Thyristor and Triac Ratings

A rating is a value that establishes either a limiting capability or a limiting condition for an electronic device. It is determined for specified values of environment and operation, and may be stated in any suitable terms. Limiting conditions may be either maxima or minima.

All limiting values quoted in this data handbook are Absolute Maximum Ratings - limiting values of operating and environmental conditions applicable to any device of a specified type, as defined by its published data.

The equipment manufacturer should design so that, initially and throughout the life of the device, no absolute maximum value is exceeded with any device, under the worst probable operating conditions.

Voltage ratings

V_{DRM}, V_{RRM} Repetitive peak off-state voltage. The maximum allowable instantaneous forward or reverse voltage including transients. The rated values of $V_{DRM(max)}$ and $V_{RRM(max)}$ may be applied continuously over the entire operating junction temperature range, provided that the thermal resistance between junction and ambient is kept low enough to avoid the possibility of thermal runaway.

Current ratings

$I_{T(AV)}$ Average on-state current. The average rated current is that value which under steady state conditions will result in the rated temperature T_{jmax} being reached when the mounting base or heatsink is at a given temperature. Graphs of on-state dissipation versus $I_{T(AV)}$ or $I_{T(RMS)}$ are provided in the data sheets. The right hand scale of each graph shows the maximum allowable mounting base or heatsink temperature for a given dissipation.

$I_{T(RMS)}$ RMS on-state current. For a given average current, the power dissipated at small conduction angles is much higher than at large conduction angles. This is a result of the higher rms currents at small conduction angles. Operating the device at rms currents above the rated value is likely to result in rapid thermal cycling of the chip and the bond wires which can lead to reliability problems.

I_{TSM} Non-repetitive peak on-state current. The maximum allowable non-repetitive peak on-state surge current which may be applied to the device. The data sheet condition assumes a starting junction temperature of 25˚C and a sinusoidal surge current at a mains frequency of 50/60 Hz. For a triac, a full sine wave of current is applied. Graphs in the data sheet show the variation of I_{TSM} with surge duration.

I^2t Device fuse rating. For correct circuit protection, the I^2t of a protective fuse must be less than the I^2t of the device. In the data sheets, the device rating is numerically equal to $I_{TSM}{}^2/200$ and assumes a 10ms fusing time.

dI_T/dt The maximum allowable rate of rise of on-state current after gate triggering. The theory underlying this rating is that, where the rate of rise of main current is very rapid immediately after triggering, local 'hot spot' heating will occur in a small part of the device active area close to the gate, leading to device degradation or complete failure. In practice, true dI_T/dt failures of this kind are very rare. The only conditions where dI_T/dt has been observed to cause failures is in triacs operated in quadrant (iv) (T2-, G+) where a combination of high dI_T/dt and high peak current (in excess of the data sheet ratings), can cause damage to the gate structure. For this reason, operation of our triacs in quadrant IV should be avoided wherever possible.

V_{BO} or dV_D/dt triggered. Where a device is triggered by exceeding the breakdown voltage, or by a high rate of rise of off-state voltage, as opposed to injecting current into the gate, it is necessary to limit the dI_T/dt. A note in the data sheet specifies the maximum allowable dI_T/dt for this mode of triggering.

Thermal ratings

Steady state thermal resistances.

$R_{th\ j\text{-}mb}$ Junction to mounting base is used for the SOT78 (TO220), SOT404 and SOT428 envelopes.

$R_{th\ j\text{-}hs}$ Junction to heatsink is used for full pack, isolated envelopes (e.g. SOT186A).

$R_{th\ j\text{-}sp}$ Junction to solder point is used for the smallest surface mounting envelope, SOT223.

$R_{th\ j\text{-}lead}$ Junction to lead is used for the SOT54 (TO92) small outline.

The maximum value of the thermal resistance is given in the data sheet, and is used to specify the device rating. The average junction temperature rise for a given dissipation is given by multiplying the average dissipation by the thermal resistance.

Note that for triacs, two values of thermal resistance are quoted; one for half cycle operation and one for full cycle operation. This is because only half of the chip carries current in each half cycle allowing the non-conducting half to cool down between conduction periods. The net effect is to reduce the average thermal resistance for full cycle conduction.

$R_{th\ j\text{-}a}$ Typical values of junction to ambient thermal resistance are given in the data sheet. This assumes that, for leaded devices intended for through-hole mounting, the device is mounted vertically on a printed circuit board in free air, and for surface mount packages the device is soldered to a given pad area on given PCB material.

