Design of Power Electronic Converters
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Lecture 21
IGBT Datasheet Example

Welcome to the course on Design of Power Electronic Converters. So, we have been discussing IGBTs, we saw the basic terms of IGBTs, then we discussed the switching characteristics, then we further discussed the important notations and performance curves in data sheets.

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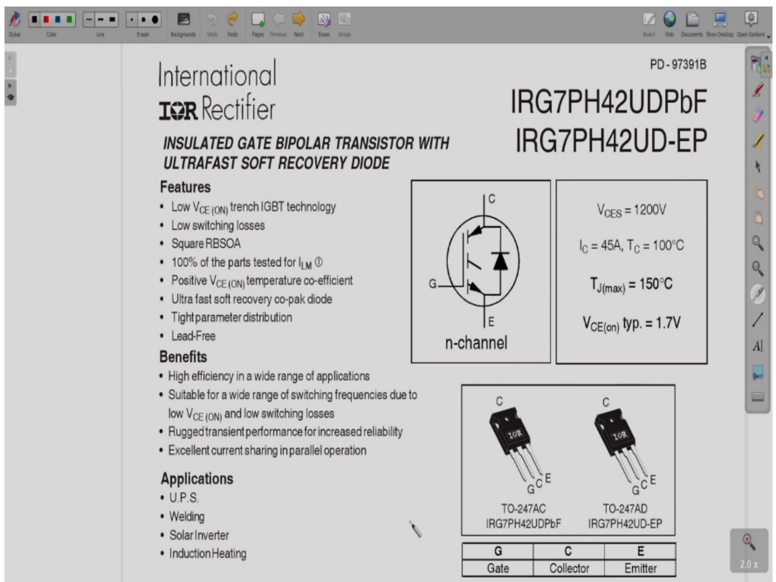

Now, let us take an example of an IGBT datasheet and let us look into what all things are provided. The datasheet I have chosen is by international rectifiers and this you can see here from the diagram itself that there is an anti-parallel diode provided in the IGBT. This is the picture of it, it uses this TO-247 package and you can see these three legs are the three terminals of the IGBTs and this is the part number of the IGBT.

And then you can see the key ratings it is a 1200 V devices so, it can block 1200 V. I_C continuous collector current rating is 45 A at 100^{0}C, maximum junction temperature is 150^{0}C, and typically this on-state voltage drop between collector and emitter is 1.7 V. And these are the key features of the IGBT that the manufacturer has given then what are the benefits and the different applications of the IGBT which are targeted by the manufacturer.

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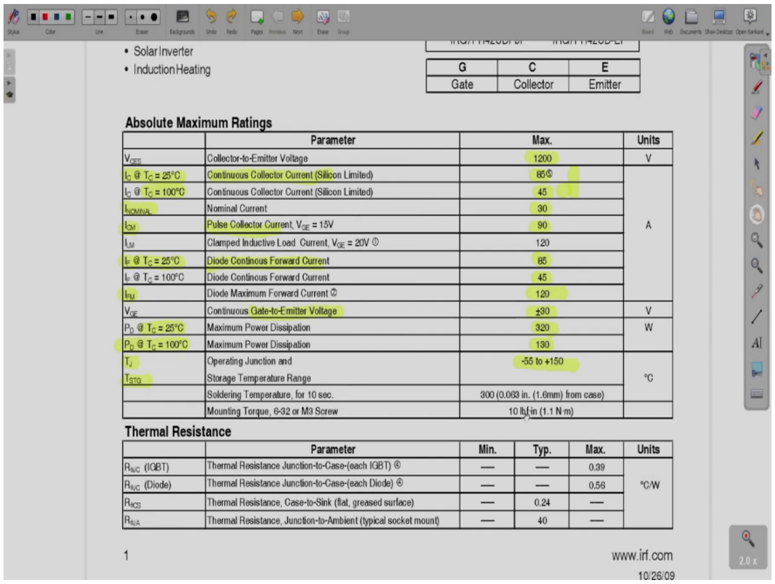
- Solar Inverter
- Induction Heating

G	C	E
Gate	Collector	Emitter

Absolute Maximum Ratings

	Parameter	Max.	Units
V_{CES}	Collector-to-Emitter Voltage	1200	V
I_C @ T_C = 25°C	Continuous Collector Current (Silicon Limited)	85⑤	A
I_C @ T_C = 100°C	Continuous Collector Current (Silicon Limited)	45	
$I_{NOMINAL}$	Nominal Current	30	
I_{CM}	Pulse Collector Current, V_{GE} = 15V	90	
I_{LM}	Clamped Inductive Load Current, V_{GE} = 20V ①	120	
I_F @ T_C = 25°C	Diode Continous Forward Current	85	
I_F @ T_C = 100°C	Diode Continous Forward Current	45	
I_{FM}	Diode Maximum Forward Current ②	120	
V_{GE}	Continuous Gate-to-Emitter Voltage	±30	V
P_D @ T_C = 25°C	Maximum Power Dissipation	320	W
P_D @ T_C = 100°C	Maximum Power Dissipation	130	
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +150	°C
	Soldering Temperature, for 10 sec.	300 (0.063 in. (1.6mm) from case)	
	Mounting Torque, 6-32 or M3 Screw	10 lbf·in (1.1 N·m)	

Thermal Resistance

	Parameter	Min.	Typ.	Max.	Units
$R_{θJC}$ (IGBT)	Thermal Resistance Junction-to-Case-(each IGBT) ④	—	—	0.39	°C/W
$R_{θJC}$ (Diode)	Thermal Resistance Junction-to-Case-(each Diode) ④	—	—	0.56	
$R_{θCS}$	Thermal Resistance, Case-to-Sink (flat, greased surface)	—	0.24	—	
$R_{θJA}$	Thermal Resistance, Junction-to-Ambient (typical socket mount)	—	40	—	

1 www.irf.com

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Then further these are continuous collector current I_C at 25^0C, you can see that it is 85 A, at 100^0C, the same I_C goes down to 45 A. Then the collector to emitter voltage this we have already seen is 1200 V, then nominal current this I had discussed with you this is given as 30 A.

Then the pulsating current rating maximum pulse current that you can see is 90 A much higher than this 45 A rating. Further important ratings that are given is I_F the forward current rating of the diode, diode continuous forward current is given as 85 A at 25^0C and 45 A at 100^0C. So, this matches with these two specifications what the IGBT can carry.

Then gate to emitter voltage. So, maximum that is allowed is this ±30 V. Then this pulsating diode current, what the diode can carry is given as 120 A. Then these are the maximum power dissipation limits at 25^0C and 100^0C. So, those are provided. Then junction temperature and storage temperature range that is also given and here the mounting torque and soldiering temperature those things are also provided by the manufacturer.

