Electronics

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Module No. # 05

Lecture No. # 04

Drain and Transfer Characteristics of E - Mosfet

We continue, our discussion on the enhancement MOSFET, the most important feature to understand, the most important characteristics rather to understand, the behavior of any electronic device is the I iv characteristics current voltage characteristics. So, we talk about drain and transfer characteristics of E MOSFET, enhancement mode MOSFET.

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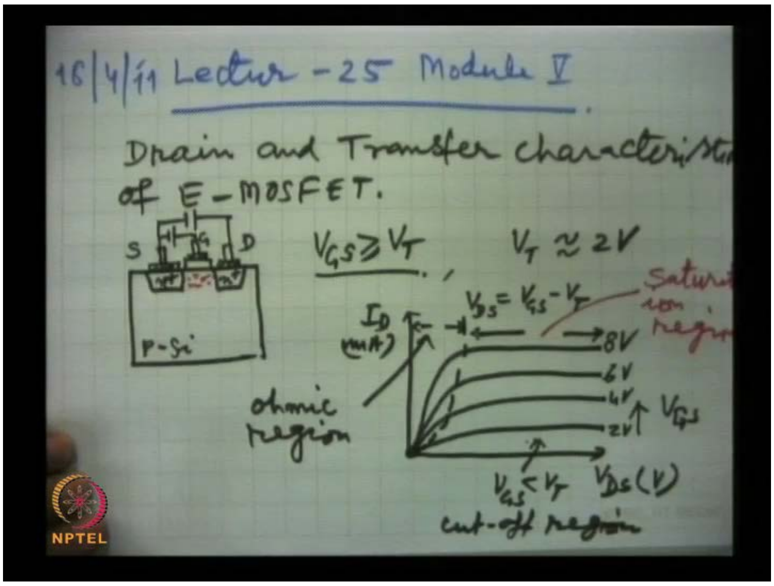

To understand these characteristics, it is the at 1 take to keep the geometry of the device in the mind. And to remind you that the geometry is like this, this is the P substrate for example, P silicon. And this is moderately doped n type, this is the electro, the metallic contact and. So, it makes it source this is the two layer, this structure we have talk and this is another electrode, then metal electrode here. And the this is drain and this is the metal electrode on the gate. So, this is gate electrode then, we establish the potential difference between source and drain. And another voltage, a positive voltage between source and gate this is gate.

And once V G S gate source, voltage is greater than the threshold voltage, which gives the channel which creates the channel by the inversion layer this, we have discussed in details that how in enhancement MOSFET, the channel is created there is no implanted channel initially there is no channel. But channel is a created between the drain and source here, this is the channel. And conduction will occur under these conditions, when V G S is greater than or equal to the threshold voltage, then the conduction between drain and source will occur and this will be controlled. By the voltage V G S between gate and source.

So, now, we are in a position to draw the characteristics, we plot these characteristics and they are between the drain current Id in mille ampere. And the this is V G S the voltage between drain and source, this is in volts. And these characteristics come out to be like this, like that and this is V G S, V G S here for example, 2 volts 4 volts 6 volts and 8 volts these are the drain characteristics is the we call for the E MOSFET. Now, and these currents is we are, we have talk earlier that this current, drain current exist only for voltage is in x is when gate source voltage is equal or greater than the threshold voltage, required for the channel creation.

Now, these characteristics, can be divided into 3 regions. here the loci of these points, where the a kind of saturation region is starts this us usual. We have seen earlier as well V D S has to b equal to V G S minus V T. And now, these are 3 regions 1 region V T is normally, the threshold voltage is of the order of 2 volts are less and. So, this region is we are V G S is less than V T and this is the cut off region. And on the left of this dividing line this is the ohmic region, ohmic region and this is the saturation region.

This is saturation region. So, these are the 3 regions in which, we can divide these current voltage characteristics. Now, we will talk about these 3 regions 1 by 1 and show the behavior of the devices, under each characteristic.

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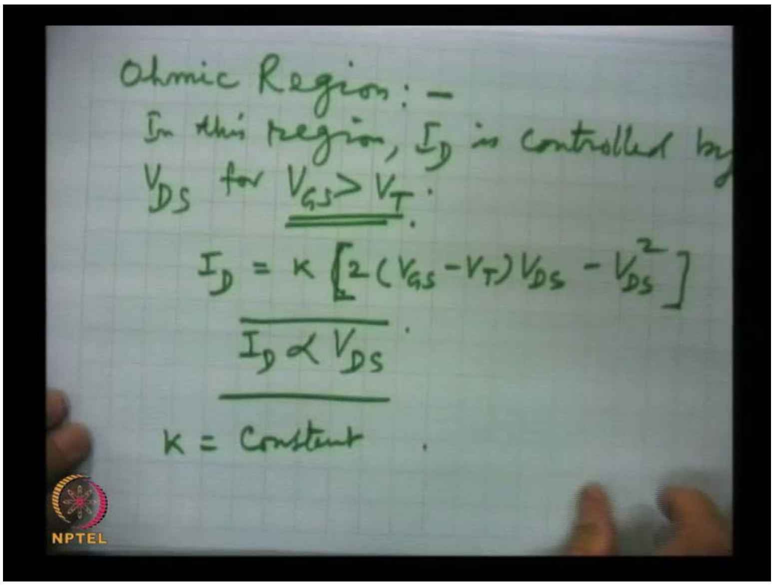

