Thyristors and Triacs

Technical Publications

Philips Semiconductors publishes many Technical Publications each year on various aspects of power semiconductors. All the publications relevant to thyristors and triacs are reproduced in this chapter. They provide some useful information on the different device types. They also give hints and ideas on how best to use thyristors and triacs.

The technical information contained within these publications always remains relevant. However due to the wide range in their issue dates, product information, where provided, will be historical and might have been superceded. Please bear this fact in mind when reading any selection tables. The up-to-date product information can be found in the selection guide at the front of this data book.

FACTSHEET 013. UNDERSTANDING Hi-Com TRIACS

Issue date August 1993 Document number 9398 510 21011

Hi-Com triacs from Philips Semiconductors are specifically designed to give superior triac commutation performance in the control of motors for domestic equipment and tools. These devices are suitable for use with a wide variety of motor and inductive loads without the need for a protective snubber. The use of a Hi-Com triac greatly simplifies circuit design and gives significant cost savings to the designer.

This product information sheet explains how the superior characteristics and performance of Hi-Com triacs removes design limitations of standard devices.

Triac commutation explained

A triac is an AC conduction device and may be thought of as two antiparallel thyristors 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 this requirement would not present any problems. However, as the two are on the same piece of silicon, there is the possibility that the "reverse recovery current" (due to unrecombined charge carriers) 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 is described as a "commutation failure" and results in the triac continuing to conduct in the opposite direction instead of blocking.

The probability of any device failing commutation is dependent on the rate of rise of reverse voltage (dV/dt) and the rate of decrease of conduction current (dI/dt). The higher the dI/dt the more unrecombined charge carriers are left at the instant of turn-off. The higher the dV/dt the more probable it is that some of these carriers will act as gate current. Thus the commutation capability of any device is usually specified in terms of the turn-off dI/dt and the re-applied dV/dt it can withstand, at any particular junction temperature.

If a triac has to be operated in an inductive load circuit with a combination of dI/dt and dV/dt that exceeds its specification, it is necessary to use an RC-snubber network in parallel with the device to limit the dV/dt. This is at a penalty of extra circuit complexity and dissipation in the snubber. The "High Commutation" triacs (Hi-Com triacs) are designed to have superior commutation capability, so that even at a high rate of turn-off (dI/dt) and a high rate of re-applied dV/dt, they can be used without the aid of a snubber network, thus greatly simplifying the circuit. The design features of Hi-Com devices that have made this possible are:

1. Geometric separation of the two antiparallel thyristors

Commutation failure can be avoided by physically separating the two 'thyristor halves' of a triac. However, separating them into two discrete chips would remove the advantage of a triac being triggerable in both directions by the same gate connection. Within the integrated structure of a Hi-Com triac the two halves of the device are kept further apart by modifying the layout of the chip in order to lessen the chance of conduction in one half affecting the other half.

2. Emitter shorting

"Emitter shorts" refer to the on-chip resistive paths between emitter and base of a transistor. A higher degree of emitter shorting means the presence of more such paths and lower resistance values in them. The use of emitter shorts in a triac has two effects on commutation.

Firstly it reduces the gain of the internal transistors that make up the triac. This means there will be fewer carriers left to recombine when the conduction current falls to zero, and therefore a smaller probability that a sufficient number will be available to re-trigger the triac. The second way in which emitter shorts help commutation is that any unrecombined carriers in the conducting thyristor at turn-off will have more chance of flowing out through the emitter shorts (of the opposite thyristor) rather than acting as gate current to trigger that thyristor on.

The Hi-Com triacs have a higher degree of emitter shorting both around the periphery of the device and in the central part of the active area. This both reduces the number of carriers available, and lessens the danger of any available carriers acting as gate current for undesirable triggering.

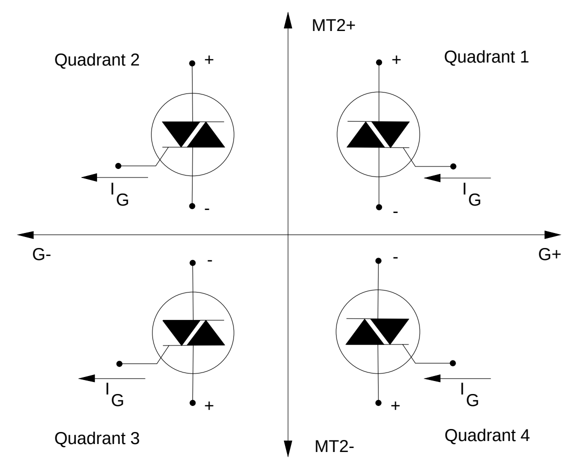

Fig. 1. Standard triac triggering quadrants.

3. Modified gate structure

The gate of a triac allows conduction in both directions to be initiated by either a positive or a negative current pulse between gate (G) and main terminal (MT1). The four different modes of triggering are often called 1+, 1-, 3- and 3+ (or sometimes quadrants 1, 2, 3 and 4) and are shown in Fig. 1.

This triggering versatility arises from the fact that the gate consists of some elements which conduct temporarily during the turn-on phase. In particular, one of the triggering modes, 3+ (or quadrant 4), relies on the main terminal 1 supplying electrons to trigger a thyristor element in the gate-MT1 boundary. Conduction then spreads to the main thyristor element from this boundary.

Unfortunately the carrier distribution in this triggering mode of operation is very similar to that existing when the triac is commutating in the 1-to-3 direction (i.e changing from conduction with MT2 positive to blocking with MT1 positive). The presence of the element in the gate to allow 3+ triggering will therefore always also undermine commutation capability in the 1-to 3 direction. For this reason the Hi-Com triacs have a modified gate design to remove this structure. This incurs the penalty that the 3+ trigger mode cannot be used, but it greatly improves the commutation performance of the device.

Conclusions

By modifications to the internal design and layout of the triac it is possible to achieve a high commutation capability triac for use in inductive and motor load applications. These modifications have been implemented in the Hi-Com range of devices from Philips Semiconductors. The devices can be used in all typical motor control applications without the need for a snubber circuit. The commutation capability of the devices is well in excess of the operating conditions in typical applications.

As the loss of the fourth trigger quadrant can usually be tolerated in most designs, Hi-Com triacs can be used in existing motor control applications without the snubber network required for a standard device. This gives the designer significant savings in design simplicity, board space and system cost.

FACTSHEET 014. USING Hi-Com TRIACS

Issue date September 1995 Document number 9397 750 00316

Hi-Com triacs from Philips Semiconductors are specifically designed to give superior triac commutation performance in the control of motors for domestic equipment and tools. These devices are suitable for use with a wide variety of motor and inductive loads without the need for a snubber. The use of a Hi-Com triac greatly simplifies circuit design and gives significant cost savings to the designer.

This product information sheet explains how the need for a triac snubber arises and how the superior performance of Hi-Com triacs removes design limitations of standard devices. The Hi-Com range is summarised in Table 1.

Triac commutation

For resistive loads the device current is in phase with the line voltage. Under such conditions triac turn-off (commutation) occurs at the voltage "zero-crossover" point. This is not a very severe condition for triac commutation: the slow rising dV_{COM}/dt gives time for the triac to turn off (commutate) easily.

The situation is quite different with inductive or motor loads. For these circuits, conduction current lags behind the line voltage as shown in Fig. 1. When triac commutation occurs, the rate of rise of voltage in the opposite direction can be very rapid and is governed by the circuit and device characteristics. This high dV_{COM}/dt means there is a much higher probability of charge carriers in the device re-triggering the triac and causing a commutation failure.

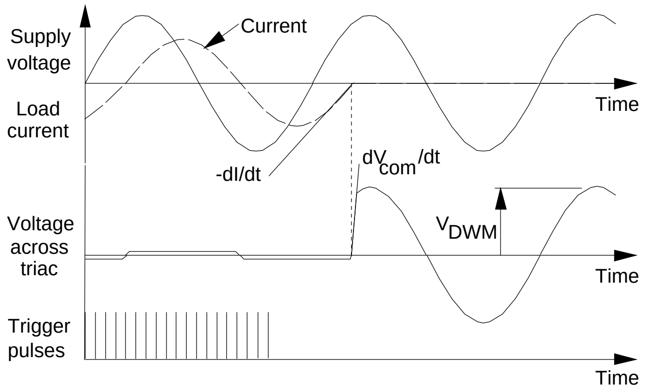

Fig. 1. Triac commutation waveforms (inductive load).

Hi-Com triacs

Hi-Com triacs are specifically designed for use with AC inductive loads such as motors. As commutation capability is not an issue for resistive load applications then standard triacs are usually the most appropriate devices for these applications. The significant advantage of a Hi-Com triac is that it can withstand a very high rate of rise of reapplied voltage at commutation. This removes the requirement for a snubber circuit in inductive load circuits. An additional advantage of the Hi-Com design is that the off-state (static) dV_D/dt capability of the device is also significantly improved.