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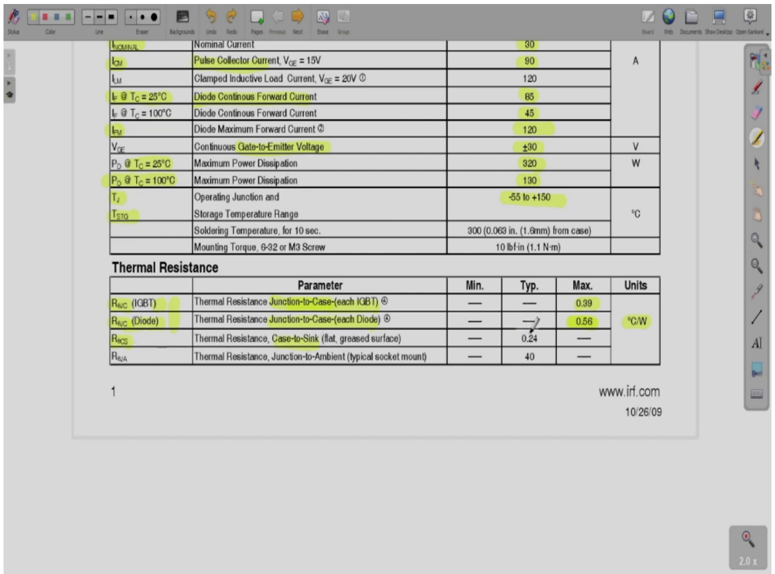

$I_{NOMINAL}$	Nominal Current	30	A
I_{CM}	Pulse Collector Current, V_{GE} = 15V	90	
I_{LM}	Clamped Inductive Load Current, V_{GE} = 20V ①	120	
I_F @ T_C = 25°C	Diode Continous Forward Current	85	
I_F @ T_C = 100°C	Diode Continous Forward Current	45	
I_{FM}	Diode Maximum Forward Current ②	120	
V_{GE}	Continuous Gate-to-Emitter Voltage	±30	V
P_D @ T_C = 25°C	Maximum Power Dissipation	320	W
P_D @ T_C = 100°C	Maximum Power Dissipation	130	
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +150	°C
	Soldering Temperature, for 10 sec.	300 (0.063 in. (1.6mm) from case)	
	Mounting Torque, 6-32 or M3 Screw	10 lbf·in (1.1 N·m)	

Thermal Resistance

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$R_{\theta JC}$ (Diode)	Thermal Resistance Junction-to-Case-(each Diode) ④	—	—	0.56	
$R_{\theta CS}$	Thermal Resistance, Case-to-Sink (flat, greased surface)	—	0.24	—	
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient (typical socket mount)	—	40	—	

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Then further these are thermal resistances. So, $R_{\theta JC}$ junction to case this is given and here this is given in ^{0}C/W and for the diode also because here the IGBT is also there and diode is also there. So, junction to case for IGBT and junction to case for diode are going to be different here. So, that is also provided, you can see here for diode it is higher and then case to sink because all of these IGBT and diode these are inside one case, so case to sink is going to be only one so, that is also provided the junction to ambient that is also given over here.

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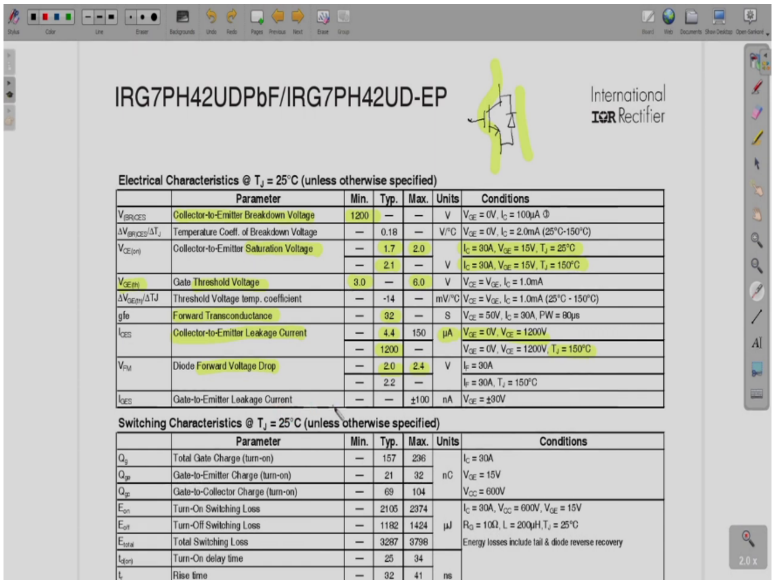
IRG7PH42UDPbF/IRG7PH42UD-EP

International IOR Rectifier

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)CES}$	Collector-to-Emitter Breakdown Voltage	1200	—	—	V	V_{GE} = 0V, I_C = 100μA ③
$\Delta V_{(BR)CES}/\Delta T_J$	Temperature Coeff. of Breakdown Voltage	—	0.18	—	V/°C	V_{GE} = 0V, I_C = 2.0mA (25°C-150°C)
$V_{CE(on)}$	Collector-to-Emitter Saturation Voltage	—	1.7	2.0	V	I_C = 30A, V_{GE} = 15V, T_J = 25°C
		—	2.1	—		I_C = 30A, V_{GE} = 15V, T_J = 150°C
$V_{GE(th)}$	Gate Threshold Voltage	3.0	—	6.0	V	V_{CE} = V_{GE}, I_C = 1.0mA
$\Delta V_{GE(th)}/\Delta TJ$	Threshold Voltage temp. coefficient	—	-14	—	mV/°C	V_{CE} = V_{GE}, I_C = 1.0mA (25°C - 150°C)
gfe	Forward Transconductance	—	32	—	S	V_{CE} = 50V, I_C = 30A, PW = 80μs
I_{CES}	Collector-to-Emitter Leakage Current	—	4.4	150	μA	V_{GE} = 0V, V_{CE} = 1200V
		—	1200	—		V_{GE} = 0V, V_{CE} = 1200V, T_J = 150°C
V_{FM}	Diode Forward Voltage Drop	—	2.0	2.4	V	I_F = 30A
		—	2.2	—		I_F = 30A, T_J = 150°C
I_{GES}	Gate-to-Emitter Leakage Current	—	—	±100	nA	V_{GE} = ±30V

Switching Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
Q_g	Total Gate Charge (turn-on)	—	157	236	nC	I_C = 30A
Q_{ge}	Gate-to-Emitter Charge (turn-on)	—	21	32		V_{GE} = 15V
Q_{gc}	Gate-to-Collector Charge (turn-on)	—	69	104		V_{CC} = 600V
E_{on}	Turn-On Switching Loss	—	2105	2374	μJ	I_C = 30A, V_{CC} = 600V, V_{GE} = 15V
E_{off}	Turn-Off Switching Loss	—	1182	1424		R_G = 10Ω, L = 200μH, T_J = 25°C
E_{total}	Total Switching Loss	—	3287	3798		Energy losses include tail & diode reverse recovery
$t_{d(on)}$	Turn-On delay time	—	25	34		
t_r	Rise time	—	32	41	ns	

Then breakdown voltage, this 1200 V we have seen before. Then saturation voltage you can see typical is 1.7 and maximum is 2 V and at what conditions they have made these measurements, they are also given, so they change with these conditions, then what is the gate to emitter threshold voltage. So, that minimum is 3 V and maximum is 6 V.

