SGS-THOMSON
MICROELECTRONICS

APPLICATION NOTE

THE TRIAC

The TRIAC* is a semi-conductor device with has been specifically designed to operate as a controlled switch in an AC power system.

With the introduction of electronic component into industrial application, the utilization of the Triac as a complement, the utilization of the Triac as a complement to, or replacement for, electromechanical switches or relays and magnetic control systems, has been rapidly expanding in this field. In addition, its availability has led to the development of new control systems which were not feasible with the previously devices.

The advantages of the Triac are its noiseless operation, its ability to be controlled at precise instants and without rebounds, its automati turn-off when the current reaches zero after the control has been removed, and its ability to withstand without wear an unlimited number of operating cycles when used in the conditions specified by the manufacturer.

We shall briefly describe the principle of operation of triacs used as controlled switches, then insist on the precautions required during utilization to maintain high reliability (section 2 and appendix 1) and, finally, give, in Section 3, examples of applications as on-off control switches, static relays and power variations units.

SYMBOLS AND TERMINOLOGY

Half wave: half cycle of the alternating input voltage V_a. The polarity (positive or negative) of each half wave is defined with reference to the potential of the triac electrode A_1.

Full wave: couple of consecutive half waves (one positive, one negative).

Trigger pulse: gate current pulse switching on the triac.

Firing: change to conduction of the triac until the current i_T flowing through it reaches the value I_L enabling it to remain in the conducting state up to the end of the half wave (until i_T has dropped below I_H): see I_H and I_L below.

v_a: instantaneous value of the alternating input voltage (mains voltage, as a generate rule)

V_{RMS}, I_{RMS}: rms values of V_a and of the load current.

V_T, **i_T**: voltage across the triac in the conduction mode, and current flowing through the triac.

V_M: "breakover voltage": voltage applied, in the static state, between A_2 and A_1 and beyond which the triac is changed to the conduction mode without gate current.

V_{DWM}: minimum guaranteed value of V_M (= peak working forward voltage: see 2.3).

I_G: gate current, or trigger pulse peak value.

I_{GT}: minimum gate current I_G required to switch-on the triac (if permitted by the load conditions: see I_L).

I_H: "holding current": minimum value of i_T required to maintain the triac in the on state (below which the triac turns off).

I_L: "latching current": minimum value of i_T required to hold the triac in the steady conducting state after the triggering pulese has been removed.

I_{TSM}: non-repetitive peak overload current in the conduction mode.

I_{RSM}: repetitive peak overload current in the conduction mode.

$\propto$: "angle of conduction" of the triac ($\propto/\pi$ represents the fraction of each half wave during which power is applied to the load).

φ: load current phase shift with respect to the input voltage v_a.

di/dt: see 2-2

dv/dt, $(\mathbf{dv/dt})_c$, : see 2-3.

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* The word "TRIAC" is an acronym for "TRIode for Alterning Current".

1. OPERATION OF THE TRIAC AS A CONTROLLER SWITCH

1.1. STRUCTURE

Like the transistor or the thyristor, the triac consist of alternate layers of p-type (majority carrier = holes) and n-type (majority carriers = electrons) semiconductor material. In the case of the triac, the imbrication of these layers is such, that the device can be compared to a power monolithic integrated circuit. Figure A illustrates a possible arrangement of the p and n regions (scale enlarged in the direction of thickness).

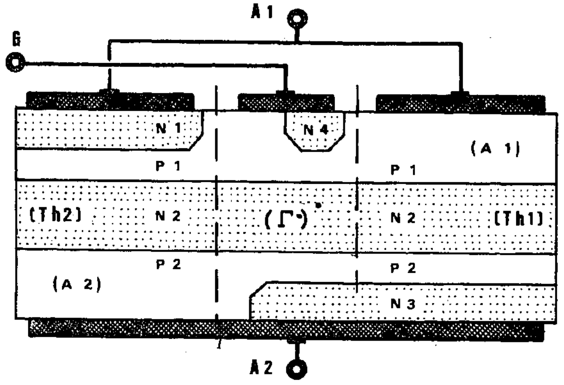
Layers P1 N2 P2 N3 form a thrystor Th 1 whose anode consists of layer P1, and the cathode, of layer N3.

Layers P2 N2 P1 N1 form a thyristor Th 2 with anode A2 on P2, which is, therefore and through the external metal connections, antiparallel connected with Th 1 as regards terminals A2 and A1.

Finally, layers P2 N2 P1 N4 form auxiliary element Γ which couples gate G of the triac with the cathode and anode gates of Th 1 and Th 2 in order to permit triggering of the triac in the various possible polarities of the gate and of electrode A2 with respect to electrode A1. Consequently, the triac can be roughly represented by the equivalent electrical schematic of Figure 1B.

Figure 1 : Structure of a Triac.

A : Example of a triac structure (vertically exaggerated sketch).



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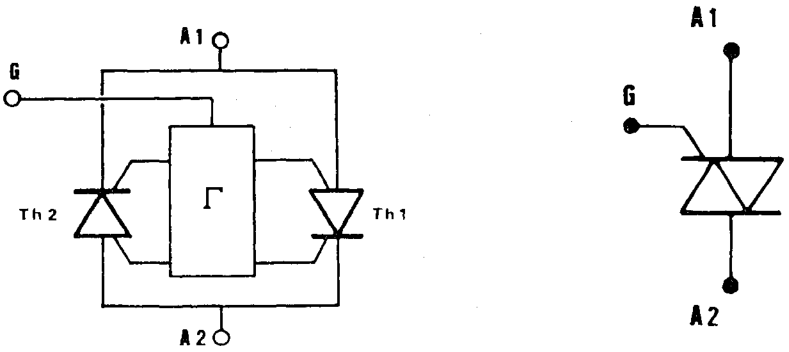
B : Simplified Equivalent Schematic.

C : Circuit Symbol.



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With no pulse applied to the gate, the current cannot begin to flow spontaneously between A1 and A2. The triac is in the "blocked state".

The application of a current pulse to gate G causes Th1 and Th2 to change to the conducting state (through auxiliary element Γ), in accordance with the polarity of the terminal voltage. Electrode A1 being taken as reference for the potentials, Th1 conducts during negative half waves (A2 negative with respect to A1) while Th2 conducts during positive half waves (A2 positive with respect to A1). The triac is said to be in the "conducting state" (refer to figure 3, P.7). When the gate current pulse is suppressed, for instance during a positive half wave, elementary triac Th2 continues to conduct and, consequently, the triac remains in the conducting state until the current decreases to almost zero, below the holding current of Th2.

1.2. OPEN-GATE STATIC CHARACTERISTICS

The study of the operation in conditions in which the voltages and currents change slowly, as in the case of a 50 or 60 Hz AC supply mains without any superimposed interference, can be carried out by starting from the I/V static characteristics of the triac (plotted point by point or observed with the aid of a curve plotter) V (on the X-axis) is the voltage applied between main terminals A2 and A1, with A1 as reference, and I is the current flowing from A2 to A1 in the triac.

The graph of figure 2 corresponds to the case where the triac is not controlled, i.e. where its gate is open ($I_G = 0$).

When a peak-amplitude alternating-current voltage V_a lower than both V_M in positive half-waves and V'_M in negative half-waves, is applied to A2, current I always remains very low and, in any case, negligible when compared with the nominal operating current. The triac is in the blocking condition.

When the load is a resistor R, its L/V characteristic in this diagram is a straight line of slope 1/R, which moves parallel to itself when the instantaneous value V_a of the supply voltage varies. The operating point moves along section A'A to the points of intersection of the static characteristic of the trias in the blocked state, with the individual load straights corresponding to the various values of V_a.

However, when an overvoltage V_P higher than V_M is temporarily applied to the circuit, the load straight can reach the position indicated by a dotted line, thus moving the operating point to B. Following the removal of the overvoltage, the operating point moves down along section CD of the static characteristic, where voltage V is low and the current high. Thus, this section corresponds to the conditions in which the triac is in the conducting state. It has been "fired" by overvoltage V_P. This hind of firing produces dangerous stresses in the triac and user circuit.

1.3. FIRING THROUGH GATE CURRENT

When a current I_G is caused to flow between gate G and electrode A1, the blocking voltage decreases abruptly when this current reaches a critical value I_G mini.

As long as I_G is equal to, or higher than, I_G mini, section MOM' of the characteristic of Figure 2 is replaced by section E'OE of the curve in dotted line (Figure 4), which joins together the "conducting state" characteristics D'x' Dx. Now, when the applied voltage varies from V_a to + V_a, the operating point describes curves C'C of these characteristics. The current varies from I_T to + I_T and the voltage across the triac varies from V_T to + V_T.