Ohmic Region :-

In this region, I_D is controlled by V_{DS} for $\underline{\underline{V_{GS} > V_T}}$.

$$I_D = K\left[2(V_{GS}-V_T)V_{DS} - V_{DS}^2\right]$$

$$\overline{\underline{I_D \propto V_{DS}}}$$

K = Constant.

First, we take the ohmic region remember this is the region, this is the region which is the ohmic region. And the drain current here in this region, the drain current I D is controlled by the drain source voltage by V D S, for gate source voltage greater than V T. And the current, can be expressed I D the drain current is given by K twice V G S minus V T V D S minus V D S square this is the expression which gives the dependence of drain current in this region, drain current on V D S. So, we can see actually, we can take V D S out a k is constant. And we will find it have what is the value of this. So, this can be from this expression, we can write that drain current is proposanal to V D S. And this constant k this is true for under this condition and in the above equation, in this equation K is a constant a device constant.

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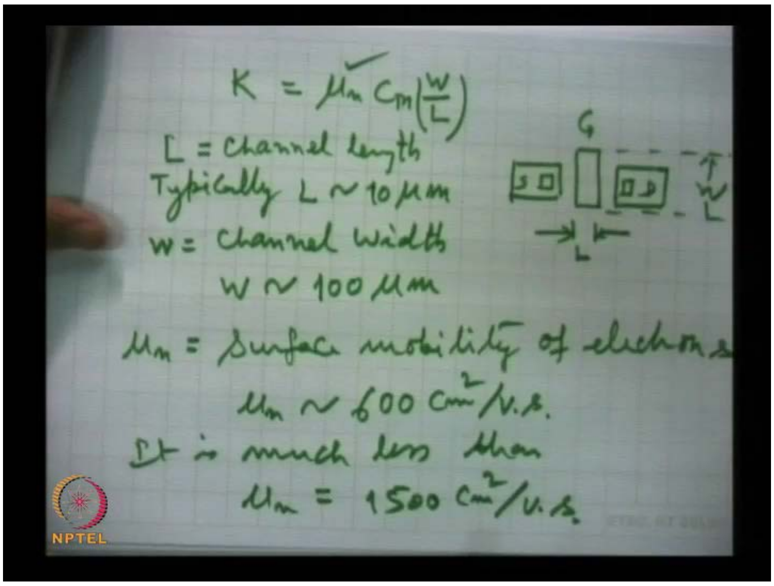

$K = \mu_n C_m \left(\frac{W}{L}\right)$

L = Channel length

Typically $L \sim 10\ \mu m$

W = Channel width

$W \sim 100\ \mu m$

μ_n = Surface mobility of electrons

$\mu_n \sim 600\ cm^2/V.s.$

It is much less than

$\mu_n = 1500\ cm^2/V.s.$

And this is, this can be shown to be equal to K can be shown to be equal to mu m cn w by L this is the expression, which defines this constant K device constant for the E MOSFET. And in this, L is the channel length, channel length typically this L of the order of 10 micrometer, the structure in of the device is like this. This is gate, this is source and this is that metallic contact. And this is the drain and this is the metal contact and this is L channel length. And you know between drain and source here drain and source, this is this red 1, this is the channel. So, this is the channel length L this is channel length L. And W is here W is channel width and typically, W is the order of 100 micrometer.

And mu m, this mu m is a surface mobility of electrons, because we are talking of normally used n channel E MOSFET. And show this channel is the containing electrons. So, we are concerned with the surface mobility of electrons. And this is around 600 centimeter square volt second, if we compare this with the bulk value and this is a the bulk value is it is much layers, it is much layers then the bulk value mu m, which is around which is 1500 centimeter square volt second this surface mobility of electrons.