When using Hi-Com triacs in inductive load applications, the trigger circuit cannot trigger the device in the fourth (3+) quadrant (Fig. 2). Fortunately the vast majority of circuit designs do not require this mode of operation and so are suitable for use with Hi-Com triacs without modification. The circuit of Fig. 3 is a typical example of the simplest type of trigger circuit. Hi-Com triacs are equally also suitable for use with microcontroller trigger circuits.

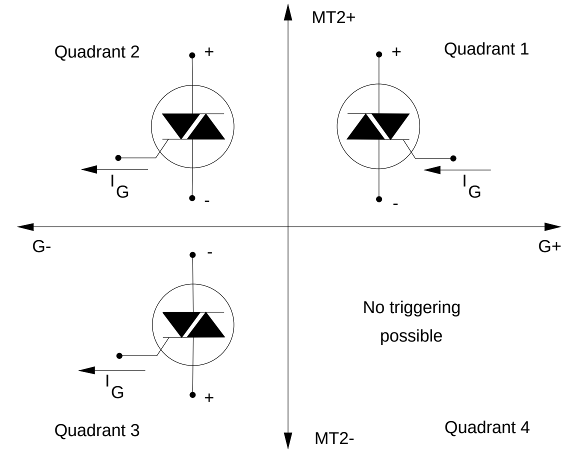

Fig. 2. Hi-Com triac triggering quadrants.

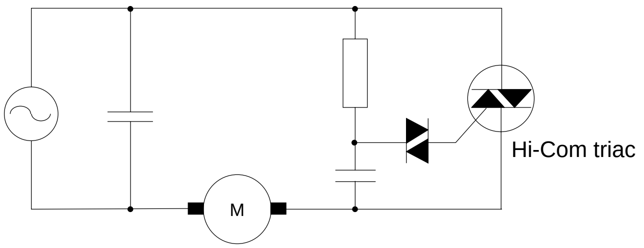

Fig. 3. Phase control circuit using Hi-Com triac.

Device limiting values

i) Trigger current, I_{GT}

Trigger current for the Hi-Com triacs is in the range 2mA to 50mA. This means that gate currents due to noise that are below 2mA in amplitude can be guaranteed not to trigger the devices. This gives the devices a noise immunity feature that is important in many applications. The trigger current delivered by the trigger circuit must be greater than 50mA under all conditions in order to guarantee triggering of the device when required. As discussed above, triggering is only possible in the 1+, 1- and 3- quadrants.

ii) Rate of change of current, dI_{com}/dt

Hi-Com triacs do not require a snubber network providing that the rate of change of current prior to commutation is less than the rating specified in the device data sheet. This dI_{com}/dt limit is well in excess of the currents that occur in the device under normal operating condition, during transients such as start-up and faults such as the stalled motor condition.

As an example, for the 12A Hi-Com triacs the limit commutating current is typically 24A/ms at 125˚C. This corresponds to an RMS current of 54A at 50Hz. For the 16A Hi-Com triacs the limit commutating current is typically 28A/ms at 125˚C. This corresponds to an RMS current of 63A at 50Hz. Typical stall currents for an 800W domestic appliance motor are in the range 15A to 20A and so the commutation capability of the Hi-Com triacs is well above the requirement for this type of application.

Conclusions

The Hi-Com range of devices from Philips Semiconductors can be used in all typical motor control applications without the need for a snubber circuit. The commutation capability of the devices is well in excess of the operating conditions in typical applications.

As the loss of the fourth trigger quadrant can usually be tolerated in most designs, Hi-Com triacs can be used in existing motor control applications. By removing the snubber the use of a Hi-Com triac gives the designer significant savings in design simplicity, board space and system cost.

	V_{DRM} (V)	$I_{T(RMS)}$ (A)	I_{GT} (mA)	dV_D/dt (V/µs)	dI_{com}/dt (A/ms)	dI_T/dt (A/µs)	Package
BTA208-600B	600	8	2 - 50	1000	14	100	SOT78
BTA208-800B	800	8	2 - 50	1000	14	100	SOT78
BTA208X-600B	600	8	2 - 50	1000	14	100	SOT186A
BTA208X-800B	800	8	2 - 50	1000	14	100	SOT186A
BTA212-600B	600	12	2 - 50	1000	24	100	SOT78
BTA212-800B	800	12	2 - 50	1000	24	100	SOT78
BTA212X-600B	600	12	2 - 50	1000	24	100	SOT186A
BTA212X-800B	800	12	2 - 50	1000	24	100	SOT186A
BTA216-600B	600	16	2 - 50	1000	28	100	SOT78
BTA216-800B	800	16	2 - 50	1000	28	100	SOT78
BTA216X-600B	600	16	2 - 50	1000	28	100	SOT186A
BTA216X-800B	800	16	2 - 50	1000	28	100	SOT186A
BTA225-600B	600	25	2 - 50	1000	44	100	SOT78
BTA225-800B	800	25	2 - 50	1000	44	100	SOT78

Table 1. Hi-Com triac range in leaded packages. (SOT78 <=> TO220.)

FACTSHEET 067. LOGIC LEVEL AND SENSITIVE GATE TRIACS

Issue date March 1996 Document number 9397 750 00759

Introduction

Triacs have been available since the early 1970s. They could be regarded as a mature technology. However, they remain an extremely popular power control device for AC mains applications because of their low cost and the simplicity of their control circuits. Nothing can better them in these two respects. There has even been an upsurge in their use in the 1990s due partly to the proliferation of domestic appliances with electronic controls. Common examples of these include air and water heaters, vacuum cleaners, refrigerators, washing machines, dishwashers and most small kitchen appliances.

Despite their maturity, triacs have not "stood still" since their first invention. They have evolved to meet the changing demands of the applications. One important change in triac requirements is the gate sensitivity specification I_{GT}. Early triac trigger circuits were built using discrete components which could supply high currents up to 100mA peak or more. Triacs therefore did not require sensitive gates. This is still relevant today for phase control circuits which use a diac such as the BR100/03 to trigger the triac. However, Integrated Circuit control is becoming ever more popular for two main reasons:

1. Stringent Electro Magnetic Compatibility regulations limit the harmonic currents that can be drawn from the mains and also limit the amount of Radio Frequency Interference that can be generated by appliances. This requires the use of either a dedicated zero crossing triac power control IC such as the OM1654 or OM1682 from Philips Australia, or a microcontroller which has been programmed to perform a similar function in which a high harmonic and RFI-generating phase control circuit is replaced by an electrically "quieter" alternative. An example might be Binary Rate Modulation power control, where varying full and half mains cycles are conducted symmetrically to ensure very low harmonic currents and zero DC component in the current waveform.

2. More intelligent appliance controls are now being demanded such as remote control, soft start, variable timing, automatic power ramp-up & ramp-down, and power reduction after full power startup for energy conservation measures (applicable to refrigerator compressors in particular). These would be very complicated, expensive or even impossible to implement using discrete components.

Integrated circuits such as the dedicated triac controller ICs and microcontrollers possess a limited drive current capability which ranges from 10mA to 15mA typically. Moreover, since the IC's supply is usually derived from the mains via a resistive/capacitive dropper and simple half wave rectifier, power dissipation in the resistor can very easily become unacceptably high if the load current is not kept to an absolute minimum. This means that the average current demand from the IC's power supply must usually be minimised. This can impose a limit on the current amplitude and duration available for triggering the triac. This is even more relevant if several triacs are controlled by one microcontroller. Examples where this holds true are fridge freezers and washing machines. This can mean that the drive current available for triac triggering is even less than the 10mA to 15mA suggested above.

Figure 1 shows a simple IC-triac arrangement. The 5.6V zener diode combined with the forward voltage drop of the rectifier diode produce an IC supply close to 5V. The advantages of connecting the zener as shown instead of directly across the IC are that full wave current is drawn from the mains supply (no DC component), and the forward conduction of the zener means that the rectifier never has to support full mains voltage. A cheap, low voltage diode can therefore be used. Attention must be paid, however, to the additional power dissipation in the resistor due to the forward zener current.

These IC-triac power control applications could not be implemented without sensitive triacs. Philips logic level D series and sensitive gate E series triacs are designed to meet fully the requirements in this burgeoning market. For a full selection guide of available types, see Tables 1 and 2.

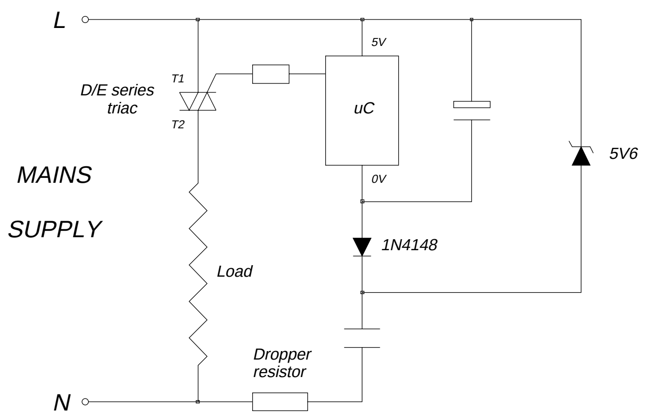

Fig. 1. A typical microcontroller / triac arrangement.

