Design of Power Electronic Converters
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Module: Gate Drivers
Lecture 25
Optocoupler Based Gate Drivers - II

Welcome back to the course on Design of Power Electronic Converters, we were discussing gate drivers and we had started with optocoupler based gate drivers. And last lecture, I told you about the important specifications that you should be looking for while choosing an optocoupler based gate driver IC.

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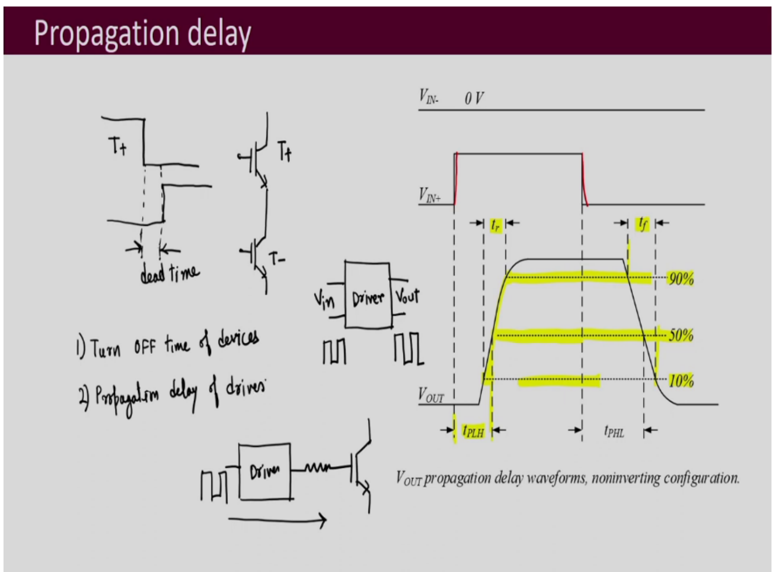

Now, continuing with that, one of the terms that our specification that is important for gate drivers is your propagation delay. So, let us see what is propagation delay. So, let us say you have this input voltage and the reference is the 0 voltage level which is explicitly shown here and you have your input voltage which goes from 0 to high. And then, so, this is shown as ideal that means, instantaneously it is becoming high but in practice there may be a little delay in that this may be little rise time maybe there and then may be little fall time maybe there but over here it is ignored.

So, when you have this driver IC. So, you have your input over here and then you have your output over here. So, the output signal it is usually non-inverting whatever we are giving here the similar nature of output is supposed to come on the other side on the secondary side so this is your driver in between.

So, what you will be having is your VOUT where what you see is that that there is a delay first as it is becoming high it does not become high immediately there is a delay and then after that there is a rise time. Now, how do we measure this rise time? This is generally measured by dividing the signal into three parts, one is 90 percent of the final level and 50 percent of the final voltage level and 10 percent of that final voltage level.

So, from 10 percent to your 90 percent whatever time it takes, that is your rise time tr of that signal. And similarly, the time it takes for to go from 90 percent to 10 percent that is taken as the fall time tf of that signal. And the delay the propagation delay is that when this input signal goes high from that point to the point at which this output signal becomes 50 percent of the output voltage level this is your propagation delay.

So, this delay is going to be there both on while it is becoming from low to high as well as when it is going to be coming from high to low. So, this is your propagation delay that is there and this is there in almost every IC that you are going to use, whether it is a driver IC or someone other IC, every circuit that you use has got some kind of a propagation delay.

Now, why are, why is it so important to be counted for in your gate driver IC. So, you may recall about the dead time I had discussed this before. So, let us say we have 1 leg of an H bridge. So, this is your T plus in this is your T minus. And we had discussed that your T plus let us say this is the signal. It goes from high to low and as it goes low that is a gap that is given which is called as the dead time after which this T minus goes high and this time is what we call as the dead time

Now, this dead time, how do you choose this dead time? How much it should not be? One is of course, that with the time it takes for these IGBTs to turn off and, why turn off not why not turn on? Because this also we had seen before turn offs are usually higher than your turn on types and they play more important role in the transitions in the circuit. And so, turn off time is what you should be checking for. So, turn off time of devices.

And the second important thing that you should be looking for while deciding your dead time is the propagation delay of the driver. And why is it important because you have this driver and then you have the gate resistor and then this gate pulse goes to the IGBT. Here is you have the PWM pulse that is coming out. So, it actually passes through the driver.

So, although your turn off times may be smaller let us say, then if you have chosen the driver where propagation delay is very high and you have decided your dead time based on your turn off times of the devices. So, that dead time will not be suitable it will not work it will create problems. Because turn off may be happening faster, but the signal the gate pulse will not reach till the driver operates, until the driver is able to transfer that signal to the output. So, that is why your propagation delay of the driver is what you should be looking into before you decide your dead time for your circuit.