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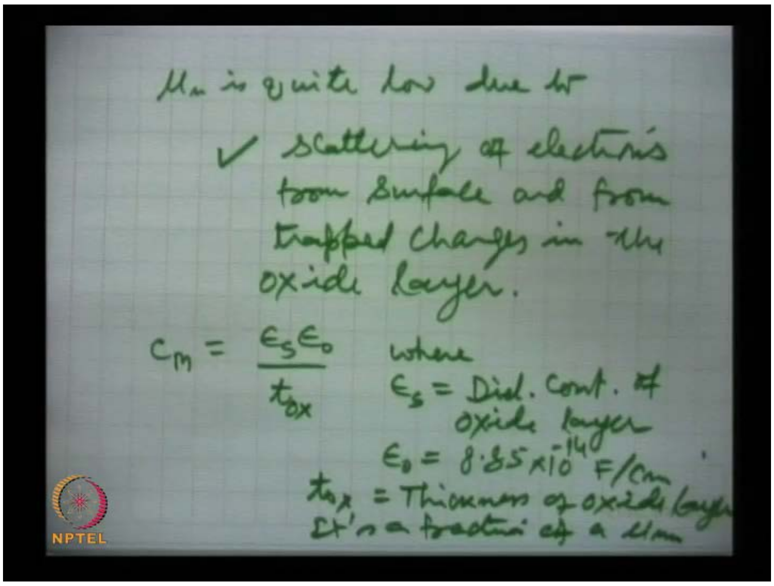

μ_m is quite low due to

✓ scattering of electrons from surface and from trapped charges in the oxide layer.

$C_m = \frac{\epsilon_s \epsilon_0}{t_{ox}}$ where

ϵ_s = Diel. Const. of oxide layer

$\epsilon_0 = 8.85 \times 10^{-14}$ F/cm

t_{ox} = Thickness of oxide layer

It's a fraction of a μm

This is much reduced in the reason is the mu m is a quite low, due to this reason. The reason is the scattering is scattering of electrons from surface and trapped. And from trapped charges in the oxide layer, what we have seeing, we are seeing that mobility of electrons normally in the bulk material is around 1500 centimeter square by volt second. And but here this is the kind of very thin layer. So, we talk of the surface mobility mu m and which is around 600, which is much less than and the reason is the scattering of these electrons from this surface.

And from these traped charges in the oxide layer C M, we have defined W we have defined length, we have defined mu m then this C M C M is this is equal to epsilon s epsilon 0 by tox, where this is the epsilon s this is the dialectic constant of the oxide layer, oxide layer which is typically around 3 and or may be more actually. And epsilon 0 is the permittivity of free space which is 8.85 10 to power minus 14 per centimeter. And tox this is thickness of oxide layer, thickness of oxide layer and typically it is a fraction of a micrometer. So, this is about the constant K sometimes, K is defined in another way, this is one possibility of in it is defined, when all geometrical parameters are known, but there is another way of defining constant.

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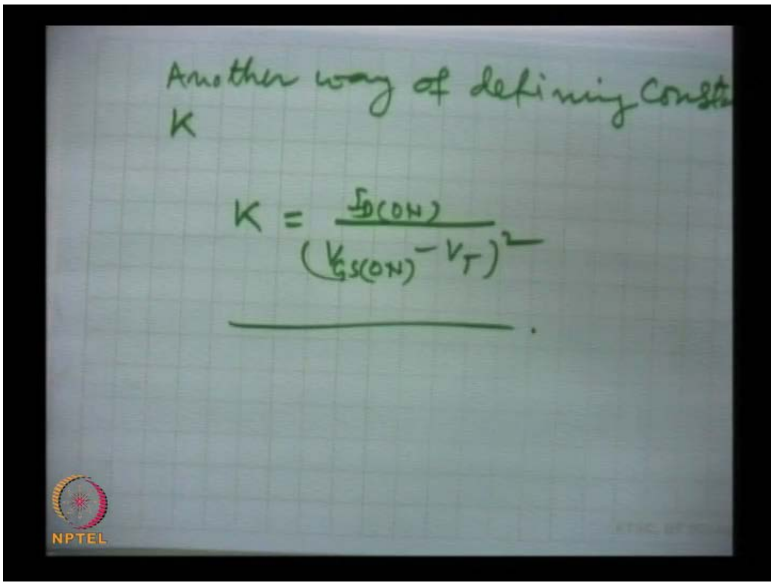

Another way of defining Consta
K

$$K = \frac{I_{D(ON)}}{(V_{GS(ON)} - V_T)^2}$$

Another way of defining constant K and this is K is equal to I D on V G S on minus V T square, these parameters can be obtained actually, from the I V characteristics for example, here this is around 10 Millie amperes then this becomes I D on becomes 10. And this is for 8 volts, then V G S is 8 volts and this is V T. So, if we use this expression, then we should know the geometry of the device completely. And if in the absence of that they have not able, then we can use this expression for the constant K, where the parameters, can be determine from the characteristics of the drain characteristics.

So, this was about the ohmic region here, here we finish the ohmic region. And then we move to, but this K, because this will be used even in saturation region and so on. Saturation region of these characteristics, where the device whenever, we want to use it in amplifying mode, as amplifier then we kept to operated in this saturation region. This we have talk in the junction field effect transistor, we have talked in the depletion mode MOSFET. And now in the drain in this E MOSFET also the same thing.