Gate trigger current I_{GT}

Philips D and E series triacs are specified to trigger in all four quadrants. However, a feature of four-quadrant triacs is that they are less sensitive and more difficult to trigger in the 4th (T2-, G+) quadrant. (For example, for the D series, max I_{GT} in quadrant 1,2,3,4 is 5,5,5,10mA, and for the E series it is 10,10,10,25mA.) The ability of triacs to support a high rate of rise of load current (dI_T/dt) after turn-on is also limited in the 4th quadrant. (dI_T/dt is 10A/µs compared with 50A/µs in the other three quadrants). For these two reasons, operation in the 4th quadrant is not recommended if it can be avoided.

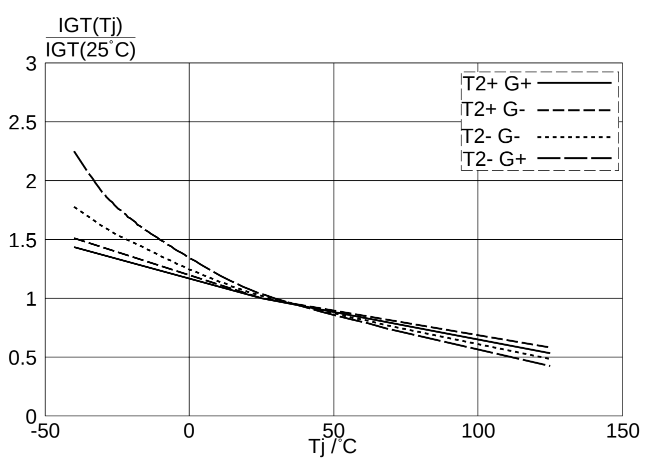

Fig. 2. BT136 series D normalised I_{GT} versus T_j.

Since the control IC operates on a single rail supply (usually +5V), its outputs are unipolar. It can be referenced to the mains circuit in order to source current (positive gate drive) or to sink current (negative gate drive). Since 4th quadrant triggering should be avoided, optimum performance will be obtained with negative gate current - i.e operation in the 2nd (T2+, G-) and 3rd (T2-, G-) quadrants (see Fig. 1).

A triac's I_{GT} varies with junction temperature. At lower temperature the I_{GT} increases. It is therefore important to ensure that the circuit supplies enough gate current at the lowest expected operating temperature for guaranteed triggering. Figure 2 shows an example of normalised I_{GT} versus T_j for the BT136 series D.

Latching current I_L

If the triac is triggered by a gate current at the beginning of a mains half cycle, the load current will build up gradually from zero. The gate current must not be removed before the triac is latched ON otherwise it will return to the blocking state. Latching occurs when the load current reaches I_L. The gate pulse must therefore be present until the load current has reached I_L.

Just as for I_{GT}, I_L also increases at lower temperature. The gate pulse duration must be specified at the lowest expected operating temperature for guaranteed triggering. Figure 3 shows an example of normalised I_L versus T_j for the BT136 series D.

How quickly the load current reaches the triac's I_L will depend on the peak load current and mains frequency. Taken to the extreme case, if the load current is so low that its peak value is equivalent to I_L, it will take one quarter cycle, or 5ms for 50Hz mains, before the triac is latched and the gate pulse can cease.

It is also important to be aware that higher current triacs have a higher I_L. This could compound problems or even lead to the triac never latching ON if the load current is lower than the triac's I_L. So, apart from the higher component cost, it would not be a good idea to use a triac whose current rating is very much higher than the load current when a lower current type is available. Tables 1 and 2 illustrate how I_L varies with the triggering quadrant and triac current rating.

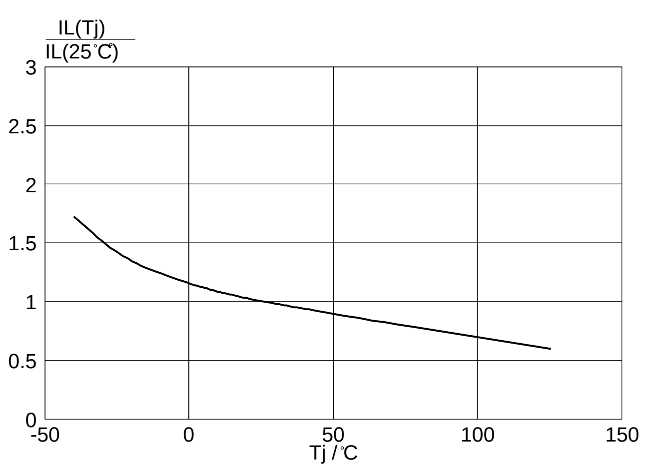

Fig. 3. BT136 series D normalised I_L versus T_j.

Minimum triac drive current calculation

Because the current demand must be minimised in many IC applications, it is necessary to calculate the gate pulse duration to be just long enough to guarantee triac triggering while avoiding unnecessary burden on the IC's power supply. The time to reach I_L, hence the gate pulse duration, can be calculated using the equation:

$I_L = I_{pk} \times \sin(2\pi ft)$. Transposing gives:

$$t = 1/(2\pi f) \times \sin^{-1}(I_L/I_{pk}).$$

The average gate current supplied by the IC is calculated by multiplying its peak gate current with t/T. Hence:

$$I_{G(ave)} = I_{G(pk)} \times t/T.$$

I_L = triac latching current at the lowest expected operating temperature,
I_{pk} = peak load current,
t = gate pulse duration,
T = gate pulse cycle time.

Note:- Since triac latching current is higher in the 2nd and 4th quadrants, and normal operation for IC triggering is in the 2nd and 3rd quadrants, the gate current calculations must always be based on the worst case quadrant 2 I_L condition.

If the load current is very low and the necessary gate pulse duration imposes too great a burden on the IC's power supply, triggering could be delayed for a few degrees to allow the supply voltage to build up a little. The time to reach I_L will then be shortened by the delay time (true for resistive loads). Now that switching occurs further from the zero crossing, there will be a slightly increased risk of RFI generation, even if the load current is very low as in this case. RFI measurements will show if filtering is necessary to meet the relevant EMC legislation.

Holding current I_H

As the load current reduces towards the end of a mains half cycle, a current, I_H, will be reached when the triac is no longer latched. It will cease to conduct in the absence of a gate current. I_H also increases with reducing temperature. Figure 4 shows an example of normalised I_H versus T_j for the BT136 series D.

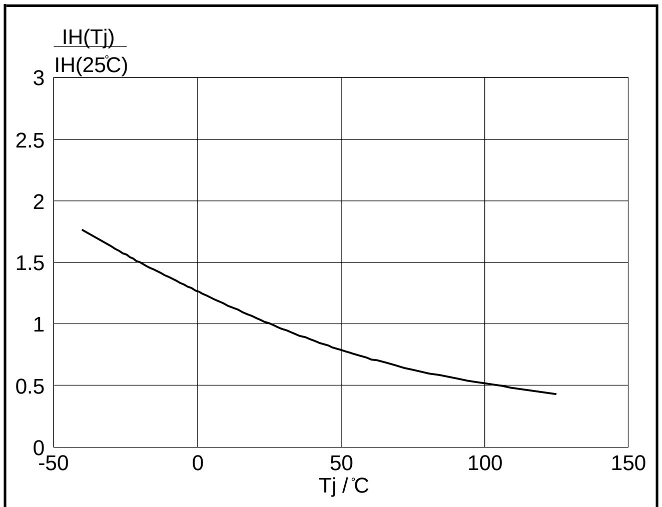

Fig. 4. BT136 series D normalised I_H versus T_j.

In some IC applications where the triac is used as a power switch, for example a precision electronic thermostat for a refrigerator compressor, continuous conduction must be maintained through the current zero crossing. (This is essential to prevent glitches and RFI generation.) Continuous conduction is achieved by monitoring the load current and applying a gate pulse before the triac's I_H is reached, and maintaining the pulse until the current has passed through zero and risen to the triac's I_L in the alternate quadrant. This condition must be met at the lowest expected operating temperature for continuous glitch-free conduction under worst case conditions.

I_H increases for the larger E series triacs. The most sensitive D series triacs, however, are designed to maintain a consistent, low I_H of 10mA @ 25˚C even for the higher 8A current rating.

Figure 5 illustrates triac load current zero crossing and the minimum gate pulse required for continuous conduction through the max I_H and I_L points. The diagram illustrates how I_H remains constant in different quadrants. The point made earlier about how I_L varies in different quadrants is illustrated by the higher I_L in the 2nd quadrant (T2+, G-). I_G duration must meet this worst case condition.

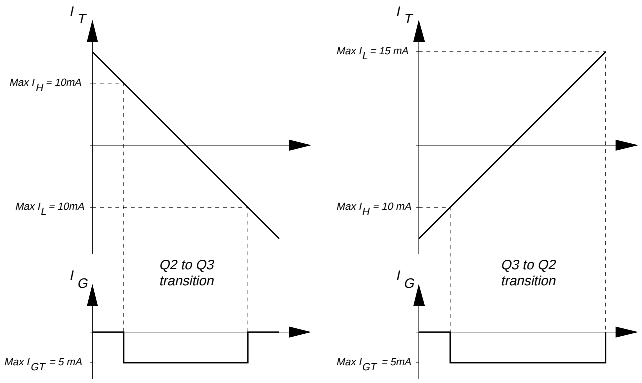

Fig. 5. Relationship between I_L, I_H and I_{GT} for BT136 series D at 25˚C.