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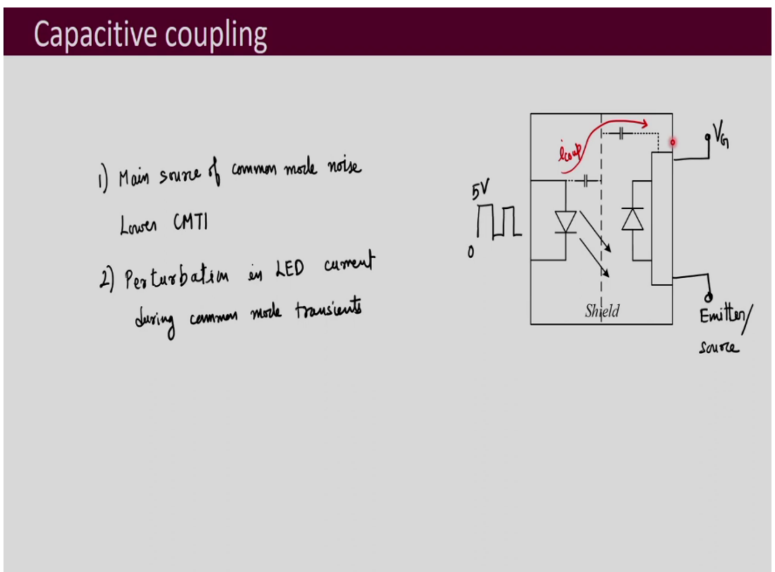

Next important specification is the capacitive coupling. So, between your input and output, usually there is a parasitic capacitance. Now, this capacitance between your input and output what happens is that it provides a path for the flow of current. Now, here on this side we may be giving a signal which is let us say from 0 to 5 volt and on the other side depending on these optocoupler based drivers, it may be connected to your whatever supply it may be VG and this other terminal may be connected to your emitter or the source of the IGBT or MOSFET.

And these levels are different what is the voltage level here as compared to what is the voltage level over here. So, there is different and moreover these are changing. So, as this transition takes place, suppose it is going from high to low voltage is changing here also it is changing and you have a capacitor in between so there is C dv by dt and so that is the current and that current is going to be flowing through this, this is your i coupling you can say that is going to flow and this current is undesirable.

Because first of all it is going to reduce the isolation level and second it leads to interference issues electromagnetic interference problems. It also reduces what is called as the common mode transient immunity. It is a source of noise and it is a problematic thing. So, we should have the capacitive coupling as small as possible.

Alright, now, how do people reduce it a your optocoupler based drivers say usually provide a shield it is called as a Faraday shield with that, to some extent this capacitive coupling is reduced although we cannot eliminate it 100 percent but it is reduced. And so, your this capacitive coupling as I told you, it is the main source of noise and this is called as what is called as the common mode noise, what is common mode and differential mode those things we will see on later on in the course

And this leads to lower what is called as the CMTI which will be just discussing now. And it leads to perturbation in LED current during common mode transients. Now, this perturbation in LED current is what if this LED current is getting perturbed. So, that will what will happen is that you will see some kind of abrupt functioning sometimes a driver all of a sudden it will shut down and then again it will start up.

So, this kind of mysterious phenomena that you may be observing while doing the experiment and you may wonder that why it is happening, you did everything right, your PWM pulses are correct, your driver circuit is as designed as it should be, but still you are seeing problems. So, all of a sudden the random effects suddenly shutting down suddenly turning on. So, that is because of this capacitive coupling and this perturbation in LED currents. So, that is why this capacitive coupling should be as low as possible.

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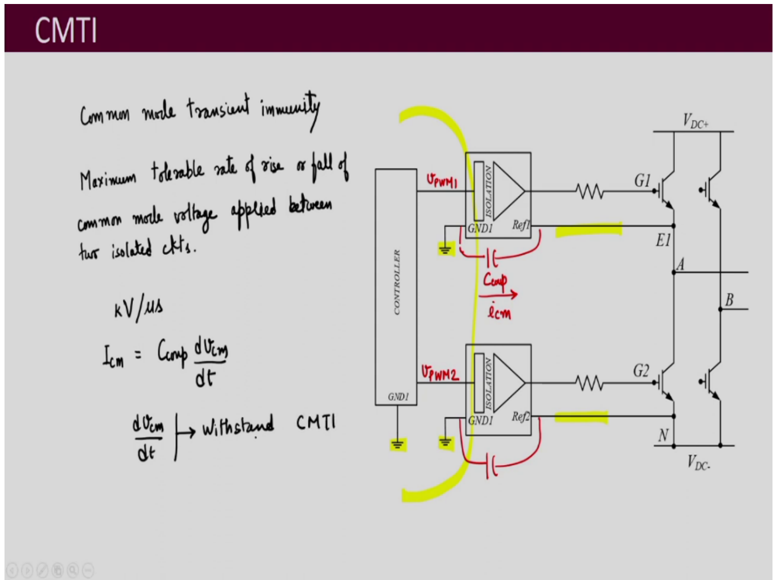

