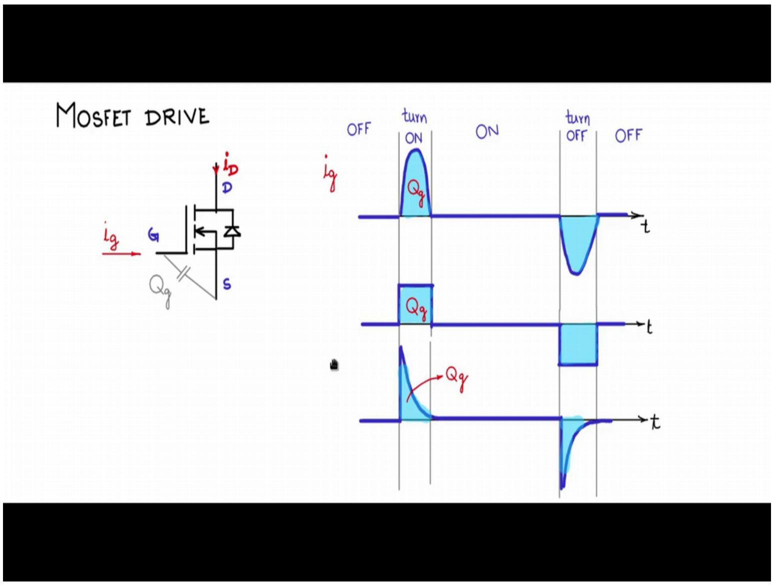
Fundamentals of Power Electronics
Prof. L. Umanand
Department of Electronics Systems Engineering
Indian Institute of Science, Bengaluru

Lecture – 86
MOSFET gate drive

(Refer Slide Time: 00:27)



MOSFET is a very popular semiconductor switch, especially for DC-DC converter we will discuss its drive. Let me draw the MOSFET symbol. So, this is called the gate and is called the drain the substrate and the source or connected. So, you have the drain source gate, there is a natural internal body diode, the arrow here pointing to the n channel inversion layer that will get formed. So, this is an n channel MOSFET.

The MOSFET is a high input impedance device meaning it takes a very very low gate current unlike the case of the BJT. So, the gate power requirement for the MOSFET is very low it is more a voltage control device has compared to the BJT which is at current control device. So, it is important that we give an amount of charge for the MOSFET as required by the data sheet of the MOSFET and if you give that amount of charge to the gate source then that will turn ON the device.

So, you can think of the current now the i D which is flowing through the drain current and then there is internally an equivalent capacitance gate source let us say and then you need to put a charge Q g into the gate source so that the device turns ON. So, imagine it in that fashion. So, let us look at the drive requirement.

So, let us say this is the time I will split it in 2 time zones, this is the OFF state of the MOSFET, this is the ON state of the MOSFET again the OFF state of the MOSFET there is an OFF to ON transition this called the turn ON period, there is a ON to OFF transition this is the turn OFF or the switch OFF period. So, during this time let us look at how the gate current i g looks like.

So, as I said this is a charge control device voltage or a voltage control device it is actually this charge that is important. So, therefore, we will see how the gate current looks like based on that argument of giving a specific amount of charge to turn ON the MOSFET.

So, during the OFF state no gate current is needed, so, that is 0. During the ON state also no gate current is needed in an ideal sense you need 0 gate current to maintain the switch in the ON state and therefore, also finally, in the OFF state 0 gate current. So, you see the gate current requirement how it looks like almost all 0 0 0. Now only difference comes in the turn ON period and the turn OFF period.

So, during the turn ON period you want to switch ON the MOSFET, you supply a specific amount of charge called Q g as defined in the data sheet for that specific MOSFET. After supply that charge the MOSFET will turn ON. So, let us say I will supply some a current with some profile like this, the area under that curve is the charge Q g.

Now if I supply this Q g amount of charge to this MOSFET then the MOSFET will turn ON the voltage across the MOSFET will be 0 and there is no charge or no current needed to maintain the MOSFET in the ON state. So, once turned ON it will remain ON that is why we say it is a high input impedance device.

