Electronics for Analog Signal Processing - I
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Lecture – 26
Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

In the last class, we were asked to find out the common emitter amplifier output impedance resistance, when the so called current source was not ideal, in the sense, we said, that current source which is occurring between collector and base; it is a reverse biased junction, so it must be having a high resistance across it of the order of megaohms, tens of megaohms.

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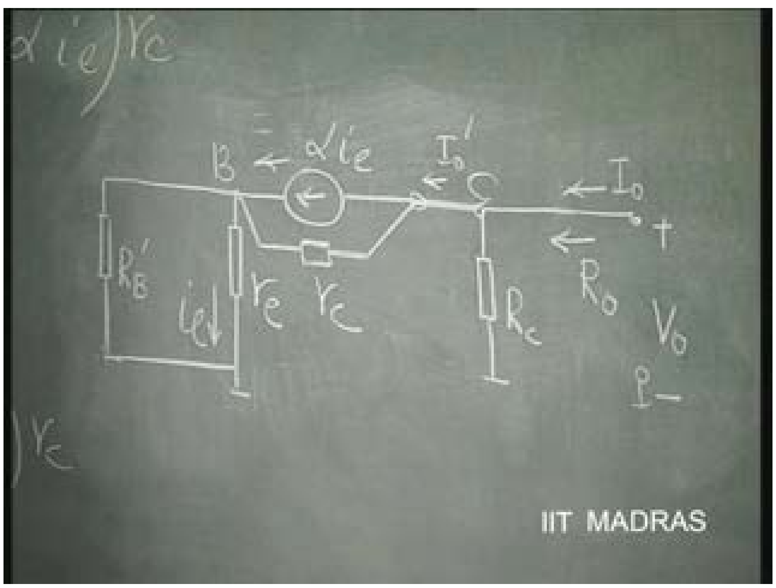

So now, if that resistance is there, we want to find out in general, what will be the effect on the output impedance, which is determined by applying a voltage V naught here and finding out the current I naught. V naught by I naught is the output impedance. R naught by definition is V naught by I naught. When I apply a voltage at the output, find out the current taken at the output.

Obviously, we can say that R C directly comes across V naught; so R C is shunting whatever impedance comes at this point. If you had not had this R C, it would have been merely this capital R C. Because of this R C, there is some effect; let us see what it is. So, we will call this as I naught prime. So, additional resistance shunting, R naught is therefore equal to R C parallel R naught prime, we will call it; R C parallel R naught prime, where, R naught prime is nothing but V naught divided by I naught prime.

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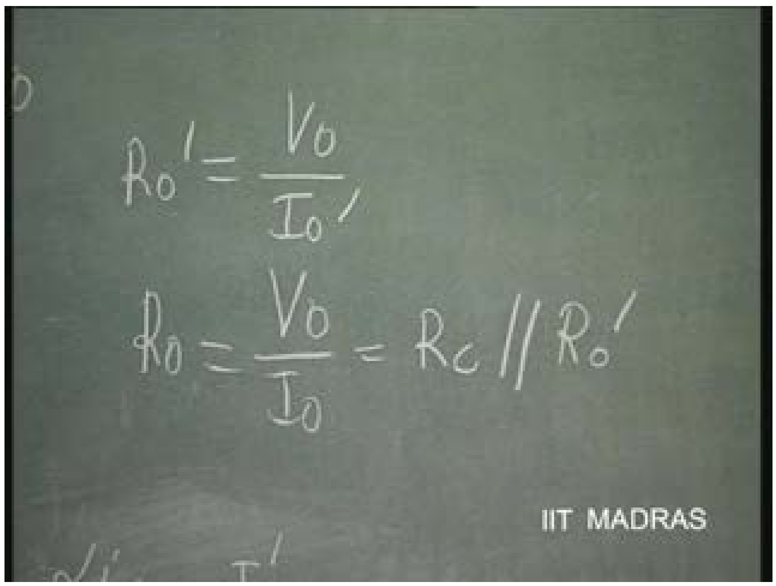

This V naught, same voltage which is occurring across R C; but another current, I naught prime. So, whatever is applied across R C is also applied across this so called R naught prime; and that is now taking a current of I naught prime. So, R naught is really R C shunted by another impedance which is simulated by the transistor output circuit. We would like to now know what it is. So, R naught prime is V naught by I naught prime. Let us now understand what it is.

Given i e here, we have Alpha times i e, always. That is our standard equivalent circuit. If this is i e, the drop across this is i e times r e. The current in this therefore is i e r e divided by R B dash. Now this R B dash is nothing but R B parallel R S because the base is connected through a DC resistance of R B to ground. Further, the source resistance also is coming to ground from the base. So, parallel combination of R B and R S will be R B dash. So, effective base is this distance to ground. So, this current plus this current is essentially I naught prime.

So, I naught prime is i e, this, plus i e r e divided by R B dash. So, this is I naught prime. I want to find out V naught divided by I naught prime. So now, I have to get V naught in terms of i e; then i e will get cancelled in that expression. So, V naught is this voltage. This is equal to, let us see. We would like to evaluate this current in this. This is Alpha times i e. Is this clear?

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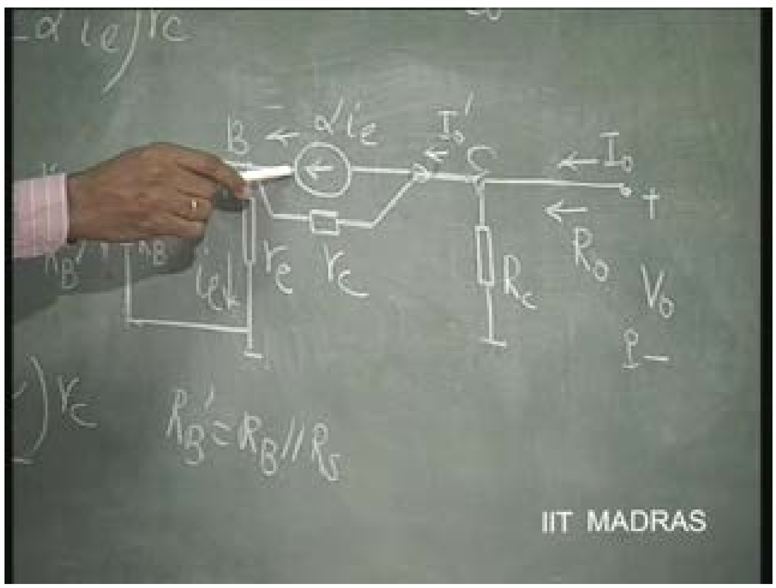

This current is Alpha times i e; and I know the current in this. Alpha times i e has to be subtracted from the total current which is i e plus i e r e R B dash. Then, that will be the current in r c. This current is i e plus, i e plus i e r e by R B dash. From this total current, I subtract this Alpha times i e. That will be the current through r c. Now, once I know the current through r c, drop across this is, that current into r c.

So, I have found out the voltage from here to here. The current, total current is i e plus i e r e by R B dash minus Alpha i e is the current flowing in this; that into r c is the potential across this. And the potential across this is, plus i e r e. So, this potential plus this potential is V naught. So now, V naught by I naught prime therefore is very clearly, i e i e will get cancelled; 1 plus r e by R B dash minus Alpha into r c divided by 1 plus r e by R B dash. This is an important expression giving, in general for you, output impedance looking in from the collector of any transistor amplifier.

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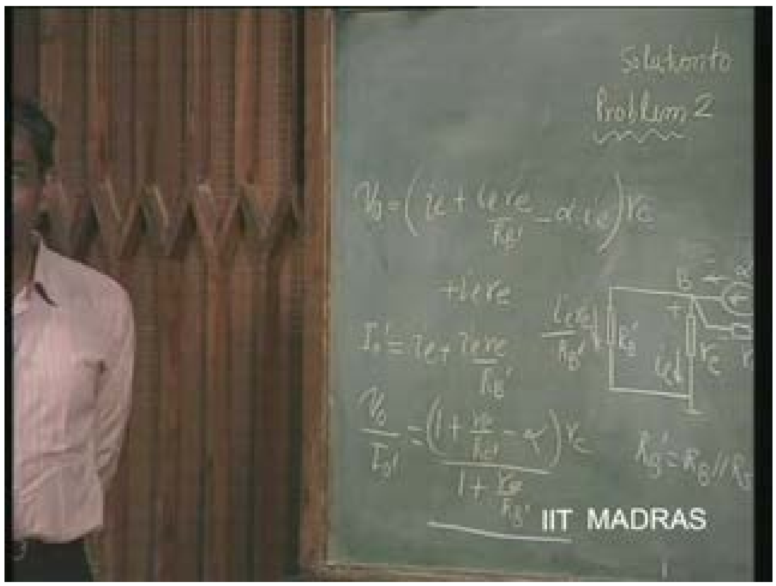

Why I am saying is, any transistor amplifier, a general transistor amplifier, can be considered as one with a resistance from emitter to ground and another resistance from base to ground. We already have a resistance from base to ground. Suppose you have a resistance from emitter to ground, let us say, capital R E; then, this expression remains essentially same except that, r e has to be changed to r e plus capital R E.

