AND9068/D

Reading ON Semiconductor IGBT Datasheets

ON Semiconductor®

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APPLICATION NOTE

Abstract

The Insulated Gate Bipolar Transistor is a power switch well suited for high power applications such as motor control, UPS and solar inverters, and induction heating. If the application requirements are well understood, the correct IGBT can easily be selected from the electrical properties provided in the manufacturers' datasheet. This application note describes the electrical parameters provided in the ON Semiconductor IGBT datasheet.

Part Number

The part numbering convention for ON Semiconductor IGBTs is shown in Figure 1. Many of the device ratings and details are described in the part number and can be understood using this code.

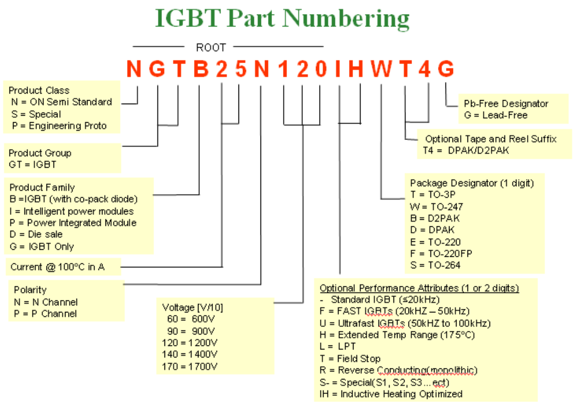

Figure 1. ON Semiconductor IGBT Part Numbering Key

Brief

This section provides a description of the device and lists its key features and typical applications.

Table 1. ABSOLUTE MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector−emitter voltage	V_{CES}	600	V
Collector current @ T_C = 25°C @ T_C = 100°C	I_C	 30 15	A
Pulsed collector current, T_{pulse} limited by T_{Jmax}	I_{CM}	60	A
Diode forward current @ T_C = 25°C @ T_C = 100°C	I_F	 30 15	A
Diode pulsed current, T_{pulse} limited by T_{Jmax}	I_{FM}	60	A
Gate−emitter voltage	V_{GE}	±20	V
Power dissipation @ T_C = 25°C @ T_C = 100°C	P_D	 130 55	W
Short circuit withstand time V_{GE} = 15 V, V_{CE} = 400 V, $T_J \leq +150°C$	t_{SC}	10	μs
Operating junction temperature range	T_J	−55 to +150	°C
Storage temperature range	T_{stg}	−55 to +150	°C
Lead temperature for soldering, 1/8" from case for 5 seconds	T_{SLD}	260	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

Absolute Maximum Ratings

The absolute maximum ratings shown in Table 1 are typical for an IGBT. This table sets the limits, both electrical

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and thermal, beyond which the functionality is no longer guaranteed and at which physical damage may occur. The absolute maximum rating does not guarantee that the device will meet the data sheet specifications when it is within that range. The specific voltage, temperature, current and other limitations are called out in the Electrical Characteristics table.

Collector−Emitter Voltage, V_{CES}

The maximum rated voltage to be applied between the collector and emitter terminals of the device is specified to prevent the device from entering avalanche breakdown and dissipating excessive energy in the device. The avalanche breakdown voltage varies with temperature and is at its minimum at low temperature. The breakdown voltage of the device is designed to meet the minimum voltage rating at −40°C.

Collector Current, I_C

The maximum collector current is defined as the amount of current that is allowed to flow continuously into the collector for a given case temperature, T_C, in order to reach the maximum allowable junction temperature, T_J (150°C). The collector current can be stated in the following equation form:

$$I_C = \frac{T_J - T_C}{R_{th(j-c)(IGBT)} \cdot V_{CE(sat)}}$$

where $R_{th(j-c)}$ is the thermal resistance of the package and $V_{CE(sat)}$ is the on−state voltage at the specified current, I_C. Since it is the current being sought after, and $V_{CE(sat)}$ is a function of current, the equation must be solved iteratively. An estimate of the $V_{CE(sat)}$ for a given collector current and temperature can found in the typical datasheet curves, discussed later.

It is very important to understand that the absolute maximum collector current is defined based on very specific electrical and thermal conditions. The capability of the IGBT to conduct current without exceeding the absolute maximum junction temperature is highly dependent on the thermal performance of the system, including heatsinks and airflow.

Pulsed Collector Current, I_{CM}

The pulsed collector current describes the peak collector current pulse above the rated collector current specification that can flow while remaining below the maximum junction temperature. The maximum allowable pulsed current in turn depends on the pulse width, duty cycle and thermal conditions of the device.

