**Design of Power Electronic Converters**
**Professor Dr. Shabari Nath**
**Department of Electronics and Electrical Engineering**
**Indian Institute of Technology, Guwahati**
**Lecture 15**
**MOSFET Datasheets-I**

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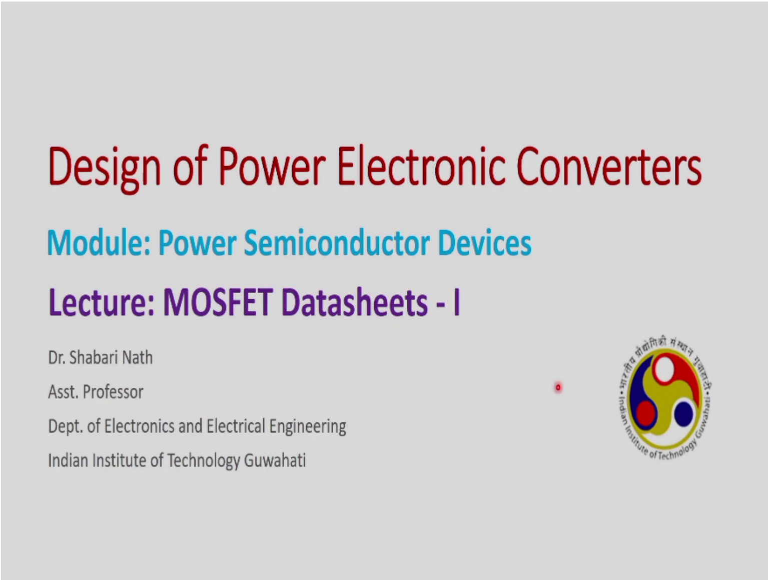


Welcome to the course on Design of Power Electronic Converters. In today's lecture, we will be discussing some of the terms that are given a data sheet of MOSFET. Prior to this, we have looked into some of the basics of MOSFETs and we have also looked into the switching characteristics of the MOSFET. So, now, when you want to design the MOSFET you have to read datasheets and what will be the important notations and performance curves that is what we are going to look now.

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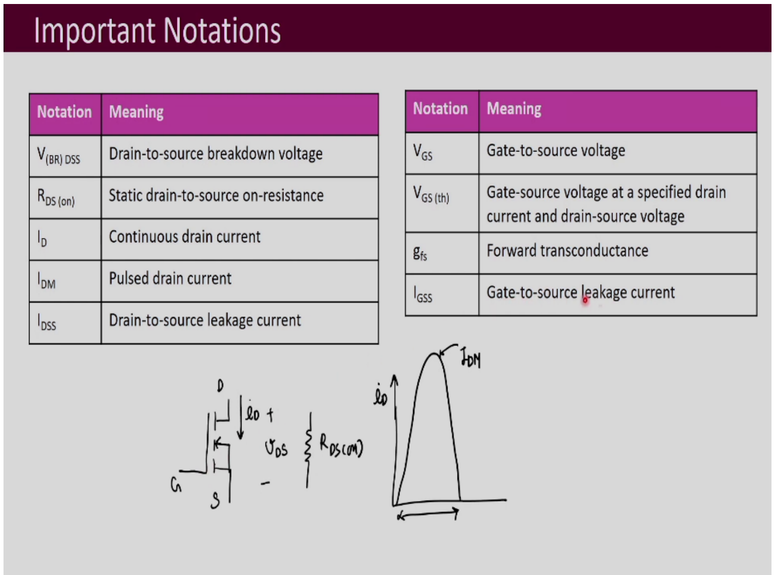


So, to explain it, let me draw the MOSFET first. So, this is your drain current $i_D$, this is drain, source and gate and then you have the drain to source voltage $V_{DS}$. So, the important notations that will be there in datasheet is the drain to source breakdown voltage, this is the maximum voltage the MOSFET can block across it.