Suppose therefore we have a resistance in series with emitter. Then you will simply say r e plus capital R E. So, this nature of the expression remains essentially same for a general common emitter amplifier or any amplifier with impedance seen from collector. Is this point clear? Impedance seen from collector therefore is always equal to 1 plus r e plus capital R E, if you have, by R B dash minus Alpha into r c divided by 1 plus r e plus capital R E divided by R B dash. This, you remember.

Now, if it is having R B dash infinity or R B dash very large compared to r e, this point, this will go to zero. R B dash if it is very large compared to r e, this will go to zero; and this will go to zero. What will it become? 1 minus Alpha into r c.

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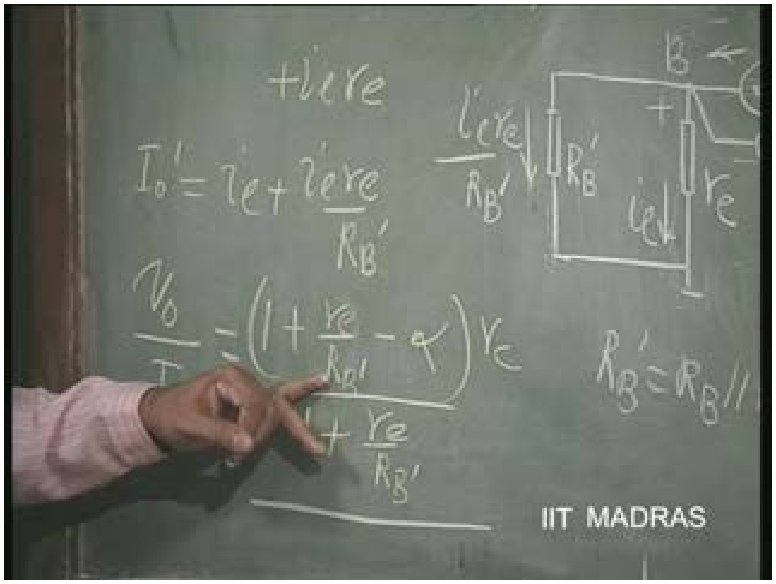

So, if r e by R B dash is much less than – we have to compare it with 1 minus Alpha – 1 minus Alpha, because this is the... Alpha is very nearly equal to 1; 1 minus Alpha is also very small quantity; so, when I neglect, I have to neglect it compared with 1 minus Alpha. So, if r e by R B dash is much less than 1 minus Alpha, then this is very nearly equal to r c into 1 minus Alpha. This is the output impedance of a common emitter amplifier.

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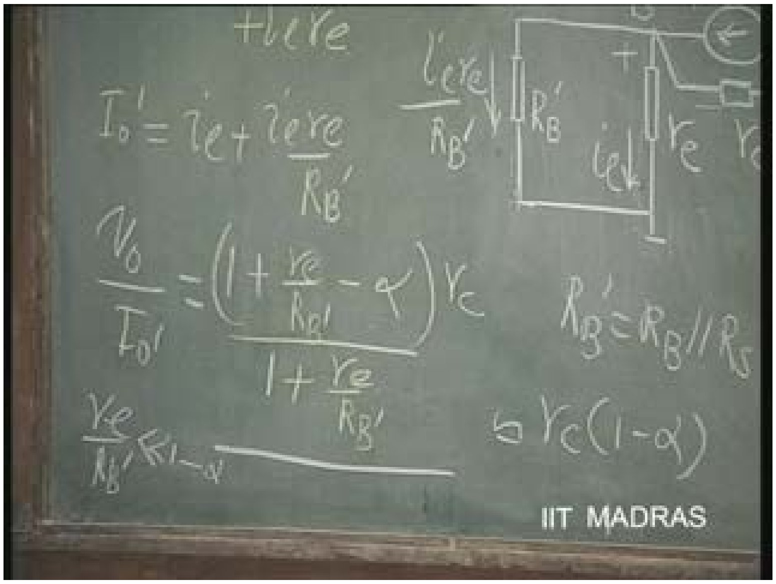

What... this is the definition for common emitter. If you have a resistance also in series with emitter, it will be r e plus capital R E divided by R B dash must be much less than 1 minus Alpha; then you will call it as a common emitter amplifier. If r e plus capital R E by R B dash is much greater than 1 minus Alpha, this is much greater than 1 minus Alpha, what happens? This will be negligible; 1 minus Alpha will be negligible. This will be r e by R B dash. This will also be r e by R B dash. So, this will go towards r c which is called common base amplifier.

So, whether it is common base or common emitter depends upon the relative magnitude of resistance in series with emitter and resistance in series with base. If resistance in series with base is dominant, then it is common emitter. If resistance in series with base is dominant, it is common emitter. If it is emitter resistance that is dominant, it is common base.

Again, if you have a resistance in series with emitter, you will put this as r e plus capital R e by R B dash. If it is much less than 1 minus Alpha, it is called common emitter configuration. If this is much greater than 1 minus Alpha, then it is called common base configuration. If it is not negligible either way, then it is a general configuration wherein the output impedance is always equal to this.

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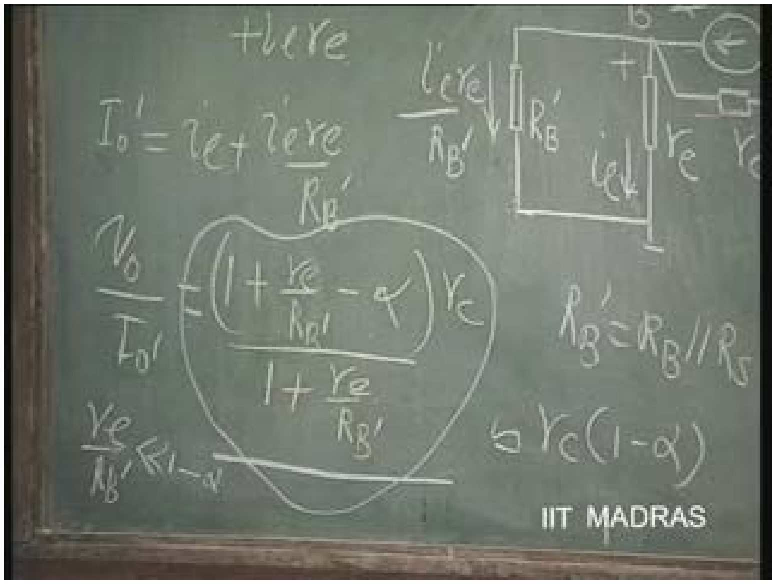

So, you can see that the output impedance asymptotically reaches r c and r c into 1 minus Alpha. What is r c into 1 minus Alpha? – also is equal to r c divided by Beta plus 1. So, this is the output impedance of a common emitter configuration and r c is the output impedance of a common base configuration.

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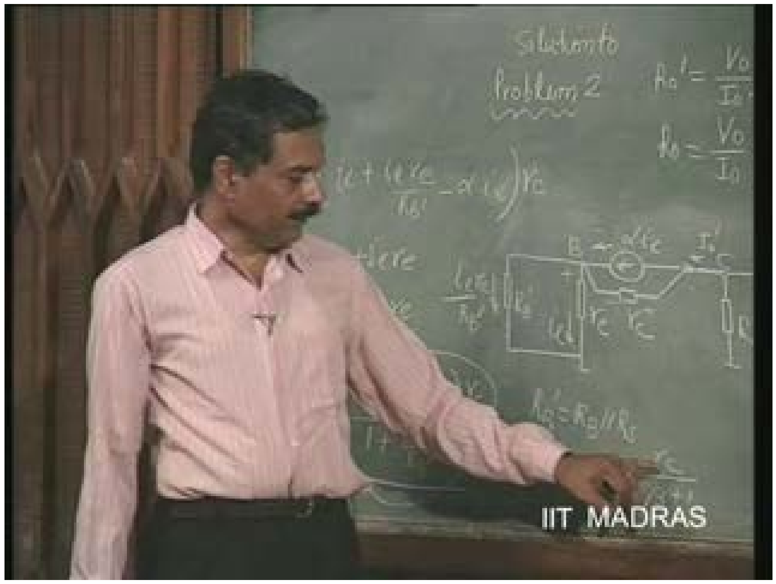

And in general, the output impedance is in between. That means output impedance of these amplifiers, common base or common emitter, will be always lying in between r c and r c into 1 minus Alpha, based on the approximation that is valid here. So, this example illustrates the effect of this non-ideality that is occurring across the transistor, common collector base junction.

