AN4504

IGBT Ratings And Characteristics

Application Note

Replaces September 2000 version, AN4504-3.0
AN4504-3.1 July 2002

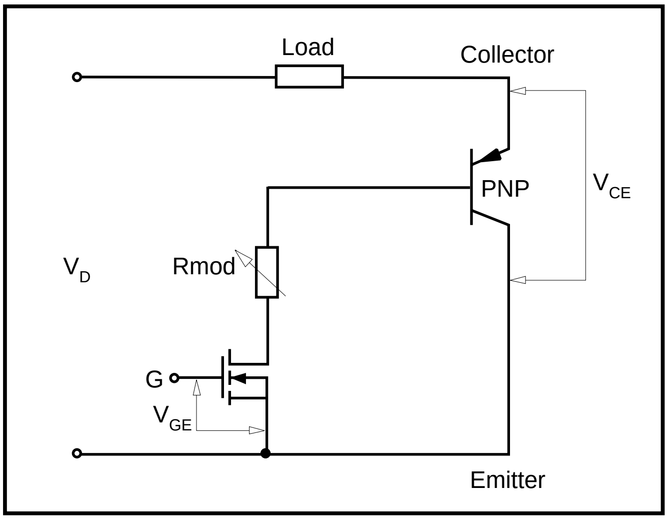


Fig. 1 IGBT equivalent circuit showing basic parameters

BASIC OPERATION AND INTRODUCTION OF PARAMETERS

As illustrated in Fig. 1, when a positive voltage, Vge, above the level of threshold voltage $V_{ge(th)}$, is applied between the gate and emitter, the power MOSFET turns on. This generates a low resistance path between the base and collector of the pnp transistor causing it to turn on also. Provided V_{ge} is great enough the pnp transistor is driven into saturation and V_{ce} falls to $V_{ce(sat)}$. Some related parameters to this operation are the maximum rated pulsed collector current, Icm and maximum power dissipation, P_{tot}.

To turn the IGBT off the gate emitter voltage is set to zero, which first causes the MOSFET to turn off and then the pnp transistor.

1. RATINGS:

Ratings are the maximum values of parameters such as current, voltage, temperature, power dissipation etc., recommended by manufacturers for their product types. To achieve reliable and long term operation of a device, it is imperative to operate the device within the specified device ratings.

After the fabrication of Dynex Semiconductor IGBT die, they are assembled onto power substrates and assembled in to plastic modules, etc.

An IGBT module consists of one or more substrates connected in parallel to achieve high current handling capability. An inverse parallel diode is also connected across the IGBT and in most applications this diode acts as a free-wheeling diode or as a protection diode. Fig. 2 illustrates the packages used by Dynex Semiconductor.

The following information attempts to give clear definitions of the ratings parameters on a typical IGBT datasheet and describes how the current and power ratings are derived.

2. I_C CONTINUOUS COLLECTOR CURRENT:

The continuous collector current, I_C, is rated for a given case temperature (for example in the case of Dynex Semiconductor IGBT module datasheets, the case temperature is specified between the range of 70 to 85°C).

This current is defined as the maximum direct current that can flow through the device while the case temperature is held at the specified level, with the junction temperature rising to its maximum permitted level due to the dissipated power of the device.