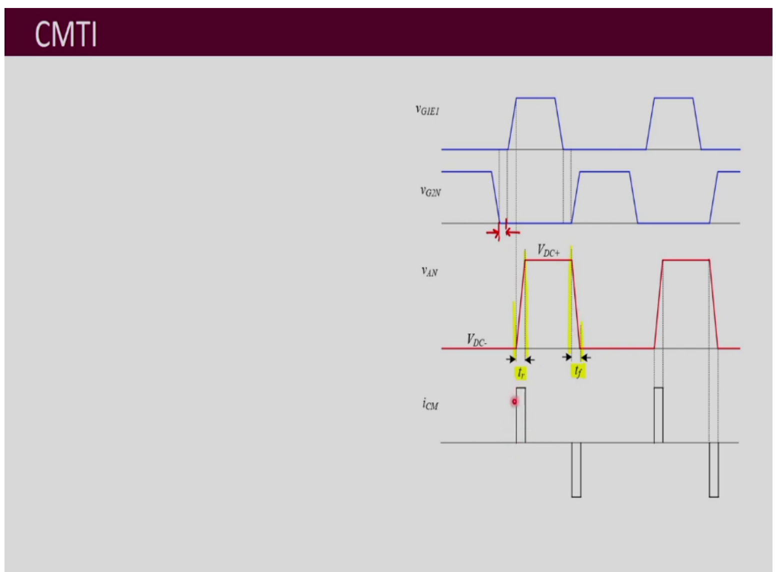

And so, related to that is next important specification of your gate drivers which is your CMTI. Now, this is called as the common mode transient immunity. So, let us understand what is common mode transient immunity. For that, I have taken this example of H bridge and then one leg of that. So, you have got these two transistors and then they are driven by this gate drivers.

So, here we have got these reference one which is your emitter one reference, then there is reference to which is your emitter two reference which is basically the N bus or the negative bus of the DC bus. Further over here on this input side we have the controller and this controller is going to give you vPWM1 and vPWM2 and these are with respect to this common reference which is ground 1 for all three of them.

So, this part of the circuit as you can see that has got the same ground. Whereas over here we have different grounds. Now, what will happen is that, you have your this capacitive coupling. So, let us draw this that is your capacitive coupling between your these two input side and output side and this can also have currents if these voltages are going to change and the levels are different. Because C dv by dt is the current.

So, they just look into the waveforms for that. So, first of all this is your vG1E1 is the gate pulse for the upper transistor, this is the gate pulse for the upper transistor whenever this is on then this is off, whenever this is on then this is off. Now, there will be some time between your this lower transistor turning off and the upper transistor turning on.

So, that and then over here we also have the dead time. So, this is our dead time. And then it takes some time for it to come down and it takes some time for it to reach to that upper level. So, whenever this is turning off and this is turning on at that time, what happens is that so this is on the voltage goes from minus VDC to plus VDC over here.

When this device was conducting this point potential A points potential with respect to N was minus VDC or 0 you can see that because this is the potential VDC minus and then you have this when this upper device turns on the potential over here, this gets connected to this bus, so, it becomes VDC plus.

So, that is what we see here after this upper transistor has turned on, this starts to increase and then we have a certain rise time because it is not going to turn on instantaneously it will not reach that it will take some time and it reaches to this VDC plus. So, this is your vAN voltage waveform how it will be appearing. It will be more or less following this vG1E1 and there will be certain rise time for the voltage to go from VDC minus to VDC plus and when it is coming down for it to come from VDC plus to VDC minus. So, this time is we are calling it as the rise time and the fall time between these two.

Now, in between that what we should observe here is that this E1 potential that means, this A potential over here is changing and this is fixed. So, this potential if it is changing as your waveform was changing, so, that will lead to certain levels of currents. So, this was your let us say Coup with it will be associated your current let us call it as the icm current common mode current, that will be there and that is that current which is plotted over here and it will be there only for the short time period of rise time tr and this fall time tf this is basically your C dv by dt current that flows through that coupling capacitor.

So, every transition in you A points voltage that means your emitter E1's point whenever this transition is happening, there will be this common mode current icm current that will be flowing. So, this current then comes to this when it is going to flow in between the output and the input of this high side driver.

So, it enters into this circuit also. So, that is where it creates the interference it is connected to the ground. So, that means, now it has entered this part of the circuit and so, it is going to be a problematic thing and not only that, this icm as I told you this will become also start disrupting the LED that may be there and it is going to disrupting the functioning of this gate driver.

For this lower side driver over here the current will not be there, because this N is fixed, this is not changing and this is also fixed. So, here, this current will not be there, but whatever is current is generated by this high side driver, that itself is a way is going to come here as well in this it can also disrupt the functioning of this low side driver.