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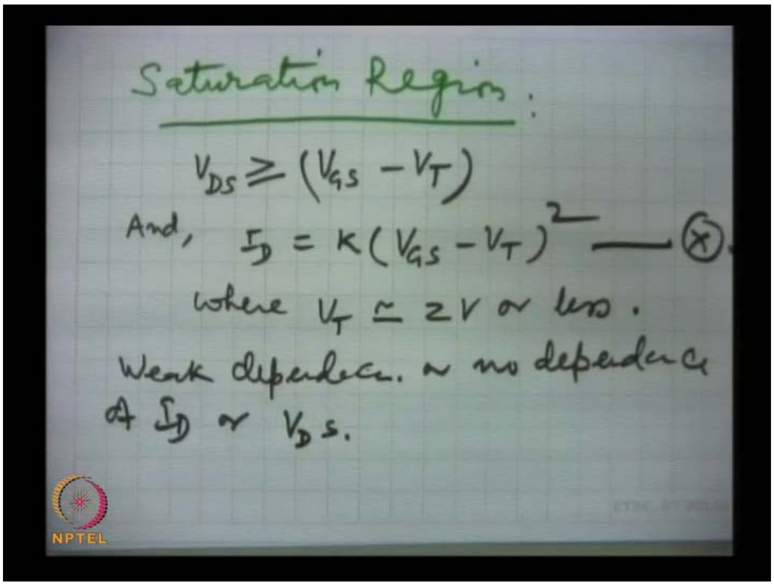

Saturation Region:

$V_{DS} \geq (V_{GS} - V_T)$

And, $I_D = K(V_{GS} - V_T)^2$ —— ⊗

where $V_T \simeq 2V$ or less.

Weak dependence or no dependence of I_D on V_{DS}.

So, next is saturation region, in the saturation region in this region V D S is greater or equal to V G S minus V T, this is you know this is the boundary here, which is defined by this. So, in the saturation region V D S has to be greater than this parameter this. And I D is given, the drain current is given by K the constant, which we have defined above and V G S minus V T square, where V T is around 2 volts or less. Now, from the characteristics, when we elaborate this saturation region, then actually here of course, there are almost horizontal. But there is a slight angle that means, here we has shown that drain current is independent of V D S, but is does different it also shows independent the drain current is independent of the drain source voltage, but we will see little later, when we gone in greater detail then there is a mild dependence. So, here in this region, there is a weak dependence or no dependence of I D on V D S. This equation is very important and it is gives raise to drain characteristics, the transfer characteristics. So, we talk about from here, this is constant for a device and K is constant. So, I D is function of V G S this is the equation of parabola. And drains current the output current and input voltage, input voltage is the gate source voltage.

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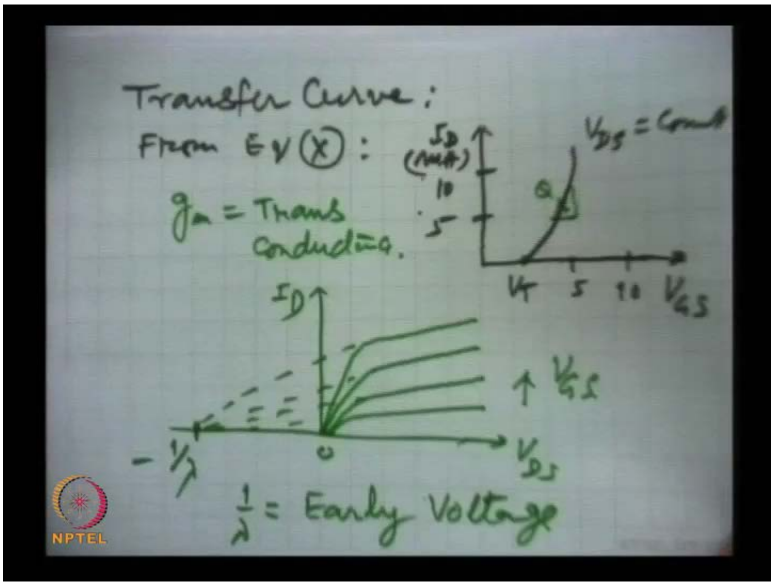

So, from here we can get transfer curve and these, curve this is from equation this x it is we have said, we can plot and this is V T, V G S. And this is I D mile amperes and this is for example, 10 5 and so on. And this is V G S this is the transfer curve for constant V D S, it is very important curve. Let me recall and remained you that, beta the was 1 of the most important parameter for a bipolar transistor B G T. F E T is a current operate is a voltage operator device and here the dependence of output current on input voltage, an input voltage is gate source voltage, output current is drain current. So, we are more concern with the dependence of this current on this voltage. Now, from here we can get. We will talk little later at on the operating point Q by putting a tangent, we can find out the most important parameter for this devices. And that is gm, which is trans conductance, that we can get from here.