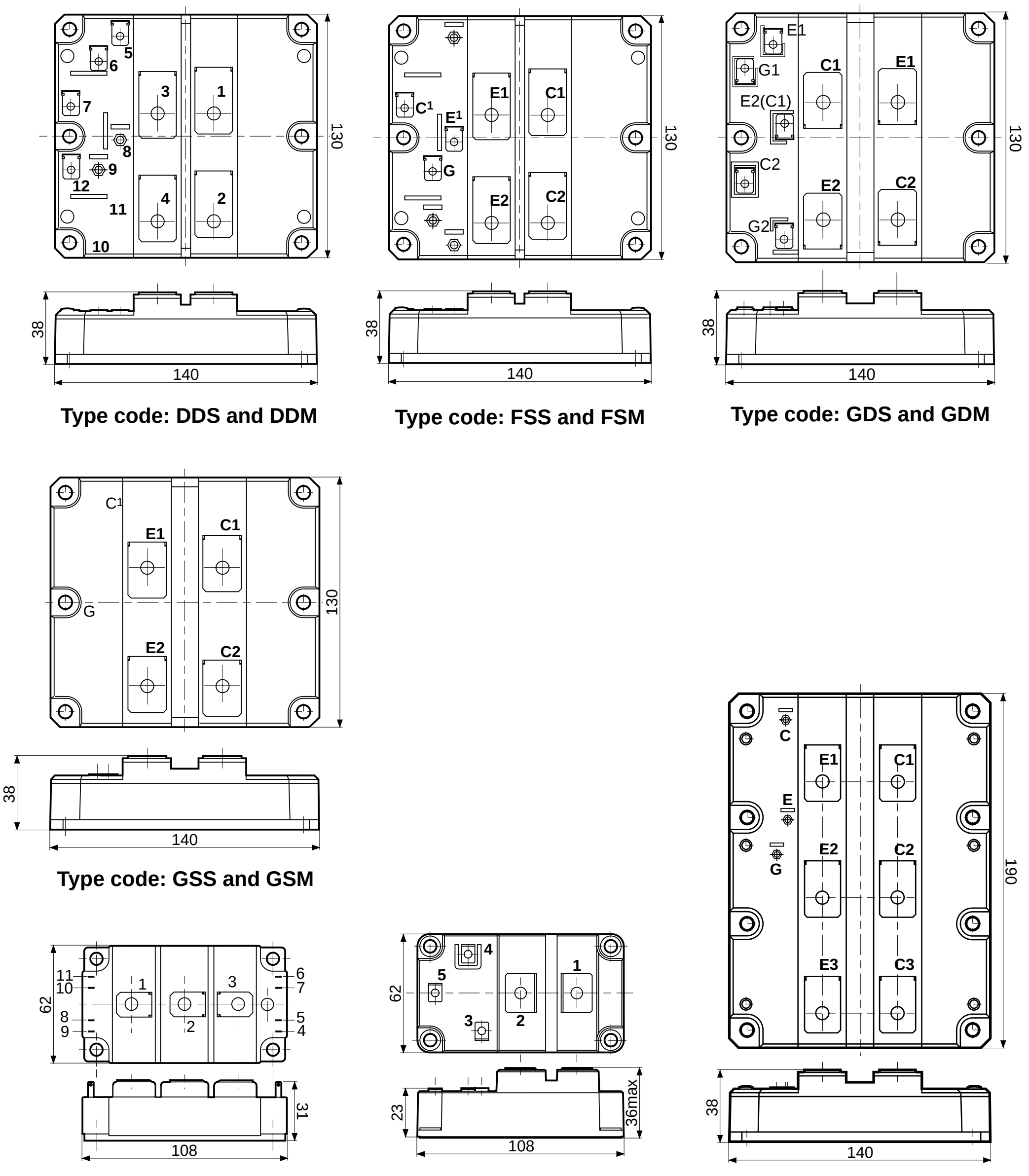
The value of I_C that is quoted depends on the case temperature, Tc that is to be specified, the maximum permitted junction temperature, T_{jmax}, the junction to case thermal resistance $R_{th(j-c)}$ and the $V_{ce(sat)}$ value. $V_{ce(sat)}$ is dependant on the applied gate emitter voltage V_{ge}. This can be shown by:-

$$(I_C \text{ at } T_c) = \frac{(T_{jmax} - T_c)}{(V_{ce(sat)} \text{ at } I_C \text{ at } T_{jmax}) \times R_{th(j-c)}}$$

For a constant power source, when the gate emitter voltage is increased, the collector emitter saturation voltage reduces and the collector current increases. This can be seen in Fig. 3. Fig. 4 shows how the rated collector current varies with case temperature.

V_{ces} - Continuous collector to emitter voltage

The continuous collector to emitter voltage, otherwise known as the device blocking voltage, is the maximum voltage that the collector to emitter junction can support. With the gate and emitter terminals shorted together (over the full operating temperature range).



Type code: DDS and DDM

Type code: FSS and FSM

Type code: GDS and GDM

Type code: GSS and GSM

Type code: MHB and MDS

Type code: LSS

Type code: ESS

Fig.2 IGBT packages used by Dynex Semiconductor

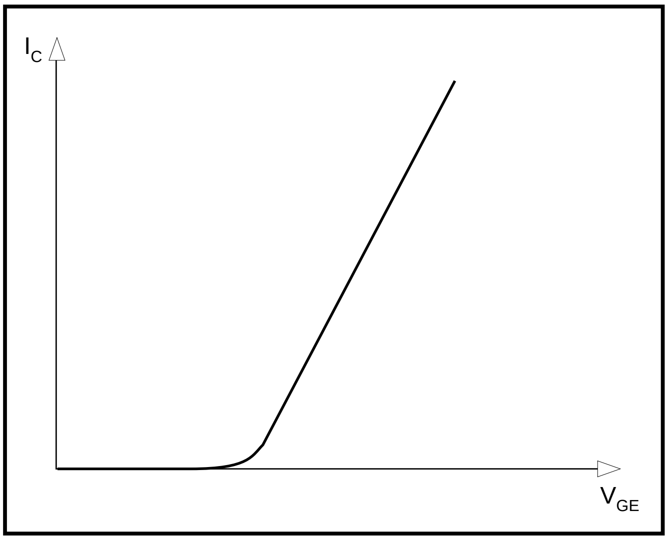


Fig. 3 Gate-emitter voltage vs collector current

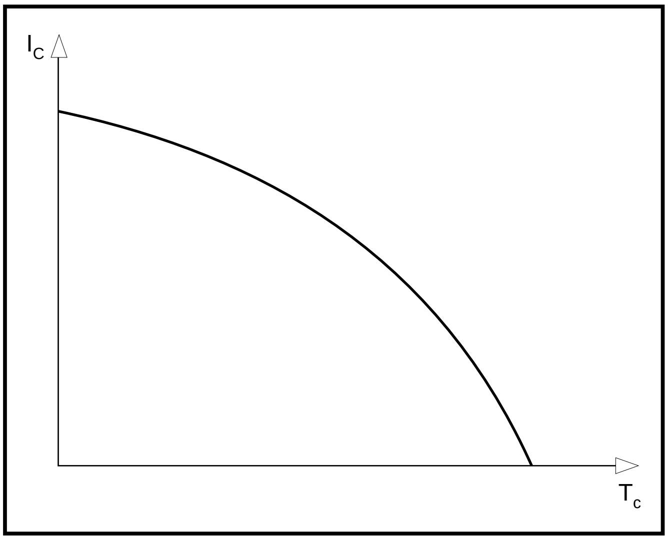


Fig. 4 Case temperature vs collector current

V_{ges} - Gate to emitter voltage

The gate to emitter voltage is the voltage that can be applied to the gate/emitter junction without degradation occurring. Although the device can often withstand a voltage higher than the rated value, it is not wise to run it above the specified level as long term reliability may be impaired. A major factor in the level of voltage that can be applied is the thickness of the gate oxide layer.