We had understood a bipolar junction transistor. In today’s class, we will be introduced to another important active device. Bipolar junction transistor as well as this active device formulates the family of active devices which are prevalent, covering almost 99 point 99 percent of the entire circuitry.

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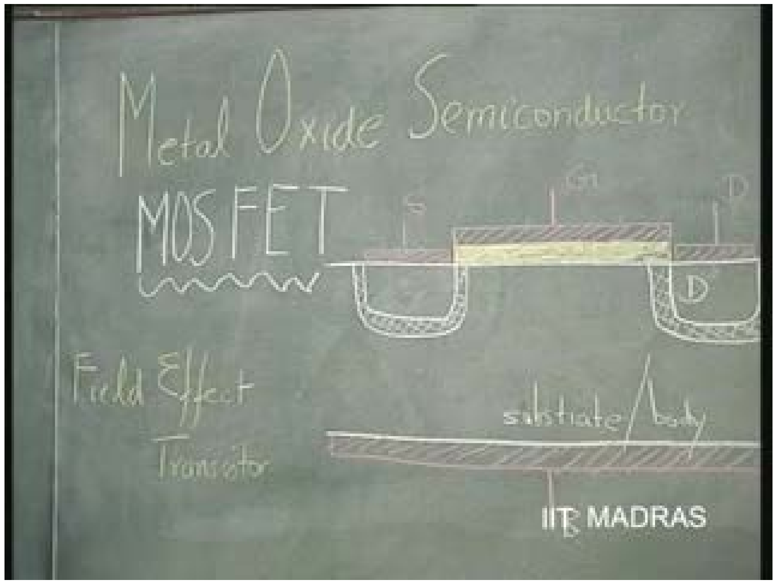

So, this important device is called Metal Oxide Semiconductor Field Effect Transistor, Metal Oxide Semiconductor Field Effect Transistor, which is abbreviated as popularly M O S FET; F E T, MOSFET. It is necessary that we understand this active device in the same way we understood bipolar junction transistor. So, I will now discuss qualitatively the characteristics of MOSFET. This is the backbone of all our MOSFET circuitry discussion.

Let us now understand what a MOSFET is. Consider, let us say, we will take this material, parent material, semiconductor material, which is a wafer. This is the thickness of the wafer; p type substrate it is called. The entire wafer is doped with p type of impurities. So, you start with p type wafer and you would like to fabricate MOSFET, let us say; then, that particular wafer, that is the body, is called substrate or body, is the material over which our device is going to be fabricated.

So, this is the substrate material, very important. So, we could start with p type or n type. I have, for illustration, started with p type substrate. Then, it is going to have a n type valve here as well as here. This is called source; this is called drain. You could call it the other way also; this as source and that as drain, if it is symmetric here.

We have the source contact, aluminum contact, here over the source. We have the drain contact, aluminum contact, over this drain. These are doped with n type of impurities. So, this is n. When we have the substrate as p, we have the source and the drain here as n. If the substrate is n, then the source and the drain will be p. Then, we have what is called the gate, which is located over a very thin oxide which is silicon oxide. This is silicon oxide; or gate oxide it is called typically, of the order of thousand Armstrongs it is. Very thin.

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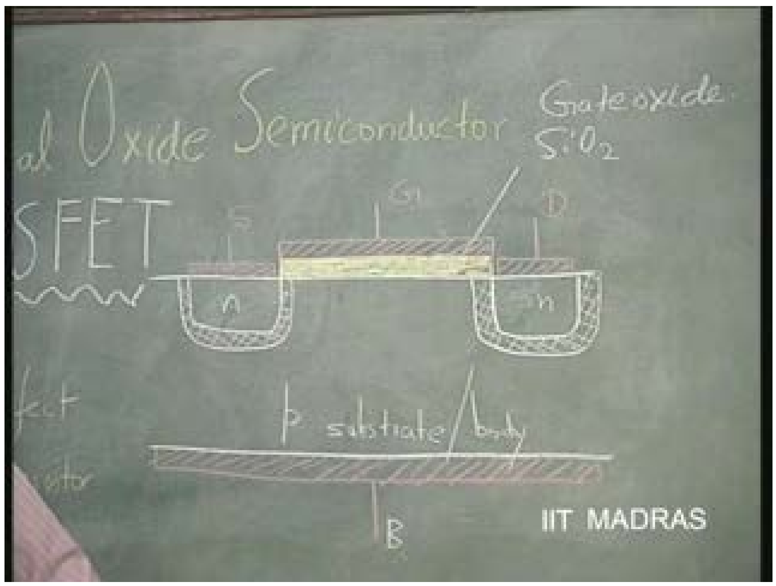

Why it is made thin is because we would like to have control over a surface by the gate electrode. So, you would like to make it as thin as possible so that the control is good. What does the voltage apply to the gate too with respect to the substrate, we will see that.

So, this a thin oxide layer over which we have the gate terminal, gate contact; aluminum again. All these red colored ones are aluminum contacts. Under this situation, let us understand what happens. We all know that the p type material has majority carriers as holes and minority carriers as electrons. The overall charge of the whole thing is space charged neutrally. For every mobile carrier given, there is an immobile atom left there which is charged in the opposite way.

In this case, every hole, there is a negative charge which is immobile. Overall space charge neutrality is still there in the whole thing. Let us see what happens when we apply a voltage here with respect to this. It is like a capacitor we have here between... this is a conductive material, let us say, and this is another conductive material. In between, we have an oxide; dielectric medium, insulator.

So, when I apply a voltage here with reference to the bulk or the substrate or the body; we call this B. So, let us apply a voltage with respect to bulk to the gate. If I now apply a voltage which is positive with respect to this, bulk, there will be positive charge all over this, corresponding to which, it has to induce negative charge on the circuit. How does the negative charge get induced?

After all, this entire thing was space charge neutral. So, what is likely to happen is, the positive voltage here will cause attraction of first, the mobile carriers which are negatively charged. What are they? Electrons. They are the minority carriers here in the p type substrate which are negatively charged; and these negatively charged ones can easily go over to the surface. So, you will have here, negative charge induced.

There will be limited number of these. What? – mobile carriers, because they are minority carriers. You apply further voltage; what happens? Most of these mobile carriers will now come to the surface. You apply still further. Then what happens is the only negative charge that can be induced here is by uncovering certain of the what? – immobile atoms which are charged negative. That means holes have to be pushed off.

Most of the mobile charge carriers which are electrons have been already attracted towards the surface. Further increase in charge, negative charge, can occur only by uncovering certain of the what? – immobile charges, negative charges. That is done by driving away the source. That way you are inducing here... First, this was positively charged, p type. It was having majority carriers, holes, establish a space charge neutrality here. There will be uncovering of charges here.

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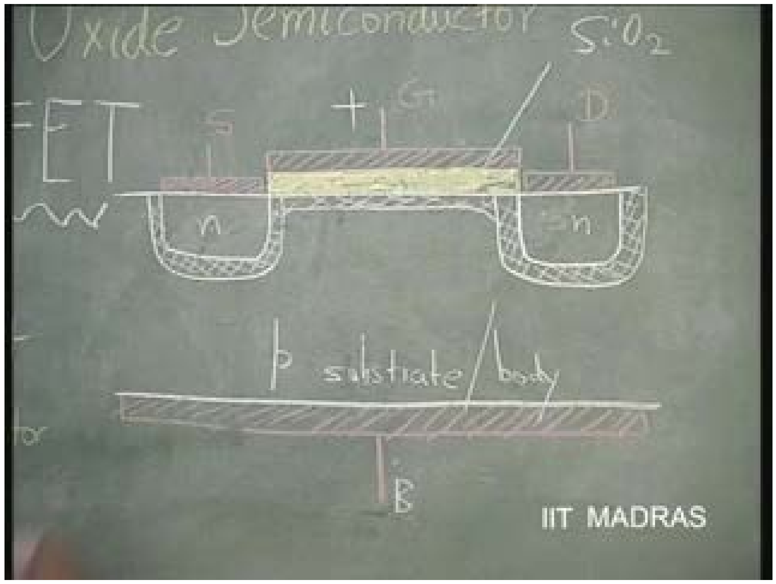

Then, further increase in this thing will make this go towards... and most of the minority carriers will now start getting accumulated here, establishing negative charge. And this region now becomes n, n instead of p. First, what will happen? It will become less p type. Then it will become space charge neutral. Then, it will become negatively charged excessively; which means, it becomes n type. This is called inversion.

The body was p type; the surface has become n type, by applying a voltage here. So, you are able to invert what? – the type of material from p to n; or, if it is n to start with, by applying a negative voltage here, you could make it p. This is an important action of the MOSFET, on the surface. These are all surface devices. So, by applying a positive voltage, I am able to invert the state of this and make it n type if it is, to start with, p type.