Further forward transconductance that is also provided and collector to emitter leakage current you can see is given in µA and the conditions are also provided here and they vary significantly with conditions. If this junction temperature goes to 150^0C, you can see that over here there is a significant increase in the leakage current.

Then, further you see this diode forward voltage drop, what is the typical and what is the maximum? Now you can compare this with over here what you are getting. So, here 2.1 is what you get at 150^0C and here this you get 2.2. So, this diode voltage drop what you can see is greater. So, whenever the diode is going to conduct the drop will be higher because depending on the direction of the current, it is either IGBT or the diode will be conducting.

So, this is IGBT. So, now, if the direction of the current is downward, so, this IGBT is going to conduct and if it is upward it is the diode which is going to conduct. So, which one conducts that decides whether this voltage drop is going to appear or this voltage drop is going to appear. Then gate to emitter leakage current that also is provided by the manufacturer.

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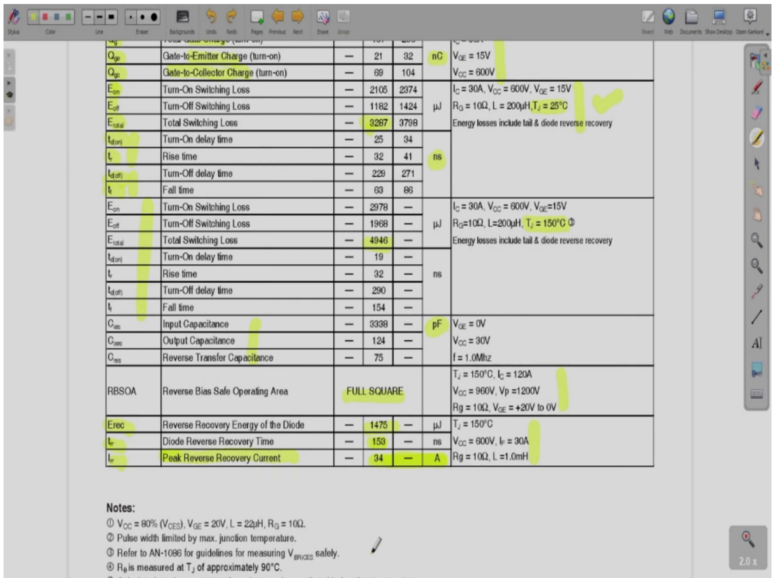

Q_{ge}	Gate-to-Emitter Charge (turn-on)	—	21	32	nC	V_{GE} = 15V
Q_{gc}	Gate-to-Collector Charge (turn-on)	—	69	104		V_{CC} = 600V
E_{on}	Turn-On Switching Loss	—	2105	2374		I_C = 30A, V_{CC} = 600V, V_{GE} = 15V
E_{off}	Turn-Off Switching Loss	—	1182	1424	µJ	R_G = 10Ω, L = 200µH, T_J = 25°C
E_{total}	Total Switching Loss	—	3287	3798		Energy losses include tail & diode reverse recovery
$t_{d(on)}$	Turn-On delay time	—	25	34		
t_r	Rise time	—	32	41	ns	
$t_{d(off)}$	Turn-Off delay time	—	229	271		
t_f	Fall time	—	63	86		
E_{on}	Turn-On Switching Loss	—	2978	—		I_C = 30A, V_{CC} = 600V, V_{GE}=15V
E_{off}	Turn-Off Switching Loss	—	1968	—	µJ	R_G=10Ω, L=200µH, T_J = 150°C ③
E_{total}	Total Switching Loss	—	4946	—		Energy losses include tail & diode reverse recovery
$t_{d(on)}$	Turn-On delay time	—	19	—		
t_r	Rise time	—	32	—	ns	
$t_{d(off)}$	Turn-Off delay time	—	290	—		
t_f	Fall time	—	154	—		
C_{ies}	Input Capacitance	—	3338	—	pF	V_{GE} = 0V
C_{oes}	Output Capacitance	—	124	—		V_{CC} = 30V
C_{res}	Reverse Transfer Capacitance	—	75	—		f = 1.0Mhz
RBSOA	Reverse Bias Safe Operating Area	FULL SQUARE				T_J = 150°C, I_C = 120A V_{CC} = 960V, Vp =1200V Rg = 10Ω, V_{GE} = +20V to 0V
Erec	Reverse Recovery Energy of the Diode	—	1475	—	µJ	T_J = 150°C
t_{rr}	Diode Reverse Recovery Time	—	153	—	ns	V_{CC} = 600V, I_F = 30A
I_{rr}	Peak Reverse Recovery Current	—	34	—	A	Rg = 10Ω, L =1.0mH

Notes:
① V_{CC} = 80% (V_{CES}), V_{GE} = 20V, L = 22µH, R_G = 10Ω.
② Pulse width limited by max. junction temperature.
③ Refer to AN-1086 for guidelines for measuring $V_{(BR)CES}$ safely.
④ R_θ is measured at T_J of approximately 90°C.

Further switching characteristics. So, Q_g, the total gate charge and gate to emitter charge and gate to collector charge those are given these are given in nC and the conditions are also mentioned here then turn on loss, turn off loss and the total switching loss these are also provided and the conditions also you can see here are also given over here. Then turn on delay times, turn off delay times, rise times and fall time. So, basically turn on times and turn off times in ns these are also provided and this is also for this condition only.

You see here these again these things are provided by the manufacturer again turn on turn off loss and turn on and turn off times these are given, but the set of conditions they change over here what you observe is that these conditions are remaining same, but here this the junction temperature is 25^0C but here the junction temperature becomes 150^0C.

So, based on it you can see here that the times are becoming different. All these turn on turn off times and losses are also becoming different. Here you can see these total switching losses 4946 µJ whereas here it is 3287 µJ. So, total loss increased with junction temperature.

Further input capacitances, output capacitances and reverse transfer capacitances they are also provided and it is given in pF. Then this RBSOA, this is defined here that this is full square. Now, it may not be full square for all of the IGBTs there is something called as because of the intrinsic nature or the how the device is designed. There may be a sloppy line there in the RBSOA. So, here for this IGBTs is not true. So, this is a full square.