So, now, the driver should be such that that each should be immune to this effect, this common mode effect and that is what is your common mode transient immunity. And the way we define it as common mode transient immunity as the maximum tolerable rate of rise or fall of common mode voltage applied between two isolated circuit and the way it is measured or you can say that it is denoted by is kV per microsecond.

$$I_{cm} = C_{coup}\frac{dv_{cm}}{dt}$$

$$CMTI = \frac{dv_{cm}}{dt}|withstand$$

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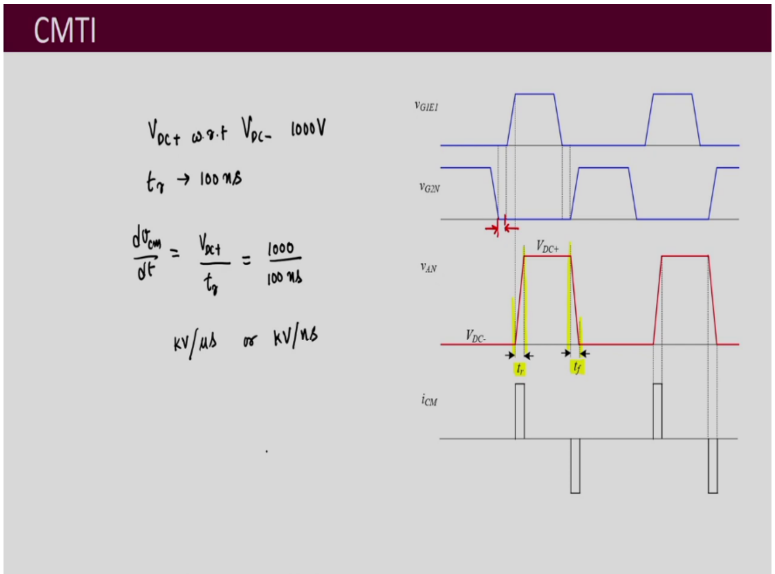

Now, for this case what we had taken let us say,

dvcm by dt, this is common mode voltage.

Then usually, this is expressed in terms of your kilo volt per microsecond or kilo volt per nanosecond is the way your CMTI levels are given in the data sheet and it should be as high as possible for the better operation of the drive.

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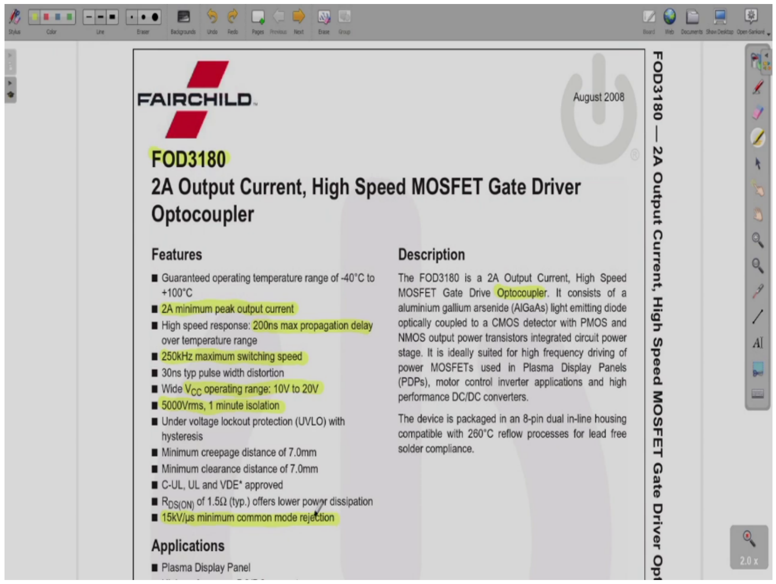

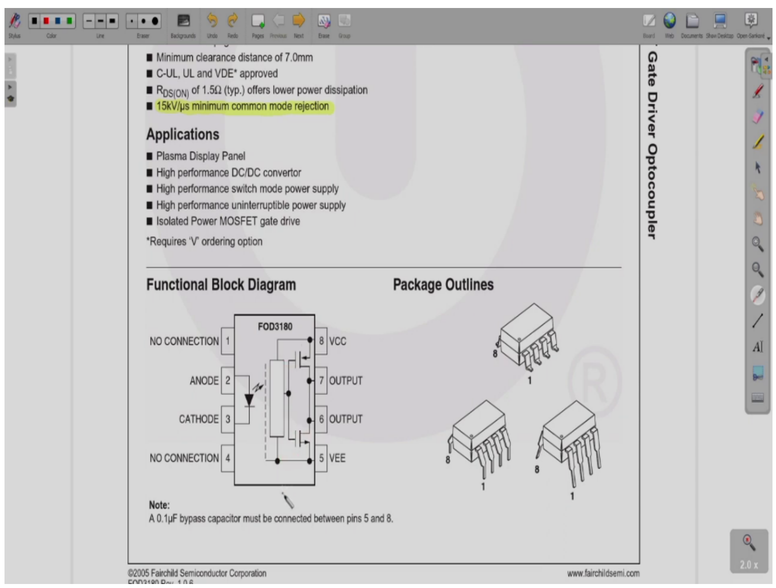

Now, let us are looking to the data sheet of an optocoupler based gate driver. So, I have chosen to show you this Fairchild semiconductors this driver FOD3180. This is an optocoupler based gate driver as you can see it is written. And what is the peak output current? It is your 2 ampere is the minimum peak output current.