Now, we said that in these, in the saturation region, the drain current is almost independent of V D S. Here the current is same almost as here, but is first pointed out that there is a weak dependence. And we look into this weak dependence. We elaborate these characteristics then, we get this, when we connect at the back, this is drain current, this is V D S, this is V G S, this is 0 then, this cuts is V D S x is on the negative side, at minus 1 by lambda this gives early, this 1 by lambda is called early voltage, early is the name of the scientist early voltage. And this is equalent to the channel bits modulation, in which is almost like the base width modulation in B G T. So, this is the when we take into a count, this weak dependence of drain current on V D S then this parameter can be taken.

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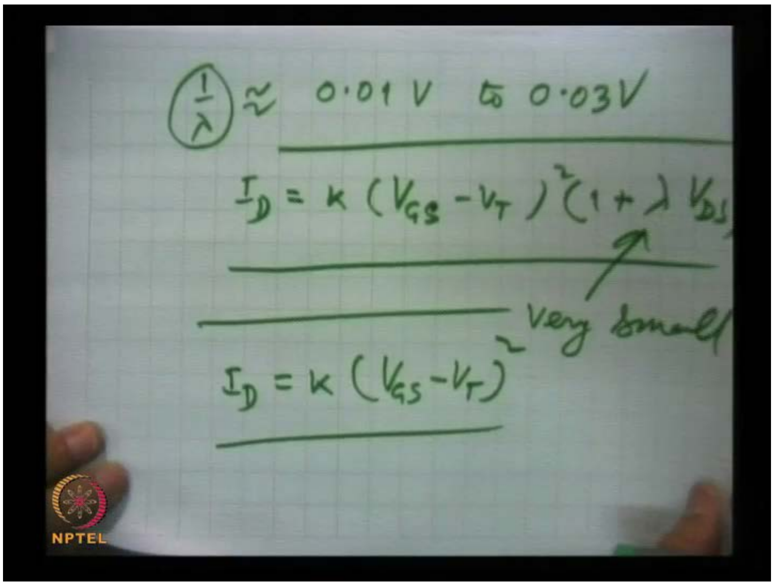

$\frac{1}{\lambda} \approx 0.01\,V$ to $0.03V$

$I_D = k(V_{GS} - V_T)^2(1 + \lambda V_{DS})$

very small

$I_D = k(V_{GS} - V_T)^2$

And that gives this is, this voltage, early voltage 1 by lambda this is of the order of point 0 1 volt to 0.03 volts of course, negative side. In the I D dependence, when we considered this early voltage then it is K V G S minus V T square 1 plus lambda V D S. This becomes this is the more accurate expression, which gives more accurately expression more accurately the drain current dependence on V D S. In normally, as we have done earlier this is very small parameter, this is small as we have seen very small. So, of in this is this is fact is neglected and I D practicality, taken as V G S minus V T in the saturation region is we have been using.

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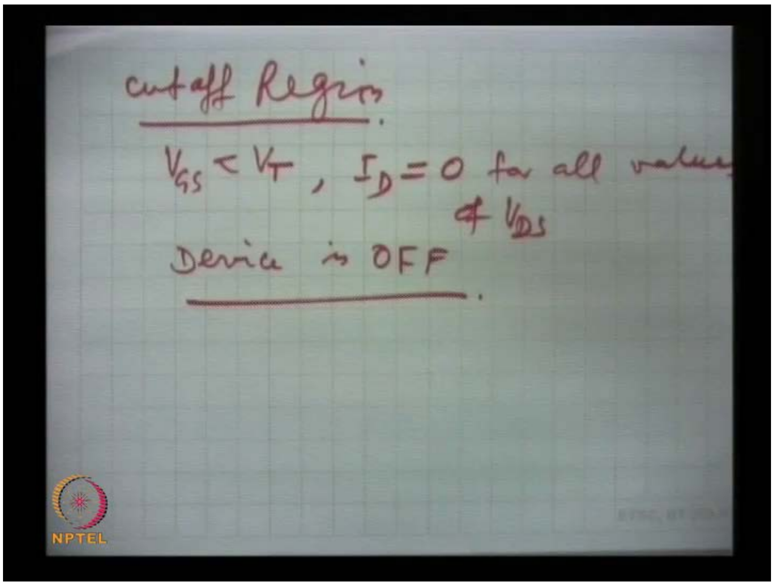

cutoff Region

$V_{GS} < V_T$, $I_D = 0$ for all values of V_{DS}

Device is OFF

And finally, in these characteristics there is the cutoff region, we said that characteristics can be divided into 3 regions the ohmic region, the saturation region. And here is the cut off region, this region. So, cut off region, in the cut off region V G S is less than V T, that is the channel is not formed, the voltage is insufficient to form the voltage to form the channel. So, the channel is not form and in the absence of the channel, there is no contact between drain and source and hence I D. The drain current will be 0 and for all values of V D S drain current will be 0. And device is set to be off, device is off. So, this is about the characteristics of I the drain characteristics, the transfer characteristics of the device. The device in the discussion just to remind you is E MOSFET, enhancement mode MOSFET, and now, we go further and we take biasing, biasing of F E T is in MOSFETS.