And they have also given the conditions from over here, then reverse recovery energy of the diode that is also provided. So, these are basically diode turn off characteristics, energy associated during the turn off, then reverse recovery time, reverse recovery current these are all provided. Now you can see that the peak reverse recovery current it can go up to 34 A. This is very significant value and the conditions of measurements are given over here.

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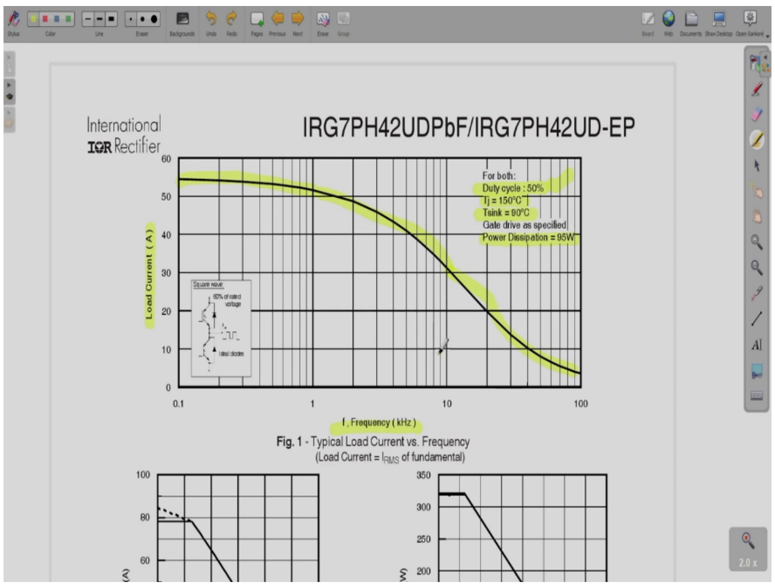

Further, this data sheet gives you some performance curves. So, you can see here that this is the load current versus frequency. So, this is for which they provided this square wave to these ones and then they had provided an inductive load and then they saw what could be the load current. And as you see here that below 1 kHz, this load current can be quite high after that as switching frequency increases, you can see here that this load current it is going to decrease and the power dissipation they have limited to 95 W, junction temperature they are maintaining it at 150^0C, heatsink temperature at 90^0C and the duty cycle given was 50%. So, this is just to give an idea that what switching frequency you could be choosing for application. Of course, you may not be having always this 50% duty ratio. So, based on this condition, this is what the curve that is provided by the manufacturer.

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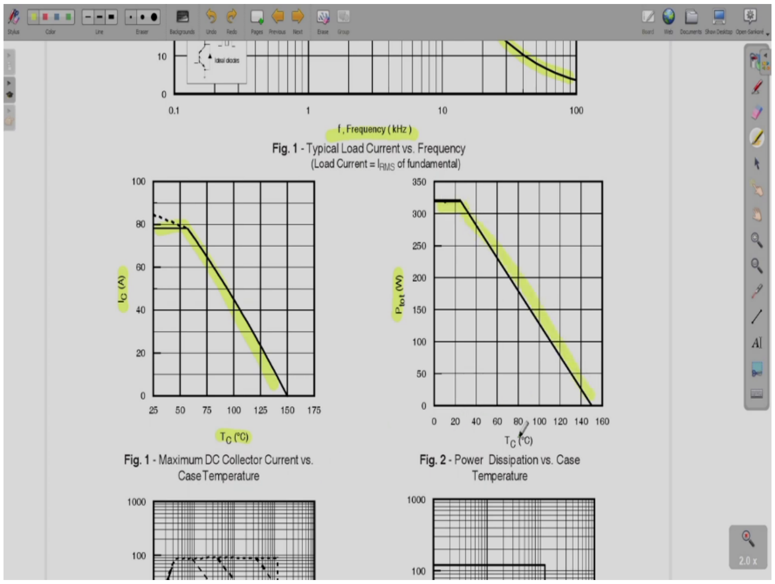

Further here this is collector current I_C versus case temperature. So, that is going to come down, this derating is going to happen as the temperature increases, then total power dissipation limit that is also going to decrease as these temperatures are going to increase.

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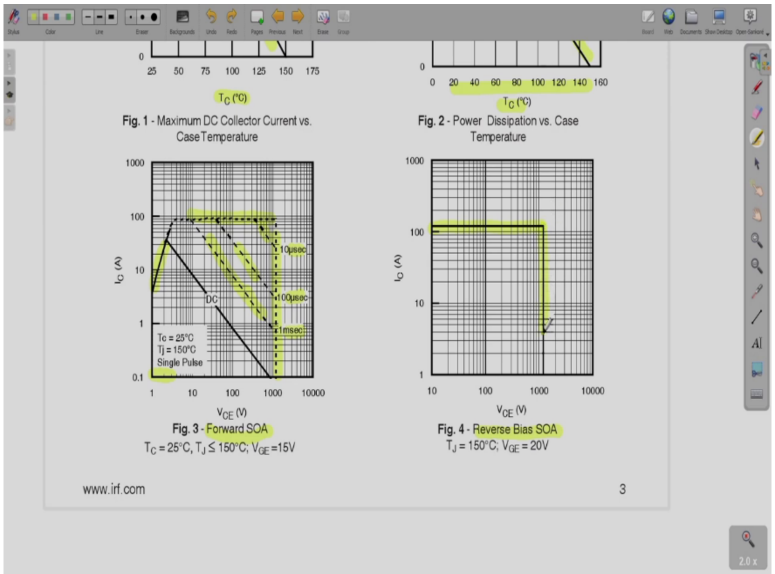

Then these are SOA curves. So, this one is basically provided by the saturation operation what is the current limit. You can see here the voltage is very small during that time and after that, this is current limit of the device, 100 A. This is the voltage limit of the device and then if we applied pulse for 1 ms, so, this is the power dissipation limit P_D.

And this we had discussed when we discussed SOA's, these are all power dissipation limits as this pulse time decreases, this limit increases and this is for DC so, this is all safe operating area the normal SOA or the forward biased SOA, FBSOA we can tell then RBSOA, reverse biased SOA. So, that is just basically two lines over here one is the current limit and another is the voltage limit.