Then, another important one is $R_{DS(on)}$ the static drain to source on resistance. So, that is whatever is the resistance associated with the MOSFET while it is conducting. Then the continuous drain current $i_D$ whatever is the continuously means DC current that can pass through it continuously that is the maximum current that will be specified. Then pulsed drain current this we had discussed before when we were discussing diodes also that it is possible that this kind of pulses may be given to the MOSFET for some short time period.

So, if it is given for some short time period then this, whatever is this peak of it, you call it is $I_{DM}$ that will be much higher than this continuous drain current. So, that also will be specified in the MOSFET data sheets, then drain to source leakage current, that means, when this device gets turned off, there will be some small leakage current that will be flowing through. Ideally we assume that no current will be flowing, but there may be a small leakage current that will be flowing. So, that is a drain to source leakage current.

Then the maximum gate to source voltage that can be applied over here. Then the threshold voltage between gate to source this is the minimum voltage that is required for the MOSFET to turn-on. So, that threshold voltage will be specified then forward transconductance $g_{fs}$ we had seen these characteristics before.

And that slope $g_{fs}$, forward transconductance will also be given and there may be some leakage current associated with this gate to source also. So, what happens is that when it turns-on at that time during the turn-on process, there is a gate current. And while it turns-off then also there is some current, while it is conducting, while the MOSFET is conducting or while it is off during that period, we expect no current to be flowing in this gate region, but there is a small current and that is the gate to source leakage current.

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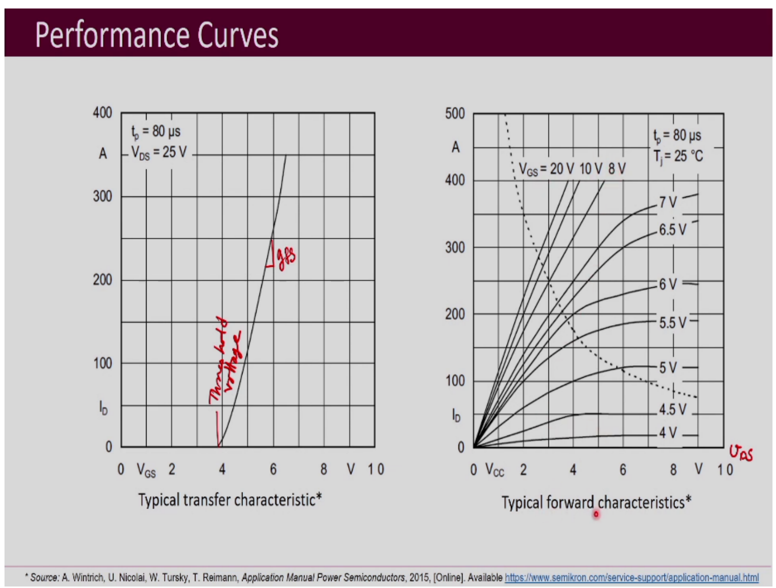


Then next, these performance curves will also be provided in the datasheet. The order, this transfer characteristics we just saw the $g_{fs}$. So, this slope will be $g_{fs}$ and this is threshold voltage. So, this is the curve between drain current $i_D$ and gate to source voltage $V_{GS}$ and what you can see is that the threshold voltage is around 4 V.

So, above that voltage, when we apply the gate to source voltage that is when the drain current will start building up. These performance curves I have taken from application manual provided by Semikron, then this shows the typical forward characteristics of a MOSFET.

So, here this is the graph between drain current and drain to source voltage $V_{DS}$. So, this is drain to source voltage $V_{DS}$ and this is the drain current. And here what you observe is that as this gate to source voltages increases, these are all gate to source voltages. As they increase it slowly goes from cut off to Ohmic region and for it to go into the Ohmic region what you observe is that the gate to source voltage has to be above 8 V.

And here what you see is that gate to source voltage below 4 V, this MOSFET is in cut off, and that is what we expect from this graph as well. And as the voltage increases, it goes to active region first and then finally, it goes to Ohmic region as the gate to source voltage further increases.