P_{tot} - Total power dissipation

P_{tot} is the maximum continuous power dissipated by the device for a given case temperature, T_c.

Total power dissipation =

On-state losses + Switching losses + Off state losses

$$\text{Power dissipation} = \frac{(T_{jmax} - T_c)}{R_{th(j-c)}}$$

The maximum power dissipation is thus related to permissible case temperature rise and the junction to case thermal resistance.

The main factor which determines the P_{tot} rating is the $V_{ce(sat)}$ level. This is dependant on junction temperature, collector current and gate to emitter voltage.

V_{isol} - Isolation voltage

This is the maximum breakdown isolation voltage for an applied rms ac voltage and is specified as between any terminal and the case.

T_j - Junction temperature range

Is the minimum and maximum limits of the permissible range of operating junction temperature.

T_{op}/T_{stg} - Operating and storage temperature range

The minimum and maximum limits for the operating and storage temperature range.

Mounting torque limits

These are the minimum and maximum limits for the screw torque. It should be emphasised that insufficient torque applied to the base plate screws may result in high thermal resistance due to poor contact to the heatsink and excessive applied torque can cause internal damage to the module.

3. STATIC ELECTRICAL CHARACTERISTICS:

These describe the behaviour of the device in steady state conditions either in the “ off-state” or “conduction / on state”.

Off-state:

I_{CES} : is the collector to emitter blocking (or collector cut-off) current. In the data sheet it is specified at the rated collector to emitter blocking voltage (V_{ces}) with gate-emitter shorted at junction temperature (T_j) of 25˚C. This parameter is a function of Vces and T_j. I_{CES} increases with increase in V_{ces} and T_j.

I_{GES} : is the gate-emitter leakage current specified at the recommended gate-emitter voltage (V_{GE}) with collector emitter shorted ($V_{CE} = 0$) and Tj = 25˚C.

Conduction state:

$\mathbf{V_{GE(th)}}$: the gate to emitter threshold voltage is the minimum gate to emitter voltage required to turn-on the IGBT at specified I_C and VCE.

$\mathbf{V_{ce(sat)}}$: is the collector to emitter saturation voltage. This voltage is a function of collector current (I_C), gate-emitter voltage (V_{GE}) and junction temperature (T_j) and so it is specified at the rated I_C, V_{GE} = 15V and T_j = 25˚C and 125˚C. V_{CE} is the ON state collector to emitter voltage drop when conducting a certain collector current and is used to calculate the ON state power dissipation in the IGBT. The IGBT is normally used as a switch and so the practical range of V_{CE} is within the saturation region. Increasing V_{GE} increases the channel conductivity and therefore reduces the $V_{ce(sat)}$, while increasing the collector current also increases the $V_{ce(sat)}$. From the equivalent circuit of the IGBT as described previously the constituents of $V_{ce(sat)}$ are as follows:

$$V_{ce(sat)} = V_{BE(PNP)} + I_{MOS}.(R_{MOD} + R_{CH})$$

where:

$V_{BE(PNP)}$ is the base-emitter voltage of PNP transistor

I_{MOS} is the drain current of the power MOSFET

R_{MOD} is the resistance of the conductivity modulated n- region

R_{CH} is the channel resistance of the power MOSFET

$V_{ce(sat)}$ is temperature sensitive and is observed to decrease with increase in temperature (negative temperature coefficient) until a certain crossover point is reached, after which $V_{ce(sat)}$ begins to increase with temperature (positive temperature coefficient). If this crossover point is well below the practical operation range of the I_C, the IGBT is said to have a positive temperature coefficient. This crossover point is a function of device geometry, its vertical structure and the level of lifetime killing which has been employed during the device fabrication.

It is desirable to have a positive temperature coefficient for Vce especially when parallel operation of devices is required as it aids the sharing of currents with increasing temperature. It also means that the on-resistance of the IGBT increases with temperature and thus prevents the onset of thermal runaway. In circuits using IGBT modules, paralleling has become a common feature due to this attribute.

The variation of V_{ce} is given in the form of an output characteristics curve where I_C vs V_{ge} is plottedV_{ce} with V_{ge} as a parameter for T_c of 25˚C and 125˚C. (See fig.5).

4. DYNAMIC CHARACTERISTICS:

These describe the behaviour of the device during the two transitional states; viz. from OFF state to ON state and from ON state to OFF state. Significant power loss is incurred during these switching states and so it is important to understand these characteristics in order to determine switching losses. Fig.6 defines various switching time parameters.

Turn-on transition:

$\mathbf{t_{d(on)}}$: is the turn-on delay time. It is defined as the time from $V_{ge} = 0$ to I_C = 10% of its final value (t_1 to t_2). During this time the n-channel is formed.