Diode Forward Current, I_F

The diode forward current is the maximum continuous current that can flow at a fixed case temperature, T_C, while remaining under the maximum junction temperature, T_J. This is determined in similar fashion to the $V_{CE(sat)}$, above.

$$I_F = \frac{T_J - T_C}{R_{th(j-c)(diode)} \cdot V_F}$$

The equation relating I_F and V_F to the temperature rise is the same, although the $R_{th(j-c)}$ for the diode is specified separately.

Diode Pulsed Current, I_{FM}

The pulsed diode current describes the peak diode current pulse above the rated collector current specification that can flow while the junction remains below its maximum temperature. The maximum allowable pulsed current in turn depends on the pulse width, duty cycle and thermal conditions of the device.

Gate−Emitter Voltage, V_{GE}

The gate−emitter voltage, V_{GE} describes maximum voltage to be applied from gate to emitter under fault conditions. The gate−emitter voltage is limited by the gate oxide material properties and thickness. The oxide is typically capable of withstanding greater than 80V before the oxide ruptures, but to ensure reliability over the lifetime of the device, and to allow for transient overvoltage conditions in the application, this voltage is limited to well below the gate rupture voltage.

Power Dissipation, P_D

The maximum power dissipation is determined using the following equation:

$$P_D = \frac{T_J - T_C}{R_{th(j-c)}}$$

where $R_{th(j-c)}$ is the thermal resistance of the package. The maximum power dissipation is given at case temperatures of 25°C and 100°C, where the maximum junction temperature is 150°C.

Short Circuit Withstand Time, t_{sc}

The short circuit withstand time describes the ability of the device to carry high current and sustain high voltage at the same time. The device must withstand at least the rated short circuit withstand time with specified voltages applied from collector to emitter and from gate to emitter. The collector−emitter voltage specified for the test will vary based on the minimum blocking voltage capability of the device. The gate−emitter voltage is usually 15 V. The current flowing through the device under these conditions can far exceed the rated current, and is limited by the IGBT forward transconductance, an electrical parameter described below. The failure mode during this fault condition is usually thermal in nature.

Operating Junction Temperature Range, T_J

This is the junction temperature range in which the device is guaranteed to operate without physical or electrical damage or reduced life expectancy.

Storage Temperature Range, T_{stg}

This is the temperature range in which the device may be stored, without electrical bias, without reducing the life expectancy of the device.

Lead Temperature for Soldering, T_{SLD}

The maximum allowable soldering temperature is limited by the thermal conduction from the leads to the junction and die attach regions of the device. The maximum lead temperature is also dependent on the duration for which the soldering iron is applied to the lead. The maximum time for application of the heat is specified in the conditions of this rating.

THERMAL CHARACTERISTICS

Table 2. TABLE OF IGBT AND DIODE THERMAL CHARACTERISTICS

Rating	Symbol	Value	Unit
Thermal resistance junction to case, for IGBT	$R_{th(j\text{-}c)}$	1.1	°C/W
Thermal resistance junction to case, for Diode	$R_{th(j\text{-}c)}$	2.4	°C/W
Thermal resistance junction to ambient	$R_{th(j\text{-}a)}$	60	°C/W

Thermal Resistance Junction−to−Case, $R_{th(j–c)}$

The value for the thermal resistance given in Table 2 represents the steady−state thermal resistance under dc power conditions, applied to the IGBT. The thermal resistance is derated for a square power pulse for reference in designing pulse width modulated applications and is described in the graph of thermal resistance for varying pulse width and duty ratio, shown in Figure 2, below.