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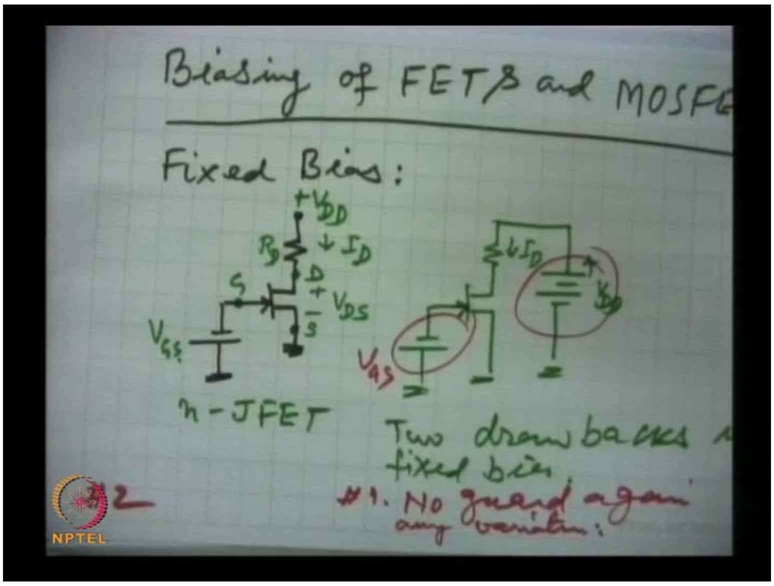

Biasing of FETs and MOSFE

Fixed Bias:

Two drawbacks

fixed bias

#1. No guard against any variation:

That is the next thing, which we have starting that is biasing of FET in journal that includes and MOSFETS, this is the next topic, why do we require to bias the device, I am sure by now understand. That it have been said, that when we want to operate the device for amplifying purpose is then. The device has to be operated in the saturation region, when the device is to be operated in the a switch, where on and off then it has to go in the cut off region. So, the region may be cut off in saturation point or the cut off and the ohmic region. So, these are the two regions, which have used only when the device is to be used as a switch, but for amplifying purpose is linear relationship between the V D S and I D is required. And when we have a constant V D S then has we increase, the gate source voltage the output current will vary in the device will work.

So, we kept to bias the device now the for the completeness, I must say that one of the biasing possibility is a fixed bias, what is fixed bias. Let us take is an example first the junction field effect transistor, this is source, this is drain, this is gate and this is V D D. And here this is resistance R D and the current I D flows through it. And here there is the voltage drop V D S and this is V G S this is for n type JFET, we can draw we will remember, that for n type JFET the gate has to be negatively biased, it should have a negative potential with respect to source. So, this battery supplies V G S and we can draw this plot.

The there is no reason to elaborated this, we have talk for example, this plot can be shown to be like this, same thing so, but there is no need to show this like this, always implied that one terminal of the batteries here, there is grounded. So, we continue with this simpler design, which is more much more frequently used then this. So, this is the fixed bias. And here why fixed, here this bias is provided by this battery V G S and it is no way connected with the output variations, variations in the output circuits. So, it is fixed what is the meaning of fixed, the fixed bias it is called fixed bias, because of his reason that, it will not provide any stability to the circuit against. The variations in the device or in the temperature device variations, we occur because of two reasons basically, by for the continuous use of the device, sometimes a characteristics change. This is one reason which is called agent.

And for the same reasons the value of these resistance for continues use, this may change. So, because of this variations or temperature variations are very common in a electronics circuit. And that will change the characteristics and unless, we question we taken this point, we have discussed in much a greater detail in the bipolar transistor, that fixed bias is no good. So, there are two drawbacks in this one, two drawbacks in fixed bias, one is it does not take any corrective measures, for any variations in the device parameters are temperature. So, no guard against any variations temperature are device parameters, another important parameter another limitation is that it leads two batteries, one is here the other is here V G S 2 batteries. So, in most circuit the use of 2 batteries, if it can be avoided should we avoided.

So, there is no requirement of additional batteries, to these are remember fixed bias is not a proper choice of a biasing. This is fixed bias here the biasing voltage is independent of any kind of variations, either in the temperature of the circuit or in the device parameters, the the most important device parameter is trans conductance. Which has some dependence on temperature or it may change, because of the fact. So, this is one region another region is the use of 2 batteries.