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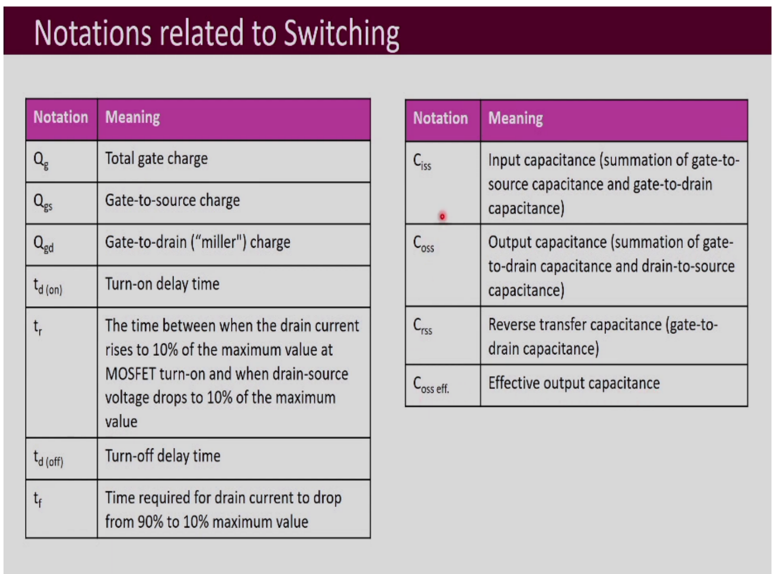

## Notations related to Switching

| Notation | Meaning |
|---|---|
| $Q_g$ | Total gate charge |
| $Q_{gs}$ | Gate-to-source charge |
| $Q_{gd}$ | Gate-to-drain ("miller") charge |
| $t_{d\,(on)}$ | Turn-on delay time |
| $t_r$ | The time between when the drain current rises to 10% of the maximum value at MOSFET turn-on and when drain-source voltage drops to 10% of the maximum value |
| $t_{d\,(off)}$ | Turn-off delay time |
| $t_f$ | Time required for drain current to drop from 90% to 10% maximum value |

| Notation | Meaning |
|---|---|
| $C_{iss}$ | Input capacitance (summation of gate-to-source capacitance and gate-to-drain capacitance) |
| $C_{oss}$ | Output capacitance (summation of gate-to-drain capacitance and drain-to-source capacitance) |
| $C_{rss}$ | Reverse transfer capacitance (gate-to-drain capacitance) |
| $C_{oss\,eff.}$ | Effective output capacitance |

The notations related to switching will be provided in the datasheet this we have discussed before also, I just wanted to show you again for the sake of completeness that gate charge, gate to source charge, gate to drain Miller charge, turn-on delay rise time $t_r$, turn-off delays and $t_f$ fall times in the turn-off those will be provided in the datasheet. Then input capacitance $C_{iss}$ will be provided, output capacitance will be provided, reverse transfer capacitance, which is $C_{gd}$ that will be also provided in the datasheet. And this effective output capacitance.

Now, as I had told you before that this capacitance is variable with drain to source voltage. So, I mean, effective output capacitances are also given, for different conditions you will be seeing this output capacitances will be provided. And then sometimes datasheets also provide the effective output capacitance.

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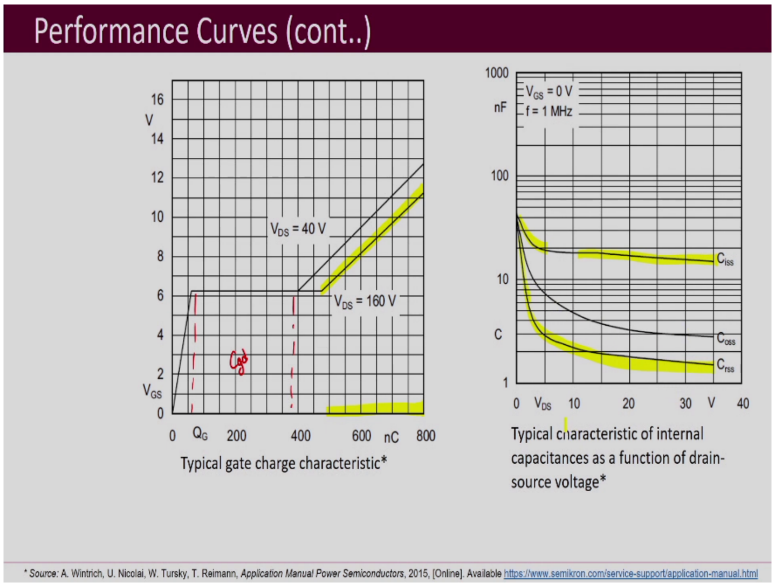