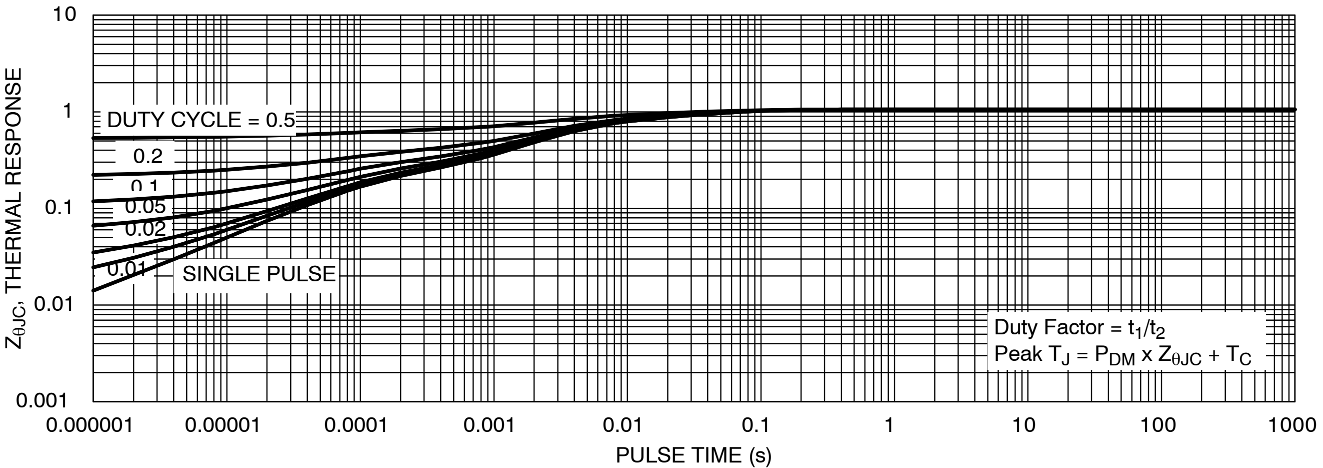

Figure 2. IGBT Transient Thermal Response Curve for Varying Duty Ratio

For a copackaged device such as the NGTB15N60EG the thermal resistance from the junction to case is specified separately for the IGBT and the diode.

Thermal Resistance Junction−to−Ambient, $R_{th(j–a)}$

This is the entire thermal resistance from the silicon junction−to−ambient.

Electrical Characteristics

Static Characteristics

The static, or dc, electrical characteristics are shown in Table 3.

Table 3. IGBT STATIC ELECTRICAL CHARACTERISTICS

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
STATIC CHARACTERISTIC						
Collector−emitter breakdown voltage, gate−emitter short−circuited	V_{GE} = 0 V, I_C = 500 μA	$V_{(BR)CES}$	600	–	–	V
Collector−emitter saturation voltage	V_{GE} = 15 V , I_C = 15 A V_{GE} = 15 V , I_C = 15 A, T_J = 150°C	V_{CEsat}	– –	1.7 2.1	1.95 2.4	V
Gate−emitter threshold voltage	$V_{GE} = V_{CE}$, I_C = 250 μA	$V_{GE(th)}$	4.5		6.5	V

Table 3. IGBT STATIC ELECTRICAL CHARACTERISTICS

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
STATIC CHARACTERISTIC						
Collector−emitter cut−off current, gate−emitter short−circuited	V_{GE} = 0 V, V_{CE} = 600 V V_{GE} = 0 V, V_{CE} = 600 V, T_J = 150°C	I_{CES}	– –	10 –	– 200	μA
Gate leakage current, collector−emitter short−circuited	V_{GE} = 20 V, V_{CE} = 0 V	I_{GES}	–	–	100	nA
Forward Transconductance	V_{CE} = 20 V, I_C = 15 A	g_{fs}	–	10.1	–	S

Collector−Emitter Breakdown Voltage, $V_{(BR)CES}$

This is the minimum off−state forward blocking voltage guaranteed over the operating temperature range. It is specified with the gate terminal tied to the emitter with a specified collector current large enough to place the device into avalanche.

Collector−Emitter Saturation Voltage, $V_{CE(sat)}$

$V_{CE(sat)}$ is an important figure of merit, since it is directly related to the conduction losses of the device. This is the voltage drop from collector to emitter for a specified gate voltage and collector current. Both a typical value and a maximum value are specified in the electrical table for both 25°C and 150°C.

In addition to the electrical limits in the table, the datasheet includes a graph describing the dependence of $V_{CE(sat)}$ on temperature, as shown in Figure 3. The graph describes the typical part and does not guarantee performance, but it can be used as a starting point to determine the $V_{CE(sat)}$ for a given temperature. The curves are given for V_{GE} = 15 V and various collector currents.