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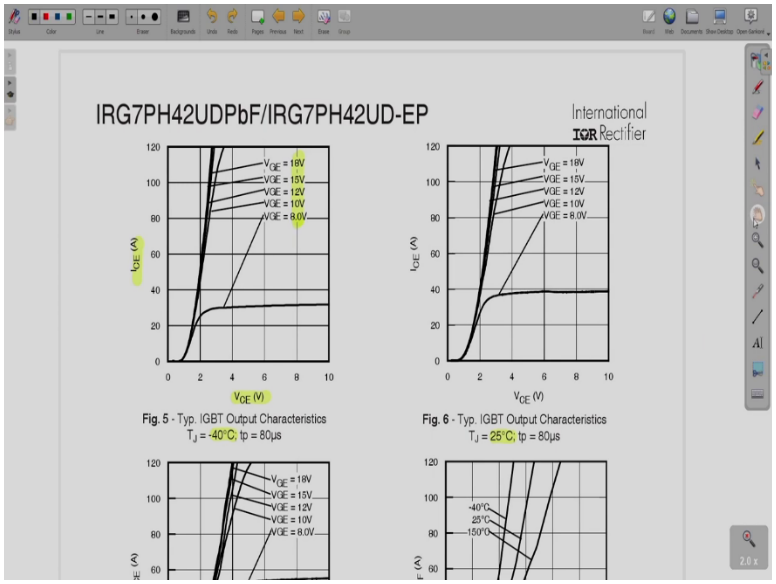

Further what you see is the output characteristics which is a graph between collector current and collector to emitter voltage and it changes with gate to emitter voltage. So, these are all the gate to emitter voltages that are applied and we can see here that it is above 12 V is what it goes into saturation and so, we should be applying more than 12 V.

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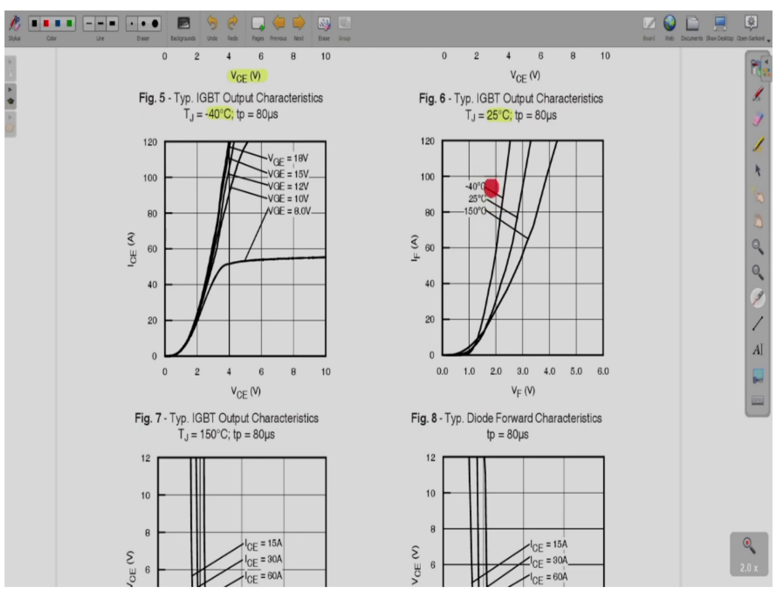

Then further this is given for your -40^{0}C. So, this same is given for 25^{0}C because this output characteristics changes with temperature. Then further the same output characteristics is provided for 150^{0}C, then this diode forward characteristics, diode current versus forward voltage drop across the diode for different temperatures that is also given by the manufacturer.

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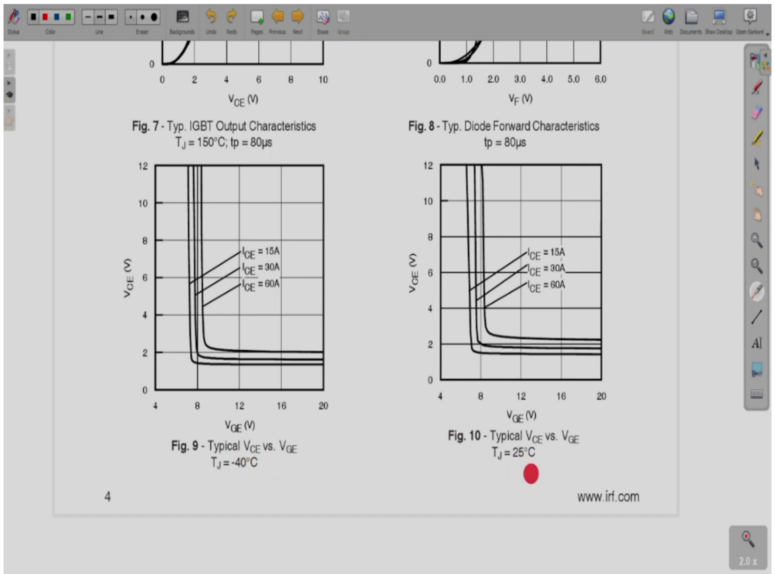

Then this one is collector to emitter voltage versus gate emitter voltage. And you can see here that as gate emitter voltage is reducing the IGBT is going into saturation and so, collector emitter voltage is decreasing and what is the corresponding collector current that is also given over here it increases with the collector current but the overall collector emitter voltage decreases greatly when this gate to emitter voltage is increased and it goes into saturation and this is given for -40^{0}C and the same is provided for 25^{0}C how this graph changes with temperature.

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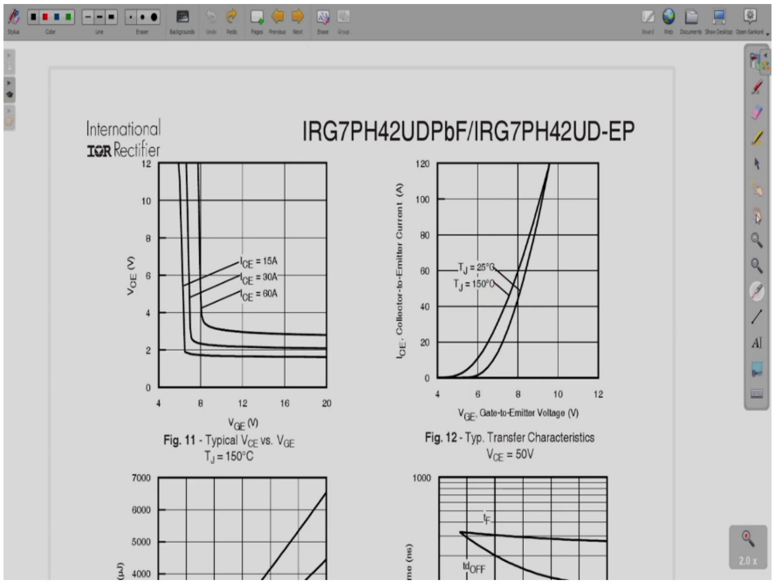

Further the same characteristics that we just saw is provided for maximum junction temperature 150^{0}C. Then this is forward transconductance. So, this you can see that it is between collector current and gate to emitter voltage. So, this is where the collector current starts to increase. So, this is where threshold voltage is going to be. And these are given for two different temperatures.

