**Analog Circuits**
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**Module - 02**
**Lecture – 05**

We know now what a nonlinear two port must look like that is what its characteristic must be in order to have a high gain. It turns out that there are many devices which have these characteristics or almost these characteristics and currently the most popular device is what is known as the MOS transistor. So, what we are going to do now is to look at the characteristic of the MOS transistor and see how it conforms to the constraints we had, and also how it deviates from the constraints we had. What we derived was what constraint we would ideally like to have, now no device exactly satisfies these, they do come very close, and we do use them to realize amplifiers and all kinds of electronic devices. Now, there are been other devices also in the past which been more popular in the past, which are now superseded by the MOSFET, and there will be devices in the future. And one of the later lesson, we will quickly look at those characteristic, but now we will concentrate on the MOS transistor. And it turns out that they are many varieties of MOS transistor and we will look at one particular variety for now.

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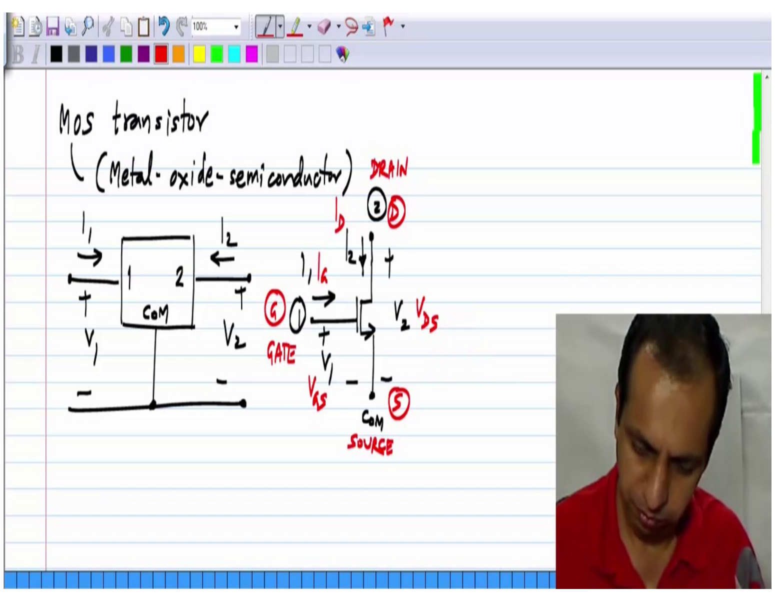

The MOS stands for Metal-Oxide-Semiconductor. Now, this was because originally MOS transistor were made using layers of metal oxide and semiconductor. Now, it may not be metal anymore, but we would not worry about it. For us what matters are the I-V characteristics of these devices. If you take courses in device physics, you will understand the internal details of a MOS transistor. Now what did we say we have a nonlinear two port. This is port one, and this is port two. In a MOS transistor does conform to this picture. Of course, we do not use a rectangle for a symbol, we use what is normally use for the MOS transistor which turns out to be like this. Now, again the details of all of these things you may find in device physics course, but for us there are three terminals it is usually drawn like this. This is port one and this is port two. You can see, it conforms exactly to this except for the orientation of the wires and so on, it is exactly the same as this.

So, this is the common terminal and this is the terminal for port two, and this is the terminal for port one. And you also see that the common terminal has an arrow like this to distinguish between that and the other terminal. Now, it turns out of course we do not call them one, two and common by generic terminology like this. In a MOS transistor, this terminal for the input port, this is known as the GATE. The terminal for the output port, this is known as the DRAIN. And finally the terminal for the common port, this is known as the SOURCE. And typically you use the letter G, letter D, the letter S to denote these three terminals. And of course, because we have named the terminals, the voltages and currents are also named in a similar way.

This voltage $V_1$ is the voltage $V_{GS}$ that is the voltage between gate and source. The voltage $V_2$ is $V_{DS}$ that is voltage between drain and source. Similarly, this current $I_2$ is $I_D$, the drain current; and this current $I_1$ is $I_G$ or the gate current. So, so far I have not done anything, I have simply drawn a different symbol for a two port, and named the terminals differently. Of course, the naming corresponds to a real device, which is the MOS transistor. So, what we will now look at are the characteristics of the MOS transistor and see how they corresponds to the ideal high gain device that we wanted to have.