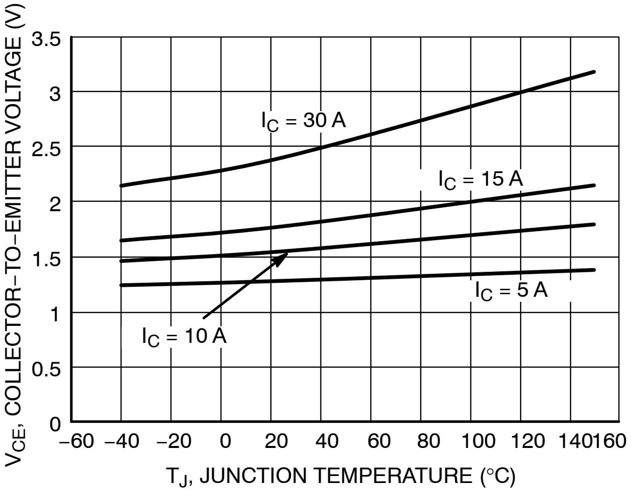

Figure 3. Graph of the Temperature Dependence of $V_{CE(sat)}$

The $V_{CE(sat)}$ values in the electrical parameter table are only given for V_{GE} = 15 V. If the gate of the IGBT is being driven by a different voltage, the output characteristics shown in Figure 4 can also be useful in approximating the $V_{CE(sat)}$. This chart shows the I_C dependence on V_{CE} for various gate−emitter voltages. The datasheet contains output characteristics for T_A = −40, 25, and 150°C.

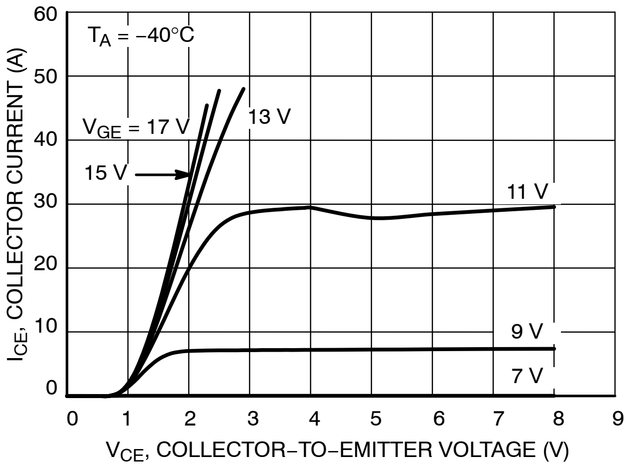

Figure 4. Graph of the Output Characteristics of the IGBT at 25°C

The characteristic curves and typical relationships should never be substituted for worst case design values. Good design practices and board−level design evaluation are critical for a reliable system.

Gate−Emitter Threshold Voltage, $V_{GE(th)}$

This parameter describes the gate to emitter voltage required for a specified amount of collector current to flow. This defines the gate to emitter voltage at which the device enters the on−state. Typically this test is based on a collector current flow proportional to the die size.

Collector−Emitter Cut−off−Current, I_{CES}

This specifies the leakage current one can expect in the off−state forward blocking mode. It is specified at the maximum rated blocking voltage, V_{CES} with the gate−to−emitter voltage equal to zero volts. The maximum allowable value of leakage current occurs at the maximum junction temperature.

Gate Leakage Current, I_{GES}

The absolute maximum value of gate leakage current is typically specified at a gate voltage of 20 V while the collector and emitter are grounded.

Forward Transconductance, g_{fs}

This is the amount of change in collector current for an incremental change in the gate to emitter voltage, measured in Siemens (or Mhos). It is specified at the room temperature rated current of the device, and typically with the device in full saturation, where a further increase in collector−emitter voltage no longer leads to an additional increase in collector current. A typical collector−emitter voltage used for this test is 20 V. Figure 5 illustrates the g_{fs} measurement.

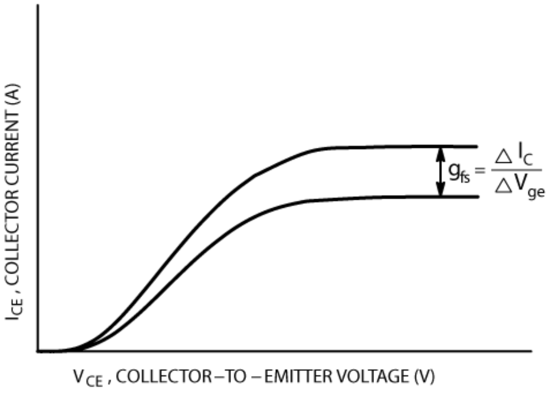

Figure 5. Illustration of the Measurement of IGBT g_{fs}

Dynamic Characteristics

Table 4. IGBT Dynamic Electrical Characteristics

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
DYNAMIC CHARACTERISTIC						
Input capacitance	V_{CE} = 20 V, V_{GE} = 0 V, f = 1 MHz	C_{ies}	–	2600	–	pF
Output capacitance		C_{oes}	–	64	–	
Reverse transfer capacitance		C_{res}	–	42	–	
Gate charge total	V_{CE} = 480 V, I_C = 15 A, V_{GE} = 15 V	Q_g		80		nC
Gate to emitter charge		Q_{ge}		24		
Gate to collector charge		Q_{gc}		33		

The dynamic electrical characteristics which include device capacitances and gate charge are given in the electrical table, as shown in Table 4.