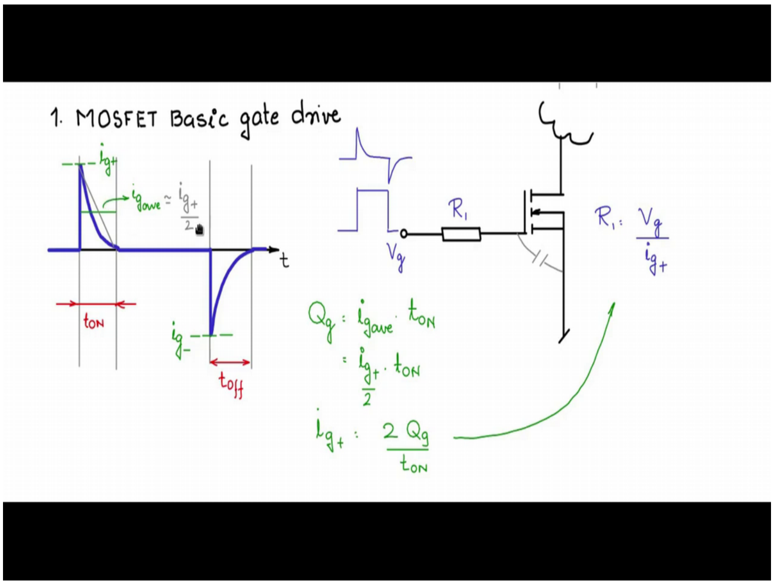
Till you want to turn it OFF, when you want to turn it OFF all you have to do is remove the charge that you have given to it while turning ON. So, whatever charge you are given remove that charge and you would have switched OFF the MOSFET. So, this is how the requirement for the gate current will look like. Now as it is a charge control device or a voltage control device, you are actually not so much interested in the shape of the current as long as I am able to give the required gate charge.

So, you can also give the gate currents in this fashion, a pulse gate current like this the area under that should be Q g. So, as long as I am giving Q g amount of charge the MOSFET will turn ON or instead of that I could give an RC an exponential decay like this as long as the area under this is Q g during on time 0. Then remove that amount of charge that you had supplied to turn it ON.

So, this is also fine as long as you are giving Q g amount of charge to turn it ON and remove Q g amount of charge to switch it OFF this is also valid. In fact, this is the type of current wave shape that we will see mostly because it is much easier to put an RC drive circuit rather than trying to achieve constant current in a constant current pulse drive circuit. So, this is this is typically the behaviour of the MOSFET the dynamic behaviour of the MOSFET.

You need to supply the MOSFET at the gate to source some fixed amount of charge Q g which will turn ON the device. If I am supplying this Q g in shorter time interval then it will turn ON faster, if I am supplying Q g over a longer time interval then the turn ON will be slower, likewise for turn OFF also.

(Refer Slide Time: 07:02)



Let us now see how the basic or the fundamental gate drive for the MOSFET looks like. It is very simple it consists of only one component that is one resistor. So, let us start from the requirements the gate drive requirements, I have this timeline I have split the timeline in to the OFF state the turn ON period the ON state turn OFF period OFF state.

So, we have just seen how the gate current looks like gate current is 0 during the OFF state and let us say you it raises and there is an exponential decay where it puts in pumps in a positive gate charge Q g in to the MOSFET gate turns ON the device and then after that you do not need any current to maintain the device in the ON state. Then when you want to turn it OFF you have to remote the remove the gate charge and then bring the device to the OFF state.

So, let us say this is i g plus and this is i g minus and the average of this in the turn ON period we can call that one as i g average and if I take a straight line approximation it is approximately equal to i g plus by 2. Let me call this period as t ON, let me call this period as t off. So, now, let us draw the gate drive circuit. So, you have the V g the gate pulse being given in this point then pass it through a resistor and connect it to the gate of the device.

The drain of the device is connected to the external load and it is the drain current that you want to switch ON and OFF and the source you connect it to the ground. There is an internal equivalent capacitance which is going to absorb the charge that you are going to pump in, we will call this V g and this is R 1. So, how to calculate R 1 very simple during the time when you want to turn it ON at the time of turn ON dynamics capacitor is a short.

So, the current that is going to flow through will be the full V c c by R 1 or V g by i g my i g plus. So, whatever this i g plus is decided then V g by i g plus is the value of R 1 and V g normally is the pulse amplitude which is V c c of the control gate drive. Now what is i g plus?

Now look at this drive requirement, you take this average the charge in this period to turn ON the device is Q g obtained from the data sheet and that is equal to i g average into t ON. t ON is the designer requirement how sooner how fast you want it to turn ON and during that period I should have given the complete Q g to the MOSFET.