Now this is open to conduction because this was n and this was n. Now, if you make this n type, what will happen? There is a channel open between source and drain. So, you are set to formulate a conductive channel by applying a suitable voltage from bulk to gate. The width of the channel can be easily controlled; the duct in this case can be easily controlled by this voltage. The higher the voltage, wider it will be. So as to compensate for the positive charge here, it has to open up wider.

So, this effect of inversion is an important phenomenon and the voltage that you have to apply to the gate with respect to the substrate in order to make the surface as conductive as the substrate is called – an important voltage – that is called threshold voltage, threshold voltage; V T it is. The voltage that is necessary to make the surface of the semiconductor as conductive as the bulk, by definition, is called the threshold voltage. This is the device definition for threshold voltage.

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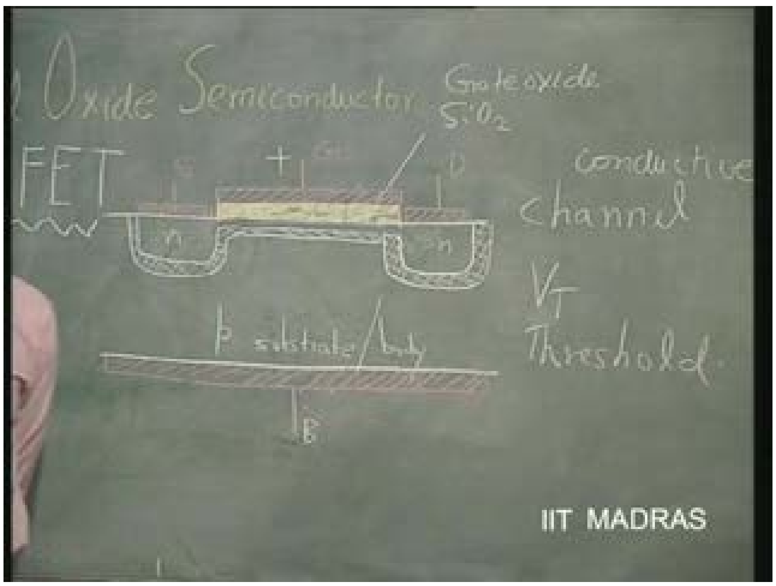

Circuit definition is very simple because it is very difficult... Circuit definition is, threshold voltage is that voltage that will permit a certain amount of current to flow from source to drain, because that can be easily measured, because we would not know what is the doping of this, in order to find out what will be the doping of this, when threshold voltage is applied.

So, the circuit definition for this threshold voltage is that voltage that is applied to the gate in order to make a certain amount of current flow from source to drain. Between source and drain, initially, there is no current because it was blocked. There was no channel existing. Because of applying a voltage, you have unblocked it. You have formulated a channel between source and drain; and you are now able to drive a current through the channel. So, threshold voltage is an important parameter associated with this kind of MOSFET. This is called Enhancement type of MOSFET.

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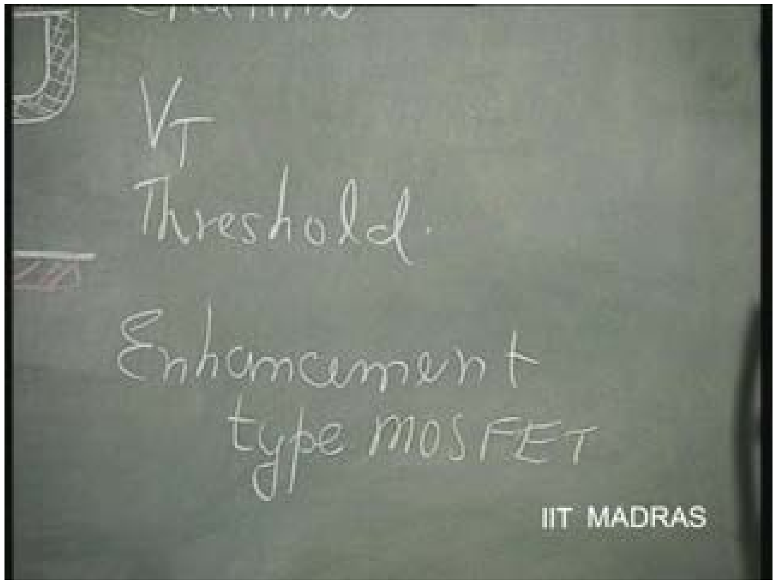

Why? The channel is formed by enhancing the what? – conductivity of this by applying a voltage. Therefore, the channel can be only formed by applying a voltage and then only it can conduct. So, this is called enhancement type of MOSFET. Now, since the channel here is n channel, this is called n channel enhancement type of MOSFET.

So, in enhancement type of MOSFET, the MOSFET action, etcetera will occur only after a voltage greater than the threshold voltage is applied between the gate and the substrate. These devices which are enhancement type of MOSFET are initially not conductive. When the gate is open; or, when the gate is not connected to any voltage; or, any gate is connected to zero volts; all these devices are off. They can become on only after crossing the threshold voltage.

So, they are very good switches. That is why these are universally adopted in all gates and digital circuits. So, this has become a popular device in digital circuits because, by nature, it is off. When the gate voltage is zero, it is not conducting between source and drain. In order to make it conduct, we have to apply voltage which is greater than the threshold voltage to the gate. Then, we can make it conduct; and the conductivity can be controlled by suitably adjusting the gate to substrate voltage. So, we will therefore say that the current in this case, current I D S, is going to depend upon this V G S minus V T.

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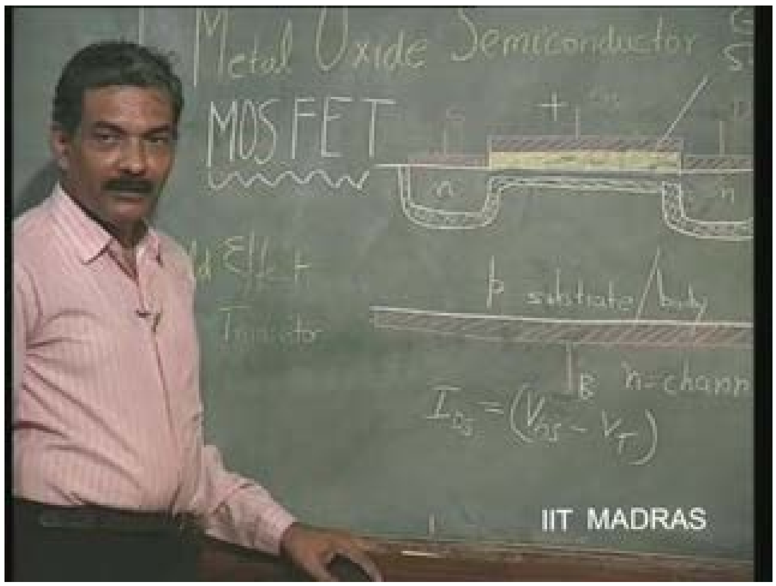

Normally, for this operation, the bulk is connected to the source. We do not want to have too many sources. We would like to minimize the independent sources which are required for biasing to a bare minimum of one or two. So, the bias voltage that is applied between source and bulk is made equal to zero. That means, source is placed at the same potential as the substrate or the bulk. So, you can connect it together and then apply a voltage with reference to the source. So, this is why it is called V G S.

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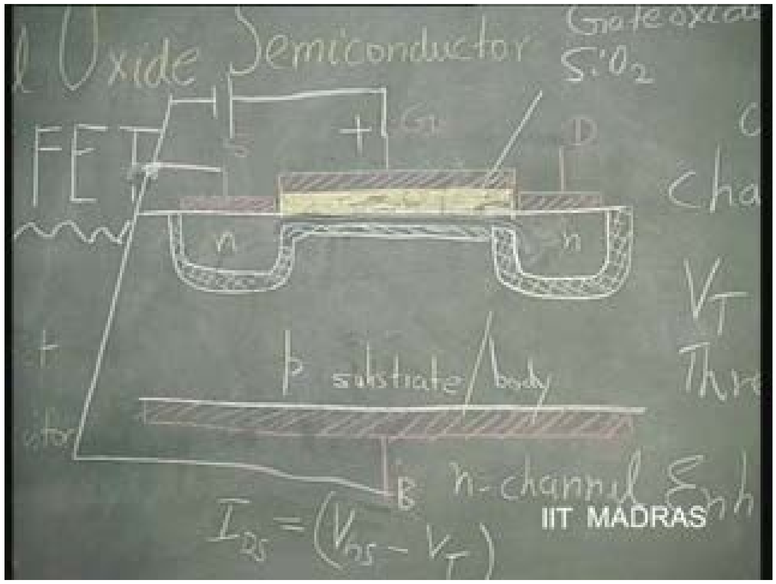

So, this voltage is zero. Now, I am applying a voltage V G S between gate and source. So, the current is going to depend upon V G S minus V T. V G S, if it is equal to V T, current is zero. It is completely blocked. There is no channel formulation. The channel formulation occurs only after V G S equal to V T occurs. Substantial amount of current can now flow. So, the current is dependent upon the factor V G S minus V T; so, dependent proportional, initially.