This voltage drop V_T generally ranges from 1 to 2 V for a peak current $i_T$eff √ 2 corresponding to the triac nominal current. Its maximum possible value V_{TM} at 25 °C is given for each triac in the applicable sheets of characteristics.

If I_G is interrupted at instant t_2 (Figure 3) when the instantaneous value of the current is still high, the operating point remains on the conducting-state characteristic drawn in full line on Figure 4, up to instant t_3 (point D) when the current has decreased to a sufficiently low value I_H. The minimum anode current I_H for which the triac remains conducting without gate current, is called **holding current** (or hypostatic current)* as in the case of the thyristors.

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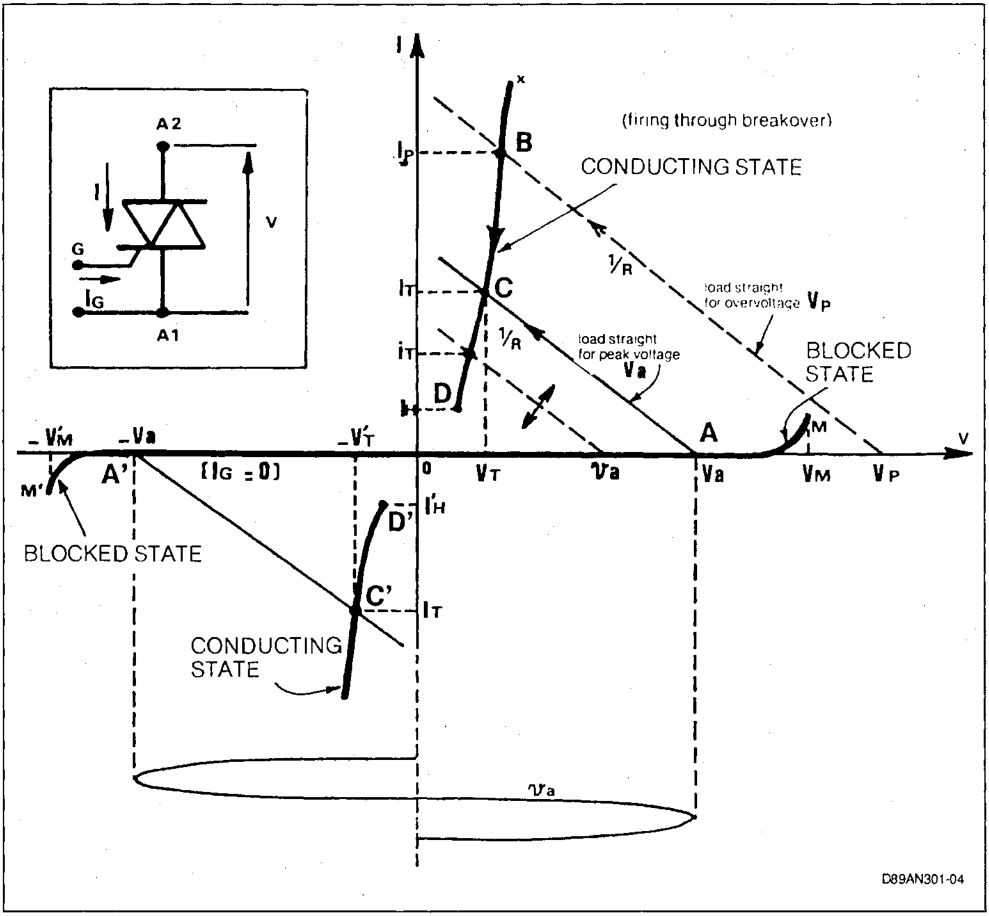
* As a matter of fact, there are two holding current values I_H and I'_H depending upon the polarity of V_a. These two values are generally very close to each other.

Figure 2 : Triac Static Characteristics with Open Gate (not to scale).



I_H is very low with respect to the triac nominal current (in the cold condition the maximum value of I_H guaranteed by the specifications never exceeds a hundred mA, even for very large triacs; in the warm condition, the value of I_H decreases considerably). Therefore, its influence on the operation as a switch does not have to be taken into consideration, as a general rule, in practical applications, except in operating conditions in which the load temporarily offers a high impedance at an instant at which the effective supply voltage is low.

The delay in the rise of the current following the application of the control does not exceed a few microseconds. But, to achieve steady firing, current I_G must be applied for a sufficiently long time.

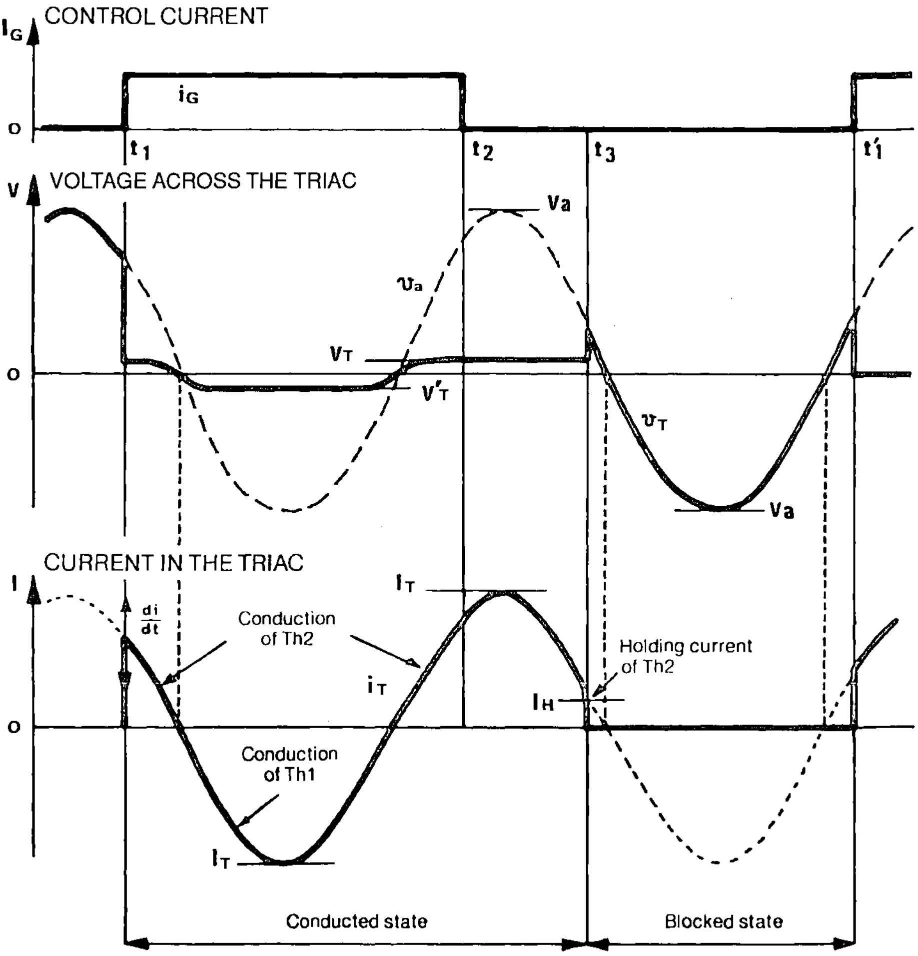
The gate pulse duration must a least be long enough for a sufficient charge to be injected into the gate region. The minimum duration Δ t of a rectangular-wave pulse of current I_G having just the specified value I_{GT} min is on the order of about twenty µs.

This required duration decreases when the value of I_G increases.

If current I_C in the load does not immediately build up (inductive load) it is necessary, in addition, to hold the gate current until the load has given passage to a minimum current I_L. The 2**latching current**“ is equal to, or higher than, i_H, depending upon the respective polarities of A2 and G. It corresponds to point E on the conducting-state characteristic (*Figure 4*).

Current I_G applie dto the gate to fire the triac with either polarity of the supply voltage, can indifferently be of positive or negative sign with, however, triggering abilities which, for average-power triacs, can be somewhat different depending upon these polarities*. There are four possible cases which are determined in accordance with four “triggering quadrants” defined in Table 1.

Figure 3 : Waveforms in a gate-controlled triac with resitive load.



(V_T and I_H exaggerated for clearness of figure).