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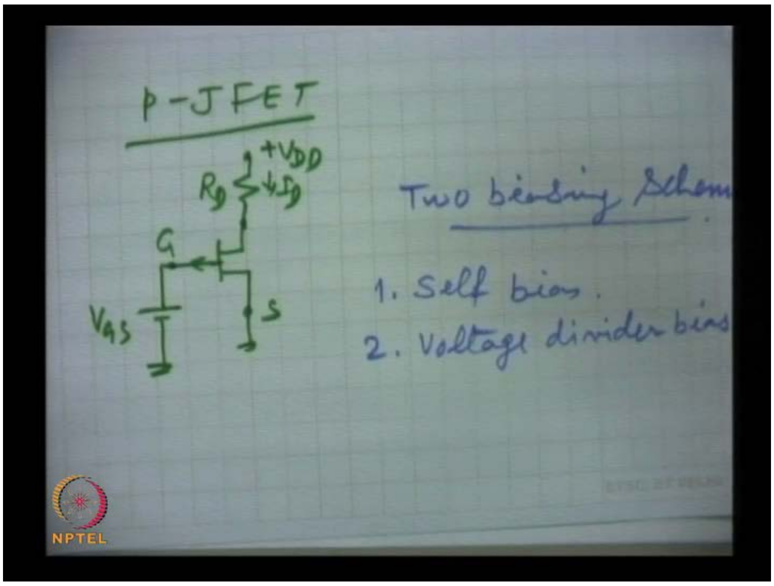

Two biasing Schem

1. Self bias.
2. Voltage divider bias

So, fixed bias is not used, this circuit I have drawn for this n JFET, this can be shown for P JFET also, simply by reversing the sign of these battery, that means, for P JFET this will be this is V D D and this is V G S. This is G, R D, I D and this is source. So, this is fixed bias for P type junction field effect transistor P channel, that are in n channel is much more widely used then this. So, then what are the choices for biasing, the fixed bias for the reasons, we have discuss is not a good advising scheme. There are two biasing scheme, which are widely used two biasing schemes, one is called self bias and the other one is voltage divided bias. Self bias and voltage divided bias, these are the two schemes which are most widely used. So, we take 1 by 1 these two practically used biasing networks, first we take self bias here the circuit is simple.

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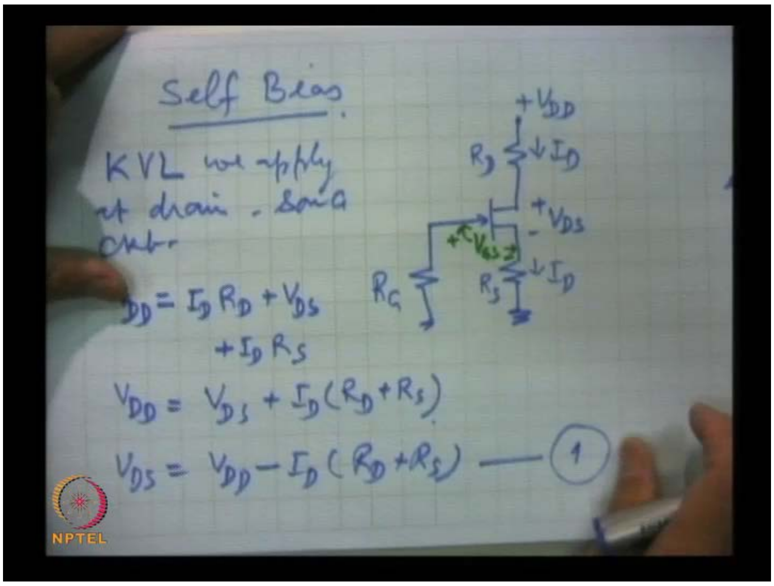

Self Bias.

KVL we apply at drain - source ckt

$$_{DD} = I_D R_D + V_{DS} + I_D R_S$$

$$V_{DD} = V_{DS} + I_D (R_D + R_S)$$

$$V_{DS} = V_{DD} - I_D (R_D + R_S) \quad \text{——} ①$$

And this is the self bias, why it is called self bias that we will explain and here, this is V G S voltage between gate and source, this is V G S. And which we are marking is plus here minus here. Now, here I D the drain current flows through this resistance, drain resistance R D, source resistance R D. And this is the voltage drop between drain and source. And show actually, we can write a voltage summation at the output circuits drain source. The voltage Kirchhoff Voltage Law we apply, at drain source circuit and we get what we get, this is summation.

So, we start with V D D, this is equal to I D R D plus V D S plus the same current flows here I D. So, I D R S this is, this can be written as V D D equal to V D S plus I D R D R S. And from here this equation, we will use later that V D S is given by V D D minus I D R D plus R S, if we call this equation 1. If these resistance are known current is known then what will be the voltage drop V D S, which is a must, we must know V D S that will decide our the drain current.