$Z_{th\ j\text{-}mb}$, $Z_{th\ j\text{-}hs}$ Whilst the average junction temperature rise may be found from the thermal resistance figure, the peak junction temperature requires knowledge of the current waveform and the transient thermal impedance. The thermal impedance curves in the data sheets are based on rectangular power pulses. The junction temperature rise due to a rectangular power pulse, is given by multiplying the peak dissipation during the pulse by the thermal impedance $Z_{th\ j\text{-}mb}$ for the given pulse width. Analysis methods for non-rectangular pulses are covered in the Power Semiconductor Applications handbook.

T_{jmax} The maximum operating junction temperature range for all of our thyristors and triacs is 125˚C. This applies in either the on-state or off-state, and for either half cycle or full cycle conduction. It is permissible for the junction temperature to exceed $T_{j\ max}$ for short periods during non-repetitive surges, but for repetitive operation the peak junction temperature must remain below $T_{j\ max}$.

T_{stg} The limiting storage temperature range for all of our thyristors and triacs is -40˚C to 150˚C.

$P_{G(AV)}$, P_{GM}, I_{GM}, V_{GM} The average and peak gate power dissipation, and the maximum gate voltage and gate current. Exceeding the gate ratings can cause the device to degrade gradually, or fail completely.

Thyristor and Triac Characteristics

A characteristic is an inherent and measurable property of a device. Such a property may be expressed as a value for stated or recognized conditions. A characteristic may also be a set of related values, usually shown in graphical form.

Static characteristics

V_T On-state voltage. The tabulated value in the data sheet is the maximum, instantaneous on-state voltage measured under pulse conditions to avoid excessive dissipation, at a junction temperature of 25˚C. The data sheet also contains a graph showing the maximum and typical characteristics at 125˚C and the maximum characteristic at 25˚C. The maximum characteristic at 125˚C is used to calculate the dissipation for a given average or rms current, and hence the graph of on-state dissipation versus average or rms current in the data sheet.

The on-state voltage/ current characteristic of a diode, thyristor or triac may be approximated by a piecewise linear model as shown in the figure below; where R_S is the slope of the tangent to the curve at the rated current, and V_O is the voltage axis intercept. The on-state voltage is then $V_T = V_O + I_T.R_S$, and the instantaneous dissipation is $P_T = V_O.I_T + I_T^2.R_S$. where I_T is the instantaneous on-state current.

It can be shown that the average on-state dissipation for any current waveform is: $P_{T(AV)} = V_O.I_{T(AV)} + I_{T(RMS)}^2.R_S$, where $I_{T(AV)}$ is the average on-state current and $I_{T(RMS)}$ is the rms value of the on-state current. Graphs in the published data show on-state dissipation as a function of average current for thyristors and versus rms current for triacs. Sinusoidal current waveforms are assumed and the graphs show dissipation over a range of conduction angles

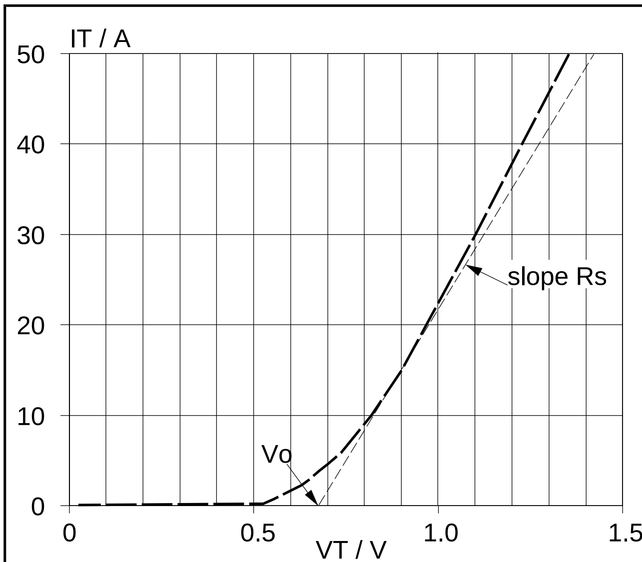

Fig. 1. Piecewise linear approximation to thyristor and triac on-state characteristic.

I_{GT} Gate trigger current. The data sheet shows the typical and maximum gate trigger current at a junction temperature of 25˚C. A graph in the data sheet shows the variation of normalised I_{GT} with temperature.