Now, look at it this way. Once the current starts flowing in the circuit... Why will the current flow? Because, the potential of D is different from potential of S. So far in this, we had assumed that V D S was zero. If this potential also is different, then, V G S is different from V G D, if V D S is not equal to zero.

So, let us now assume that the voltage applied to the drain is this. This is V D S. I am trying to make this drain more positive than the source. What happens to now V D G? When V D S was zero, V G S was same as V G D. Do you agree to that? That means the depletion layer width in all these places will be the same because the voltages are the same. So, whatever happens here will now happen at the source and also, same amount of channel will be uncovered in both the ends.

Now, my question is, if I apply a V D S, what happens at this end as compared to what happens here? The voltage is positive with respect to this; this is also positive. Then, this V D G is going to be less than V G S.

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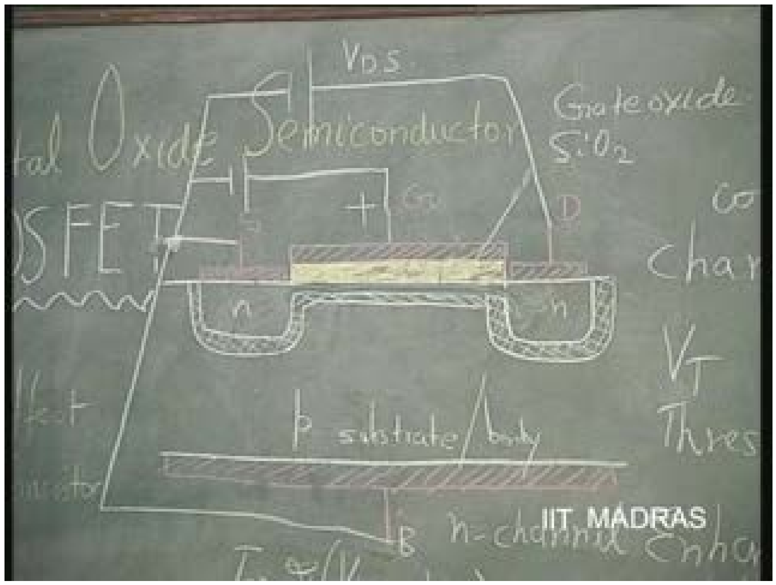

Whatever V G S you have applied, the V D G is going to be less by a factor of V D S. So, this depletion layer width here or this channel width here has to decrease. This channel width will keep on decreasing until, what happens? V D S becomes equal to V G S, equal to V T.

Suppose this voltage, that is, V G S minus V G S... Let us say, V G S is equal to V D S. Then, the voltage applied is zero. That means we have already gone to a state of zero voltage between this and this. It has stopped conducting long ago, even prior. That means, when V D S was equal to V T itself, it has got blocked here.

So now, once again let us see. This is V G S. The voltage V D G is equal to V G S minus V D S. So, if V D S keeps on increasing at a point equal to what? – V G S minus V T. V D G is equal to V D S minus V, V D S plus V S G. Or, this is equal to V D S minus V G S. Is this clear?

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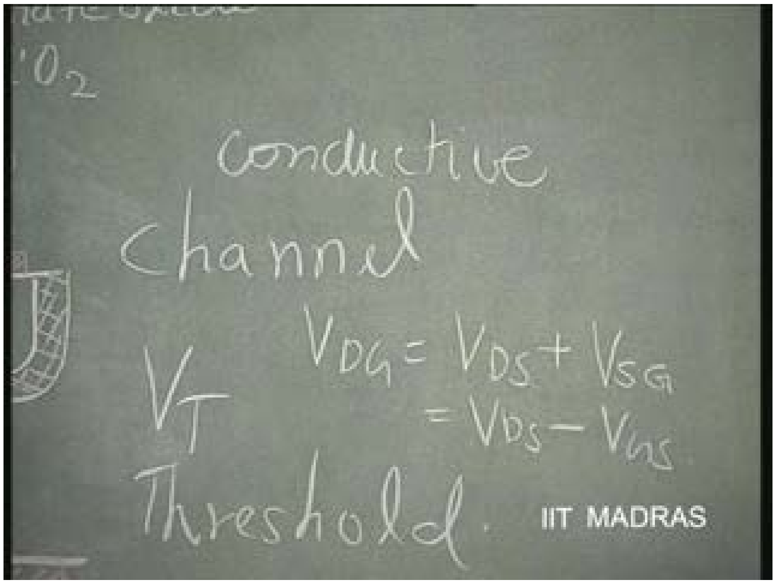

V D G is equal to V D S minus V G S. This is V D S plus V S G. Then, V D S minus V G S. So, let us say, V G S, V D S was zero; then, the V D G is going to be minus V G S which is all right. The same amount of voltage which was earlier applied here is going to be applied here. V G D, V G D is equal to V G S minus V D S. So, same amount of voltage as V G S will occur as V G D, if V D S is zero.

Now, let us say, V D S is increasing. It takes on a value which is V G S minus V T. Then, what is V G D? This is equal to... V G S, V G S will get cancelled. This is equal to V T.

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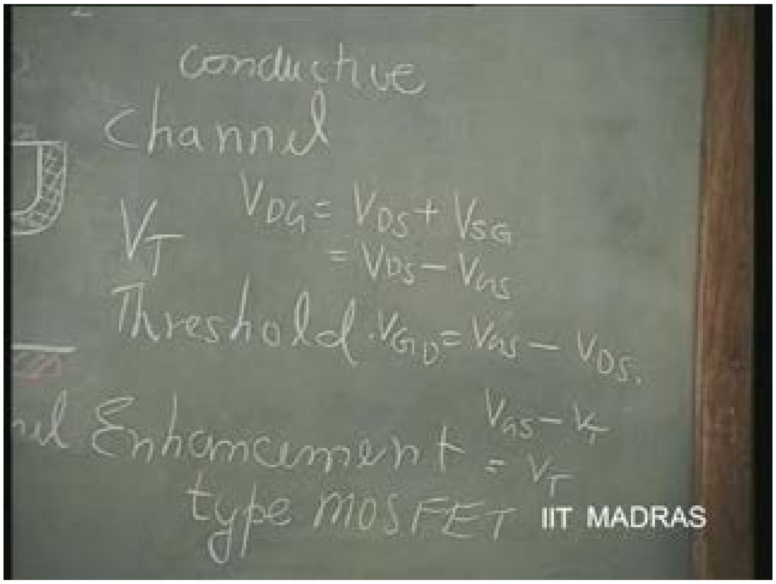

So, at that particular point, you have only threshold voltage as the voltage applied between drain and gate. That means, the entire this thing has been blocked to a certain extent here. When you apply threshold voltage, the channel has just got formulated. The channel width will be dependent upon the excess voltage over and above V T that you are having between that terminal and gate.

Suppose V T is 1 volt and V G S is equal to 2 volts. Then, the channel width is corresponding to 2 minus 1, 1 volt. Suppose V G S has now become 3 volts. The width is going to be further enhanced by an amount which is equal to 3 minus 1, corresponding to 2 volts. So, this width will be more than the width corresponding to the earlier voltage of 2 volts.

So, if I have widened it by an amount equal to 1 volt... So, let us say, V T equal to 1 volt, V G S I have applied was 2 volts. So, I have now a channel width corresponding to 2 minus 1 throughout, when V D S was equal to zero. When will the channel get closed? When I apply in the opposite direction, a voltage of what? – 1 volt, because 2 minus 1 is the excess volt. The channel will get closed when I apply in the opposite direction a voltage of 1 volt. Let us again take this. V G S was 3 volts; V T was 1 volt. The channel width corresponds to 3 minus 1 volt. When will the channel get closed at the drain end? When V D S becomes equal to 2 volts.