So, I had told you that output current is a specification that you should be seeing. So, gate current it can provide is maximum up to your 2 ampere so, whatever IGBT or MOSFET that you will be choosing 2 ampere should be sufficient to drive it that is what you should check in your calculations.

Then the next important thing is propagation delay you can see here this is given 200 nanoseconds propagation delay, then 250 kilo hertz maximum switching speed so, you can use a switching frequency less than 250 kilo hertz if you want to use this gate driver. Then further other important is your VCC operating range 10 to 20 volts which is a wide enough range for your MOSFETs and IGBTs.

Then your isolation level is given as 5 kV. So, this is also important. Then other important thing is your common mode rejection and your CMTI which is given us 15 kilovolt per micro second. Then let us see further. So, applications will also be provided. So, this is the block diagram of this IC it shows that this uses optocoupler then it further uses some totem pole arrangement as well and in different packages it is available.

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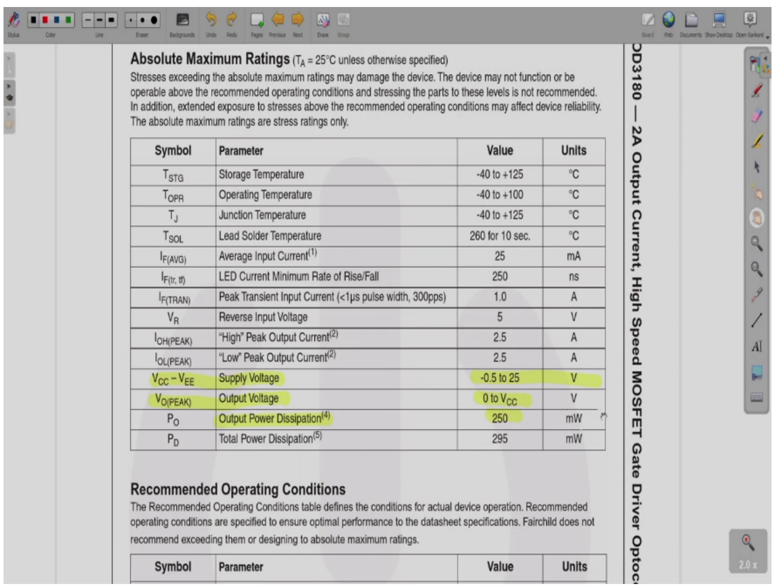


Absolute Maximum Ratings (T_A = 25°C unless otherwise specified)

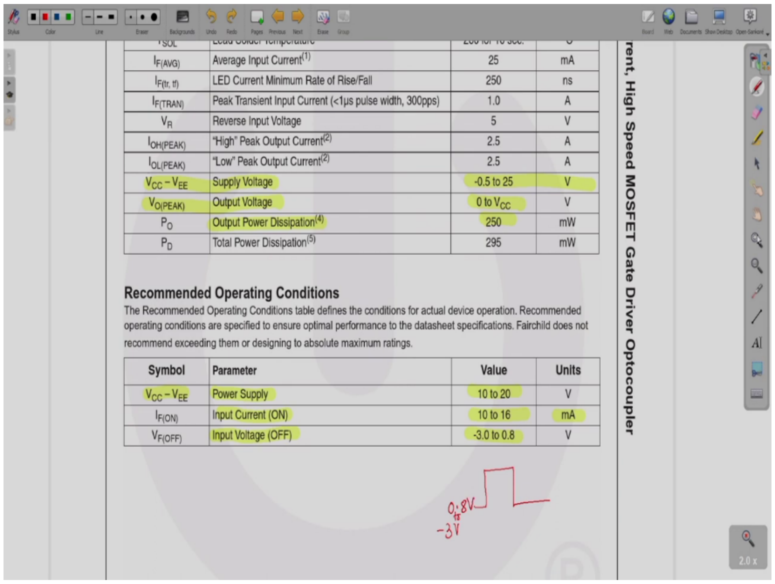
Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only.