When designing a triac gate trigger circuit, triggering in quadrant (iv) (T2-, G+) should be avoided if possible. The gate trigger current in this quadrant is much higher than in the other three quadrants and the device is more susceptible to turn-on dI_T/dt failure.

V_{GT} Gate trigger voltage. The data sheet shows the typical and maximum gate trigger voltage at a gate current equal to I_{GT}, at a junction temperature of 25˚C. A graph in the data sheet shows the variation of normalised V_{GT} with temperature.

To ensure that a device will not trigger, the gate voltage must be held below the minimum gate trigger voltage. The data sheet quotes $V_{GT(min)}$ at the maximum junction temperature (125˚C), and the maximum off-state voltage ($V_{DRM(max)}$).

I_L Latching current. The latching current is the value of on-state current required to maintain conduction at the instant when the gate current is removed. A graph in the data sheets shows the variation of normalised I_L with temperature.

To trigger a thyristor or triac, a gate current greater than the maximum device gate trigger current I_{GT} must be applied until the on-state current I_T rises above the maximum latching current I_L. This condition must be met at the lowest junction temperature.

I_H Holding current. The holding current is the value of on-state current required to maintain conduction once the device has fully turned on and the gate current has been removed. The on-state current must have previously exceeded the latching current I_L. A graph in the data sheet shows the variation of normalised I_H with temperature.

To turn off (commutate) a thyristor or triac, the load current must remain below I_H for sufficient time to allow a return to the off-state. This condition must be met at the highest operating junction temperature (125˚C).

I_D, I_R The maximum off-state leakage current, specified at rated $V_{DRM(max)}$, $V_{RRM(max)}$ at 125˚C.

Dynamic characteristics

dV_D/dt Critical rate of rise of off-state voltage. Displacement current caused by a high rate of rise of off-state voltage can induce a gate current sufficient to trigger the device. Devices with sensitive gates are particularly susceptible to dV_D/dt triggering, and since gate trigger current decreases as junction temperature increases, the condition is worse when the device is hot. The data sheet figure is specified at 125˚C using an exponential waveform and a maximum applied voltage of 67% $V_{DRM(max)}$. The dV_D/dt is measured to 63% of the maximum voltage.

To prevent sensitive gate devices from false triggering due to high rates of rise of off state voltage, 1 kΩ resistor in parallel with a 10nF capacitor may be fitted between gate and cathode (gate and terminal 1 for a triac). This approach is less effective for standard gate devices. In this case, the preferred option is to fit an RC snubber between anode and cathode (T2 and T1 for a triac) to reduce the dV_D/dt below the critical value.

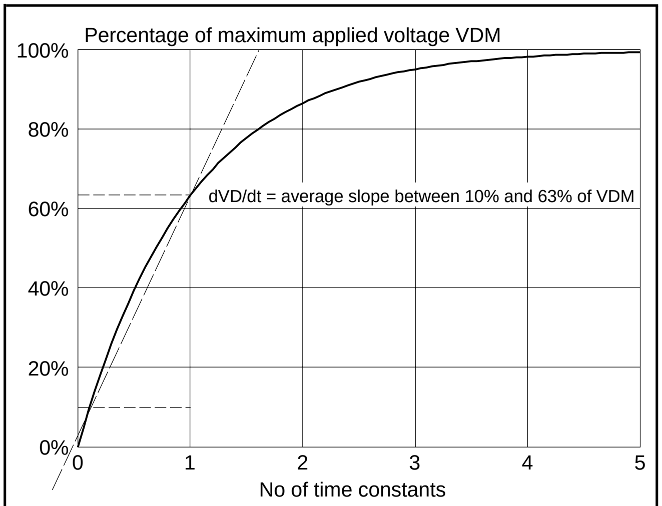

Fig. 2. Exponential waveform used for measurement of critical off-state dV_D/dt. The dV_D/dt is the average slope between 10% and 63% of the maximum applied voltage V_{DM}.

t_{gt} Gate controlled turn-on time. A typical turn on time of 2 µs is specified for all our thyristors and triacs.

t_q Circuit commutated turn-off time. A typical turn off time of 70 µs is specified for standard gate thyristors and 100µs for sensitive gate thyristors.