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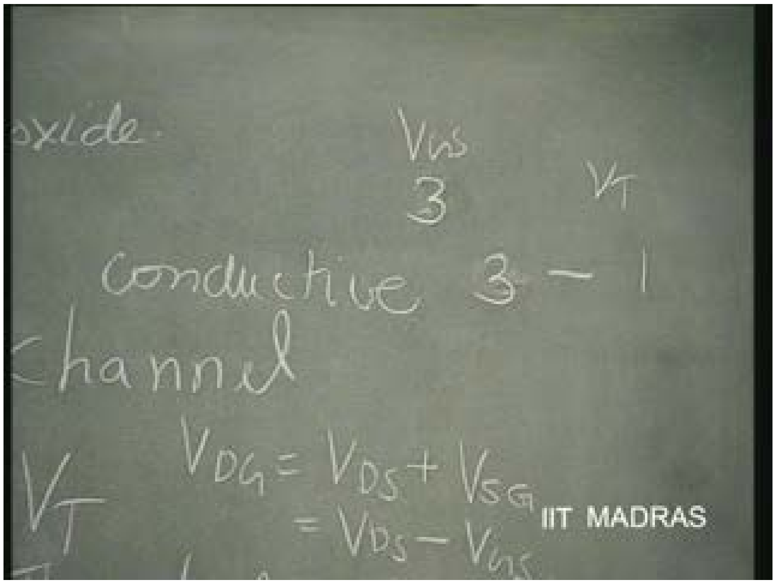

This V G S was increased to 4 volts. The channel width corresponds to, throughout, 4 minus 1 volt.

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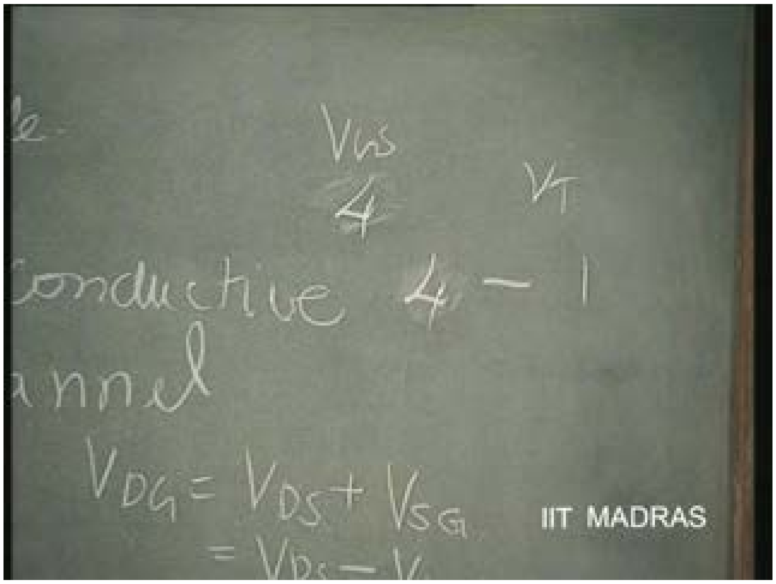

When will the channel get closed? Or, we will call this term as pinch off, pinching off the channel. So, this voltage at which pinch off occurs corresponds to a drain to source voltage of 4 minus 1 volt – 3 volts. So, if this is 5 volts, it will correspond to a voltage of 5 minus 1 volt, 4 volts. So, that is what is called pinch off point; after which, the channel at that point is going to remain closed.

So, let us picturize this. What is going to happen when I voltage, apply a voltage like this? It is that the depletion layer width is going to sort of extend here and close the channel. This point where the channel is completely closed is called pinch off point.

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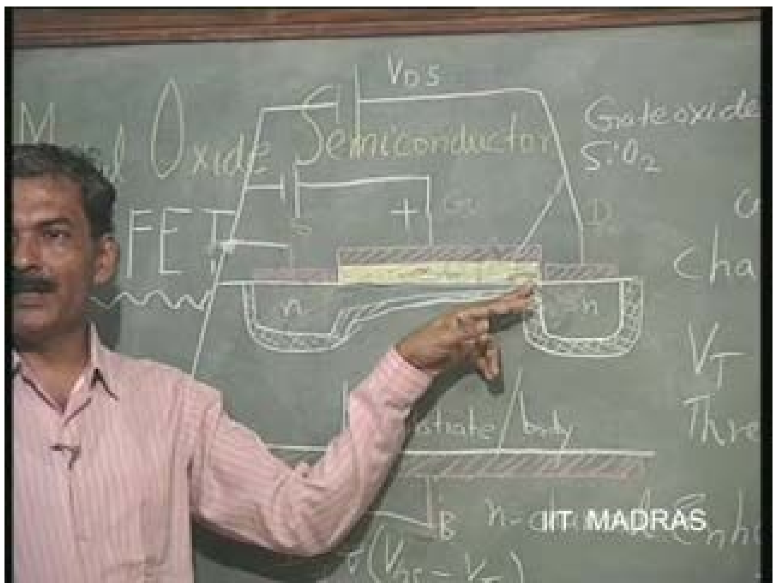

The pinch off point corresponds to the excess voltage over and above V G S minus V T that you have applied to cause the enhancement. V G S minus V T is the voltage that has caused the enhancement of the channel. In order to deplete that channel width, in order to close that channel width, you have to apply that same voltage in the opposite direction. So effectively, therefore, V D S that you have to apply at this point to close the channel corresponds to simply V G S minus V T.

Now, let us see what happens. Initially, I have applied a substantial voltage as V G S when V D S was zero.

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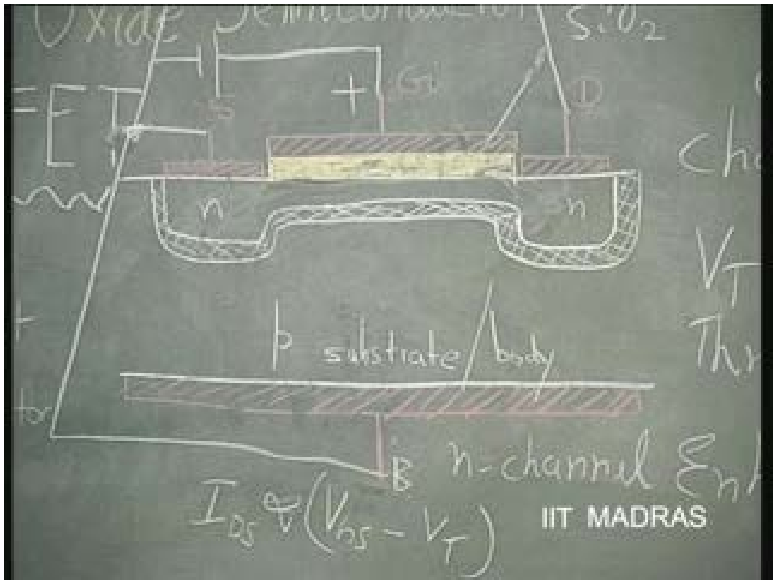

So, let us consider, when V D S was equal to zero or very close to zero, what happens? Let us picturize this. When V D S was zero, we have I D S, let us say, versus V D S, let us call it. It is acting like a mere resistance, because this width is going to remain constant throughout. As I apply more and more of this voltage, gate voltage, this width is going to increase, the depth is going to increase and therefore, the conductivity of the thing is going to increase or resistivity is going to decrease, of the channel. The resistance of the channel is going to decrease.

So, this particular thing, as more and more area is uncovered here, the resistance, total resistance of the channel is going to decrease, in which case, it is acting like a voltage dependent resistor or V D R or voltage variable resistor. By applying a gate voltage, I can change the conductance of this or resistance of this.

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So, one corresponding to, let us say, one value of voltage. This corresponds to V G S 1 minus V T. This is the characteristic. Another characteristic for a higher value of V G S 1 than this; let us say V G S 2. What will be the characteristic looking like? The resistance is lower; that means characteristic will be having a slope like this. V G S 2 greater than V G S 1. This is the characteristic. For V G S equal to V T, what will be the characteristic? V G S equal to V T, what will be the characteristic? The channel is just getting formulated; current is just flowing adequate. That means almost nearly zero current. This corresponds to V G S equal to V T.

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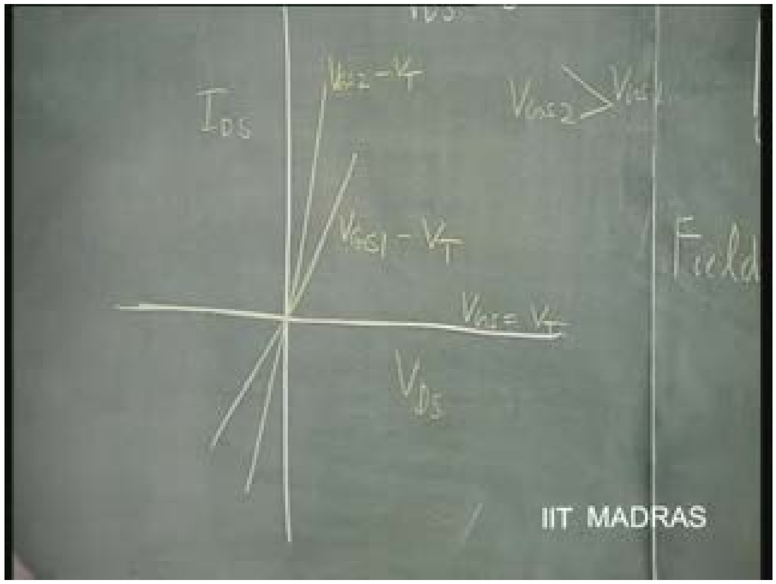

So, that means by varying this V G S, I can vary the what? – resistance of this. This is an important application of the field effect transistor. It is a voltage dependent resistor or voltage variable resistor. So, there is something that we have to still understand. We have understood that these – whatever has been uncovered here – depends upon V G S minus V T. If you want to cover it up, you have to apply a voltage in the opposite direction. For field effect transistor action, like transistor action we discussed, what we have to do is cover it up. That means the voltage that you have to apply here is of the same polarity as that of the voltage that is applied to the gate, so that effective voltage between drain and gate will be opposing one another.