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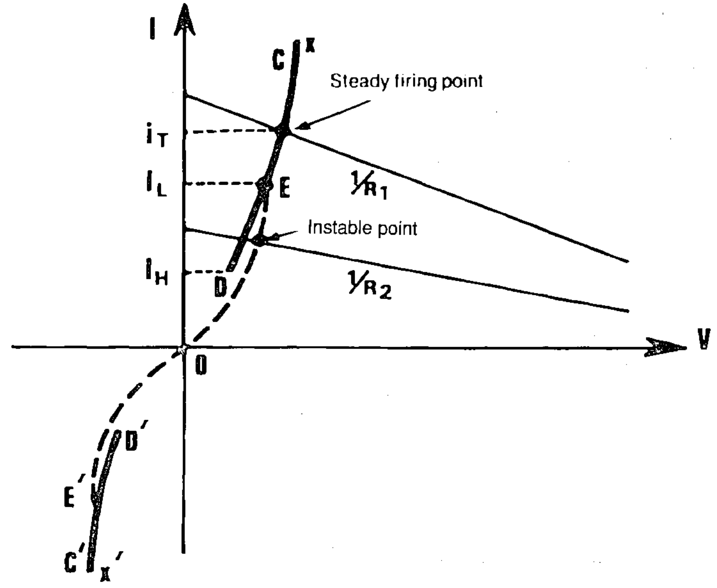
Certain series are not specified in quadrat IV as regards firing current.

Figure 4 : Static Characteristics with $I_G = I_{GT}$ (exaggerated around zero).



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Load straight 1/R1 : ensures steady firing ($i_T > I_L$).
Load straight 1/R2 : does not ensure steady firing ($i_T < I_L$).

Table 1.

Triggering Quadrant	Polarity with Respect to A1		Firing Conditions for Small Triacs	
	of A2	of G	I_{GT}	I_L/I_H
Q. I	+	+	Low	= 1
Q. II	+	—	Medium	2 to 5
Q. III	—	—	Medium	= 1
Q. IV	—	+	High	1.5 to 3

1.4. VARIOUS MODES OF CONTROL OF THE TRIAC

On Figure 3, instants t_1 of gate current application were supposed to occur randomly with respect to input voltage V_a. This operation is similar to that of an electromechanical relay; the difference, however, is that the triac switch becomes conducting at the precise instant (to within a microsecond) of application of the control, and blocks again, after the control has been removed, at the precise instant at which the current drops below I_H (i.e. practically to zero with respect to the nominal current).

This precision can be made use of to carry out the control in exact synchronism with voltage V_a, in order to sample periodically the voltage applied to the load over intervals of several half waves * (control by half-wave trains), or over half-wave fractions (control by conduction angle). By causing the respective durations of the "conducting" intervals to vary with respect to the "blocked" intervals, a variation of the power applied to the load is achieved.

Whenever permitted by the inertia of the user circuits, the control by half-wave trains offers substantial advantages when, in addition, the firing of the triac is allowed to occur only close to the point where the voltage across the triac goes through zero (i.e. just after zero crossing of the current). Since the triac will next stop conduction also at the zero crossing of the current, this mode of control always ensures a whole number of complete "conducting" half waves (*Figure 5 a*). On the other hand, triggering on going through zero eliminates any sudden variation of the current flowing through the load, which avoids parasitic radiations and strains in the triac and user circuits. With this type of control, the mean power allied to the load is merely:

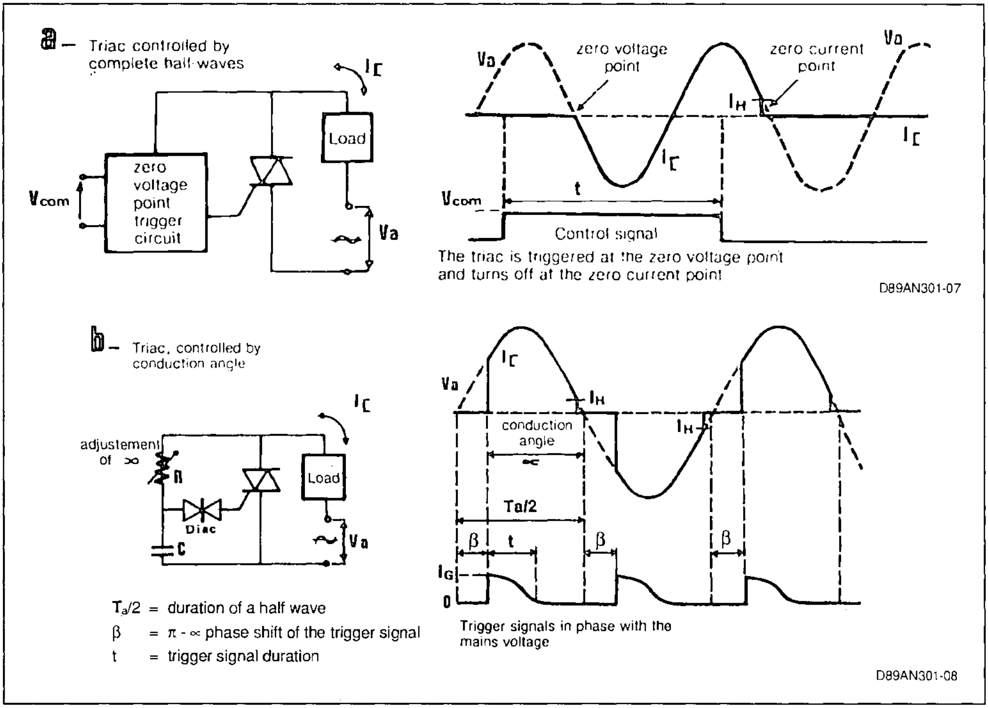
$$P_{AV.} = \frac{n\,T_a}{2\,T_e}\,V_{RMS} \cdot I_{RMS} \qquad (1)$$

with: n = number of "conducting" half waves in each sampling period T_e.

T_a = period of the mains current (20 ms in the case of a 50 Hz mains).

V_{RMS}, I_{RMS} = rms values of the input voltage and current.

Figure 5 : Modes of Control of the Triac in Syncronism with the Mains Voltage (theoretical waveforms on resistive load).



$T_a/2$ = duration of a half wave
β = π - ∝ phase shift of the trigger signal
t = trigger signal duration

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* The term « half wave » designates each (positive or negative) half of the mains current alternating wave.

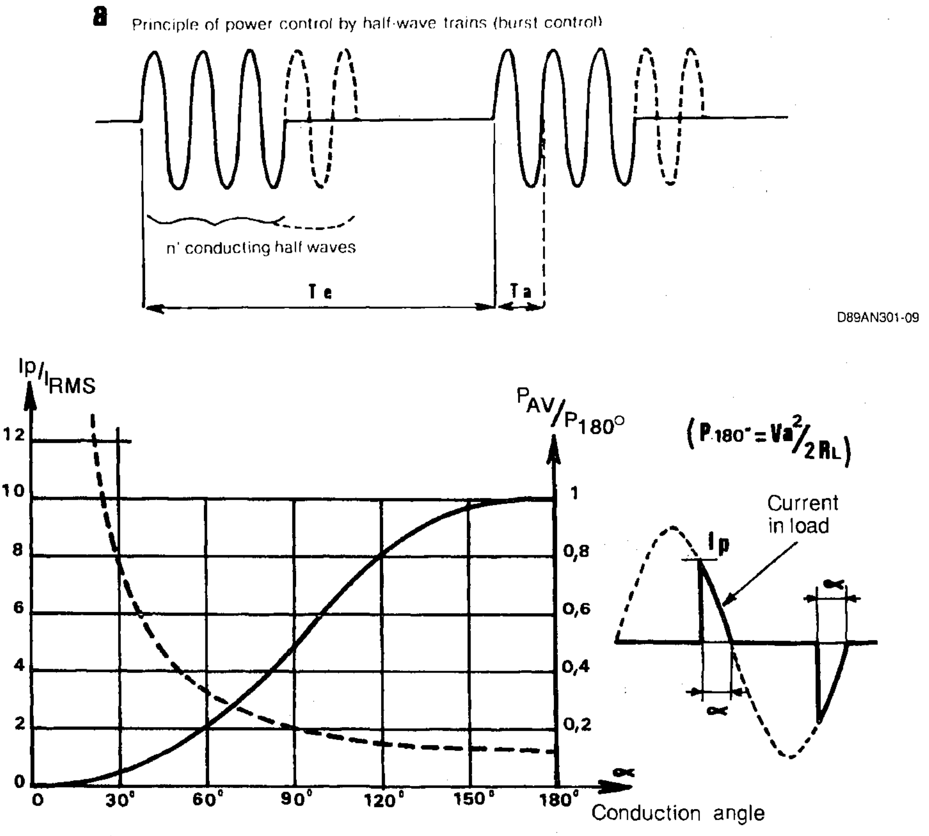
The fineness of adjustment of P_{AV} obviously improves when T_e increases with respect to T_a. A sampling period of 1 second permits adjustment in steps of 1/100. If the load does not not stand any dc component, it is necessary to add to the circuit a system of variation per couples of half waves (full waves) requiring, for the same fineness of adjustment, a double sampling period.