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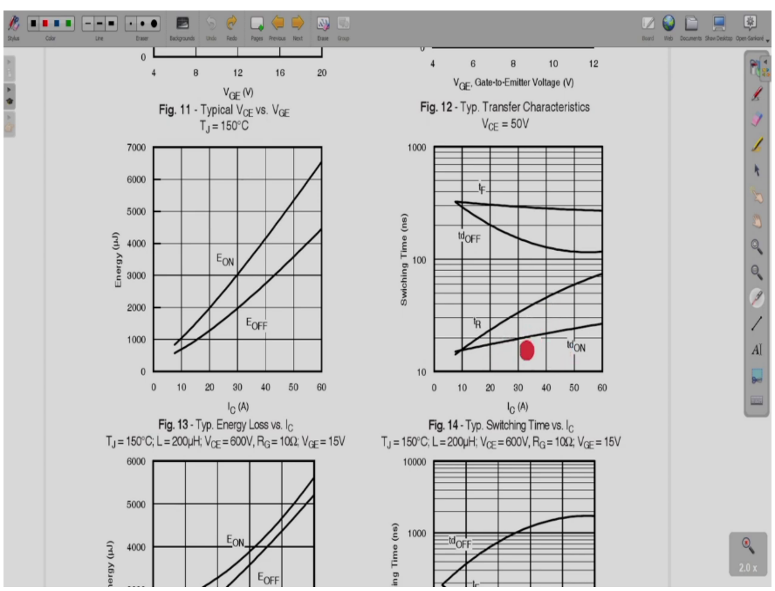

Then next is these losses with respect to collector current. So, you can see that this turn on losses they increase with collector current and turn off losses they also increase with collector current and the switching times how they change with collector current, you can see that this t_f not much change, delay time it reduces, rise times and $t_{d(on)}$ time delay, in on time is increasing with collector current.

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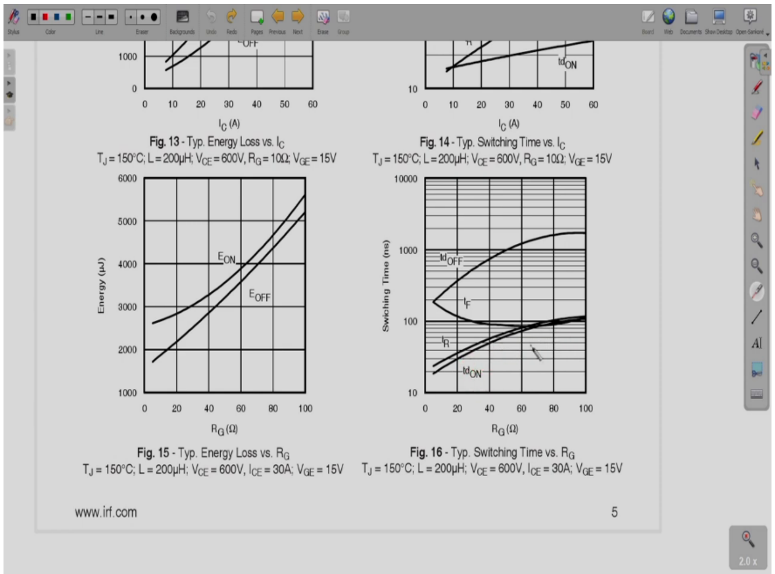

Then those same energy loss with respect to gate resistor R_g how they are varying that is also provided over here. So, both of these for this IGBT what we see is that the turn on losses and turn off losses they both increase with gate resistor and this is what we normally expect and the turn on and turn off times how they change with R_g. So, turn off delay increases, t_f it somewhat decreases but not much change, rise time and delay time during turn on that increases with R_g.

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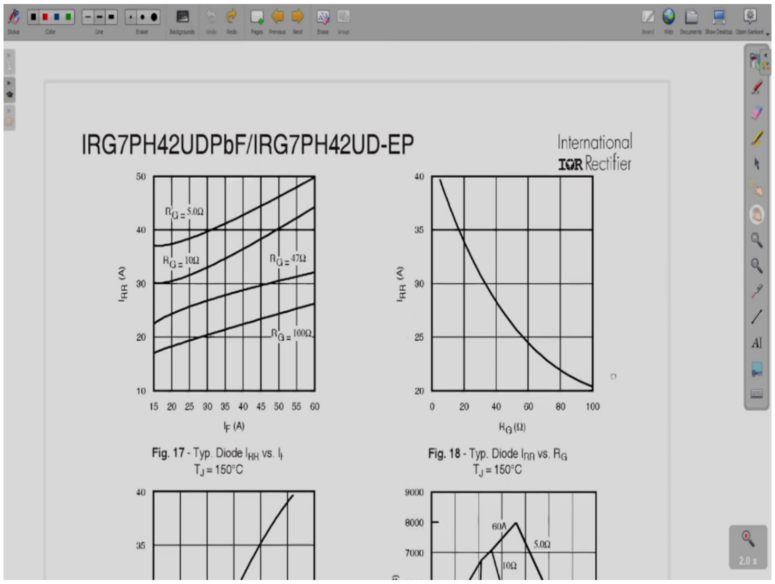

Then, what we see here is the manufacturer provided the reverse recovery current versus forward current I_F, means while the diode was conducting how much current was and then correspondingly how the reverse recovery current changes, you can see here those are given. And you can see this is in A. So, the reverse recovery current for this diode is quite significant. And for different gate resistor values these are provided over here. And this is for 150^0C they have provided and this is how this I_{RR} changes with the gate resistor that also has got an effect on I_{RR} and so that is what is provided by the manufacturer.

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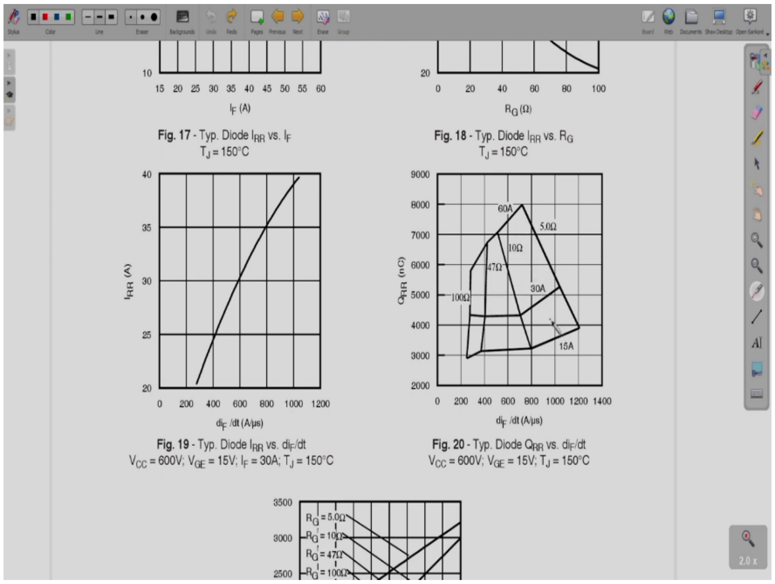

Then how this reversed recovery current I_{RR} changes with $\frac{di}{dt}$, this we had discussed when we discussed the diodes that these are also associated with the rate of change of current and so as $\frac{di}{dt}$ changes, reverse recovery current is increasing as this is increasing. Then further it also gives reverse recovery charge of the diode versus rate of change of current and further you can see this for different resistance values and the limits are also given over here.