So, the V D S that I have to apply here in order to close this channel at this point corresponds to V G S 1 minus V T, if it is V G S 1. V G S 2 minus V T, if it is V G S 2 that I have applied to the gate, so on... So, that means, as I keep on increasing this voltage, the width here of the channel will decrease; this width will remain constant, because V D S is, V D G is changing but V G S or V S G is remaining constant; this as we maintain constant. So, this width here remains unaltered. So, this keeps changing. This keeps on decreasing.

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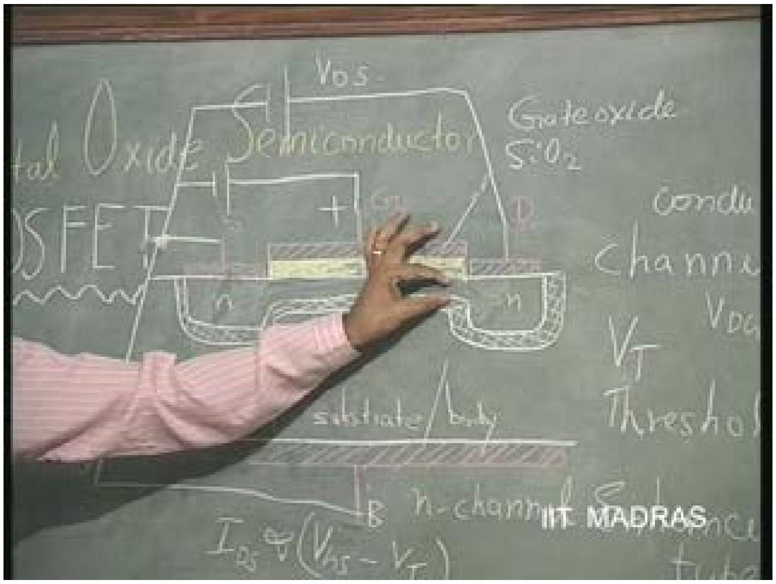

What should happen? The increment value of current let us say... we will go to this. There is an increment current here corresponding to the increment in voltage. There is an increment in current. The next increment in voltage will not give me the same increment in current because this particular thing has decreased. Effective incremental resistance has increased. Follow this carefully.

That means for the next increment in voltage, I will not have same increment in current. It will be corresponding to a lesser... for the same increment in voltage. This increment in voltage can be made as small as you please. So, it will look like a curve rather than a line. For the next increment in voltage, the increment in current will still be smaller. For the next increment in voltage, the increment in current may not be there. What is that point?

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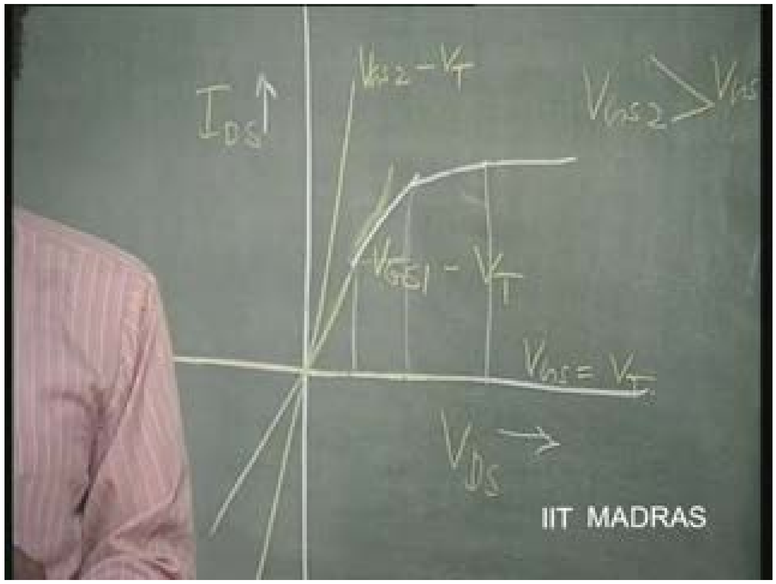

That is the point when the channel is completely closed. The incremental resistance there is infinity. The slope is zero. This is what is meant by pinch off. Channel, when it is getting pinched off, it will sustain a current; but it will not cause further incremental change in current for an incremental change in voltage. That is how we have to understand this pinching off. So, this particular thing will cover itself completely here, corresponding to pinch off. Thereafter, current is going to remain constant. This is what is called the saturation current. For the field effect transistor, this is going to be the saturation current.

Similarly, for the next voltage which is higher, same thing will happen. For that increment in voltage, increment in current is lesser, lesser and lesser; and it is going to get pinched off at a higher V D S because, what is the voltage at which it gets pinched off? – V G S 2 minus V T. So, the voltage V D S corresponding to which it is getting pinched off is V G S 2 minus V T. Here, it is corresponding to V G S 1 minus V T.

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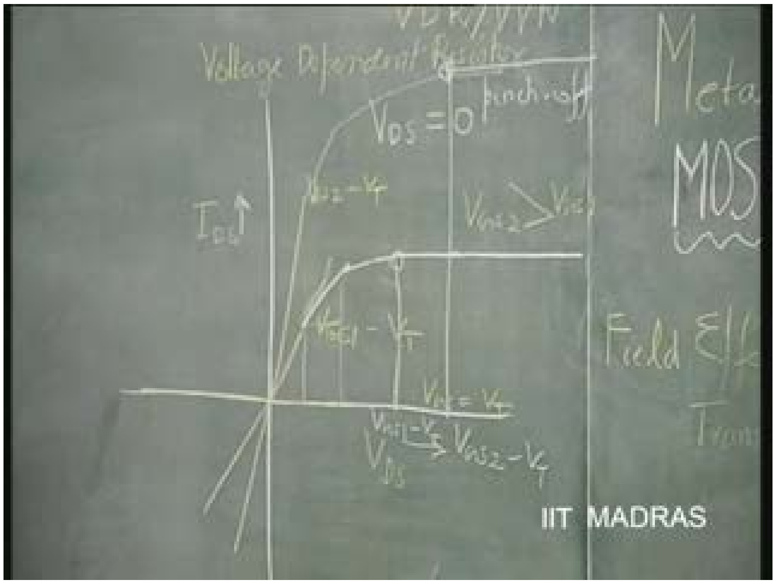

So, this is called pinch off. So, this is called the F E T action. What is FET action? Causing it to pinch off and letting the current go to saturation. That will happen corresponding to V D S greater than V G S minus V T. Therefore, transistor is said to be in current saturation region.

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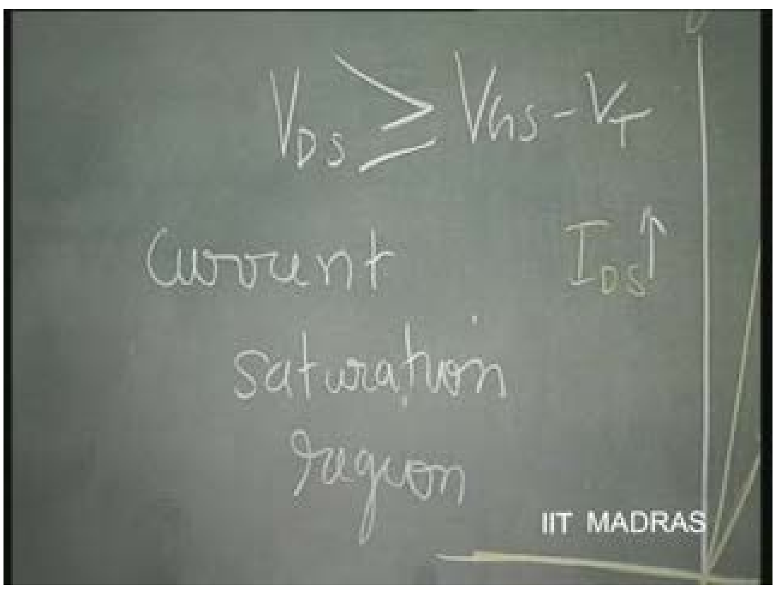

Current is independent of V D S; or, I D S which is dependent upon V G S minus V T. And it is equal to K times V G S minus V T whole square; important relationship. It is a square law relationship. How is it dependent upon V G S minus V T? – in a square law manner. So, I D S is K, the constant factor, which depends upon the w by l ratio of the channel; w is the width of the channel, l is the length of the channel.