In many cases, however (for instance for light dimmers, for the control of highly loaded low-inertia motors or for regulators with low time constant), it is necessary to sample the power at the frequency of the ac supply mains. To do this, it is only necessary to control the gate by current pulses occuring with a phase shift (π α) with respect to the beginning of each half wave. Figure 5b illustrates the principle of this control, with waveforms obtained on resistive loads as well as a simple example of practical application. The conduction angle of the current is α and the mean applied to the load is fairly equal to:

$$P_{AV.} = \frac{1}{\pi}\,\frac{(V_{RMS})^2}{R_L}\int_0^{\alpha}\sin^2\alpha .\, d\,\alpha$$

$$\text{or } P_{AV.} = \frac{2\,\alpha + \sin^2\alpha}{2\,\pi}\,\frac{(V_{RMS})^2}{R}$$

Figure 6 : Triac Power Control.



In full line (right-hand scale) = Relative change of the power delivered to a resistive load R_L (operation at constant input power).
In dotted line (left-hand scale) = Change in the ratio I_P/I_{RMS} of the peak current to the effective current on resistive load R_L (operation at constant delivered current).

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Figure 6 b shows the change in the delivered power P as a function of conduction angle α, when the input power is kept constant. As can be seen, the relationship between P and α is highly non-linear. To obtain a linear relationship between the mean vol-tage on the load and an adjustment voltage V_r, the latter must act on α with an inverse law.

Figure 6 b also shows (in dotted line) the curve of the change in peak current I_p as a function of the conduction angle with left kept constant, i.e. for a constant power in the load. The curve clearly shows the dangerous condition which exists in case of operation at low power with a low conduction angel when I_p exceeds the permissible repetitive surge current.

1.5. OPERATION ON INDUCTIVE LOAD

In the case illustrated by figure 3, where the triac operates on a pure resistive load ($\cos\varphi = 1$), the current reaches immediately the value V_a/R_L when the gate current I_G is applied. This is a theoretical case, for the leads connecting the triac to the mains and load always offer an inductive component which slows down the rate of rise di/dt of the current, and causes a slight phase shift of the instant of current interruption with respect to the zero input voltage point.

With a load offering a high inductive component ($\cos\varphi$ lower than 1), inductance L limits the current rate of rise to:

$$\frac{di}{dt} = \frac{V_a}{L} \qquad (3)$$

where V_a is the instantaneous value of the input voltage at the instant of application of the firing control. If the gate signal is applied for a duration which is long with respect to that, $T_a/2$, of a half wave of V_a, the waveforms shown in full lines on figure 7 are obtained. Following a periodo of transition, current I_C reaches the value:

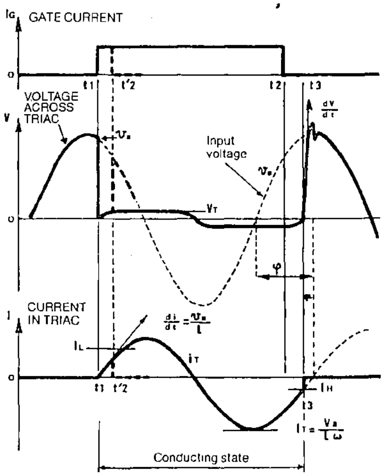
$$\frac{V_a}{L\omega} \sin(\omega t + \varphi), \text{ with } \omega = \frac{2\pi}{T_a}$$

φ represents the phase shift of I_C with respect to V_a, close to /2 when the load is highly inductive. After $\pi/2$ the control has been removed, the current is maintained in the load, as mentioned previously, until its instantaneous value drops below I_H. But, due to phase shift φ, the value of the input voltage is different from zero at that instant. Consequently, the vol-tage across the triac increases suddenly up to value v_a (close to V_a), at a high rate of rise dV/dt which is limited only by capactive elements possibly present in the circuit.

If the triac control had been removed at time t_2, immediately after reaching value I_G (short-duration gate pulse), the current in the inductance might not have had the time to reach value I_L of the triac latching current. Firing would not have taken place in a steady way, and the voltage would have increased again up to v_a as indicated by the dotted lines on figure 7.

During operation on an inductive load with short-during gate pulses, other unwanted conditions may be present when these pulses are applied at the beginning of each half wave of V_a, within angle φ.

Figure 7 : Waveforms with Inductive Load.



– **in full line** : long gate signal.
– **in dotted lines** : effects of too short a gate signal.

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These conditions are represented by the full-line waveforms on figure 8: when the first gate pulse (a) appears, for instance at the beginning of a positive half wave, current I_C increases up to a value at least equal to that of the steady state current and, then, decreases again to a value below I_H only after the time corresponding to angle φ during the next negative half wave. Since the new control pulse (a') already ends at t'_2, i.e. prior to the cancellation of the current, there will be no gate current at t_3 to fire agin the triac during the negative half wave. The next firing will not occur until t''_1, through pulse a", during the subsequent positive half wave.

Thus, with this control, the triac behaves like a unilateral switch, conducting only on the positive half waves (similarly, if the first pulse (a) had appeared during a negative half wave, the current would pass only during negative half waves). This results in a rectifying effect introducing a high mean positive (or negative) current into the load. When the latter consists of a coil wound on a magnetic core with small air gap, or of a transformer primary coil, the operating point describes a large portion of the hysteresis loop. This presents the risk of creating a situation in which the core is almost satured, with the disastrous consequence of an extremely high surge current.

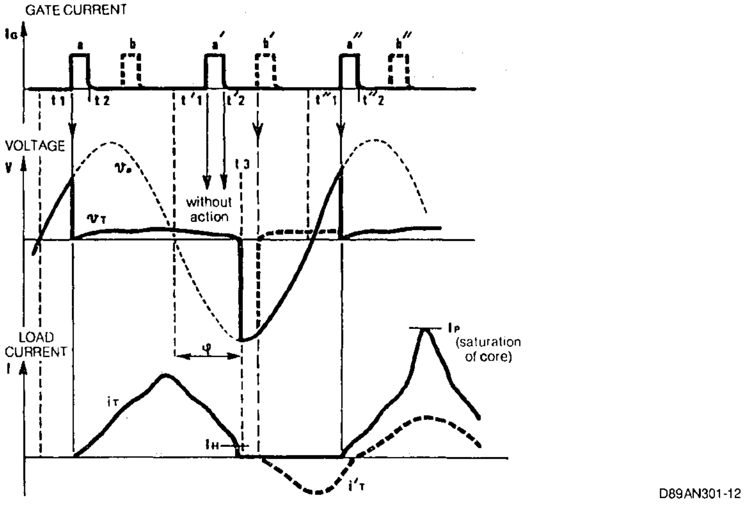
This abnormal operation woud not have taken place if the pulses had a duration equal to, or higher than, that corresponding to angle φ, at the price higher control energy. The effect of the rectification phenomenon can suppressed through a power-saving means which consist in controlling the triac by pulse trains instead of only one pulse for each half wave. As a matter of fact, figure 8 shows (waveforms in dotted lines) that a new pulse (b') occuring immediately after the current has been concelled, permits triggering again the triac during the negative half wave. There still remains a dissymmetry between the positive and negative current arches, but the rectifying effect can be considered negligible when the pulses are sufficiently closely spaced.

The various modes of control illustrated by figure 5 in the case of a resistive load, can be used as well with an inductive load, provided the following precautions are taken:

A) - For control by half-wave trains, the gate pulses should be centred around the zero point of the current that is to say when the voltage is re-applied. This permits ensuring re-firing of the triac immediately after the cancellation of the current (instant t''_2 on figure 8).

B) - For control by conduction angle, gate pulses of sufficiently long duration, or pulse trains starting from (π - α) corresponding to the required opening angle, and ending toward the end of the half wave, should be used.

Figure 8 : Control by Wide Conduction Angle on Inductive Load with Short-Duration Gate Pulses.



– **in full lines :** Rectification effect due to the combination of a narrow pulse with a wide angle.
– **in dotted lines :** Waveforms with two-pulse trains for each half wave.

2. SAFE-OPERATION PARAMETERS

The reliability of the triac is dependent upon a number of utilization precautions which cannot be taken without a thorough knowledge of the stresses or spurious phenomena to which the triac is liable to be exposed.

We shall examine the influence of thermal stresses and of current surges on its service life, and of overvoltages on its blocking capability. Finally, we shall indicate a few means of protection against these parasitic conditions.