Then, another graph which you will find in the datasheets is this gate charge characteristics how $Q_G$ varies with $V_{GS}$. So, this nature we had observed in switching characteristics for $V_{GS}$. So, what happens is initially this increases and it has to cross this threshold voltage which was around 4 V. And then it has to reach to the Miller voltage, which is around 6 V for the MOSFET for which this graph is shown. And then during this time is Miller period and this Miller period, how much it is, it slightly varies with what is the drain to source voltage that is applied.

So, as you can see that as this $V_{DS}$ drain to source voltage increases Miller period is also increasing and somewhere around here you have threshold voltage. And then this is how the $Q_G$ is increasing. So, in this region $Q_G$ you can observe it is increasing and gate to source voltage is also increasing further what happens is that the voltage does not increase.

But it is the charge which continues to increase and this is mainly associated with $Q_{GD}$, not $Q_{GD}$ actually, this part is associated with $C_{gd}$ or you can call it $Q_{GD}$ also if you want. And then over here what happens is that after the Miller period is over, the gate to source voltage increases further and it settles to finally whatever is the gate voltage that is provided by the driver.

And at that time also you can see that this $Q_G$ charge keeps on increasing. Then this is the graph for capacitance how these different capacitances, input capacitance, output capacitance and reverse transfer capacitances how they are going to vary with drain to source voltage $V_{DS}$. So, we can see here that input capacitance this is not varying a lot, the drop is less, but reverse transfer capacitance this is varying a lot as $V_{DS}$ increases and output capacitance also you can see that it is varying.

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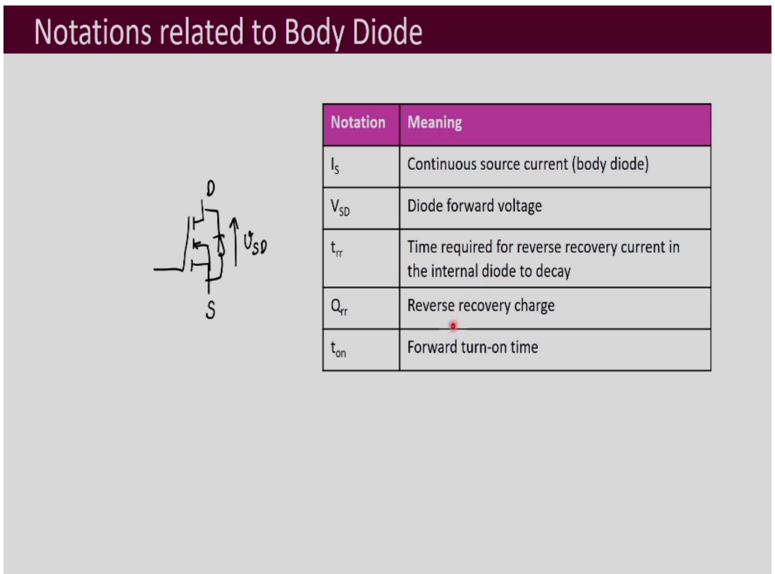


Then notations related to body diode in the datasheet what is the current rating of the body diode that will be provided, then diode forward voltage drop. So, when we have this MOSFET and then you have this anti parallel body diode. So, as this conducts it has a forward voltage drop and that is written as $V_{SD}$, because the current flows from source to drain when the diode conducts. Then $t_{rr}$, the reverse recovery time and reverse recovery charge $Q_{rr}$, and sometimes datasheet will also provide the reverse recovery current $I_{rr}$, and the turn-on time may also be provided.