$\mathbf{t_r}$: is the rise time of I_C to increase from 10% to 90% of its final value (t_2 to t_3). The rise time is influenced by the IGBT gate characteristics.

$\mathbf{t_{on}}$: is the sum of t_d and t_r.

$\mathbf{E_{on}}$ **:** is the turn-on energy loss defined as per Fig.6.

Turn-off transition:

$\mathbf{t_{d(off)}}$: is the turn-off delay time and defined as the time from V_{ge} = 90% of its initial value to I_C = 90% of its initial value (t_8 to t_9). During this time the n-channel is removed and further supply of electrons from the emitter is cut off.

$\mathbf{t_f}$: is the fall time of I_C and defined as the time between I_C = 90% to 10% of its initial value (t_9 to t_{10}). The fall time also includes the tail period which is the time taken to recombine excess charges stored in n^- region. The current tail introduces higher switching losses and limits the operating frequency of the device. The tail time is reduced by speeding up the recombination process. Various lifetime killing techniques (such as electron irradiation) and or by introduction of n^+ -buffer layer to the structure to collect the minority charges at turn-off are used to speed up this process.

$\mathbf{t_{off}}$ **:** is the sum of $t_{d(off)}$ and t_f.

$\mathbf{E_{off}}$: is turn-off energy loss defined as per Fig.7.