2.1. THERMAL STRESSES

The data sheets give a limit value of the junction temperature: (T_j) max. When the effects of a high-temperature operating environment and of the increase of semiconductor self heating due to the dissipated power, cause the triac junctions to reach a temperature higher than (T_j) max, the result can be a temporary alteration of the performances, then a irreversible degradation gradually evolving to the complete destruction of the device when that situation remains unchanged for an extended period of time, or occurs repeatedly. Any degradation will be accelered in cases where an excessive temperature combines with other stresses (overvoltages, short spikes of current or of di/dt etc). In case where the occurence of such conditions in anticipated, appropriate measures have to be taken to keep the junctions at a temperature substantially lower than the maximum specified value.

Direct measurement of junction temperature T_j is hardly possible during operation. An approximation of its average value can be obtained from the case temperature t_{case}, specified junction/case thermal resistance $(R_{th})_{jc}$ and dissipated power P_{AV}.:

$T_j - T_{case} = (R_{th}\ j\text{-}c).\ P_{AV}$ (5)

The data sheets often give curves of P_{AV} versus condition angle α, showing a decrease of P_{AV}, and consequently of the mean temperature, at small angles α. But, it is to be remembered that the instantaneous junction temperature at small conduction angles may rise substantially higher than T_j AV.

In case of full conduction, an excess value for the dissipated power can be easily calculated by considering that voltage drop V_T in the triac is of the form:

$V_T = Vto + Rt.I_T$

In which Vto is the threshold voltage and Rt, is the dynamical resistance of the on-state characteristic. These 2 parameters are given in the data sheet of each part number. For a sinusoidal current I_{TRMS} the power dissipation of the triac is:

$P = 2\sqrt{2}/\Pi)\ I_{TRMS}\ Vto + Rt.I^2_{TRMS}$

2.2. CURRENT STRESSES

In many practical applications the triac may have to withstand current surges. Let us mention more particularly:

- shor-circuits of the load,
- user circuits including a capacitive component,
- utilization with incandescent lamps (resistance when cold 10 to 20 times lower than when hot),
- utilization with coils wound on magnetic cores liable to saturation,
- spurious firing of the triac by high-energy overvoltages.

NON-REPETITIVE CURRENT SURGES

The dtasheet indicates a limit value I_{TSM} for the peak of the non repetitive* current allowed to flow through the triac during one, half cycle of the supply mains.

As a general rule, this limit value is 6 to 7 times higher than the nominal peak current I_{TM} of the triac (i.e. 8 to 10 times higher than the nominal rms current). Most of the devices are capable of withstanding without destruction an even higher non-repetitive current peak when its duration is lower than 10 ms.

The specification give a limit value for the expression $\int i^2dt$ for current surge durations ranging from a few milliseconds to some ten milliseconds. This expression fairly well characterizes the operation of a cutout; its value is helpfull in selecting the "I^2t" of a fastacting fuse intended to protect the device against possible shor-circuits of the load. However, it should be used cautiously when the value of the permissible peak current is to be deduced from it, because it is only valuable to represent the surge capability of the triac for a given pulse duration within a narrow interval. For lower durations ranging from a hundred microseconds to a few milliseconds, the permissible non-repetitive current surge in the triac follows a curve closer to that given by the expression:

$$\int i^4dt = \text{constant}$$

as repsented on the theoretical curves of figure 9.

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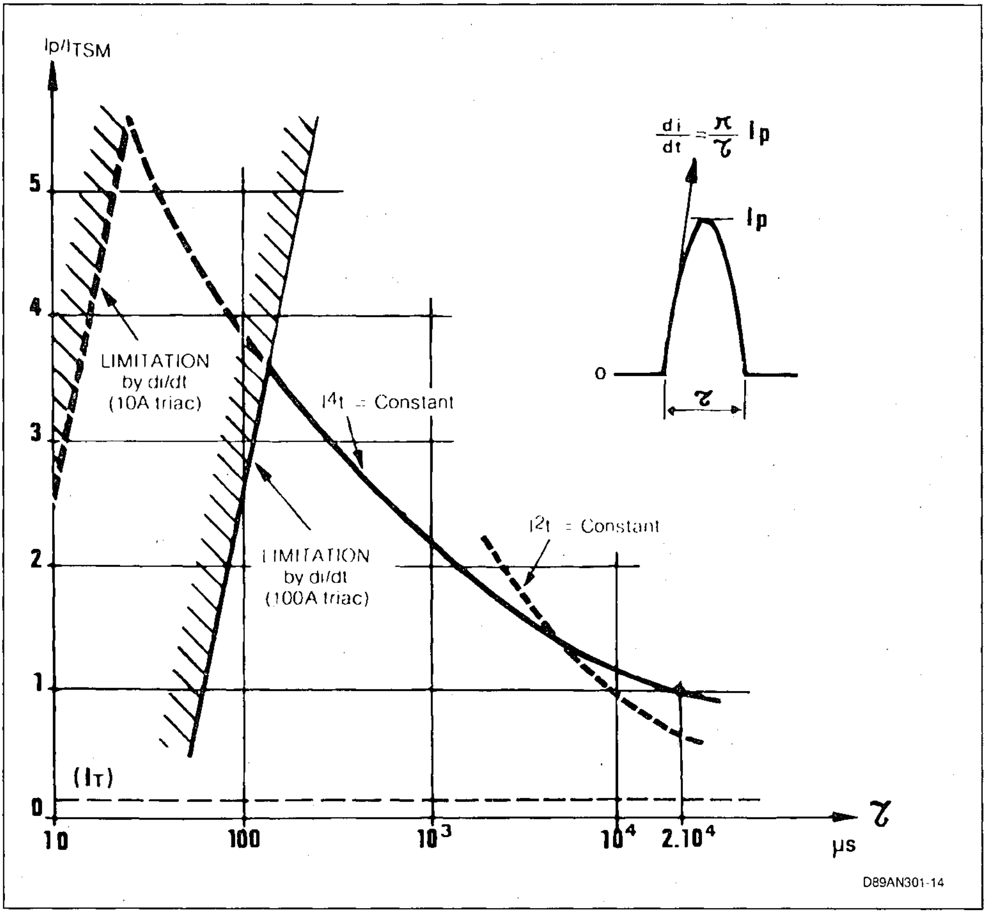
* The device is supposed to withstand this non-repetitive anomaly a limited number of times (a hundred times, according to the JEDEC standards) during its lifetime

Figure 9 : Permissible non-repetitive current surge Ip in the case of a sine wave arch of duration τ.



Finally, for very short current-pulse durations, the permissible current surge is mainly limited by the rate of rise di/dt of the current, which necessarily associated (figure 9).

The limitation by di/dt occurs in a more critical way at the instant the triac is fired (willingly or accidentally) on a low-resistante load with low inductance. An examination of the waveforms of figure 3 shows that firing on a purely resistive load outside of the zero voltage point, entails an extremely fast increase of the current. Practically, there always exists, fortunately, a small inductive component (due to the leads connecting the device to the mains and load) which limitis the rate of rise of the current. But, that rate of rise can reach prohibitive values at the instant the current reaches an high value due, for instance, to the presence of capacitances on the triac terminals, or to a very low instantaneous value of the voltage (spurious firing by an overvoltage).

The harmful effect of a high rate of rise di/dt can be explained, as for the thyristors, by the concentrations of current, and, consequently, by hot points, produced at the instant of the firing, due to the fact that firing first occurs in a very narrow region before spreading out over the full area of the junctions. Since the spreading speed of the conducting region increases when the gate current increases, the behaviour in the presence of non-repetitive high di/dt values will be considerably improved when the triac is fired by a current I_G rapidly reaching a high value.

REPETITIVE CURRENT SURGES

Repetitive stresses with surge current values much lower than the limit value indicated for non-repetitive stresses can lead to an alteration of the triac performances as a result of the cumulative elevation of the instantaneous junction temperature which accompanies them.

This is particularly the case when the triac operates continuously with a small conduction angle while delivering high power. This mode of operation corresponds to high peak currents during short periods of time. At the instant of each passage of the current peak, thereis a risk of the triac junctions reaching a prohibitive temperature. The knowledge of the global transient thermal impedance of both the triac and the heat sink, permits verifying that the instantaneous value of the junction temperature does not exceed (T_j) max.

For very small conduction angles with a resistive or capacitive load, another limitation is given by the rate of rise di/dt of the current in the repetitive state, as will be seen hereafter.