IGBT capacitances are similar to those described for power MOSFETs. The datasheet describes the measurable terminal capacitances, C_{ies}, C_{oes}, and C_{res}. They are specified in the electrical table at a fixed collector bias voltage; however, the capacitances are voltage dependant, as can be seen in Figure 6. The capacitances specified on the datasheet are convenient and easily measured. They relate to the pin to pin capacitances shown in Figure 7 and described below.

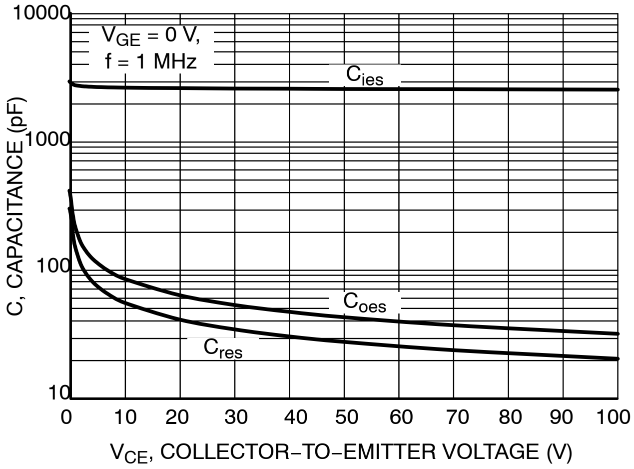

Figure 6. IGBT Capacitance versus Collector−Emitter Voltage Showing Voltage Dependance of C_{oes} and C_{res}

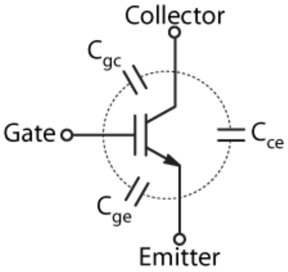

Figure 7. Pin−to−pin Capacitances of the IGBT

$C_{ies} = C_{ge} + C_{gc}$ with C_{ce} shorted

$C_{oes} = C_{gc} + C_{ce}$

$C_{res} = C_{gc}$

Input Capacitance, C_{ies}

The input capacitance is made up of the parallel combination of gate−emitter and gate−collector capacitances, when the collector and emitter are tied together. The gate−emitter capacitance is constant, as it consists mainly of the metal−oxide−semiconductor capacitance. The gate−collector capacitance is a combination of a fixed oxide capacitor and a p−n junction capacitor. This results in a voltage dependence that is slightly more complex than that of a p−n junction.

Output Capacitance, C_{oes}

The output capacitance is formed by the parallel combination of the gate−collector and collector−emitter capacitances. As mentioned above, the gate−collector capacitance is voltage dependant. This is also true for the collector−emitter capacitance. The voltage dependence of the collector−emitter junction is that of a p−n junction.

Transfer Capacitance, C_{res}

The transfer capacitance is composed only of the gate−collector capacitance. Its role in the device operation is critical, as it provides negative feedback between the collector and the gate. This capacitance is responsible for the plateau on the gate charge curve. The change in collector−emitter voltage forces a current through C_{res} which reduces the gate drive current while the collector voltage is changing.

Gate Charge, Total, Q_g

Input capacitance is useful, but in terms of gate drive design, the more important figure of merit is the gate charge. It is used to size the gate drive components and predict switching losses in the driver. To measure gate charge the IGBT gate is driven with a current and the gate voltage change is monitored versus time. The resulting gate voltage versus gate charge curve is shown in Figure 8 for a constant current gate drive signal.

Q_g is the total charge required on the gate to raise V_{GE} to a specified gate voltage. ON Semiconductor devices are specified at $V_{GE} = 15$ V.