Selection guide

Type number	$I_{T(RMS)}$ (A)	V_{DRM} (V)	I_{GT} max (mA)	I_L max (mA)	I_H max (mA)	Package
BT134W-...D BT134-...D BT136-...D BT136F-...D BT136X-...D	1 4 4 4 4	500,600	5,5,5,10	10,15,10,15	10	SOT223 SOT82 SOT78 SOT186 SOT186A
BT137-...D BT137F-...D BT137X-...D	8 8 8	500,600	5,5,5,10	15,20,15,20	10	SOT78 SOT186 SOT186A

Tabe 1. Philips D series logic level triacs.

Type number	$I_{T(RMS)}$ (A)	V_{DRM} (V)	I_{GT} max (mA)	I_L max (mA)	I_H max (mA)	Package
BT134W-...E BT134-...E BT136-...E BT136F-...E BT136X-...E	1 4 4 4 4	500,600 500,600,800	10,10,10,25	15,20,15,20	15	SOT223 SOT82 SOT78 SOT186 SOT186A
BT137-...E BT137F-...E BT137X-...E	8 8 8	500,600,800	10,10,10,25	25,35,25,35	20	SOT78 SOT186 SOT186A
BT138-...E BT138F-...E BT138X-...E BT139-...E BT139F-...E BT139X-...E	12 12 12 16 16 16	500,600,800	10,10,10,25	30,40,30,40	30	SOT78 SOT186 SOT186A SOT78 SOT186 SOT186A

Table 2. Philips E series sensitive gate triacs.

NOTE: SOT78 is equivalent to TO220AB.

THYRISTORS AND TRIACS - TEN GOLDEN RULES FOR SUCCESS IN YOUR APPLICATION

Issue date May 1996 Document number 9397 750 00812

This Technical Publication aims to provide an interesting, descriptive and practical introduction to the golden rules that should be followed in the successful use of thyristors and triacs in power control applications.

Thyristor

A thyristor is a controlled rectifier where the unidirectional current flow from anode to cathode is initiated by a small signal current from gate to cathode.

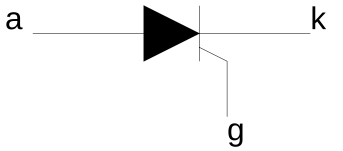

Fig. 1. Thyristor.

The thyristor's operating characteristic is shown in Fig. 2.

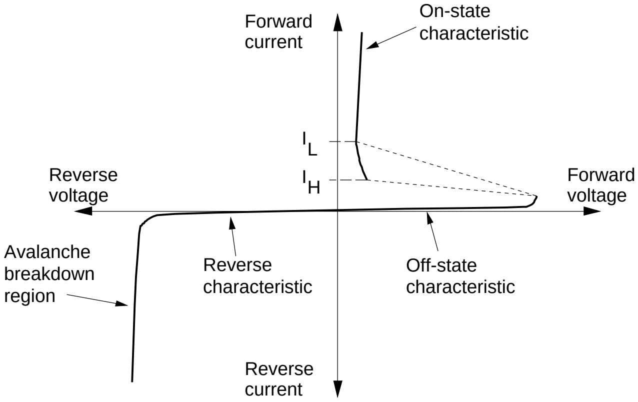

Fig. 2. Thyristor V/I characteristic.

Turn-on

A thyristor is turned on by making its gate positive with respect to its cathode, thereby causing current flow into the gate. When the gate voltage reaches the threshold voltage V_{GT} and the resulting current reaches the threshold current I_{GT}, within a very short time known as the gate-controlled turn-on time, t_{gt}, the load current can flow from 'a' to 'k'. If the gate current consists of a very narrow pulse, say less than 1μs, its peak level will have to increase for progressively narrower pulse widths to guarantee triggering.

When the load current reaches the thyristor's latching current I_L, load current flow will be maintained even after removal of the gate current. As long as adequate load current continues to flow, the thyristor will continue to conduct without the gate current. It is said to be latched ON.

Note that the V_{GT}, I_{GT} and I_L specifications given in data are at 25 ˚C. These parameters will increase at lower temperatures, so the drive circuit must provide adequate voltage and current amplitude and duration for the lowest expected operating temperature.

Rule 1. To turn a thyristor (or triac) ON, a gate current $\geq I_{GT}$ must be applied until the load current is $\geq I_L$. This condition must be met at the lowest expected operating temperature.

Sensitive gate thyristors such as the BT150 can be prone to turn-on by anode to cathode leakage current at high temperatures. If the junction temperature T_j is increased above T_j max, a point will be reached where the leakage current will be high enough to trigger the thyristor's sensitive gate. It will then have lost its ability to remain in the blocking state and conduction will commence without the application of an external gate current.

This method of spurious turn-on can be avoided by using one or more of the following solutions:

1. Ensure that the temperature does not exceed T_j max.
2. Use a thyristor with a less sensitive gate such as the BT151, or reduce the existing thyristor's sensitivity by including a gate-to-cathode resistor of 1kΩ or less.
3. If it is not possible to use a less sensitive thyristor due to circuit requirements, apply a small degree of reverse biasing to the gate during the 'off' periods. This has the effect of increasing I_L. During negative gate current flow, particular attention should be paid to minimising the gate power dissipation.

Turn-off (commutation)

In order to turn the thyristor off, the load current must be reduced below its holding current I_H for sufficient time to allow all the mobile charge carriers to vacate the junction. This is achieved by "forced commutation" in DC circuits or at the end of the conducting half cycle in AC circuits. (Forced commutation is when the load circuit causes the load current to reduce to zero to allow the thyristor to turn off.) At this point, the thyristor will have returned to its fully blocking state.

If the load current is not maintained below I_H for long enough, the thyristor will not have returned to the fully blocking state by the time the anode-to-cathode voltage rises again. It might then return to the conducting state without an externally-applied gate current.

Note that I_H is also specified at room temperature and, like I_L, it reduces at higher temperatures. The circuit must therefore allow sufficient time for the load current to fall below I_H at the maximum expected operating temperature for successful commutation.

> *Rule 2. To turn off (commutate) a thyristor (or triac), the load current must be < I_H for sufficient time to allow a return to the blocking state. This condition must be met at the highest expected operating temperature.*

Triac

A triac can be regarded as a "bidirectional thyristor" because it conducts in both directions. For standard triacs, current flow in either direction between the main terminals MT1 and MT2 is initiated by a small signal current applied between MT1 and the gate terminal.

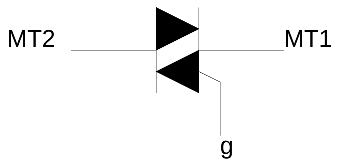

Fig. 3. Triac.

Turn-on

Unlike thyristors, standard triacs can be triggered by positive <u>or</u> negative current flow between the gate and MT1. (The rules for V_{GT}, I_{GT} and I_L are the same as for thyristors. See Rule 1.) This permits triggering in four "quadrants" as summarised in Fig. 4.

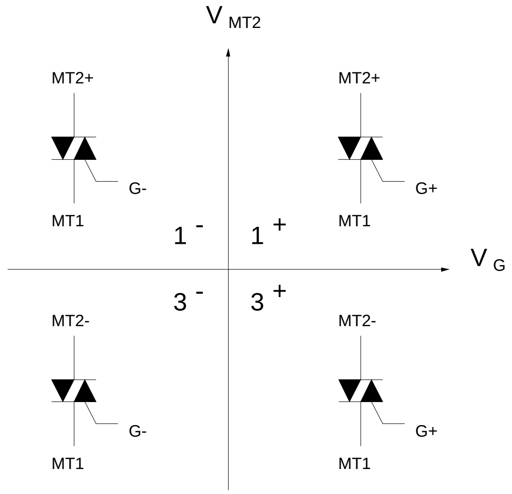

Fig. 4. Triac triggering quadrants.

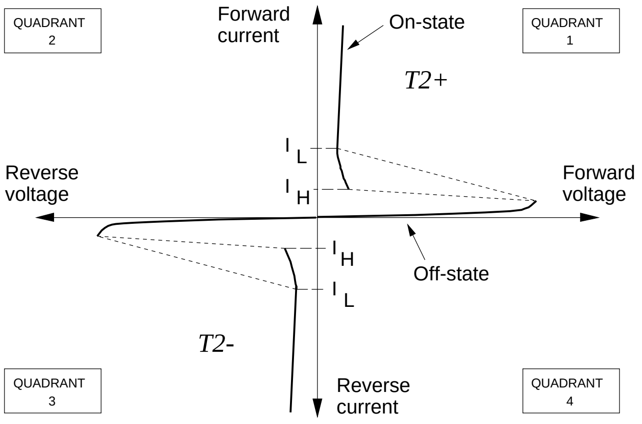

Fig. 5. Triac V/I characteristic.