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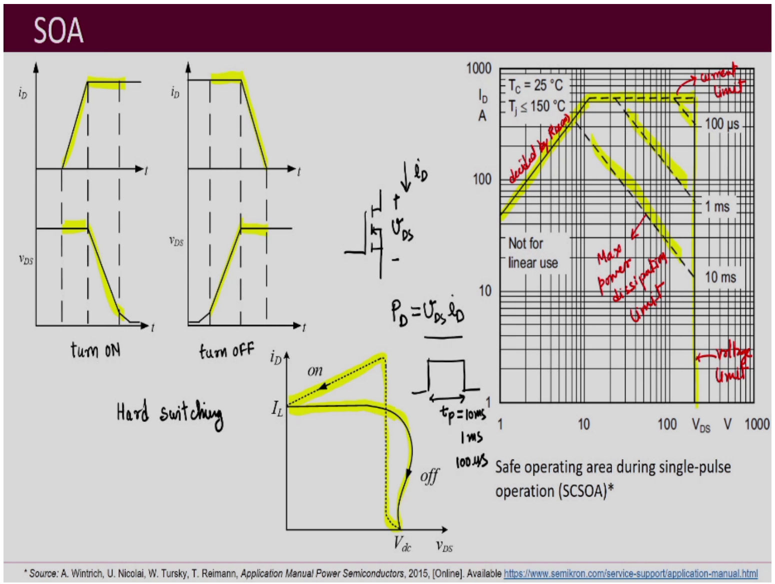


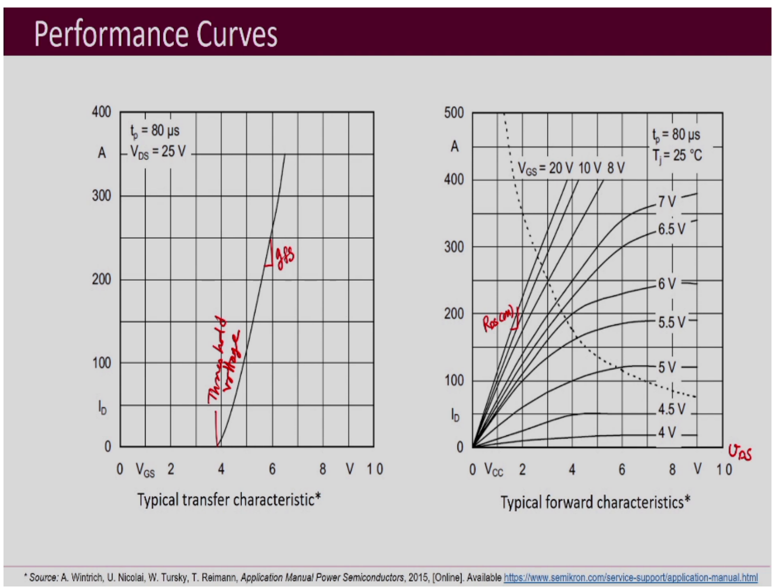


Now, we will be discussing another important graph that is given in the datasheet, which is called as safe operating area. So, before that let us recall the turn-on and turn-off characteristics that we have seen before. So, this is drain current and this is drain to source voltage.

And we had observed that, during these two intervals, both drain current and drain to source voltages are high together. So, this is for turn-on and this is for turn-off. Now, if we look into the trajectory, if we plot trajectory by plotting a graph between $i_D$ and $V_{DS}$, what we will be observing is that as it turns-on, what we see is that first the current increases.

So, here what we observe is that, as it is going to turn-on voltage remaining close to the blocking voltage, the current increases. So, this is how the current increases. And then after that the current has almost reached to what it is supposed to be carrying. While it is on this drain to source voltage decreases.