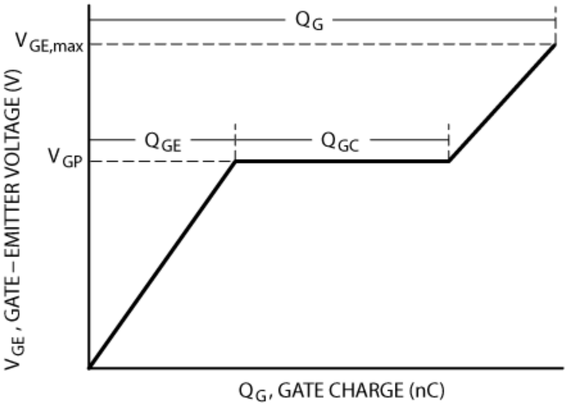

Figure 8. Theoretical Gate Charge Curve showing V_{GP}, Q_G, Q_{GE}, and Q_{GC}

Gate to Emitter Charge, Q_{ge}

Q_{ge} is the amount of charge required to reach the plateau voltage V_{GP}. This charge contributes to turning on the MOS channel, at which time the collector−emitter voltage begins to transition from high to low voltage. The level of V_{GP} is dependent on the load current being switched and can be approximated by determining the V_{GS} that corresponds to the switching current level from the transconductance curves in Figure 5.

Gate to Collector Charge, Q_{gc}

Q_{gc} is the amount of charge required to charge the junction capacitor while the voltage from collector to emitter is decreasing in the transition between the off−state and on−state. This plateau corresponds to the charging of what is also known as the Miller capacitance.

Switching Characteristics

The IGBT switching characteristics are of great importance because they relate directly to the switching energy losses of the device. Switching losses can be substantial, especially at higher frequencies and increasing temperature, where the switching losses increase.

When voltage is applied to the gate, the input capacitance must first be charged to the threshold voltage, $V_{GE(th)}$. This leads to a delay ($t_{d(on)}$) before the IGBT collector current begins to flow. Once the collector current begins to flow, the depletion layer that blocks the voltage during the off−state begins to collapse. The voltage drops to the on−state voltage drop, $V_{CE(sat)}$. This is illustrated in Figure 9.

During turn−off, the gate voltage is reduced to zero and the opposite occurs. The channel for the MOSFET current is closed and the current begins to drop abruptly. The voltage begins to rise from $V_{CE(sat)}$ as the charge due to current flow is removed. The voltage across the device reaches the supply voltage, and minority carriers that remain in the device after turn−off cause a tail current that continues to flow. This is illustrated in Figure 10.

The switching characteristics are given in the electrical parametric table for T_J = 25 and 150°C. These are shown in Table 5.

Table 5. INDUCTIVE SWITCHING ELECTRICAL CHARACTERISTICS OF THE IGBT

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
SWITCHING CHARACTERISTIC , INDUCTIVE LOAD						
Turn−on delay time	T_J = 25°C V_{CC} = 400 V, I_C = 15 A R_g = 22 Ω V_{GE} = 0 V / 15 V	$t_{d(on)}$		78		ns
Rise time		t_r		30		
Turn−off delay time		$t_{d(off)}$		130		
Fall time		t_f		120		
Turn−on switching loss		E_{on}		0.900		mJ
Turn−off switching loss		E_{off}		0.300		
Total switching loss		E_{ts}		1.200		
Turn−on delay time	T_J = 150°C V_{CC} = 400 V, I_C = 15 A R_g = 22 Ω V_{GE} = 0 V / 15 V	$t_{d(on)}$		76		ns
Rise time		t_r		33		
Turn−off delay time		$t_{d(off)}$		133		
Fall time		t_f		223		
Turn−on switching loss		E_{on}		1.10		mJ
Turn−off switching loss		E_{off}		0.510		
Total switching loss		E_{ts}		1.610		

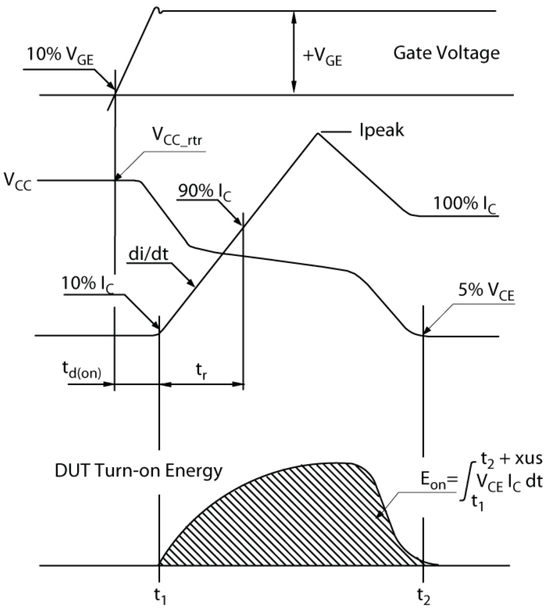

Figure 9. Turn−on Switching Illustration Showing the Definitions of the Turn−on Switching Characteristics

Turn−on Delay Time, $t_{d(on)}$

$t_{d(on)}$ is the time delay between the rising edge of the gate pulse and the rising edge of the IGBT collector current. The measurement considers the point at which both the gate voltage and collector current reach 10% of their final specified value.