Where the gate is to be triggered by DC or unipolar pulses at zero-crossing of the load current, negative gate current is to be preferred for the following reasons.

The internal construction of the triac means that the gate is more remote from the main current-carrying region when operating in the 3^+ quadrant. This results in:
1. Higher I_{GT} -> higher peak I_G required,
2. Longer delay between I_G and the commencement of load current flow -> longer duration of I_G required,
3. Much lower dI_T/dt capability -> progressive gate degradation can occur when controlling loads with high initial dI/dt (e.g. cold incandescent lamp filaments),
4. Higher I_L (also true for 1^- operation) -> longer I_G duration <u>might</u> be needed for very small loads when conducting from the beginning of a mains half cycle to allow the load current to reach the higher I_L.

In standard AC phase control circuits such as lamp dimmers and domestic motor speed controls, the gate and MT2 polarities are always the same. This means that operation is always in the 1^+ and 3^- quadrants where the triac's switching parameters are the same. This results in symmetrical triac switching where the gate is at its most sensitive.

Note:- The 1^+, 1^-, 3^- and 3^+ notation for the four triggering quadrants is used for brevity instead of writing "MT2+, G+" for 1^+, etc. It is derived from the graph of the triac's V/I characteristic. Positive MT2 corresponds with positive current flow into MT2, and vice versa (see Fig. 5). Hence, operation is in quadrants 1 and 3 only. The + and - superscripts refer to inward and outward gate current respectively.

> *Rule 3. When designing a triac triggering circuit, avoid triggering in the 3^+ quadrant (MT2-, G+) where possible.*

Alternative turn-on methods

There are undesirable ways a triac can be turned on. Some are benign, while some are potentially destructive.

(a) Noisy gate signal

In electrically noisy environments, spurious triggering can occur if the noise voltage on the gate exceeds V_{GT} and enough gate current flows to initiate regenerative action within the triac. The first line of defence is to minimise the occurrence of the noise in the first place. This is best achieved by keeping the gate connections as short as possible and ensuring that the common return from the gate drive circuit connects directly to the MT1 pin (or cathode in the case of a thyristor). In situations where the gate connections are hard wired, twisted pair wires or even shielded cable might be necessary to minimise pickup.

Additional noise immunity can be provided by adding a resistor of 1kΩ or less between the gate and MT1 to reduce the gate sensitivity. If a high frequency bypass capacitor is also used, it is advisable to include a series resistor between it and the gate to minimise peak capacitor currents through the gate and minimise the possibility of overcurrent damage to the triac's gate area. **Alternatively, use a series H triac (e.g. BT139-600H). These are insensitive types with 10mA min I_{GT} specs which are specifically designed to provide a high degree of noise immunity.**

Rule 4. To minimise noise pickup, keep gate connection length to a minimum. Take the return directly to MT1 (or cathode). If hard wired, use twisted pair or shielded cable. Fit a resistor of 1kΩ or less between gate and MT1. Fit a bypass capacitor in conjunction with a series resistor to the gate.
Alternatively, use an insensitive series H triac.

(b) Exceeding the max rate of change of commutating voltage dV_{COM}/dt

This is most likely to occur when driving a highly reactive load where there is substantial phase shift between the load voltage and current waveforms. When the triac commutates as the load current passes through zero, the voltage will not be zero because of the phase shift (see Fig. 6). The triac is then suddenly required to block this voltage. The resulting rate of change of commutating voltage can force the triac back into conduction if it exceeds the permitted dV_{COM}/dt. This is because the mobile charge carriers have not been given time to clear the junction.

The dV_{COM}/dt capability is affected by two conditions:-
1. The rate of fall of load current at commutation, dI_{COM}/dt. Higher dI_{COM}/dt lowers the dV_{COM}/dt capability.
2. The junction temperature T_j. Higher T_j lowers the dV_{COM}/dt capability.

If the triac's dV_{COM}/dt is likely to be exceeded, false triggering can be avoided by use of an RC snubber across MT1-MT2 to limit the rate of change of voltage. Common values are 100Ω carbon composition resistor, chosen for its surge current handling, and 100nF. **Alternatively, use a Hi-Com triac.**

Note that the resistor should never be omitted from the snubber because there would then be nothing to prevent the capacitor from dumping its charge into the triac and creating damaging dI_T/dt during unfavourable turn-on conditions.

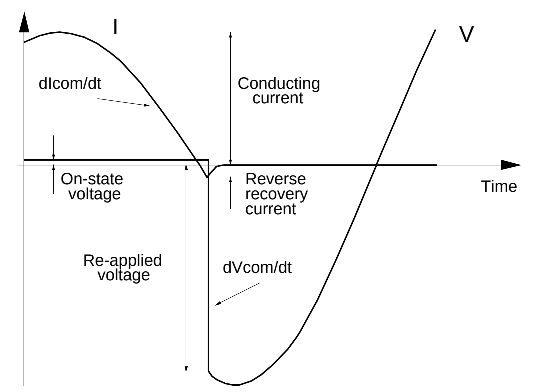

Fig. 6. Triac dI_{COM}/dt and dV_{COM}/dt.

(c) Exceeding the max rate of change of commutating current dI_{COM}/dt

Higher dI_{COM}/dt is caused by higher load current, higher mains frequency (assuming sinewave current) or non sinewave load current. A well known cause of non sinewave load current and high dI_{COM}/dt is rectifier-fed inductive loads. These can often result in commutation failure in standard triacs as the supply voltage falls below the back EMF of the load and the triac current collapses suddenly to zero. The effect of this is illustrated in Fig. 7.

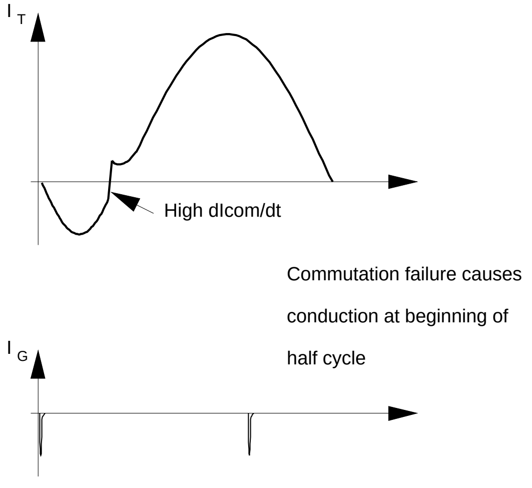

Fig. 7. Effects of rectifier-fed inductive load on phase control circuit.

During this condition of zero triac current, the load current will be "freewheeling" around the bridge rectifier circuit. Loads of this nature can generate such high dI_{COM}/dt that the triac cannot support even the gentle reapplied dV/dt of a 50Hz waveform rising from zero volts. There will then be no benefit in adding a snubber across the triac because

dV_{COM}/dt is not the problem. The dI_{COM}/dt will have to be limited by adding an inductor of a few mH in series with the load. **Alternatively, use a Hi-Com triac.**

(d) Exceeding the max rate of change of off-state voltage dV_D/dt

If a very high rate of change of voltage is applied across a non-conducting triac (or sensitive gate thyristor in particular) without exceeding its V_{DRM} (see Fig. 8), internal capacitive current can generate enough gate current to trigger the device into conduction. Susceptibility is increased at high temperature.

Where this is a problem, the dV_D/dt must be limited by an RC snubber across MT1 and MT2 (or anode and cathode). **In the case of triacs, using Hi-Com types can yield benefits.**

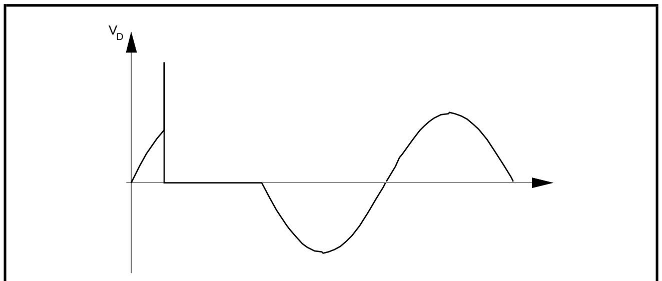

Fig. 8. Triac turn-on by exceeding dV_D/dt.

Rule 5. Where high dV_D/dt or dV_{COM}/dt are likely to cause a problem, fit an RC snubber across MT1 and MT2.
Where high dI_{COM}/dt is likely to cause a problem, fit an inductor of a few mH in series with the load.
Alternatively, use a Hi-Com triac.

(e) Exceeding the repetitive peak off-state voltage V_{DRM}

If the MT2 voltage exceeds V_{DRM} such as might occur during severe and abnormal mains transient conditions, MT2-MT1 leakage will reach a point where the triac will spontaneously break over into conduction (see Fig. 9).

If the load permits high inrush currents to flow, extremely high localised current density can occur in the small area of silicon that is conducting. This can lead to burnout and destruction of the die. Incandescent lamps, capacitive loads and crowbar protection circuits are likely causes of high inrush currents.