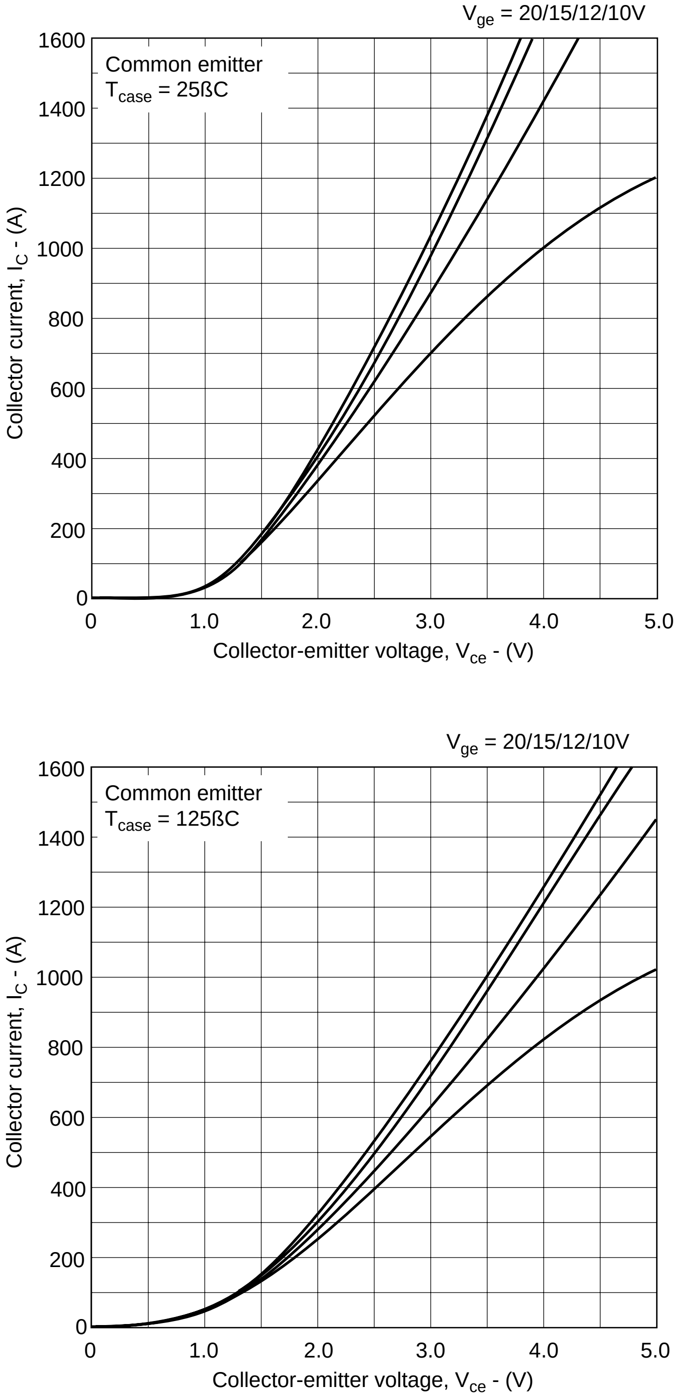


Fig. 5 Typical output characteristics at T_{case} 25˚C and T_{case} 125˚C

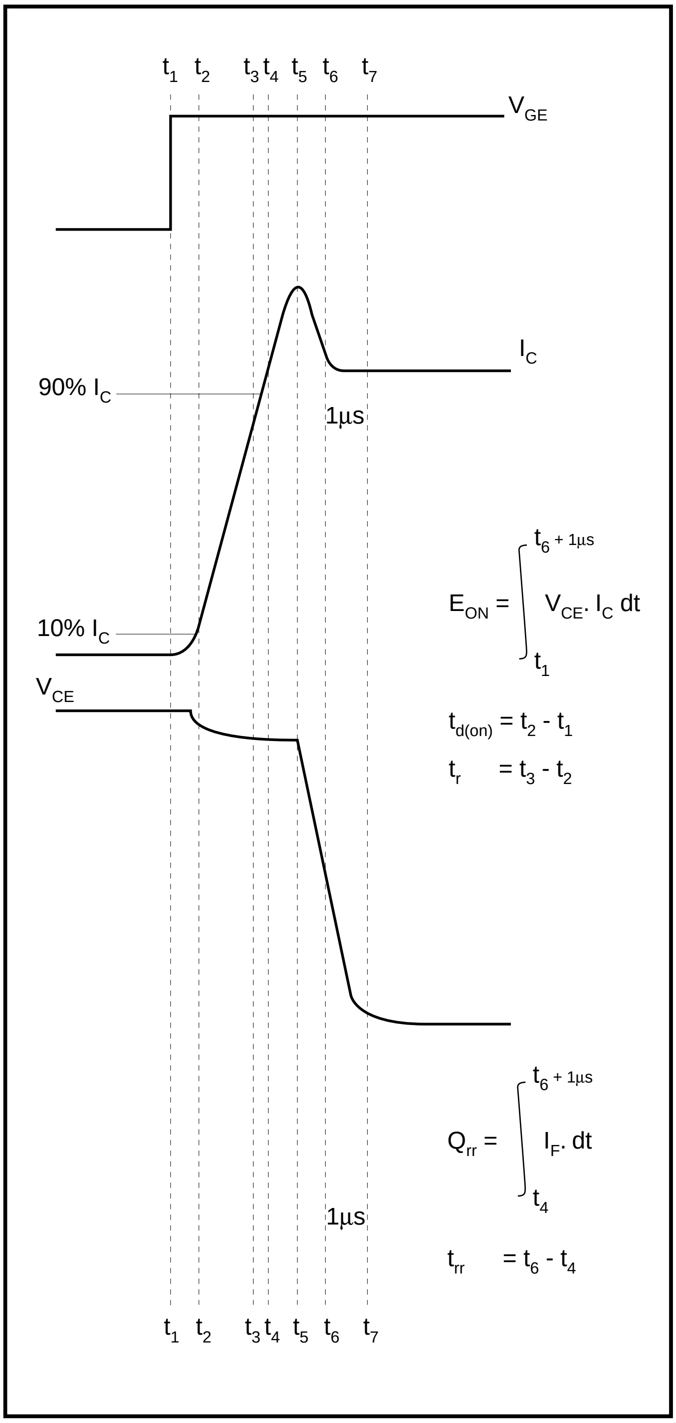


Fig. 6 Typical turn-on switching waveforms

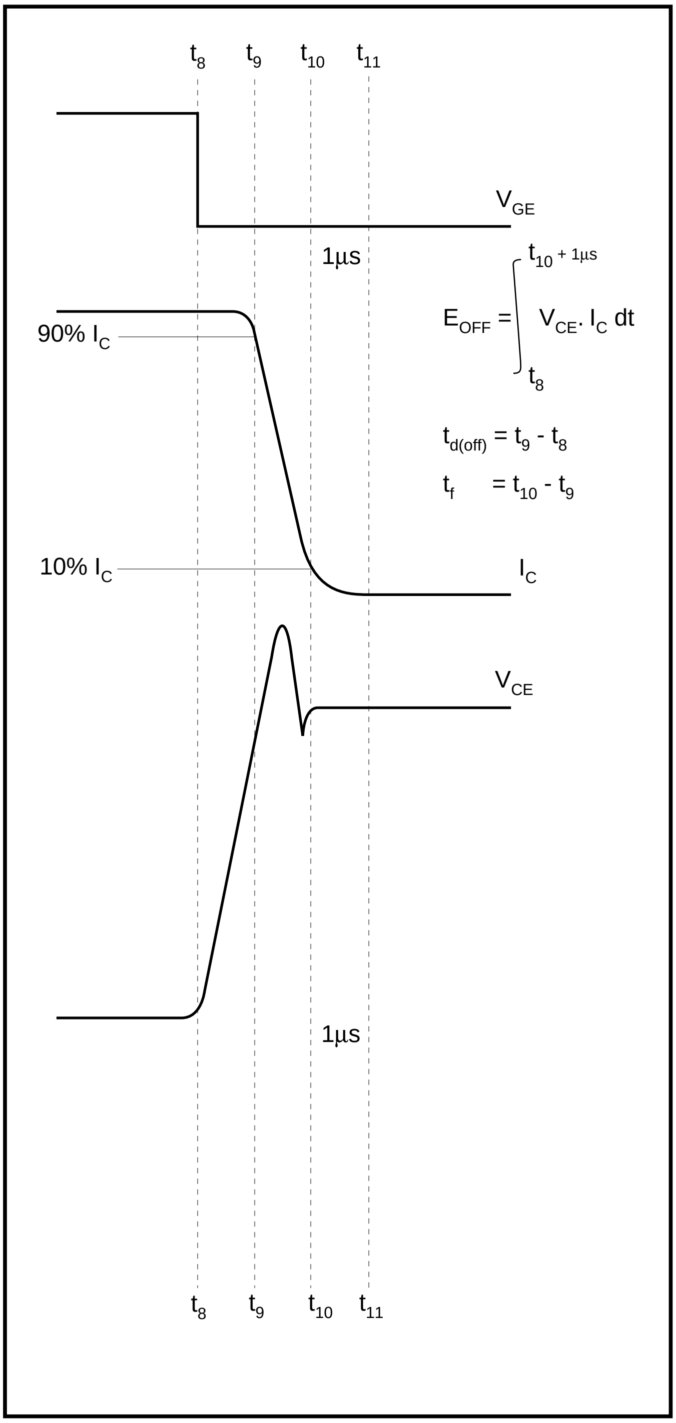


Fig. 7 Typical turn-off switching waveforms

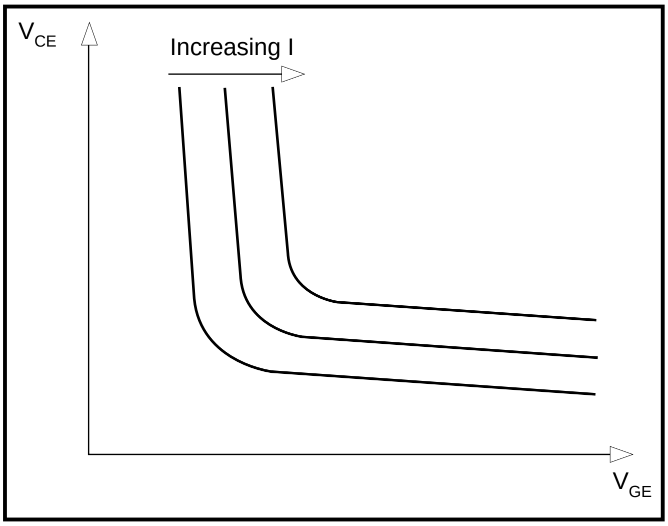


Fig. 8 Collector-emitter voltage vs gate-emitter voltage

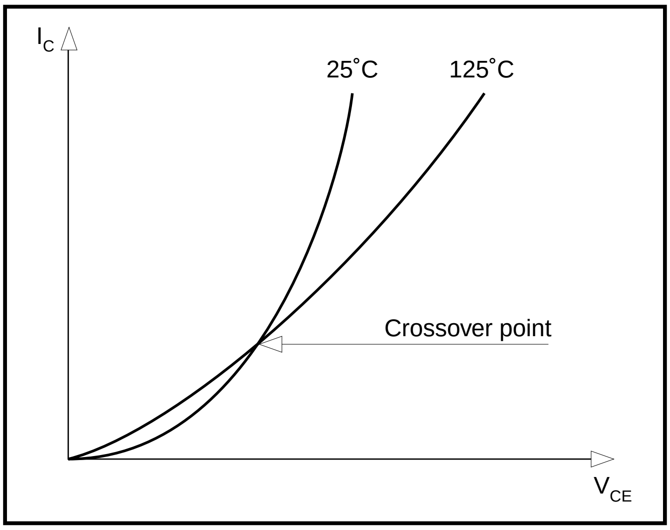


Fig. 9 Collector-emitter voltage vs collector current

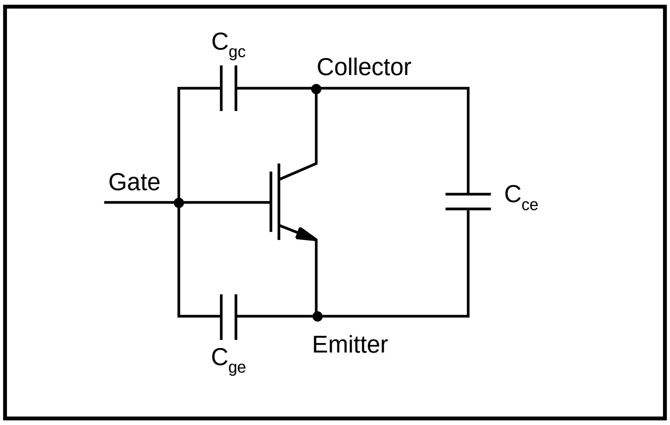


Fig. 10 Capacitance parameters of an IGBT

V_{ce}, V_{ge}, P_{tot}, I_C and T_j Relationships

These parameters are closely linked with each other and variance in one can affect all the others. The main control parameter is the gate to emitter voltage, V_{ge}. If this is increased the device effectively turns on harder causing $V_{ce(sat)}$ to be smaller. This reduces the power dissipation as shown above. The maximum V_{ge} level is usually 20V with a recommended value of 15V. Fig. 8 shows the effects of V_{ge} on V_{ce}. $V_{ce(sat)}$ can also be affected by changes in collector current and temperature. As shown in Fig. 9, $V_{ce(sat)}$ increases with an increase of collector current which in turn increases power dissipation. $V_{ce(sat)}$ will increase with an increase in temperature if there is a high collector current. This is the device operating in the positive temperature coefficient region. However if the collector current is low, $V_{ce(sat)}$ decreases with an increase in temperature. This is the device operating in the negative temperature coefficient region. It can be useful to operate in this region as $V_{ce(sat)}$ will reduce as the temperature rises and power dissipation falls making the device more efficient. Fig. 9 illustrates the effect of temperature and collector current on $V_{ce(sat)}$.

5. DEVICE CAPACITANCES:

The capacitances quoted in datasheets are derived from three measured capacitances as shown in Fig. 10.