Rise Time, t_r

The interval between the time the collector reaches 10% of its specified current value and the time it reaches 90% of its final value is defined as the rise time.

Turn−on Switching Loss, E_{on}

The turn−on switching losses are calculated by integrating the power dissipation (I_C x V_{CE}) over the time interval starting when the collector current reaches 10% of its final value and ending when the collector−emitter voltage reaches 5% of its peak value.

Turn−off Delay Time, $t_{d(off)}$

$t_{d(off)}$ is the time delay between the falling edge of the gate pulse and the falling edge of the collector current. The measurement is the time between the point at which the gate voltage falls to 90% of its maximum value and the collector current reaches 10% of its final specified value.

Fall Time, t_f

The fall time is defined as the time required for the collector current to drop from 90% to 10% of its initial value.

Turn−off Switching Loss, E_{off}

The turn−off switching energy losses are calculated to include the overlap of the rising collector−emitter voltage and the falling collector current. Because the IGBT is a minority carrier device, the collector current continues to flow after the time where the collector voltage has fully risen. This residual current, called tail current, eventually decays to zero. It is customary to add a fixed length of time to the end of the turn−off time to capture the energy lost during the entire tail current. This added time is denoted as xμs in Figure 10.

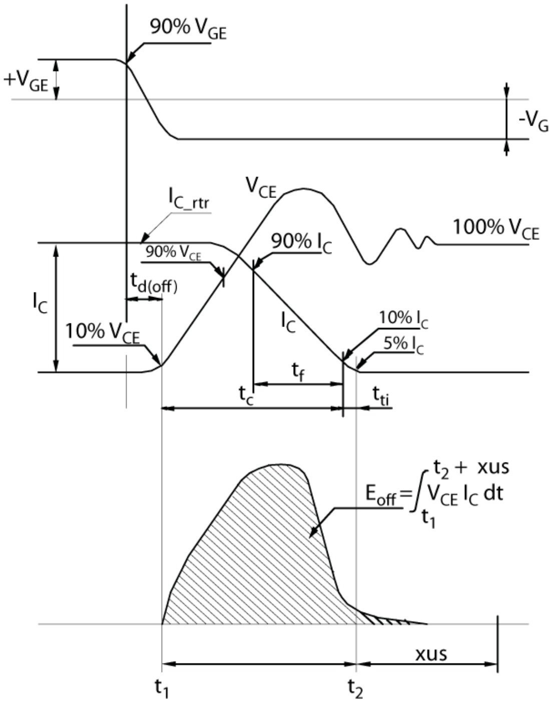

Figure 10. Turn−off Switching Illustration Showing the Definitions of the Turn−off Switching Characteristics

Total Switching Loss, E_{ts}

The total switching losses comprise the sum of the turn−on and turn−off switching losses.

Typical switching time and switching energy loss graphs are given that describe the dependence of the switching characteristics on a variety of system variables. The dependence on junction temperature, collector current, collector−emitter voltage, and gate resistance are all provided to aid in the design process.

Diode Characteristics

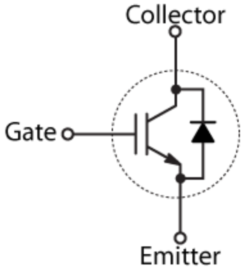

Figure 11. Copackaged IGBT and Freewheeling Diode

IGBTs are frequently used in applications where the load is inductive, such as motor control. These applications are hard switching and require that the IGBT be in parallel with a freewheeling diode. ON Semiconductor offers copackaged IGBT and diode devices. The diode cathode and IGBT collector are connected together and the diode anode and IGBT emitter are also connected, as shown in Figure 11. The freewheeling diode takes the place of the body diode that otherwise exists in a power MOSFET. For IGBTs that are copackaged with a freewheeling rectifier diode, the datasheet will also include electrical specifications for the diode, as shown in Table 6.