Turn-on by exceeding the triac's V_{DRM} or dV_D/dt is not necessarily the main threat to its survival. It's the dI_T/dt that follows which is most likely to cause the damage. Due to the time required for conduction to spread out over the whole junction, the permitted dI_T/dt is lower than if the triac is correctly turned on by a gate signal. If the dI_T/dt can be limited during these conditions to this lower value, which is given in data, the triac is more likely to survive. This could be achieved by fitting a non saturable (air cored) inductor of a few µH in series with the load.

If the above solution is unacceptable or impractical, an alternative solution would be to provide additional filtering and clamping to prevent the spikes reaching the triac. This would probably involve the use of a Metal Oxide Varistor as a "soft" voltage clamp across the supply, with series inductance followed by parallel capacitance upstream of the MOV.

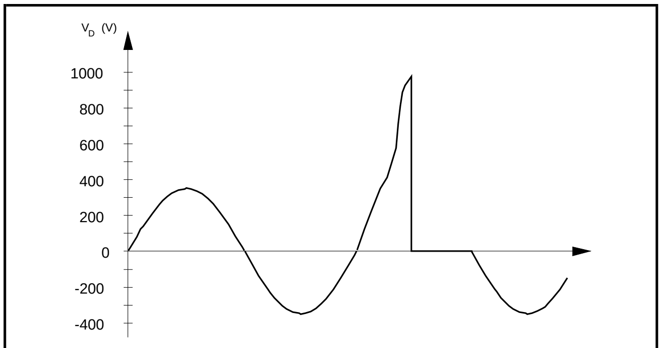

Fig. 9. Triac turn-on by exceeding V_{DRM}.

Doubts have been expressed by some manufacturers over the reliability of circuits which use MOVs across the mains, since they have been known to go into thermal runaway in high ambient temperatures and fail catastrophically. This is due to the fact that their operating voltage possesses a marked negative temperature coefficient. However, if the recommended voltage grade of 275V RMS is used for 230V mains, the risk of MOV failure should be negligible. Such failures are more likely if 250V RMS MOVs are used, which are underspecified for 230V RMS use at high ambient temperatures.

Rule 6. If the triac's V_{DRM} is likely to be exceeded during severe mains transients, employ one of the following measures:
Limit high dI_T/dt with a non saturable inductor of a few µH in series with the load;
Use a MOV across the mains in combination with filtering on the supply side.

Turn-on dI_T/dt

When a triac or thyristor is triggered into conduction by the correct method via its gate, conduction begins in the die area immediately adjacent to the gate, then quickly spreads to cover the whole active area. This time delay imposes a limit on the permissible rate of rise of load current. A dI_T/dt which is too high can cause localised burnout. An MT1-MT2 short will be the result.

If triggering in the 3^+ quadrant, an additional mechanism further reduces the permitted dI_T/dt. It is possible to momentarily take the gate into reverse avalanche breakdown during the initial rapid current rise. This might not lead to immediate failure. Instead, there would be progressive burnout of the gate-MT1 shorting resistance after repeated exposure. This would show itself by a progressive increase in I_{GT} until the triac will no longer trigger. Sensitive triacs are likely to be the most susceptible. Hi-Com triacs are not affected as they do not operate in the 3+ quadrant.

The dI_T/dt capability is affected by how fast the gate current rises (dI_G/dt) and the peak value of I_G. Higher values of dI_G/dt and peak I_G (without exceeding the gate power ratings) give a higher dI_T/dt capability.

Rule 7.	*Healthy gate drive and avoiding 3⁺ operation maximises the triac's dI_T/dt capability.*

As mentioned previously, a common load with a high initial surge current is the incandescent lamp which has a low cold resistance. For resistive loads such as this, the dI_T/dt would be at its highest if conduction commenced at a peak of the mains voltage. If this is likely to exceed the triac's dI_T/dt rating, it should be limited by the inclusion of an inductor of a few µH or even a Negative Temperature Coefficient thermistor in series with the load. Again, the inductor must not saturate during the maximum current peak. If it does, its inductance would collapse and it would no longer limit the dI_T/dt. An air cored inductor meets the requirement.

A more elegant solution which could avoid the requirement for a series current-limiting device would be to use zero voltage turn-on. This would allow the current to build up more gradually from the beginning of the sinewave.

Note: It is important to rememember that zero voltage turn-on is only applicable to resistive loads. Using the same method for reactive loads where there is phase shift between voltage and current can cause "halfwaving" or unipolar conduction, leading to possible saturation of inductive loads, damagingly high peak currents and overheating. More advanced control employing zero current switching and / or variable trigger angle is required in this case.

Rule 8.	*If the triac's dI_T/dt is likely to be exceeded, an air cored inductor of a few µH or an NTC thermistor should be fitted in series with the load.* *Alternatively, employ zero voltage turn-on for resistive loads.*

Turn-off

Since triacs are used in AC circuits, they naturally commutate at the end of each half cycle of load current unless a gate signal is applied to maintain conduction from the beginning of the next half cycle. The rules for I_H are the same as for the thyristor. See Rule 2.

Hi-Com triac

Hi-Com triacs have a different internal construction to conventional triacs. One of the differences is that the two "thyristor halves" are better separated to reduce the influence that they have on each other. This has yielded two benefits:

1. Higher dV_{COM}/dt. This enables them to control reactive loads without the need for a snubber in most cases while still avoiding commutation failure. This reduces the component count, board size and cost, and eliminates snubber power dissipation.

2. Higher dI_{COM}/dt. This drastically improves the chances of successfully commutating higher frequency or non sinewave currents without the need for a dI_{COM}/dt-limiting inductor in series with the load.

3. Higher dV_D/dt. Triacs become more sensitive at high operating temperatures. The higher dV_D/dt of Hi-Com triacs reduces their tendency to spurious dV/dt turn-on when in the blocking state at high temperature. This enables them to be used in high temperature applications controlling resistive loads, such as cooking or heating applications, where conventional triacs could not be used.

The different internal construction also means that 3⁺ triggering is not possible. This should not be a problem in the vast majority of cases because this is the least desirable and least used triggering quadrant, so direct substitution of a Hi-Com for an equivalent conventional triac will almost always be possible.

Hi-Com triacs are fully described in two Philips Factsheets:
Factsheet 013 - Understanding Hi-Com Triacs, and
Factsheet 014 - Using Hi-Com Triacs.

Triac mounting methods

For small loads or very short duration load current (i.e. less than 1 second), it might be possible to operate the triac in free air. In most cases, however, it would be fixed to a heatsink or heat dissipating bracket.

The three main methods of clamping the triac to a heatsink are clip mounting, screw mounting and riveting. Mounting kits are available from many sources for the first two methods. Riveting is not a recommended method in most cases.

Clip mounting

This is the preferred method for minimum thermal resistance. The clip exerts pressure on the plastic body of the device. It is equally suitable for the non-isolated packages (SOT82 and SOT78) and the isolated packages (SOT186 F-pack and the more recent SOT186A X-pack). Note: SOT78 is otherwise known as TO220AB.

Screw mounting

1. An M3 screw mounting kit for the SOT78 package includes a rectangular washer which should be between the screw head and the tab. It should not exert any force on the plastic body of the device.
2. During mounting, the screwdriver blade should never exert force on the plastic body of the device.
3. The heatsink surface in contact with the tab should be deburred and flat to within 0.02mm in 10mm.
4. The mounting torque (with washer) should be between 0.55Nm and 0.8Nm.
5. Where an alternative exists, the use of self-tapping screws should be avoided due to the possible swelling of the heatsink material around the fixing hole. This could be detrimental to the thermal contact between device and heatsink. (See 3 above.) The uncontrollable mounting torque is also a disadvantage with this fixing method.
6. The device should be mechanically fixed before the leads are soldered. This minimises undue stress on the leads.

Riveting

Pop riveting is not recommended unless great care is taken because the potentially severe forces resulting from such an operation can deform the tab and crack the die, rendering the device useless. In order to minimise rejects, the following rules should be obeyed if pop riveting:

1. The heatsink should present a flat, burr-free surface to the device.
2. The heatsink mounting hole diameter should be no greater than the tab mounting hole diameter.
3. The pop rivet should just be a clearance fit in the tab hole and heatsink mounting hole without free play.
4. The pop rivet should be fitted with its head, <u>not the mandrel</u>, on the tab side.
5. The pop rivet should be fitted at 90 degrees to the tab. (The rivet head should be in contact with the tab around its complete circumference.)
6. The head of the rivet should not be in contact with the plastic body of the device after riveting.
7. Mechanical fixing of the device and heatsink assembly to the PCB should be completed before the leads are soldered to minimise stressing of the leads.

> *Rule 9. Avoid mechanical stress to the triac when fitting it to the heatsink. Fix, then solder. Never pop rivet with the rivet mandrel on the tab side.*

Thermal resistance

Thermal resistance R_{th} is the resistance to the flow of heat away from the junction. It is analogous to electrical resistance;

i.e. just as electrical resistance R = V/I, thermal resistance $R_{th} = T/P$,

where T is the temperature rise in Kelvin and P is the power dissipation in Watts. Therefore R_{th} is expressed in K/W.