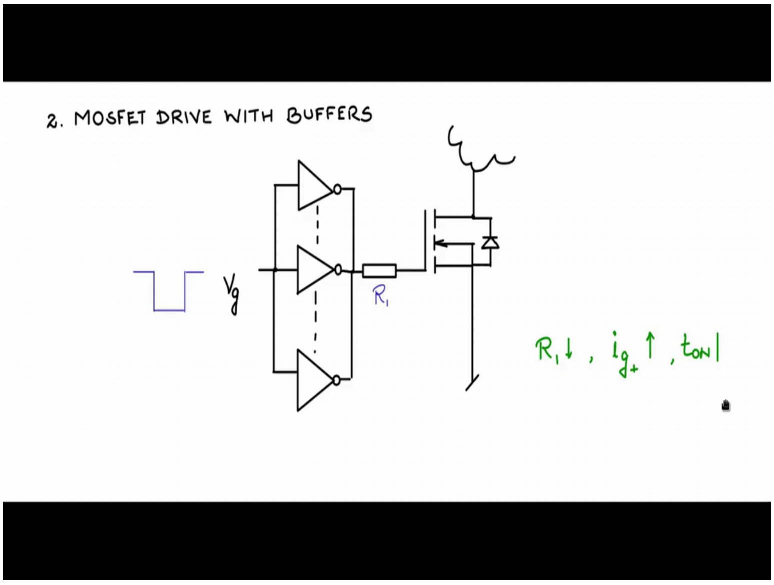
So, i g average into t ON will be Q g and i g average is approximately i g plus by 2 and therefore, i g plus is 2 Q g by t ON. So, this can be the value of i g plus you plug it in here and then you can get the value of R 1 V g you substitute V c c control power supply voltage. So, if you actually give a pulse like this, you can expect the current here gate current here to flow something like this in this like a differentiated value of this square pulse.

So, whenever you have a discontinuity here going from low to high you will get a positive current spike due to this RC. And this will decay as the capacitance here charges up to plus minus and then when you want to remove it bring this to ground, here you are making it 0 and the V g should have sinking capability there should be current being capable of flowing in a negative direction. So, whatever charge is there in the capacitance, internal capacitance will discharge through R 1 and the external V g circuit. So, therefore, you get this negative pulse and charge removal.

So, this way the MOSFET will be turned ON and OFF. Remember you need some charge to turn ON the MOSFET, you do not need charge to maintain the MOSFET in the ON state, you do not need charge and you to maintain you do not need a gate current to maintain. The MOSFET in the OFF state you need only current for turning ON and you need current to flow in the opposite direction for turning OFF.

And it is a charge control device, it is very very important to see that the area under this curve is equal to Q g as declared by the data sheet for that MOSFET; so, that MOSFET can turn ON. So, this is this simple basic building block gate drive for the MOSFET and all complex MOSFET gate drives are built using just this. So, this is a 1 resistor gate drive. Just like in the case of the BJT you had a 2 resistor gate drive as the basic gate drive in the case of the MOSFET a 1 resistor gate drive is the basic drive for the MOSFET.

(Refer Slide Time: 12:58)



Let us discuss another MOSFET drive gate drive with buffers CMOS buffers, this can improve the turn ON speeds and turn OFF speeds. Let us see the circuit I have the MOSFET here the drain is connected to the external circuit and the drain current is what you need to control switch ON and OFF. The source as usual is connected to the ground is a Gora ground based gate drive is an internal body diode and the gate is connected to the resistor the 1 resistor gate drive.

And now here you apply the gate drive pulse and the normal one drive 1 1 resistor gate drive. So, when you apply the gate drive pulse you have the charge being pumped into the gate and that MOSFET turns ON. But the turn ON time is decided by the amount of i g plus that can be drawn at that given instant of turn ON and that is dependent on this sourcing capability of the source.

If the sourcing capability of the source is low then even if you reduce over reduce its resistance the charge that will be pumped in to the gate will be over a period of time and therefore, turn ON time may be longer the turn ON may be slower.

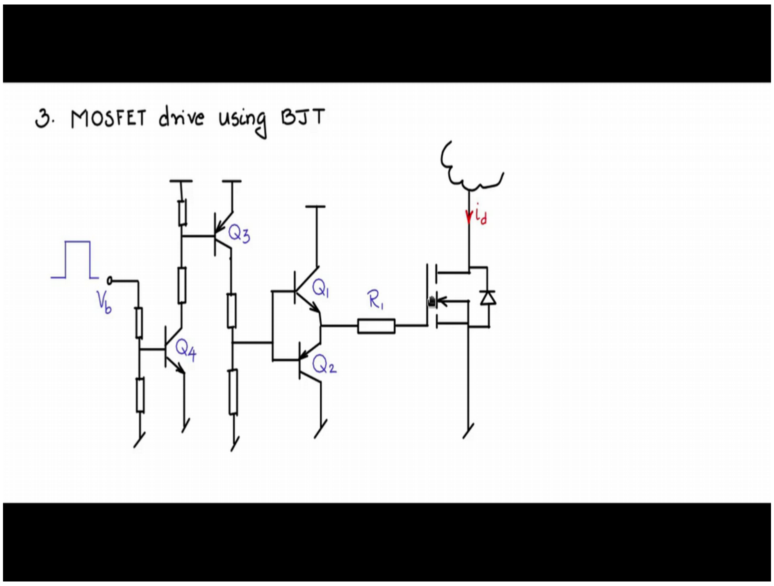
In order to speed this up we can use a buffer, I could use a non inverting buffer like this. Typical non inverting buffers like the CD CMOS buffers 4050 this a typical non inverting buffer which can sink 5 milliamps and source slightly more than 1 milliamp or you could use an inverting buffer like this CD 4049 and apply V g at the input.