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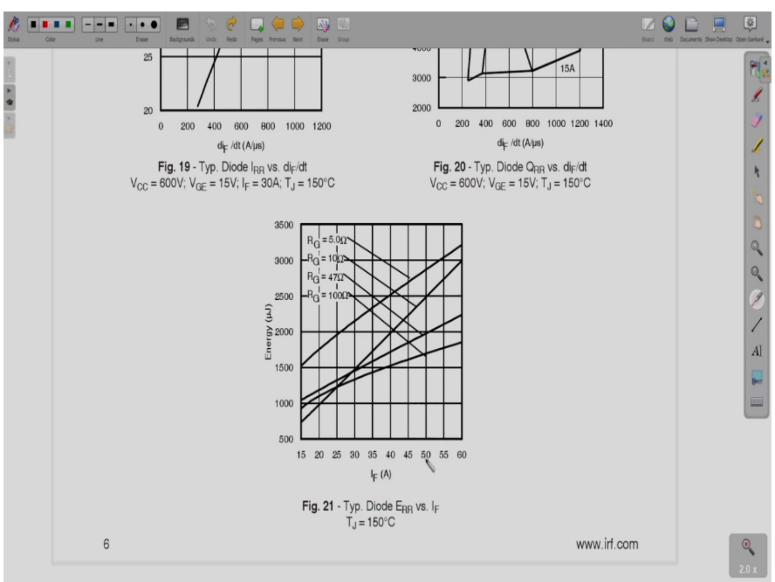

Then these are diode loss, and loss with respect to the diode current what the diode is going to carry. So basically, these are all diode characteristics that are provided by the manufacturer.

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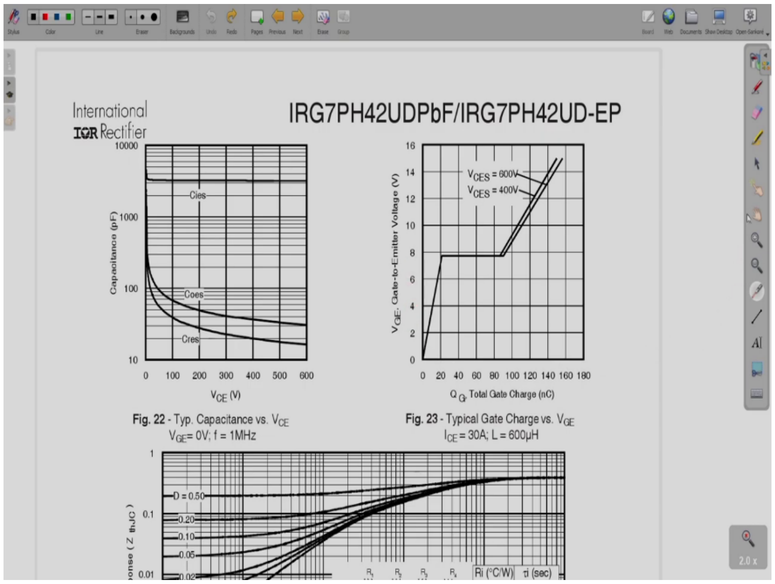

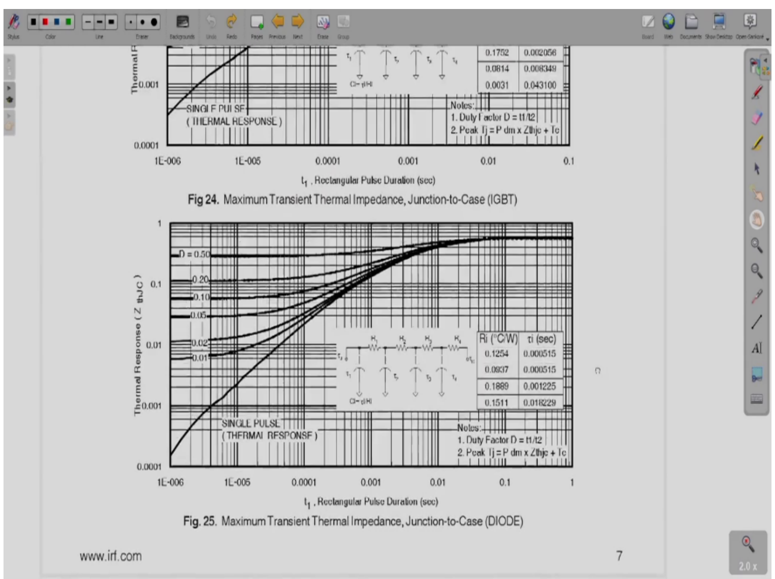

Further what you see here is this capacitance of the IGBTs, the input capacitance, output capacitance and reverse transfer capacitance how they are changing with collector to emitter voltage and this is gate charge characteristics this we had discussed how this gate charge as it increases how gate emitter voltage changes. Further thermal response also will be provided by the manufacturer for the IGBT as well as for the diode. This we will not look into now, but later we will take it up in the course.

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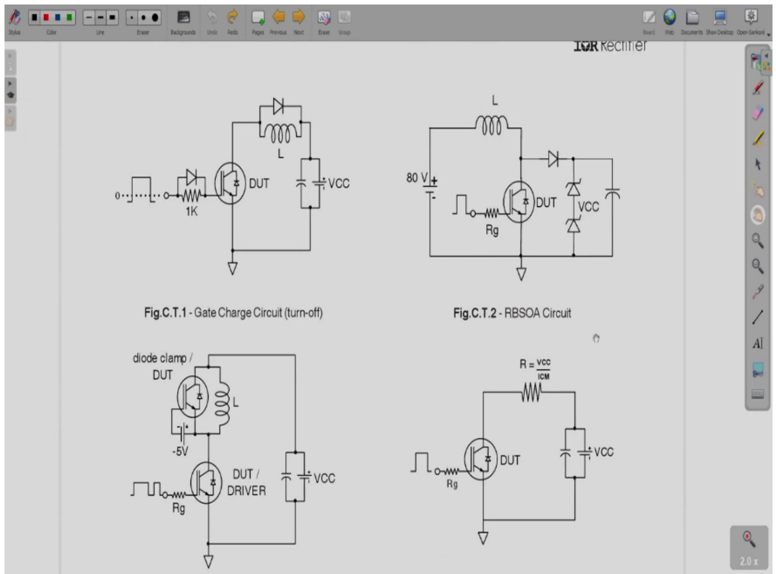

Then apart from that the manufacturer may also give you different test circuits that they might have used so that is what is provided here.