For a device mounted vertically in free air, the thermal resistance is dictated by the junction-to-ambient thermal resistance $R_{th\,j\text{-}a}$. This is typically 100K/W for the SOT82 package, 60K/W for the SOT78 package and 55K/W for the isolated F-pack and X-pack.

For a non isolated device mounted to a heatsink, the junction-to-ambient thermal resistance is the sum of the junction-to-mounting base, mounting base-to-heatsink and heatsink-to-ambient thermal resistances.

$$R_{th\,j\text{-}a} = R_{th\,j\text{-}mb} + R_{th\,mb\text{-}h} + R_{th\,h\text{-}a} \text{ (non isolated package).}$$

The use of heat transfer compound or sheet between the device and heatsink is always recommended. In the case of isolated packages, there is no reference made to "mounting base", since the $R_{th\,mb\text{-}h}$ is assumed to be constant and optimised with heat transfer compound. Therefore, the junction-to-ambient thermal resistance is the sum of the junction-to-heatsink and heatsink-to-ambient thermal resistances.

$$R_{th\,j\text{-}a} = R_{th\,j\text{-}h} + R_{th\,h\text{-}a} \text{ (isolated package).}$$

$R_{th\,j\text{-}mb}$ or $R_{th\,j\text{-}h}$ are fixed and can be found in data for each device.

$R_{th\,mb\text{-}h}$ is also given in the mounting instructions for several options of insulated and non-insulated mounting, with or without heatsink compound.

$R_{th\,h\text{-}a}$ is governed by the heatsink size and the degree of unrestricted air movement past it.

Calculation of heatsink size

To calculate the required heatsink thermal resistance for a given triac and load current, we must first calculate the power dissipation in the triac using the following equation:

$$P = V_o \times I_{T(AVE)} + R_s \times I_{T(RMS)}^2.$$

Knee voltage V_o and slope resistance R_s are obtained from the relevant V_T graph in data book SC03. If the values are not already provided, they can be obtained from the graph by drawing a tangent to the max V_T curve. The point on the V_T axis where the tangent crosses gives V_o, while the slope of the tangent (V_T/I_T) gives R_s.

Using the thermal resistance equation given above:

$$R_{th\,j\text{-}a} = T/P.$$

The max allowable junction temperature rise will be when T_j reaches T_j max in the highest ambient temperature. This gives us T.

$R_{th\,j\text{-}a} = R_{th\,j\text{-}mb} + R_{th\,mb\text{-}h} + R_{th\,h\text{-}a}$. SC03 data gives us the values for $R_{th\,j\text{-}mb}$ and $R_{th\,mb\text{-}h}$ for our chosen mounting method, leaving $R_{th\,h\text{-}a}$ as the only unknown.

Thermal impedance

The above calculations for thermal resistance are applicable to the steady state condition - that is for a duration greater than 1 second. This time is long enough for heat to flow from the junction to the heatsink. For current pulses or transients lasting for shorter than 1 second, however, heatsinking has progressively less effect. The heat is simply dissipated in the bulk of the device with very little reaching the heatsink. For transient conditions such as these, the junction temperature rise is governed by the device's junction-to-mounting base thermal impedance $Z_{th\,j\text{-}mb}$.

$Z_{th\,j\text{-}mb}$ decreases for decreasing current pulse duration due to reduced chip heating. As the duration increases towards 1 second, $Z_{th\,j\text{-}mb}$ increases to the steady state $R_{th\,j\text{-}mb}$ value.

The $Z_{th\,j\text{-}mb}$ curve for bidirectional and unidirectional current down to 10µs duration is shown for each device in the SC03 data book.

> *Rule 10. For longterm reliability, ensure that the $R_{th\,j\text{-}a}$ is low enough to keep the junction temperature within T_j max for the highest expected ambient temperature.*

Range and packaging

Philips thyristors range from 0.8A in SOT54 (TO92) to 25A in SOT78 (TO220AB).

Philips triacs range from 1A in SOT223 to 25A in SOT78. Conventional types (4-quadrant triggering) and Hi-Com types (3-quadrant triggering) are available. SOT54 types are planned for 1996.

The smallest package is the surface mount SOT223 for the smaller thyristors and triacs (Fig. 10). The power dissipation is governed by the degree of heatsinking offered by the PCB onto which it is soldered.

The same respective chips are also available in SOT82 which is a non isolated package (Fig. 12). The improved heat removal of this package when heatsunk allows higher current ratings and improved power dissipations.

Figure 11 shows SOT54 in which the very smallest devices are mounted. Smaller chips than those accommodated by SOT223 go into this package, which offers the most compact non surface mount solution.

SOT78 is the most common non isolated package in which most of our devices are supplied (Fig. 13).

Figure 14 shows SOT186 (F-pack). This has been the traditional Philips isolated package. It offers an isolation voltage of 1,500V peak between device and heatsink under clean conditions.

The more recent SOT186A package (X-pack) shown in Fig. 15 possesses several advantages over the older type.

1. It has the same dimensions as the SOT78 package for pin spacing from the mounting surface, so it can directly replace SOT78 devices to provide isolation without the need for modification of the mounting arrangement.
2. It has no exposed metal at the top of the tab, and creepage distances from pins to heatsink are greater, so it can offer an improved true isolation of 2,500V RMS.
3. It is a fully encapsulated SOT78 replacement.

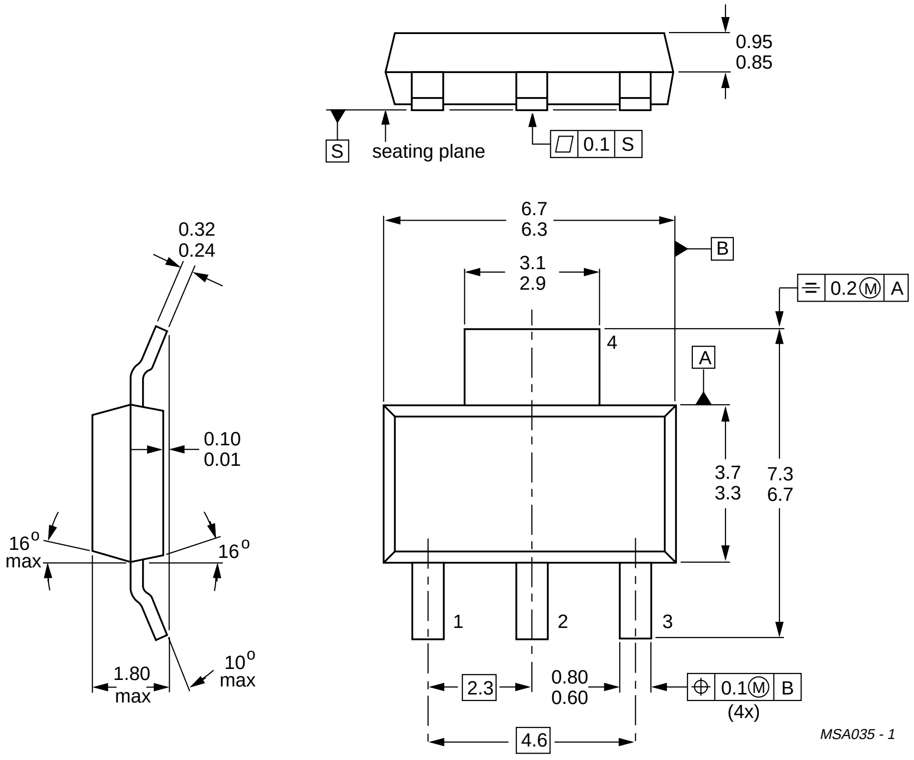

Fig. 10. SOT223.

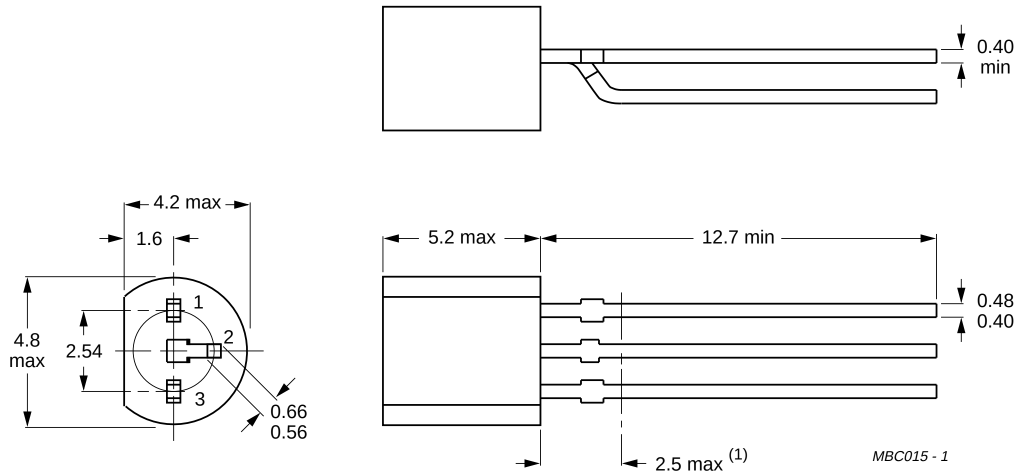

Fig. 11. SOT54 (TO92).