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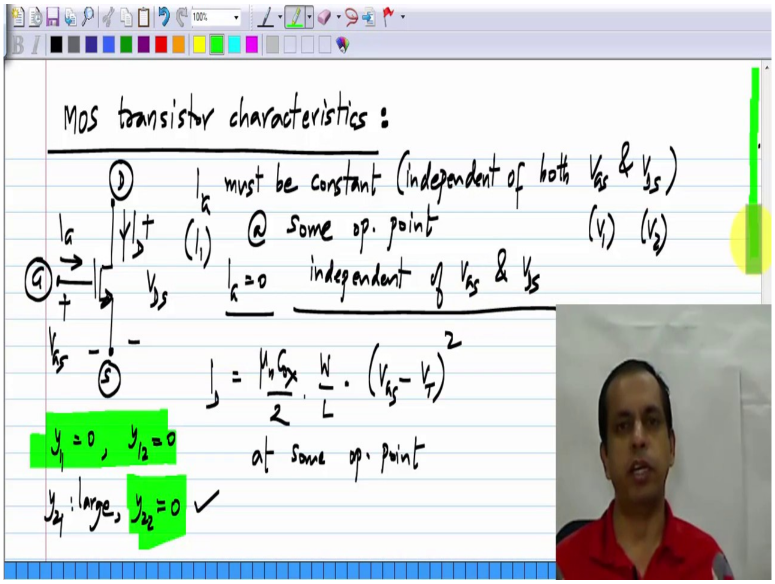


So, again let me repeat the symbol and the notation. This is the source – S, the drain – D and the gate – G. We have the gate source voltage – $V_{GS}$, and the gate current $I_G$, the drain source voltage – $V_{DS}$, and the drain current $I_D$. We do not use generic terminology like $V_1$ and $V_2$. We will use something that relates to the actual naming of the terminals. Now, what did we want for the small signal characteristics, $y_{11} = 0$, $y_{12} = 0$, $y_{21}$ to be very large, and $y_{22} = 0$. Now the combinations of these two here $y_{11}$ and $y_{12}$ being zero, it said that $I_1$ or the current $I_G$ must be constant that is independent of both $V_{GS}$ and $V_{DS}$. Just show that you can relate this to the earlier convention, I will show this as $I_1$ and $V_1$ and $V_2$, but I would not do this for too much longer. We will use the terminology associated with the MOS transistor.So, this must be constant, it should be independent of both $V_{GS}$ and $V_{DS}$ at some operating point.

Now, it turns out that the MOS transistor follows this and in fact, it is quite ideal it turns out that $I_G$ is actually zero, and it is completely independent of $V_{GS}$ and $V_{DS}$. Now, this is true only when the applied signals are dc or very low frequency, but that is ok. For now we will stick to low frequencies, and it turns out this is the case, because the gate terminal of a MOS transistor looks like a capacitor; and in a capacitor, there can be no dc, no steady state constant current flowing, so that is why the gate current is zero. It is very good approximation and in this respect we are lucky it is actually exactly the ideal stuff that we want. We were actually we would be happy if $I_G$

were just a constant in fact we get a constant I 10. So if this is the case, you can clearly see that $y_{11}$ and $y_{12}$ will be identically equal to zero.

Now, what about $I_D$, so $I_D$ must of course dependent on $V_{GS}$ right, because $y_{21}$ that is $I_2$ versus $V_1$ should show a very strong variation. So, $I_D$ must depend on $V_{GS}$ , but it must be independent of $V_{DS}$ that is what the meaning of $y_{22}$ being zero. It turns out this is also more or less satisfied. The expression for the drain current at some operating point, will see what they are, these are some constants which I will describe later. So, the characteristics are that $I_D$ is $\mu nCox\frac{W}{L}(Vgs-Vt)^2$ are at some operating point. So, the point is this $I_D$ depends on $V_{GS}$, it does not depend on $V_{DS}$. So this is also satisfied; $y_{22}$ is zero, because you see that this expression does not contain $V_{DS}$.

Now, $y_{21}$ is large, now of course, $y_{21}$ is the conductance, so how large it is, it has to be compared to something else in the circuit. It turns out it should be large compared to the load conductance and so on. And we will get some dependents on $V_{GS}$, you can see that $I_D$ has a square dependents on $V_{GS}$, which appears to be quite strong. So, MOS transistor does in fact fit the bill, it does have the input current to be zero which automatically makes $y_{11}$ and $y_{12}$ to be zero. And it also has the output side current, the drain current to be dependent on $V_{GS}$, but not on $V_{DS}$, so it does satisfy all the constraints that we had, and that is why it such a popular amplifier. Now, another device which is kind of similar, the input current is not exactly zero, but very small that is the bipolar junction transistor that will be treated in some other lesson. For now we will stick to the MOS transistor.