Triac Commutation

A triac is an AC conduction device and may be thought of as two thyristors in antiparallel, monolithically integrated onto the same silicon chip. In phase control circuits, the triac often has to be triggered into conduction part way into each half cycle. This means that at the end of each half cycle the on-state current in one direction must drop to zero and not resume in the other direction until the device is triggered again. This commutation turn-off capability is at the heart of triac power control applications. If the triac were truly two separate thyristors in antiparallel, this requirement would not present any problems. However, as the two are on the same piece of silicon there is the possibility that the unrecombined charge of one thyristor as it turns off may act as gate current to trigger the other thyristor as the voltage rises in the opposite direction. This phenomenon is called commutation failure.

There are two components of current which can act as gate current to cause commutation failure. One of these is the displacement current generated by the reapplied dV_{COM}/dt. The other is the recombination current, which is mainly determined by the rate of fall of commutating current, dI_{COM}/dt. Both tend to create a lateral volt drop in the cathode of the opposing thyristor which triggers the device in the opposite direction to the original current flow.

At low rates of fall of current, dI_{COM}/dt, the amount of unrecombined charge is small and commutation failure occurs mainly because of the rate of rise of off-state voltage, dV_{COM}/dt. This situation is worse for inductive loads where the rate of rise of voltage can be very high when commutation occurs. The conventional remedy for this type of commutation failure is to fit a snubber across the device to limit the rate of rise of off-state voltage dV_{COM}/dt.

At high values of dI_{COM}/dt as would occur with a rectifier-fed DC motor, the recombination current dominates and, above a critical value of dI_{COM}/dt, the device will not commutate even at fairly low values of dV_{COM}/dt. Under these conditions, a snubber will not prevent commutation failure, and the best option is to use a High Commutation Triac.

Three Quadrant Triacs

Philips three quadrant triacs, which include Hi-Com types, attempt to separate the two antiparallel thyristor structures to prevent the unrecombined charge from the conducting half becoming gate current in the other half. This is accomplished by lateral separation of the top and bottom emitters, more extensive emitter and peripheral shorting, and by a modified gate design which prevents triggering in quadrant (iv).

The device design, in addition to giving high immunity to commutation failure, also improves the off-state dV_D/dt capability. They will commutate the full rated current up to 125˚C without the aid of a snubber and will also withstand extremely high rates of rise of off-state voltage, in excess of 1000 V/µs. High commutation triacs can simplify circuit design by eliminating the need for RC snubbers. Typical applications include:

Motor starting, where the triac may be required to commutate the starting current;

Switching of DC operated relay coils or motors, where the time constant of the coil is much greater than the mains period;

Static switching, where it is required to turn the triac off whilst it is carrying an overload current.

dV_{COM}/dt Critical rate of rise of commutating voltage. For conventional, as opposed to high commutation triacs, the data sheet conditions specify a junction temperature of 95˚C and a dI_{COM}/dt given by $2.\sqrt{2}.\pi.f.I_{T(RMS)}$, where f is the mains frequency (assumed to be 50Hz). This value is the maximum rate of change of current which occurs at the zero crossing for a sine wave current equal to the rated rms value, $I_{T(RMS)}$. Graphs in the data sheet show the variation of dV_{COM}/dt and with junction temperature with dI_{COM}/dt as a parameter.

dI_{COM}/dt Critical rate of change of commutating current. High Commutation Triacs are intended for use in circuits where high values of both dI_{COM}/dt and dV_{COM}/dt can occur. Commutation capability is specified in terms of dI_{COM}/dt, without a snubber and at the highest junction temperature, T_{jmax} = 125˚C. A graph in the data sheet shows the variation of dI_{COM}/dt with junction temperature.

Operation up to 150˚C

The maximum operating junction temperature, T_{jmax} of Philips thyristors and triacs is 125˚C. Operation above T_{jmax} for long periods, particularly in the off-state, can give rise to reliability problems due to changes in characteristics which occur as a result of mobile charge in the glass passivation.

Furthermore, as a thyristor or triac gets hot, it becomes more susceptible to false gate triggering, off-state dV_D/dt triggering, thermal runaway and commutation failure.

However, it has become apparent that some customers have applications which require operation of thyristors and triacs at higher junction temperatures.

Recent improvements in Philips glass mesa technology backed up by extensive reliability testing has shown that, for certain applications, our thyristors and triacs can be operated reliably at junction temperatures up to 150˚C.

Typical applications where 150˚C operation may be allowed include:- static switching of resistive loads, power switches for domestic appliances and electric heating applications where the device is mounted on a high temperature substrate.

Extending the upper operating junction temperature to 150˚C depends very much on the application. For this reason we recommend that customers wishing to use our thyristors and triacs at 150˚C contact the Field Applications Engineer at their Regional or National sales office.

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