Symbol	Parameter	Value	Units
T_{STG}	Storage Temperature	-40 to +125	°C
T_{OPR}	Operating Temperature	-40 to +100	°C
T_J	Junction Temperature	-40 to +125	°C
T_{SOL}	Lead Solder Temperature	260 for 10 sec.	°C
$I_{F(AVG)}$	Average Input Current(1)	25	mA
$I_{F(tr, tf)}$	LED Current Minimum Rate of Rise/Fall	250	ns
$I_{F(TRAN)}$	Peak Transient Input Current (<1μs pulse width, 300pps)	1.0	A
V_R	Reverse Input Voltage	5	V
$I_{OH(PEAK)}$	"High" Peak Output Current(2)	2.5	A
$I_{OL(PEAK)}$	"Low" Peak Output Current(2)	2.5	A
$V_{CC} - V_{EE}$	Supply Voltage	-0.5 to 25	V
$V_{O(PEAK)}$	Output Voltage	0 to V_{CC}	V
P_O	Output Power Dissipation(4)	250	mW
P_D	Total Power Dissipation(5)	295	mW

Recommended Operating Conditions

The Recommended Operating Conditions table defines the conditions for actual device operation. Recommended operating conditions are specified to ensure optimal performance to the datasheet specifications. Fairchild does not recommend exceeding them or designing to absolute maximum ratings.

Symbol	Parameter	Value	Units



$I_{F(AVG)}$	Average Input Current[1]	25	mA
$I_{F(tr, tf)}$	LED Current Minimum Rate of Rise/Fall	250	ns
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Symbol	Parameter	Value	Units
$V_{CC} - V_{EE}$	Power Supply	10 to 20	V
$I_{F(ON)}$	Input Current (ON)	10 to 16	mA
$V_{F(OFF)}$	Input Voltage (OFF)	-3.0 to 0.8	V

Further other maximum ratings are also given in tabular form, you can go through all of them. Most of it is self explanatory and the important ones for you to look one is your VCC VEE supply voltage that has to be below 25 volt and your output voltage is from 0 to VCC that means, whatever is the supply voltage that you apply maximum that much output you can obtain and output power dissipation this is giving as 250 milli watt.

So, this is a 250 milli watt is the loss that is going to happen. So, based on it you can see how much power loss or cooling requirement usually these do not require any other further cooling. Then next your this one this power supply voltage levels recommended is 10 to 20 volts then input current is in milli amperes and this is very important as I told you it should not load the your controller so, this is the input current which is low enough.

Then the input voltage what your controller I mean off state it is from 0.8 to minus 3 volt. So, what it means is that when you have this kind of a pulse coming up so, this can be the low one will be detected if it is between minus 3 volt to 0.8 volt. Because whatever controller you are using accordingly you can see whether the low what will be considered as low by the driver, the way it is designed.

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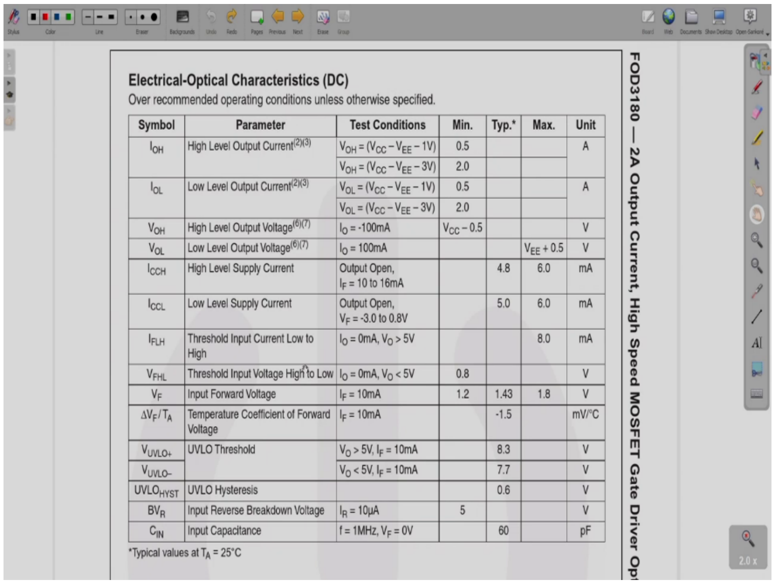

Electrical-Optical Characteristics (DC)

Over recommended operating conditions unless otherwise specified.

