage; if the gate source voltage, which is the primary control, this is port one right, primary control for the transistor if it is less than this threshold voltage, you can say that the transistor is off, the current is zero. Now, one more thing I want to emphasize here is that these equations are written assuming that both V G S and V D S are positive.

Now, when you encounter the transistor, you may find that you will be able to operate it with different polarities, but for our purposes we will consider V G S and V D S to be positive. So, if the gate source voltage is below the threshold voltage, the transistor does not conduct and the current is zero. And there is this constant mu n which is the mobility of electrons which are charge carriers in this particular type of MOS transistor. And there is C ox which is some oxide capacitance per unit area; it turns out that at the heart of the MOS transistor is a capacitor, and this is the capacitance density of the capacitor; capacitance per unit area. And W is the width of the transistor and L is the length of the transistor. It turns out that if you look at the physical plan view of the MOS transistor, there is a certain length, this side is the source, this side is the drain, and there is a certain width. So, this is how it is and the current flows from drain to source across the width of the transistor, it goes from drain to source. The distance between drain to source is the length, and the width of this region through which the current flows that is the width W.

Now, we do not have to know all of these things for our purposes; now it turns out that when you design an IC, you have a freedom to choose your own W and L; but when you have a discrete transistor, W and L are fixed for you. So, as far as we are concerned we can take this entire product which appears here, mu n C ox W by L, mu n C ox W by L, which appears in all these expressions as some single constant; mu n C ox W by L, I will define that as K n, this is known as the current factor of the MOS transistor. So, as far as we are concern K n is fixed, and there may be some problem in activities or assignments where W and L are varying, but mu n C ox; it is just a given constant for us. It is a property of the processing with which the transistor is made, and we cannot change that.

And similarly V T is another constant for us. So, there are two constants in this description of the MOS transistor, the current factor K n, and the threshold voltage V T. Now earlier I showed you only this expression, the last one, why is that, because in this case, you can see that drain strongly depends on the gate source voltage, the voltage at port one; and it does not depends on port two voltage, the drain source voltage at all. And this is the region, you would like to operate as an amplifier, because if you look at this other region, first of all the first region where the transistor cut off this is useless, there is no current at all. There cannot possibly be any amplification from the device. Now in this region, you can see that the current depends on both V G S and V D S, and this is not the desirable one, because in this case, you see that the parameter y 2 2 will not be zero. Whereas here it is zero and this is the desirable region of operation.

So, this region where the transistor is not conducting any current, this is known as cut off; and this happens if the gate source voltage is below the threshold voltage, that is why it is called the threshold voltage. And the second region, where there is current but it depends on both V G S and V D S; this is known as triode region or linear region. Later, we will see why it is called either triode or linear region. And this is the region of most interest to us, this is known as saturation region. There are some historical reasons why it is called saturation region and so on, but all we need to know is that V G S has to be greater than V T for the transistor to be on; and V D S has to be greater than V G S minus V T that is all we are saying is this voltage across port two, this drain source voltage has to be larger than a certain value.

Now there is a wide variety of transistors. First of all, this particular transistor corresponds to one particular type called the nMOS transistor. And even in nMOS transistors, there are different types, where you can have V T to be either positive or negative; and for simplicity, and also because it is the most commonly used case, we will assume a case where the threshold voltage is also positive, so that is the quick summary of the characteristics of the MOS transistor. So, in summary, we have at least one region of operation, some set of operating points, where the current is strongly dependent on V G S, but not on V D S. So, when we want to realize an amplifier, we have to set the operating point in this region in the saturation region. This point will become clearer and clearer as we go further and further into the small signal model and see what happens.