These measured capacitances are used to give the following parameters on datasheets.

a) C_{res} - Reverse transfer capacitance

This is the gate to collector capacitance, C_{gc}, which is equivalent to the “reverse transfer” or “Miller” capacitance in bipolar transistors.

b) C_{ies} - Input capacitance

The input capacitance, C_{ies}, is the sum of the gate to collector and gate to emitter capacitance, C_{gc} and C_{ge}.

c) C_{oes} - Output capacitance

The output capacitance, C_{oes}, is the sum of the gate to collector and collector to emitter capacitance, C_{gc} and C_{ce}, with the gate shorted to the emitter.

6. RBSOA (REVERSE BIASED SAFE OPERATING AREA):

The reverse biased safe operating area curve, RBSOA, gives the maximum current and voltage which the device can be switched at provided T_{jmax} is not exceeded. If the device is operated inside this limit curve it will not breakdown. The curve is defined as the maximum simultaneous collector current and collector to emitter voltages that the device can handle without causing breakdown. The maximum collector current is usually 200% rated current at 85% V_{ces} with a T_j of 125°C. This occurrence is present during turn-off of the device. The RBSOA curve is determined using an inductive load as this produces the worst case condition. Fig. 11 shows a typical RBSOA curve, Fig. 12 shows the test circuit and Fig. 13 shows an idealized waveform of this parameter.

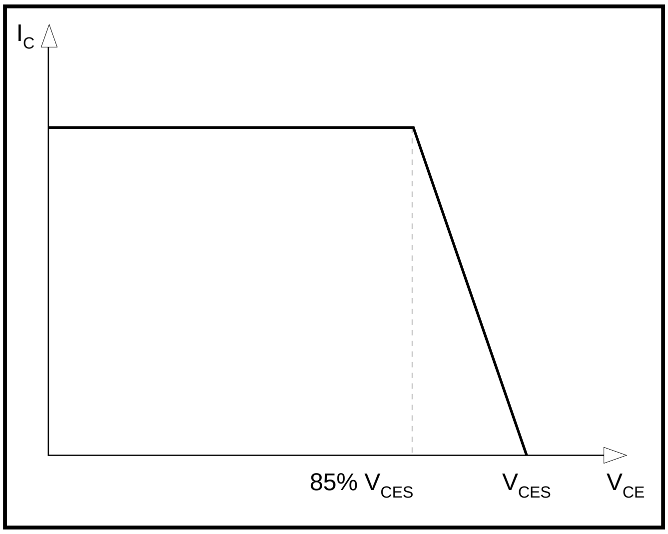


Fig. 11 Reverse bias safe opearting area curve

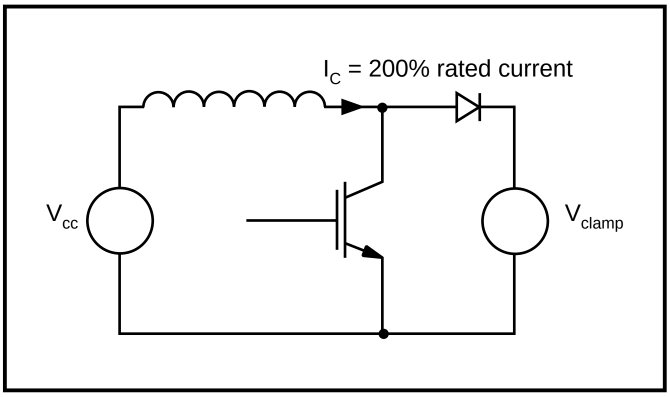


Fig. 12 RBSOA test circuit

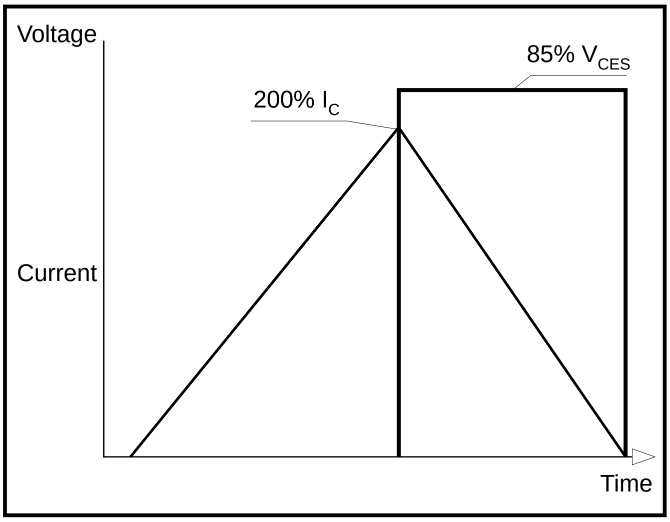


Fig. 13 Idealized waveforms

Short circuit rating

To prevent damage by short circuit currents in IGBT circuits it is usual to detect the overcurrent condition and generate an inhibit signal to turn off the IGBT gate drive. However, an allowance must be made for the time delay between the start of the overcurrent and the subsequent turning off of the IGBT. The delay is in the reaction time of the overcurrent detect circuit and the storage time of the IGBT. During the delay period the IGBT must withstand the full short circuit at full circuit voltage without damage.

IGBTs are usually rated for a short circuit withstand time of 10µs. Note that the actual value of the short circuit current is determined by the IGBT characteristics. IGBT's are designed to have a comparatively low gain in order to limit short circuit current.