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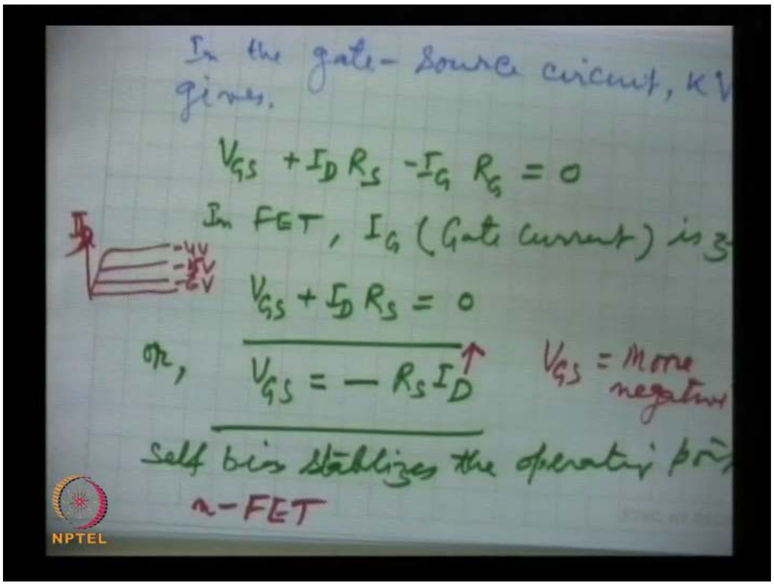
In the gate-source circuit, KV
gives.

$$V_{GS} + I_D R_S - I_G R_G = 0$$

In FET, I_G (Gate current) is z

$$V_{GS} + I_D R_S = 0$$

or, $$V_{GS} = -R_S I_D \uparrow$$

V_{GS} = More negativ

Self bias stabilizes the operating poi

n-FET

Now, in the gate source circuit here, let say the current I G flows, then in the gate source circuit in the gate source circuit here. There are the voltage drop across this, because of I G the voltage drop across R S. now, this point which are I am now discussing will illustrate that, why it is called self bias. And how it provides the stability to the circuit the operating point, once chose in will remain is stable against, the device temperature variations or variation in device parameters. So, the 3 voltages are involved 1 across this because of current I G and this voltage V G S and the drop across R S, because the circuit, input circuit the gate source circuit is this.

So, here summation R Kirchhoff Voltage Law gives, V G S plus I D R S minus I G R G equal to 0. And in F E T S we know that this current, the gate current is normally, very close to 0. It is in Pico amperes are less in well design devices. So, in F E T or even for MOSFETS the I G gate current is 0. So, when we put I G 0 here, we get V G S plus I D R S equal to 0 or from here or V G S is equal to minus R S I D this is the gate source voltage, which we were providing in the fixed bias circuit by another battery, in the self bias that is available is the voltage drop across, this resistance R S that is why it is called self bias, there is no extra battery to provide this voltage V G S. But it is available as a drop across this.

Now, several important features can we discuss, with is 1 is if R S is 0, then actually no voltage the voltage V G S will be 0, we will be in the cutoff region. So, in self bias R S the value of RS decides, the value of this voltage of course, that will depended on I D as well. So, this total drop across this resistance gives then voltage. Now, we say that self, this very important self bias, self bias is stabilizes the operating point. Once, we have choose in the value of for example, this is the operating point here. So, we have these all these voltages. And currents the value of V D S is fixed this is called V D S Q, this is called I D Q at the Q point.

What is the voltage drop and what is this and how much the V G S all parameters are known. This operating point once, choose in will be is stable against all kinds of variations. Let us look at this point suppose, temperature increases temperature of the ambiance, where the circuit is working are of the circuit parts, there is always the resistance are there and whenever ,the current flows there is a heating. And I square R that is the heat thermal energy generated. So, the temperature changes, semi conductor device is MOSFET are semi conductor devices. So, normally the drain current will increase. So, if drain current increases, then in a fixed bias circuit like this, if the drain current increases.

That will change this V D S and of course, drain current meaning the operating point will shift. The drain current will increase and so the operating point will shift. There is nothing to take corrective measure in the fixed bias, while in the self bias, if this current increases then this voltage will be more negative, more negative, if this increases this will be more negative V G S more negative, if you remember the characteristics for example, of a n JFET which is an in the present discussion more negative means. I D will fall, the characteristics where like this is minus 4 volts minus 3 minus 5 minus 6 I D. So, this way, if this current increases then this will reduced, that means, it will make gate source voltage more negative.

And hence this will take the corrective measures. So, whatever are the reasons for the variations, they will be taken here, if for some reasons the parameters fall. So, that the drain current falls. If drain current falls, then this will be less negative and hence the drain current will stabilized will be fall. In the drain current will be checked by this voltage drop, because this voltage drop is a function of I D. And this voltage is the part of the input circuit, the gate source circuit, an hence self bias is very widely used here, last point that I G we have taken 0. So, the current flow through this R G, so R G is that x high voltage, above high voltage proof there is no current through it enhance, R G can be taken in the range of 50 kilo ohms to 100 kilo ohms. So, all the short comings, of the fixed bias or removed in the self bias, in this self bias circuit. And this is widely used with the junction field effect transistor and it can be used for the depletion MOSFET also, because there also the proper sign of the voltage required is this we will continue.