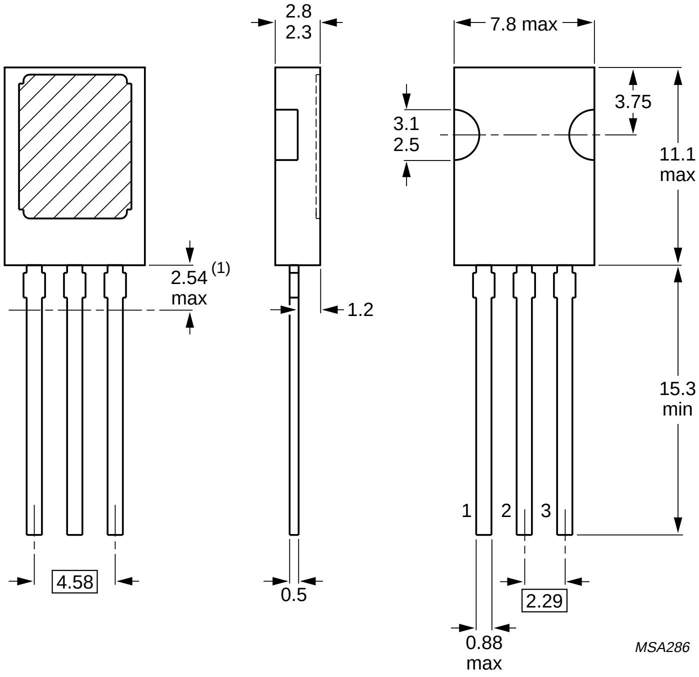

Fig. 12. SOT82.

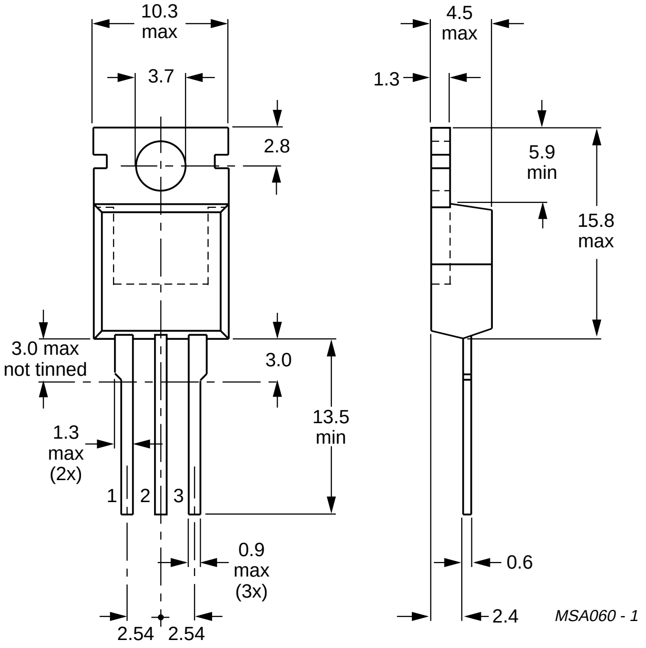

Fig. 13. SOT78 (TO220AB).

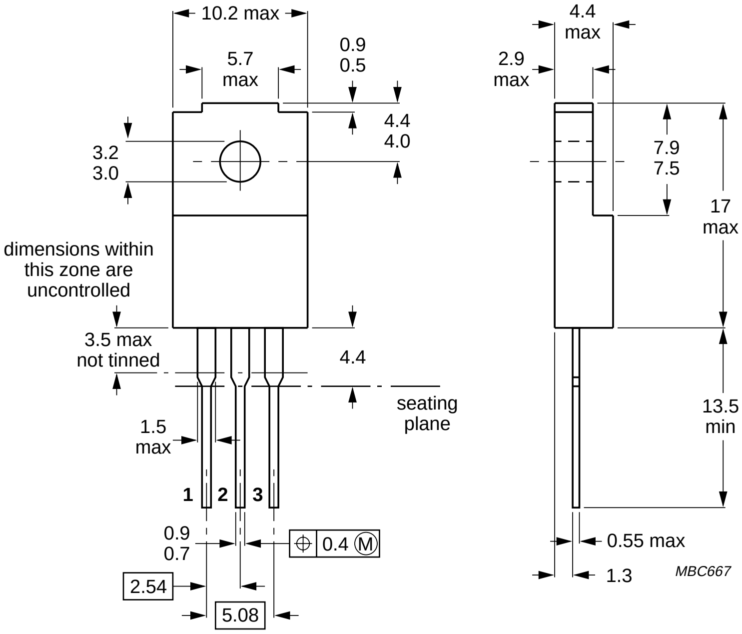

Fig. 14. SOT186 F-pack.

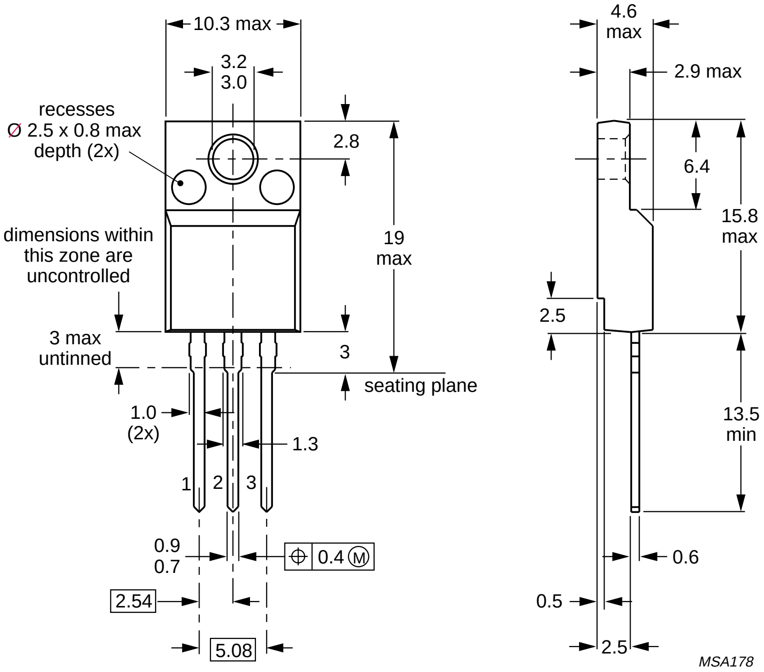

Fig. 15. SOT186A X-pack.

The Ten Golden Rules Summarised

Rule 1.	To turn a thyristor (or triac) ON, a gate current $\geq I_{GT}$ must be applied until the load current is $\geq I_L$. This condition must be met at the lowest expected operating temperature.
Rule 2.	To turn off (commutate) a thyristor (or triac), the load current must be $< I_H$ for sufficient time to allow a return to the blocking state. This condition must be met at the highest expected operating temperature.
Rule 3.	When designing a triac triggering circuit, avoid triggering in the 3^+ quadrant (MT2-, G+) where possible.
Rule 4.	To minimise noise pickup, keep gate connection length to a minimum. Take the return directly to MT1 (or cathode). If hard wired, use twisted pair or shielded cable. Fit a resistor of 1kΩ or less between gate and MT1. Fit a bypass capacitor in conjunction with a series resistor to the gate. Alternatively, use an insensitive series H triac.
Rule 5.	Where high dV_D/dt or dV_{COM}/dt are likely to cause a problem, fit an RC snubber across MT1 and MT2. Where high dI_{COM}/dt is likely to cause a problem, fit an inductor of a few mH in series with the load. Alternatively, use a Hi-Com triac.
Rule 6.	If the triac's V_{DRM} is likely to be exceeded during severe mains transients, employ one of the following measures: Limit high dI_T/dt with a non saturable inductor of a few µH in series with the load; Use a MOV across the mains in combination with filtering on the supply side.
Rule 7.	Healthy gate drive and avoiding 3^+ operation maximises the triac's dI_T/dt capability.
Rule 8.	If the triac's dI_T/dt is likely to be exceeded, an air cored inductor of a few µH or an NTC thermistor should be fitted in series with the load. Alternatively, employ zero voltage turn-on for resistive loads.
Rule 9.	Avoid mechanical stress to the triac when fitting it to the heatsink. Fix, then solder. Never pop rivet with the rivet mandrel on the tab side.
Rule 10.	For longterm reliability, ensure that the $R_{th\ j\text{-}a}$ is low enough to keep the junction temperature within T_j max for the highest expected ambient temperature.

SURFACE MOUNTED TRIACS AND THYRISTORS

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西安分公司：西安高新开发区 20 所(中国电子科技集团导航技术研究所)
西安劳动南路 88 号电子商城二楼 D23 号
TEL：029-81022619 13072977981 FAX:029-88789382