The value of di/dt repetitive is lower (in a ratio of 2 to 3, as a general rule) than the value of di/dt specified for non-repetitive current surges. Such repetitive di/dt values are particularly harmful when the circuit is capacitive. For asynchronous operation (*figure 3*) or for operation with a small conduction angle (*figure 5b*), it is highly recommended to connect a low-value resistor (a few tens of ohms) in series with the capacitances possibly present on the triac terminals.

Operation with "zero voltage point" triggering (*figure 5 a*) does not give rise to any difficulty due to a **repetitive** di/dt subce tge truac us fured at the precise instant at which the voltage, hence the current draw, is null. (but, non-repetitive di/dt values are still liable to occur when all the required precautions have not been taken for the avoidance of untimely triggering at instants at which the voltage value is different from zero).

2.3. BLOCKING CAPABILITIES

PEAK VOLTAGE AT BLOCKED STATE: V_{DWM}.

In normal working conditions, with an input voltage of low frequency (lower than 100 Hz) free of strong parasitic transients, the triac behaves like an open circuit so long as no gate current is applied and that the ac voltage amplitude does not exceed the V_{DWM} value guaranteed by the data sheet particular to this triac. That specified vol-tage V_{DWM} is actually guaranteed for a value notably lower than V_M and V'_M (figure 2) throughout the authorized temperature range. For that voltage, the leakage current, "peak current in the blocked state", has a maximum value guaranteed at the maximum authorized temperature.

CRITICAL RATE OF RISE OF THE VOLTAGE IN THE BLOCKED STATE: "STATIC" dv/dt.

During operation in the presence of parasitic transients, the triac may lose its blocking capabilities, even if the peak voltage of the transient does not exceed V_{DWM}, but when its rate of rise dv/dt is higher than a critical value. As a matter of fact, in such a case current C_T dv/dt developed across the spacecharge capacitance C_T of the reverse biased junction with reverse bias in the blocked state, acts as a gate current liable to fire the triac. This susceptibility to steep voltage leading edges obviously increases with a higher sensitivity of the triac (low I_{GT}) and a higher temperature of the semiconductor. The datasheets indicate a value of dv/dt withstanding capability with a leading edge of 0.6 V_{DWM} amplitude and with a junction temperature close to the permissible maximum. These values are typically on the order of a few hundreds of volts/µs for low-sensitivity devices and decrease down to some ten volts/µs for highly sensitive devices.

CRITICAL RATE OF RISE OF THE VOLTAGE DURING SWITCHING: $(dv/dt)_c$

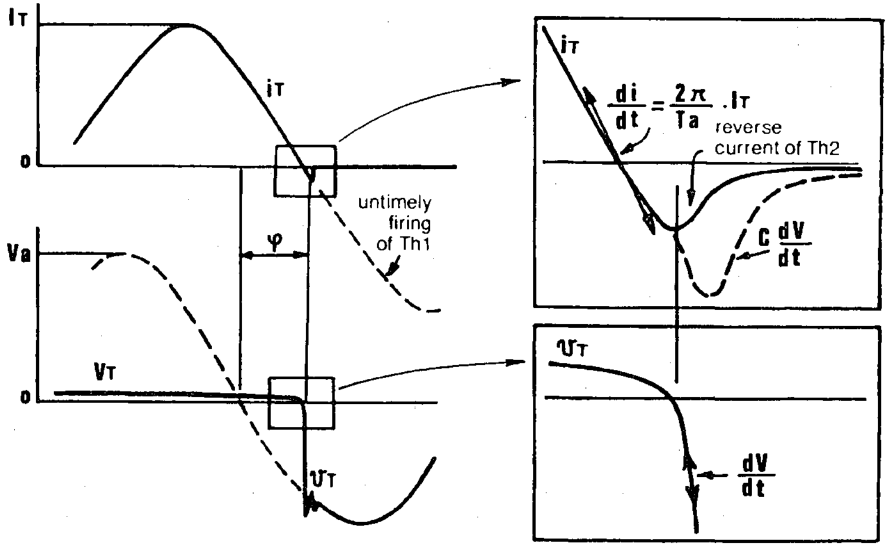
The susceptibility to dv/dt of the triac in the blocked state is based on the same phenomenon, and leads to values of the same order as in the case of the thyristors. However, in a conventional triac, the two elementary thristors Th1 and Th2 illustrated by figure 1 (section 1) being strongly coupled, one can expect reactions between these elements, which are liable to affect the blocking capabilities when the current cancels after each reversal of the input voltage polarity.

In extreme cases, this coupling can cause the triac to remain conducting without gate current, through the following process: when, following the suppression of the control signal, the current reverses in the load, for instance, by positive values (*figure 11A*), "internal thyristor" element Th2, which was in the conducting state, keeps stored charges. The discharge of these charges results in a reverse current (curve in full lines of figure 11 B) which can act as gate current for the other "internal thyristor" element Th1 of the triac and, thus, spontaneously fire the triac on the subsequent negative half wave.

However, the risk of spontaneous self-firing of the triac from one half wave to the other, exists only if the slope of the current decay $(di/dt)_c$ at the instant of turn-off is too high.

With the usual passive loads of fairly linear I/V characteristics, the di/dt at turn-off is proportional to I_{RMS}/Ta. With a 50 or 60 Hz supply mains and a junction temperature lower than t_{vj} MAX, the first unfavourable condition only arises, when the triac controls a very high rms current I_{RMS} (high-power applications). However, there are risks of high di/dt

Figure 10 : Spurious re-firing by “ commutating dv/dt” on inductive load (cos ≠ 1).



A : Application of the voltage at the instant of commutation.

B : Exaggerated commutation region

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values occuring on turn-off, even with effective currents of not very high nominal intensity:

a) when the frequency of the ac input voltage is much higher than 60 Hz

b) or when the triac switches the ac terminals of a single-phase rectifier with inductive load, or, still, in certain cases of switching on polyphase rectifers,

c) or, finally, after the passage of a high current surge, as can be the case when turn-on occurs on a load including a saturable core, or on lamps of very low resistance when cold.

However, on a resistive load there is a risk of spontaneous self-firing only when the junction reaches an instantaneous temperature higher than the specified limit value. (this situation can arise, for instance, following an overload, or when, through poor knowledge of the transiente thermal impedance, the user operates the triac at a small opening angle with high peak currents and a high case temperature).

A second parasitic phenomenon occurs when the load is an inductive one: since the inductive component of the load causes a phase shift of the current with respect to the voltage, the voltage across the triac tends to change, at the instant of turn-off of Th2, from a very low value (V_T at low current) to a high value which is the input voltage value at that instant (*figure 10 A*). The resulting voltage wavefront adds to the reverse current and additionnal current C dV/dt (in dotted line on figure 10 B) which contributes to the firing of the other element Th1.

Conventionally, the immunity of triacs to self-firing is characterized by the value of dV/dt to be introduced by an inductive load at the instant of switching, in order to cause the spontaneous re-firing of a triac from one half wave to the other.

This “commutating dv/dt” parameter is generally given by the data sheets for a specified value of di/dt on turn-off (as a general rule, the value corresponding to the nominal operating current at 50 Hz of the triac), and for specified values of the peak voltage and junction temperature (voltage V_{DWM} and maximum permitted temperature, as a general rule).

In all usual circumstances, without turn-off di/dt higher than the nominal value for the 50 or 60 Hz supply mains, the most appropriate precautions warranting the triac blocking capabilities at commutation, consist in selecting a device of not too high a sensitivity and, above all, in using a heat sink sufficient to prevent the instantaneous junction tem-

perature from ever exceeding 80° to 90°C. An additional preventive measure in case of an inductive load is the addition, to the triac terminals, of an RC network limiting the rate of rise of the voltage. The dimensioning of such a protective network will be discussed later on.
Spurious firing actions through dV/dt are detrimental to the triac only when the entail excessive overloads through surge current and di/dt.

3. APPLICATION EXAMPLES

The filed of application of the triac is extremely wide. As a matter of fact, it covers the control of all the equipment operating on alternating current. We shall merely give here the diagrams of a few examples of typical application, and recall, at the end of this note, the general precautions recommended for the utilization of triac (APPENDIX 1).

Before describing these examples, we shall add a few precisions of pratical order to the information given in Sub-section 1.3 about the control of triacs, by referring more particularly to Table I.

As can be seen on table I, the best gate sensitivity homogeneity with either polarity of the mains voltage (applied to A2) is obtained in firing quadrants II and III, which corresponds to gate pulses of negative polarity with respect to A1 (*figure 11 b*). Recent triac control ICs are, generally, designed for this mode of firing.