Symbol	Parameter	Test Conditions	Min.	Typ.*	Max.	Unit
I_{OH}	High Level Output Current(2)(3)	$V_{OH} = (V_{CC} - V_{EE} - 1V)$	0.5			A
		$V_{OH} = (V_{CC} - V_{EE} - 3V)$	2.0			
I_{OL}	Low Level Output Current(2)(3)	$V_{OL} = (V_{CC} - V_{EE} - 1V)$	0.5			A
		$V_{OL} = (V_{CC} - V_{EE} - 3V)$	2.0			
V_{OH}	High Level Output Voltage(6)(7)	I_O = -100mA	$V_{CC} - 0.5$			V
V_{OL}	Low Level Output Voltage(6)(7)	I_O = 100mA			$V_{EE} + 0.5$	V
I_{CCH}	High Level Supply Current	Output Open, I_F = 10 to 16mA		4.8	6.0	mA
I_{CCL}	Low Level Supply Current	Output Open, V_F = -3.0 to 0.8V		5.0	6.0	mA
I_{FLH}	Threshold Input Current Low to High	I_O = 0mA, V_O > 5V			8.0	mA
V_{FHL}	Threshold Input Voltage High to Low	I_O = 0mA, V_O < 5V	0.8			V
V_F	Input Forward Voltage	I_F = 10mA	1.2	1.43	1.8	V
$\Delta V_F/T_A$	Temperature Coefficient of Forward Voltage	I_F = 10mA		-1.5		mV/°C
V_{UVLO+}	UVLO Threshold	V_O > 5V, I_F = 10mA		8.3		V
V_{UVLO-}		V_O < 5V, I_F = 10mA		7.7		V
$UVLO_{HYST}$	UVLO Hysteresis			0.6		V
BV_R	Input Reverse Breakdown Voltage	I_R = 10μA	5			V
C_{IN}	Input Capacitance	f = 1MHz, V_F = 0V		60		pF

*Typical values at T_A = 25°C

FOD3180 — 2A Output Current, High Speed MOSFET Gate Driver Opt

Then apart from that many other specifications will be given high level of output current, low level of output current and voltages. So, there all these are mostly self explanatory or if you do not understand it, you should be able to get application notes from the manufacturer where you this terms meanings are given. And you should be reading all of these data sheets on your own by now and the important ones is your this capacitance here this input capacitance is given it is 60 picofarad.

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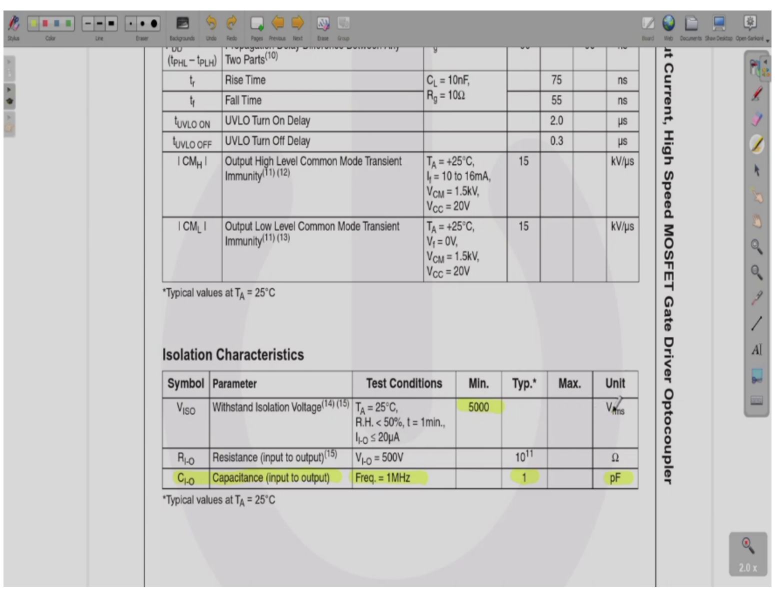

Symbol	Parameter	Test Conditions	Min.	Typ.*	Max.	Unit
($t_{PHL} - t_{PLH}$)	Two Parts(10)					
t_r	Rise Time	C_L = 10nF, R_g = 10Ω		75		ns
t_f	Fall Time			55		ns
$t_{UVLO\ ON}$	UVLO Turn On Delay			2.0		μs
$t_{UVLO\ OFF}$	UVLO Turn Off Delay			0.3		μs
$\lvert CM_H \rvert$	Output High Level Common Mode Transient Immunity(11) (12)	T_A = +25°C, I_f = 10 to 16mA, V_{CM} = 1.5kV, V_{CC} = 20V	15			kV/μs
$\lvert CM_L \rvert$	Output Low Level Common Mode Transient Immunity(11) (13)	T_A = +25°C, V_f = 0V, V_{CM} = 1.5kV, V_{CC} = 20V	15			kV/μs

*Typical values at T_A = 25°C

Isolation Characteristics

Symbol	Parameter	Test Conditions	Min.	Typ.*	Max.	Unit
V_{ISO}	Withstand Isolation Voltage(14) (15)	T_A = 25°C, R.H. < 50%, t = 1min., $I_{I-O} \leq 20\mu A$	5000			V_{rms}
R_{I-O}	Resistance (input to output)(15)	V_{I-O} = 500V		10^{11}		Ω
C_{I-O}	Capacitance (input to output)	Freq. = 1MHz		1		pF

*Typical values at T_A = 25°C

ut Current, High Speed MOSFET Gate Driver Optocoupler

Then for isolation characteristics your this input to output which is your basically your coupling capacitor which is given us 1 picofarad isolation voltage level this we have already seen its 1000 volts rms and resistance input to output is also provided in the isolation characteristics.