So, that is what we observe here, this current increases and it goes down and this drain to source voltage is going to decrease. And if we turn-off, what do we observe at that time, first the voltage increases and at that time the current does not increase much. So, that is what we see here, first this voltage is increasing and current does not decrease and here the current is going to decrease and voltage is almost same at that time. So, this is where this current is going to decrease.

So, what we observe is that this is stressing under an area and the limits have to be also within an area for safe operation, then we can ensure that the device is not getting damaged. So that is represented by this SOA safe operating area.

So, here what you see that this is a graph between $i_D$ drain current and $V_{DS}$ and this graph basically shows the limits of operation. So, first of all what you see when this drain to source voltage is small at that time this $i_D$ is going to increase, the $i_D$ limit is increasing. And this actually is coming from this forward characteristic that you have seen.

So, here what you see that when it is in the Ohmic region at that time this is governed by this slope and this slope is basically resistance $R_{DS(on)}$. So, that is what we are going to observe while the $V_{DS}$ voltage is small. So, it will be limited by the Ohmic characteristics. So, this part is basically decided by $R_{DS(on)}$ over here after that, what happens is that this one is current limit whatever is the maximum current that the device can carry. So, this is current limit.

And then this is voltage limit this line. Now, in between also we see these different, different lines and they are associated with this pulse times and what we observe is that as the pulse time decreases, this line the slope line this goes up. And what is the origin of this line, this actually is due to the maximum power dissipation limit. Now, we know that this MOSFET the maximum power dissipation will be governed by $P_D$, which is $V_{DS}$ multiplied by $i_D$.

So, this time this maximum power dissipation is going to be a fixed limit on it and the greater the pulse width is the smaller is the maximum power dissipation that can be allowed. So, if you say that this is pulse width $t_p$, which may be 10 ms here or 1 ms or 100 ms.

So, as pulse period increases the maximum power dissipation that is allowed is going to decrease and that is what we observe over here that as this pulse time is reducing maximum power dissipation limit is increasing. So, these are the various limits that you can observe in safe operating area and accordingly when we do this kind of switching and this type of switching is called as hard switching. So, when we are going to do this hard switching at that time you have to be careful whether you are under this SOA limits or not.

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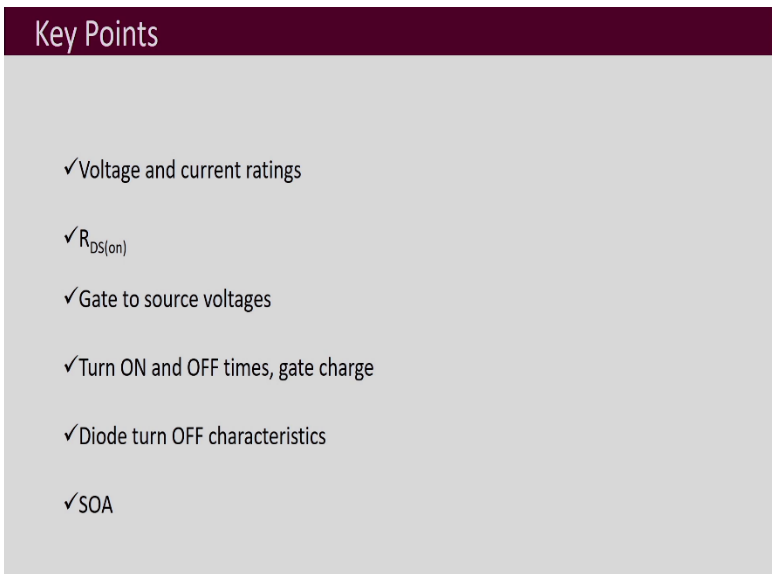


So, what are the key points of this lecture. That voltage and current ratings are the important ratings that will be provided in the datasheet then you should also be looking for $R_{DS(on)}$ value, then gate to source voltage what is the threshold voltage that also you should be looking for, then turn-on and turn-off times and associated gate charges in capacitances as well. Then diode turn-off characteristics is also something important to look for in the datasheet and SOA graph. Thank you.