But, when the latching current constitutes a critical parameter (operation at very low or highly variable current, or at low conduction angle on an inductive load), it is preferable to control the gate by alternate pulses in accordance with the mains voltage polarity (quadrants I, III, figure 11 a). The switches shown on figure 13 and 14, and the diac controllers which will be described in Sub-section 3.2 operate in these conditions.

When the control circuit does not directly deliver alternate pulses, or when the control power is insufficient with respect to the gate sensitivity of the triac to be used, there always remains the possibility of controlling that triac through low-energy pulses by inserting a sensitivie auxiliary static switch between A2 and G. Such a switch can consist either of a small triac (*figure 12 A*), or of a diode bridge switched by a sensitive thyristor (*figure 12 B*). Thus, the main triac will be fired in quadrants I, III, and its

Figure 11.

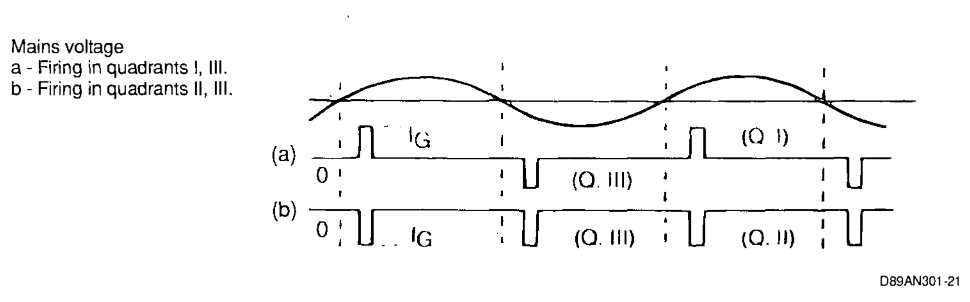
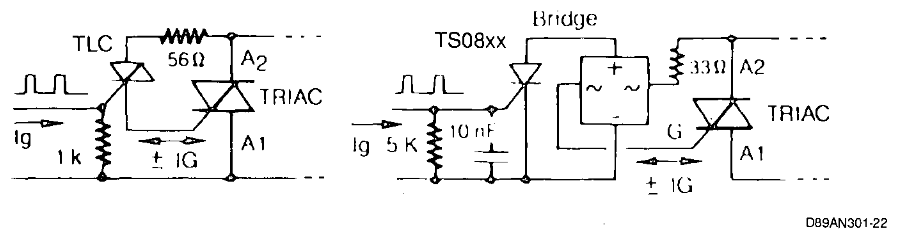


Figure 12.



A) 5 mA control pulse

B) 0.1 mA control pulse

gate current automatically adjusted for the amplitude and duration required for steady firing of the triacs.

3.1. STATIC SWITCHES

The use of a triac as an "on/off" device in an alterning-current circuit represents the simplest application of that semiconductor switch. Such a utilization offers many advantages with respect to mechanical and electromechanical devices:

low control power with respect to the controlled power,

short response time on closing of the circuit, and absence of contact bounce,

possibility to select the firing instant within the phase,

in particular, possibility of firing at the zero voltage point, thus minimizing interference caused by the mains and environment,

no wear related to the number of switching cycles,

automatic breaking of the circuit at the zero current point, i.e. without arcing, even an inductive load.

MICROSWITCH-CONTROLLED STATI SWITCH (PERMANENT CONTACT).

With the circuit represented by the diagram of figure 13, the control energy is taken from anode A2 of the triac, i.e. directly from the mains power through the load, which permits providing a gate current of the required intensity. As soon as triac T is fired, the voltage across it almost cncels, as well as the gate current which is thene exactly proportioned to achieve steady firing (R_1 is of low value, 15 to 50 ohms, so that each re-firing after closing occurs near the zero voltage point, with a sufficiently steep leading edge).

"ON/OFF" SWITCH CONTROLLED BY MOEMENTARY-CONTACT SWITCH (*fig. 14*).

Closing of the "on/off" switch is controlled through a (momentary-contact) push-button switch M; operation is then ensured by the capacitor current which is in phase quadrature with the input voltage.

Opening of the switch is then achieved either by short circuting between the control electrode and electrode "1" of the triac (momentary-contact switch A), or by opening the gate circuit.

STATI SWITCHES CONTROLLED AT THE "ZERO VOLTAGE POINT"

To meet the requirements of the standards concerning the limitation of interference injected into the mains through electrical house appliances, it is necessary to eliminate any sudden current surge at each firing and re-firing of the triac.

With single-phase voltage and a purely resistive load (cos φ = 1), this is achieved by firing the triac with pulses centred on the zero crossing of the mains voltage. But, with a phase shift φ between load current and mains voltage (inductive load or polyphase circuits), it is absolutely necessary to synchronize the gate pulses with the voltage across the triac (see sub-section 1.5) and not with the mains voltage.

Figure 13 : Asynchronous Triggering Through Microswith.

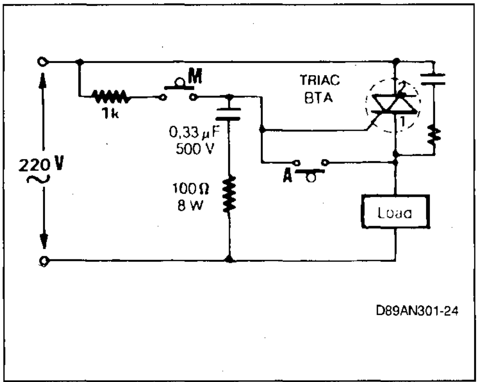
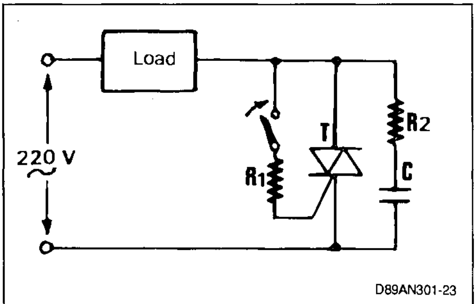


Figure 14 : Setup of an «On/Off» Switch.



T = triac or alternistor
(C = 0,1 µF ; R_1 = 33 Ω ; R_2 = 100 Ω)

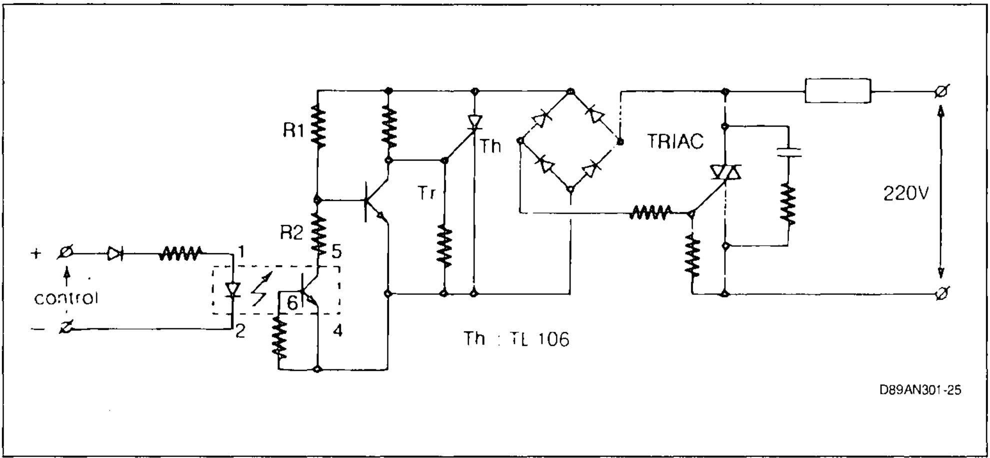
STATIC RELAY INSERTED ON ONE LEAD.

The switche shown by figure 13 can be inserted on one lead, without access to the other mains pole. But, it cannot be directly used for the synchronization on a zero crossing of the AC voltage. However, it is possible to set up a static relay with zero-point firing, in accordance with the same principle of gate current supply from the voltage across the triac, by replacing the mechanical contact with the arrangement shown by figure 12 B, and by controlling the sensitive thyristor through a photocoupler (*fig. 15*).

The triac gate pulse is provided by the thyristor. Transistor Tr enables inhibiting firing of the thyristor depending on the instantaneous amplitude of the mains voltage and the photocoupler control.
If the photocoupler is not supplied, transistor Tr is continuously saturated. It prevents firing of the thyristor.

When the photocoupler is controlled by the voltage divider consisting of resistor R1 and R2, transistor Tr is blocked only when the mains voltage is close to 0 V. The triac is then controlled at the mains zero voltage point.