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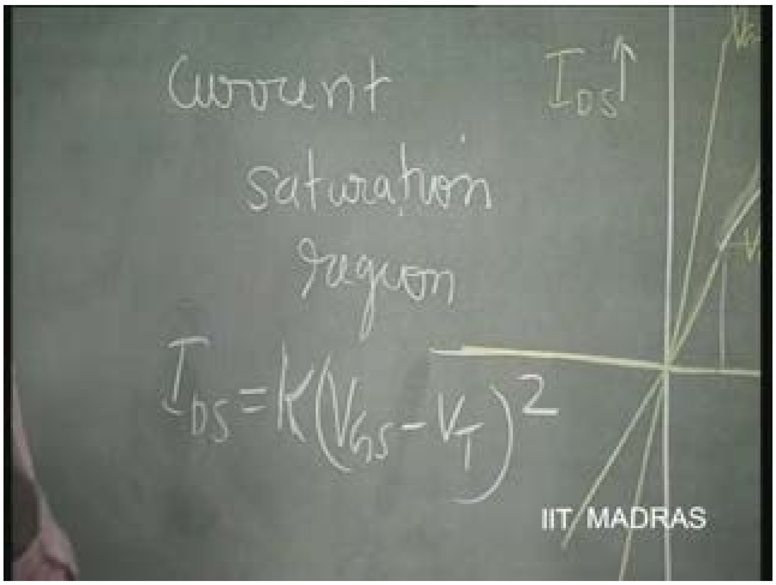

Length of the channel and the width of the channel. This is the depth of the channel. So, it depends upon w by l ratio. Obviously, current is... it is the resistance; depends upon the dimension of the channel. So, w by l ratio. So K is a factor which is the property of the field effect transistor; this into V G S minus V T the whole square. And what is current saturation region? V D S greater than V G S minus V T for n channel device only. For the p channel device, this voltage is going to be negative with respect to source. This also is going to be negative and the threshold voltage also is going to be negative; and therefore, V D S less than or equal to V G S minus V T is the region where the current saturation occurs. Is this clear?

So, please remember this important point. This region is called triode region. Why it is called triode region? We do not have to explain, because the triode characteristic is somewhat like this; so, like a resistor characteristic. So, this region which is V D S less than V G S minus V T is called the triode region.

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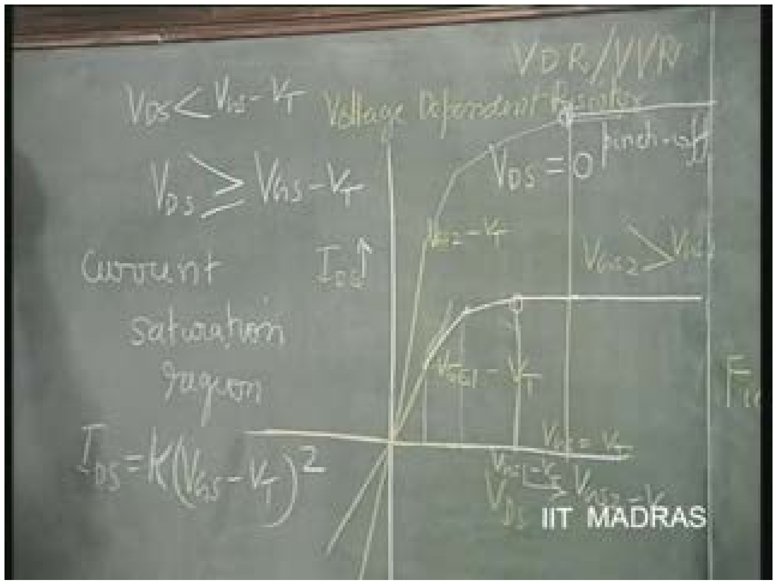

There, the characteristic is going to be I D S equals 2 K times V G S minus V T whole square into, sorry, this into V D S minus V D S square by 2.

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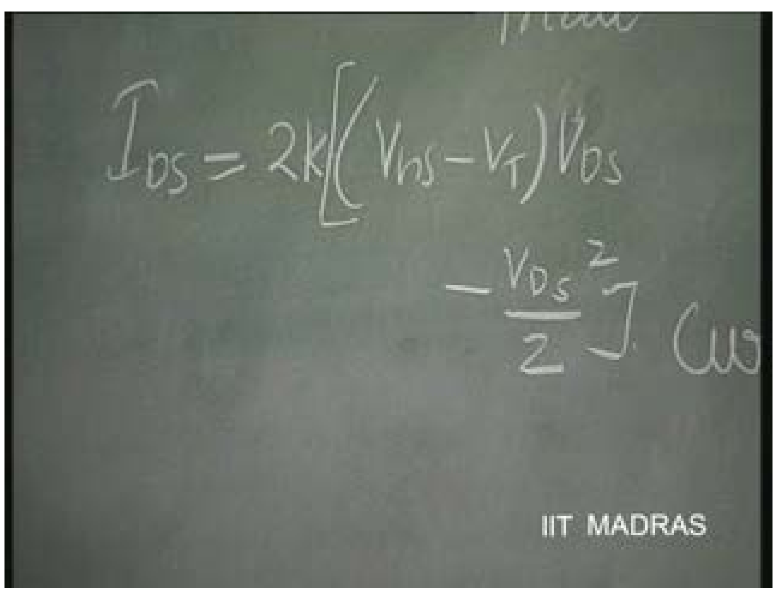

There, for low values of V D S, it is directly proportional to V D S; that is, it is acting as a resistant. You can see, linear. For V D S very small, it is directly proportional to V D S and also V G S minus V T. Then, there is a subtraction. There is a reduction from the linearity, reduction from the linearity. That reduction is a square law again.

This relationship is valid up to V D S equal to V G S minus V T. So, if you substitute V D S minus, V D S equal to V G S minus V T, you should get this value. So, substitute this V D S equal to V G S minus V T. You will get this from this.

So, V D S equal to V G S minus V T. So V G S minus V T whole square minus V G S minus V T whole square by 2. 2, 2 gets cancelled. You get K into V G S minus V T whole square. So, at exactly this point, both these relationships merge into one. So, this is the exact relationship. Below this, when V D S is very small, we can neglect this square law and assume it to be perfectly linear and treat it as a resistance corresponding to V D S by I D S, V D S very small. Then, V D S by I D S is equal to 2 K, sorry, 1 over 2 K into V G S minus V T, a resistance.

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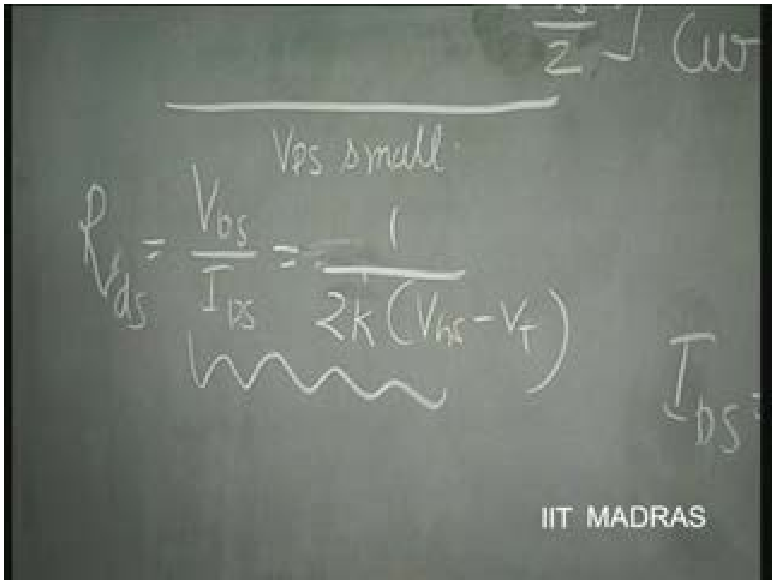

I am putting it as capital R saying that it is a resistance like any other resistance; not small signal or something. It is actually a resistance like any other resistance. Voltage can go both positive as well as negative as long as this square law is ((neg…Refer Slide Time: 55:20)).

So, with this we are somewhat familiar with the MOSFET characteristics. We will see the other types of MOSFETs like p channel MOSFET, enhancement type, ... now, there should be another type called depletion type of MOSFET and junction field effect transistors, in the next class.