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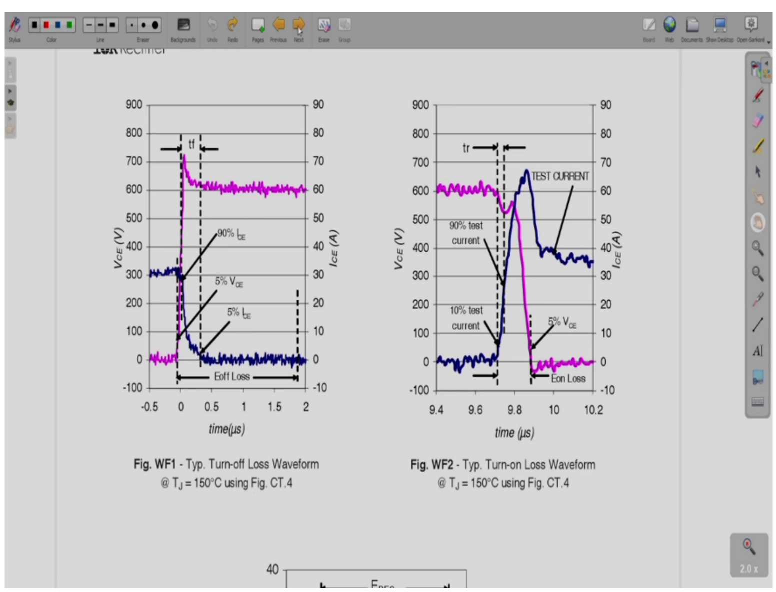

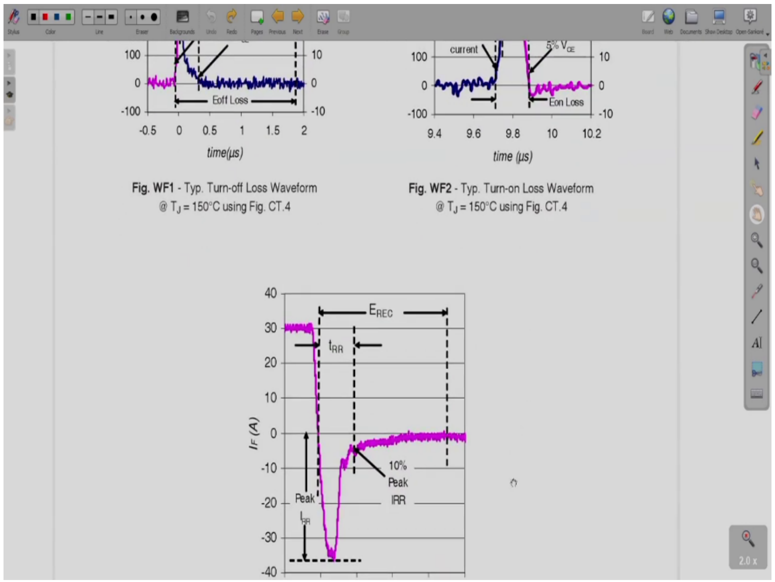

Then the manufacturer also has given different waveforms that they observed. So those results are provided here you can see that this is all diode reverse recovery waveform and then turn on loss waveform and turn off loss waveform this is what the manufacturer has provided.

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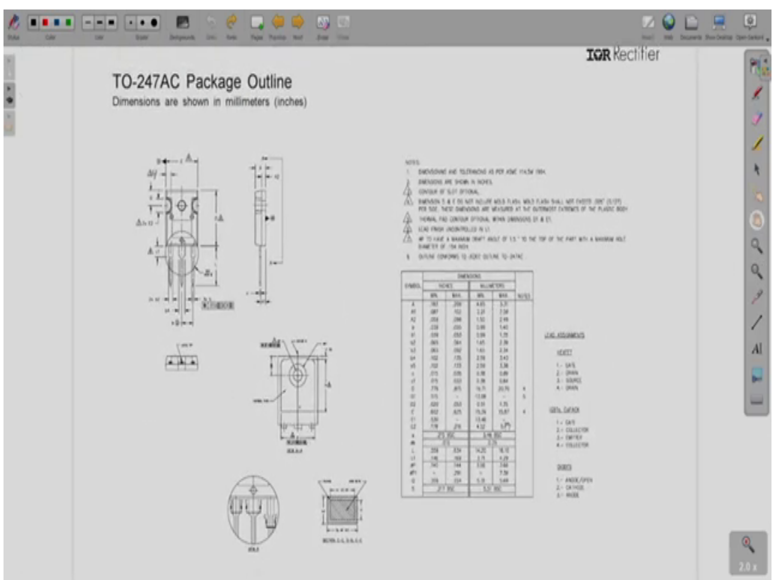

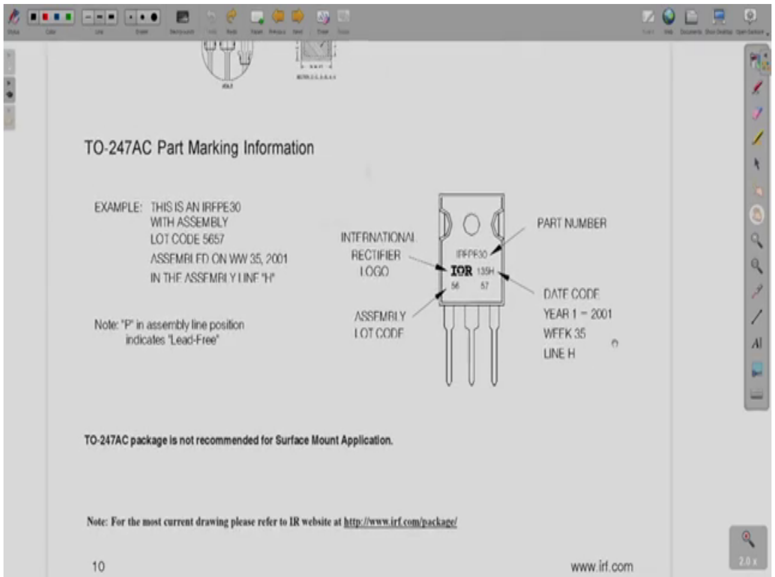

Then usually on the last page of the datasheet you may be given the package information. So, the different dimensions corresponding to the device that are given in the datasheet, so like this, you can read through different data sheets and then choose the IGBT with the antiparallel diode that is suitable for your application. Thank you