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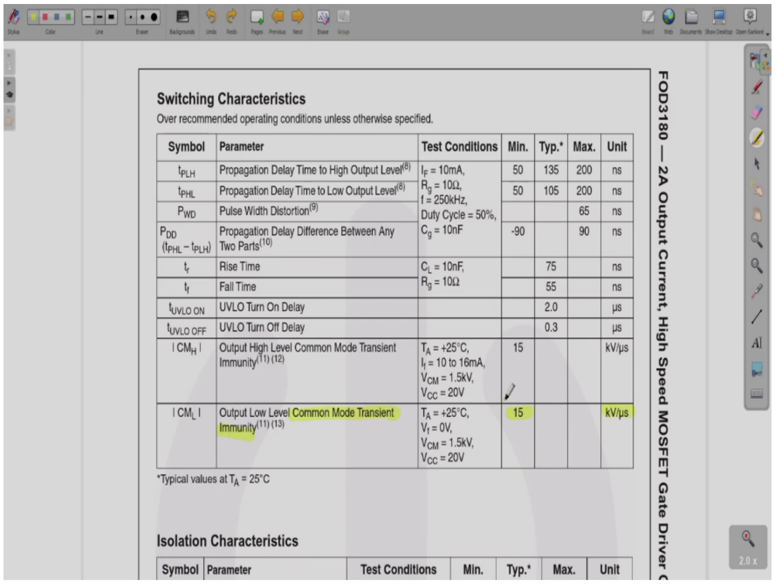

Switching Characteristics

Over recommended operating conditions unless otherwise specified.

Symbol	Parameter	Test Conditions	Min.	Typ.*	Max.	Unit
t_{PLH}	Propagation Delay Time to High Output Level(8)	I_F = 10mA, R_g = 10Ω, f = 250kHz, Duty Cycle = 50%, C_g = 10nF	50	135	200	ns
t_{PHL}	Propagation Delay Time to Low Output Level(8)		50	105	200	ns
P_{WD}	Pulse Width Distortion(9)				65	ns
P_{DD} ($t_{PHL} - t_{PLH}$)	Propagation Delay Difference Between Any Two Parts(10)		-90		90	ns
t_r	Rise Time	C_L = 10nF, R_g = 10Ω		75		ns
t_f	Fall Time			55		ns
$t_{UVLO\ ON}$	UVLO Turn On Delay			2.0		μs
$t_{UVLO\ OFF}$	UVLO Turn Off Delay			0.3		μs
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*Typical values at T_A = 25°C

Isolation Characteristics

Symbol	Parameter	Test Conditions	Min.	Typ.*	Max.	Unit

FOD3180 — 2A Output Current, High Speed MOSFET Gate Driver

And further your common mode transient immunity this is giving as 15 kV per microsecond this also we had seen before in the important specification the first page of the datasheet. So, those are further your given in more detail. So, there may be several other this kind of specifications that will be given in this optocoupler based gate driver IC's datasheet and you can go through them and you can read for yourself that what are the important things that you should be looking for.

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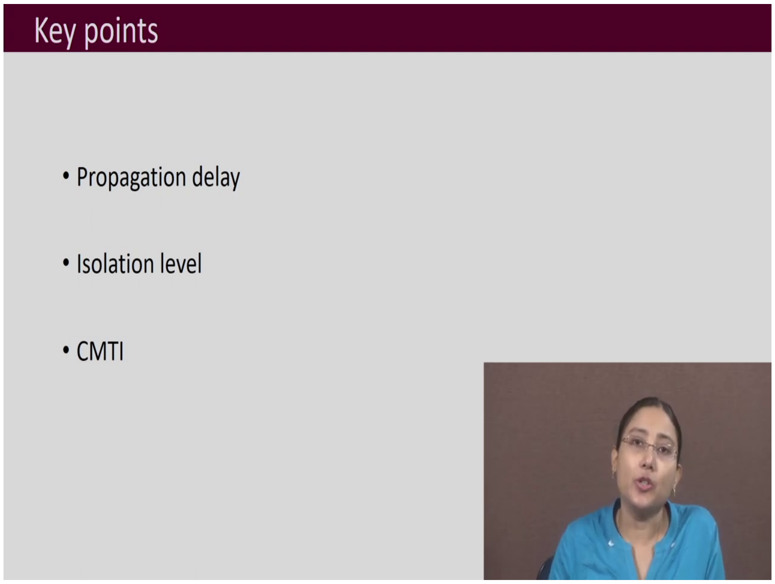

So, what are the key points of this lecture? So, propagation delay we discussed that is something important in the gate driver to note down. Then next was your isolation level your optocoupler based if it is optical isolation levels you should be checking for an associated with that as your capacitive coupling that also you should be checking that it should not be too high.

And with the capacitive coupling is also associated is your CMTI common mode transient immunity this level should be as high as possible. And this denotes how much your driver is going to be sensitive to noise or different transients, transitions that are going to happen in your power electronic circuit. Thank you.