7. THERMAL CHARACTERISTICS:

Z_{th} - Transient thermal resistance curve

This curve shows how the junction to case thermal resistance of the device increases with time, as measured from the start of power dissipation. The curve is used to calculate junction temperature of devices under a pulsed power condition. For explanation see application note AN4506, 'Calculation Of Junction Temperature'.

R_{th} - Thermal resistance, steady state

Thermal resistance relates to the heat conduction properties of the device. It is quoted in terms of temperature per unit of power, °C/W. Rth can be broken down into several parts i.e. $R_{th(j-c)}$, thermal resistance from the device junction to the device case, $R_{th(h-a)}$, thermal resistance from the heatsink to ambient and $R_{th(c-h)}$, the contact thermal resistance, often known as the thermal resistance of the contact between the device case and the heatsink. The contact resistance can vary quite substantially. The quality of the contact depends on the flatness of the two surfaces, the contact grease thickness and the mounting torque. The mounting torque is usually specified according to the base plate and module design. A maximum value is quoted. To improve the contact a thermal mounting grease or other compound should always be used. Details of recommended compounds are given in application note AN4505, 'Heatsink Requirements For IGBT Modules'.

8. EXTERNAL SERIES GATE RESISTANCE R_G:

The charging and discharging of the input capacitance is controlled by the value of a series gate resistor connected to the output of the gate drive circuit. A smaller value will result in faster charging and discharging of the input capacitance and hence reduce the switching times and switching losses, but will not provide adequate noise immunity. Also when an IGBT is used with a free wheel diode (FWD), smaller valuesof R_G cause the IGBT to switch at a higher di/dt, forcing the FWD to recover at higher dV/dt, and thus producing an over-voltage transient. Due to collector to gate capacitance, the dV/dt generated during diode recovery produces a displacement current in the IGBT which flows through R_G. If the value of R_G is sufficiently high then the voltage developed across it can turn the IGBT on. This resistor has marked influence on the RBSOA and short circuit rating. Manufacturers of IGBTs generally give recommended values of R_G (having considered various effects).

9. ANTI-PARALLEL DIODE:

The main function of the diodes connected across the IGBT elements is to provide a path for the free wheeling current when inductive loads are used. They also prevent any high reverse voltages appearing across the IGBT in all circumstances.

The diode current rating If is usually about 2/3 of that of the IGBT. This is suitable for most applications. Blocking voltage and maximum junction temperature ratings are the same as for the IGBT.

The current rating mainly relates to on-state voltage V_{FM}, thermal resistance and maximum junction temperature. However for high frequency applications the diode reverse recovery characteristics have to be taken into account.

The anti-parallel diode may have to reverse recover with high values of dIf/dt which can produce snap-off recovery and high voltage transients. Anti-parallel diodes for IGBT circuits are therefore designed to have a soft recovery characteristic. The power losses due to reverse recovery must be added to steady state losses, leading to a reduction in diode current rating at high frequencies.

POWER ASSEMBLY CAPABILITY

The Power Assembly group was set up to provide a support service for those customers requiring more than the basic semiconductor, and has developed a flexible range of heatsink and clamping systems in line with advances in device voltages and current capability of our semiconductors.

We offer an extensive range of air and liquid cooled assemblies covering the full range of circuit designs in general use today. The Assembly group offers high quality engineering support dedicated to designing new units to satisfy the growing needs of our customers.

Using the latest CAD methods our team of design and applications engineers aim to provide the Power Assembly Complete Solution (PACs).

HEATSINKS

The Power Assembly group has its own proprietary range of extruded aluminium heatsinks which have been designed to optimise the performance of Dynex semiconductors. Data with respect to air natural, forced air and liquid cooling (with flow rates) is available on request.

For further information on device clamps, heatsinks and assemblies, please contact your nearest sales representative or Customer Services.

DYNEX SEMICONDUCTOR

http://www.dynexsemi.com

e-mail: power_solutions@dynexsemi.com

HEADQUARTERS OPERATIONS
DYNEX SEMICONDUCTOR LTD
Doddington Road, Lincoln.
Lincolnshire. LN6 3LF. United Kingdom.
Tel: +44-(0)1522-500500
Fax: +44-(0)1522-500550

CUSTOMER SERVICE
Tel: +44 (0)1522 502753 / 502901. Fax: +44 (0)1522 500020

SALES OFFICES
Benelux, Italy & Switzerland: Tel: +33 (0)1 64 66 42 17. Fax: +33 (0)1 64 66 42 19.
France: Tel: +33 (0)2 47 55 75 52. Fax: +33 (0)2 47 55 75 59.
Germany, Northern Europe, Spain & Rest Of World: Tel: +44 (0)1522 502753 / 502901.
Fax: +44 (0)1522 500020
North America: Tel: (613) 723-7035. Fax: (613) 723-1518. Toll Free: 1.888.33.DYNEX (39639) /
Tel: (949) 733-3005. Fax: (949) 733-2986.

These offices are supported by Representatives and Distributors in many countries world-wide.

Datasheet Annotations:

Dynex Semiconductor annotate datasheets in the top right hard corner of the front page, to indicate product status. The annotations are as follows:-

Target Information: This is the most tentative form of information and represents a very preliminary specification. No actual design work on the product has been started.

Preliminary Information: The product is in design and development. The datasheet represents the product as it is understood but details may change.

Advance Information: The product design is complete and final characterisation for volume production is well in hand.

No Annotation: The product parameters are fixed and the product is available to datasheet specification.