Table 6. ELECTRICAL CHARACTERISTICS OF THE DIODE

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
DIODE CHARACTERISTIC						
Forward voltage	V_{GE} = 0 V, I_F = 15 A V_{GE} = 0 V, I_F = 15 A, T_J = 150°C	V_F		1.6 1.6	1.85	V
Reverse recovery time	T_J = 25°C I_F = 15 A, V_R = 200 V di_F/dt = 200 A/μs	t_{rr}		270		ns
Reverse recovery charge		Q_{rr}		350		nc
Reverse recovery current		I_{rrm}		5		A
Reverse recovery time	T_J = 125°C I_F = 15 A, V_R = 200 V di_F/dt = 200 A/μs	t_{rr}		350		ns
Reverse recovery charge		Q_{rr}		1000		nc
Reverse recovery current		I_{rrm}		7.5		A

Forward Voltage, V_F

The forward voltage of the rectifier is measured while the IGBT gate and emitter terminals are tied together, ensuring the IGBT is in its off−state. A forcing current enters the emitter terminal and the emitter−collector (anode−cathode) voltage is measured.

Forward voltage is an important parameter in hard switching applications. V_F is specified in the electrical table for a given current and is specified at T_J = 25 and 150°C. The datasheet also includes a graph showing the I_F-V_F relationship for a typical part at T_J = −40, 25, and 150°C, as shown in Figure 12.

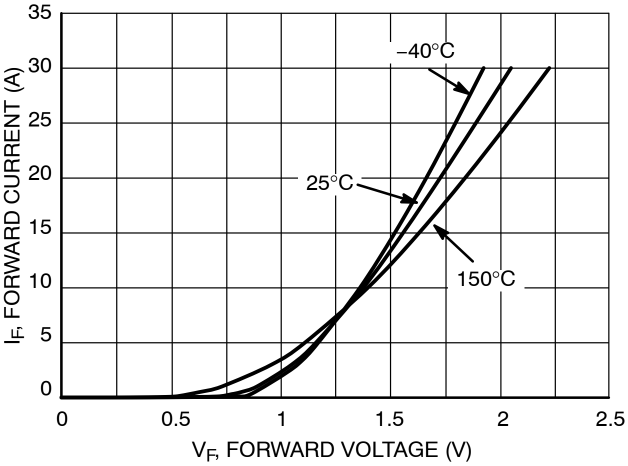

Figure 12. Diode Forward Characteristic Curves for T_J = −40, 25, and 150°C

Reverse Recovery Time, t_{rr}

The reverse recovery time, t_{rr}, defines the time the diode takes to enter the reverse blocking state after conducting in the forward direction. It is defined as the length of time required for the reverse current to return to 10% of its peak reverse value (I_{rrm}). It is measured from the point in time where the diode current crosses zero. The time period is labeled in Figure 13.

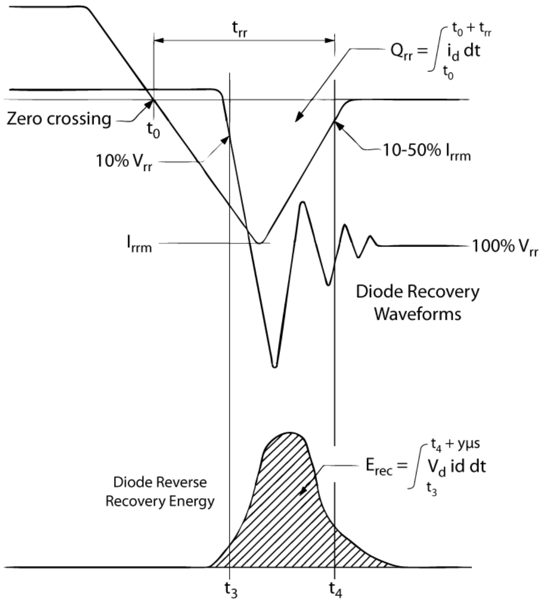

Figure 13. Diode Reverse Recovery Illustration Showing the Definitions of the Reverse Recovery Characteristics

Reverse Recovery Charge, Q_{rr}

The amount of charge that is recovered from the diode during turn−off is referred to as reverse recovery charge, Q_{rr}. It is calculated by taking the integral of the reverse recovery current over the time period, t_{rr}.

Reverse Recovery Current, I_{rrm}

I_{rrm} is the peak current reached during diode turn off. I_{rrm} depends on the initial forward diode current and the rate of change of the diode current, dI/dt, used to turn the diode off.

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