So, when you apply an inverting V g pulse, you will see that when the pulse goes low the buffer output goes high and then pumps in the gate charge and turns ON the MOSFET. Now in order to improve the speed of turn ON you can put more buffers in parallel, if I erase there and then make some space. Let us say I put one more buffer here and then let us say one more buffer here connect them in parallel in this fashion.

In fact, I can put many more buffers in parallel. So, normally the CD 4040 4050 and 4049 series come with come as hex buffers. So, there will be 6 buffers in a pack and then you can connect all 6 of them in parallel and then you can effectively get close to 10 milliamp sourcing and then of you can get around 30 milliamp sinking capability.

So, the idea here is that now we enhance the sourcing capability of the input. So, therefore, by decreasing R 1 you will be increasing the i g plus value and therefore, more gate charge can be given in a given time or could say the same amount of gate charge can be given in a lesser amount of time and therefore, t ON can be reduced. This is evident by the equation that we saw here i g plus is 2 Q g by t ON. So, as i g plus increases t ON can reduce. So, in this way you can improve this speed of turn ON and turn OFF. So, this is one interesting speed up gate drive for the MOSFETs.

(Refer Slide Time: 17:20)



All BJT drive circuits can be used for MOSFET gate drive. Let us see an example I will draw the MOSFET, drain connected to the external load, source connected to the ground there is a body diode and we need to monitor i d and switch the drain current the gate drive is the 1 resistor R 1.

Now, the source for this gate is coming from the BJT drive circuit and you can adjust the sourcing and the sinking capability to whatever value of i g plus you would like to give to the gate drive of the MOSFET. So, therefore, with BJT drive circuits stage by stage you can enhance the i g plus value to get faster and faster turn ON and turn OFF speeds.

So, at this point let me put an NPN PNP combination totem pole directly across V c c and let me connect both the basis together and let me drive these basis with a 2 resistor base drive circuit which we are familiar with and the drive for this is coming from let us say a PNP stage the PNP stage gets its base drive from another 2 resistor drive stage which is driven by an NPN stage, which is driven by another 2 resistor drive stage.

So, you see like this stage by stage the current starts decreasing, the current here the i g plus whatever requirement here would be lesser here on the base by base side of this. On the base side of the PNP it will be still further lesser still further lesser here till at the source V b it can be of the order of micro amps to milliamps.

So, let us say we need to give a pulse in this fashion here. Let us say this is Q 1 R 1 Q 2 Q 3 Q 4, we have 4 transistors. So, whenever b V b is low there is no drive current flowing through this resistor path no base drive for Q 4; Q 4 is OFF and Q 4 is OFF there is no current in this path therefore, no base drive for Q 3 base therefore, Q 3 is OFF. Q 3 is OFF this is OFF no base drive current flowing through this path and no base current for this and Q 1 is OFF.

When Q 1 is OFF there is no drive current to charge up the gate of the MOSFET, so, the MOSFET is OFF. So, when V b is low MOSFET is OFF, i d is 0. Now when V b goes high there is a drive current flowing through this 4 times 2 times i b ON and i b ON flows through this and i b ON in to Q 4; Q 4 is ON. When Q 4 is ON there is an i b there is 2 i b ON flowing through this resistor corresponding to Q 3 base drive there is an i b ON here there is an i b ON here Q 3 is ON and Q 3 is ON there is a drive current flowing through this path into Q 1 and Q 1 is ON.

When Q 1 is ON V c c minus V c e sat appears here and it will drive a current through R 1 in to the gate source capacitance of the MOSFET and charge up the capacitance. So, Q g amount of charge will be pumped in and the MOSFET will turn ON. So, in this way the MOSFET will be switched ON and OFF. The value of i g plus can be controlled by having the number of stages. So, the more number of stages means I can have more amplification. So, let us say this particular at this particular point you have a 10 milliamp sourcing capability, it could become 100s of milliamps sourcing capability at this point it can increase by another factor of h f e sat here. So, you can get in terms of amps another factor by h f e sat you can get in terms of 10s of amps.

So, you can get really very high sourcing capability at this point when you are having multistage BJTs to amplify whatever the current here to a large value of i g plus. So, once i g plus is very large you can charge up you can give the gate charge for the gate capacitance of the MOSFET in a very short time.

So, the turn ON times can be really small likewise the turn OFF times can also be really small because you will be discharging through these high current devices. So, this is a high speed MOSFET gate drive circuit using BJTs.