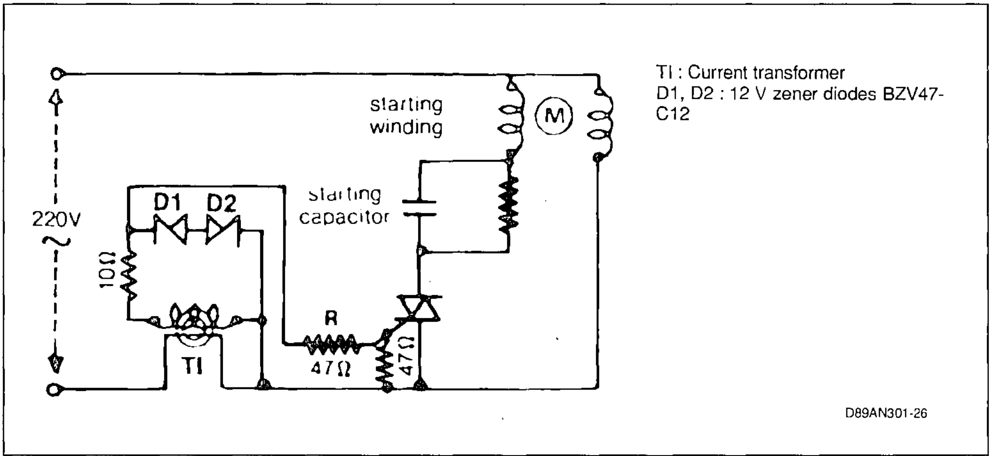
Figure 15.



STARTING OF AC MOTORS (*figure 16*).

The triac is controlled by means of two zener diodes which detect, on the secondary side of a current transformer, the current surge due to the starting of the motor. The semi-conductor device operates only during the time required by the motor to reach synchronism. Consequently, it is not necessary to use a large heat sink. But the compromise between I, R and the transformation ratio of TI has to be correctly adjusted.

Figure 16 : AC Motor Starting Control



3.2. POWER CONTROLLERS

The systems for burst or phase control mentioned in Sub-section 1.4 (*figures 5 and 6*) are used to vary the average power delivered to a load (lamp, motor, heating elements, transformers etc).

We shall give the diagrams of a few power controllers as examples. By feeding back to their control terminals the information provided by suitable sensors coupled to the user circuits, it is possible to make up lighting, speed, pressure, temperature, voltage or current regulators.

DIAC CONTROLLERS.

This is the simplest method for power variation through phase control. In spite of its lowe accuracy, this method is applicable without particular difficulty for power control on resistive loads, or for speed variation of small motors.

To ensure a satisfactory adjustment range, and improve the reversibility of the adjustment, it is advisable to complete the circuit shown by figure 5 b, by an additional RC network, known as "antihysteresis" network (6.8 kΩ and 100 nF on the light dimmer diagrams of *figure 17*).

Slave control of the phase angle by the ambiant lighting, or by an external light phenomenon bay be required to ensure a constant illumination level. With the circuit shown by figure 25 a, this will be achieved by connecting a photoresistor in parallel with the phaseshift capacitor for varying the charging voltage of the latter in accordance with the illumination level.

A variation of the luminous flux of a fluorescent strip light can be obtained in the same manner. This is a particularly attractive application, since the colour of the visible light produced by a fluorescent lamp is almost entirely independent of the luminous intensity, which is not the case with incandescent lamps. With the set-up shown by figure 17 b, highly progressive intensity variation is achieved over a wide luminosity range by connecting the triac in parallel with the fluorescent lamp. Thus, the lamp conduction angle corres-ponds to the triac off-state angle and, consequently, commences at the beginning of each mains voltage half wave.

Figure 18 illustrates a circuit used for speed control of a fan drive motor. Since this type of motor generally comes to a stop long before the conduction angle has decreased down to the triac turn-off point, no antihysteresis network is required. A limitation of the speed adjustment range (resistor R3, possibly adjustable) may be sufficient to avoid hysteresis problems.

However, in this example a partial antihysteresis effect is accessorily produced by the circuit consisting of R_1, R_2 and dioded D_1, D_2, the main purpose of which is to linearise the speed adjustment and, above all, to render it substantially independent of mains voltages variations.

Figure 17 : Luminosity Adjustment of an Incandescent (a) or Fluorescent (b) Lamp.

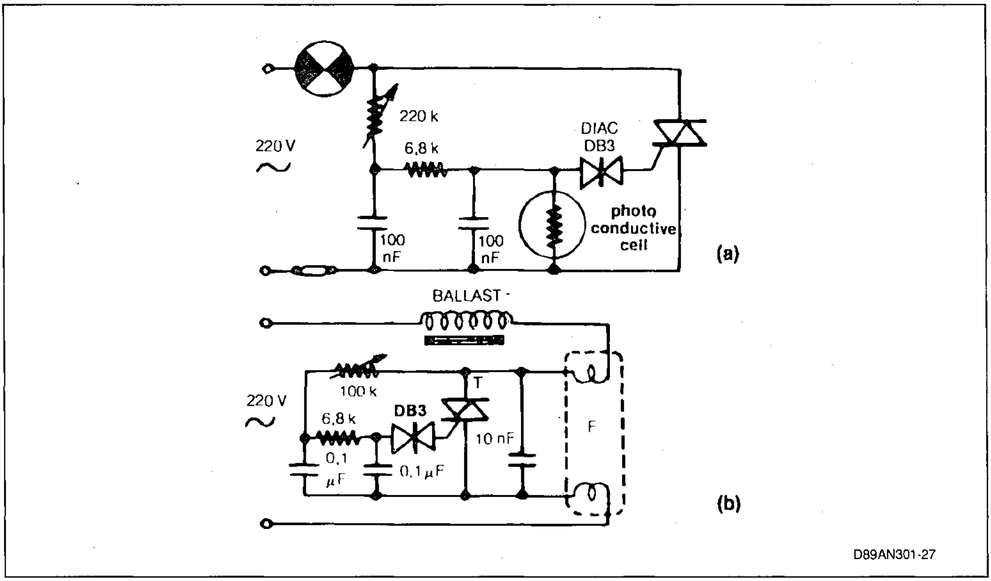
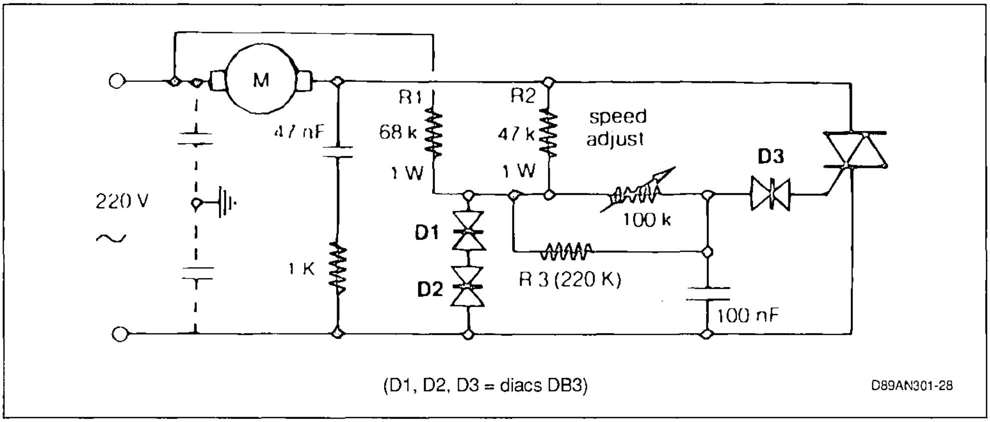


Figure 18 : Motor Speed Adjustment with Compensation of Mains Voltage Variations.



(D1, D2, D3 = diacs DB3)

3.3. SWITCHING OF TRANSFORMERS

As a general rule, the switching of taps on the secondary does not give rise to any particular overload difficulties: it is only necessary to comply with the previously given instructions relative to thermal dissipation (sub-section 2.1), and operation on inductive load (Sub-sections 1.5 and 2.3), particularly when the load on the secondary is a rectifier.
When switching the primary connections (figure 19 a), applying power at a random instant can entail destructive current surges. Such current surges have two origins:

building up of the magnetizing current to a value twice that of the transformer nominal current,

remanence of the magnetic circuit consecutive to the preceding turn off, which can lead to its saturation when power is applied.

To avoid these two difficulties, it would be advisable to control the triac at the maximum of the supply voltage, and at a polarity of this voltage opposite to that in which the transformer remained at the preceding turn-off. Unless the switching of the primary of a transformer of very high induction is concerned, such a sophisticated control circuit is not required, as a general rule, and the following recautions may be sufficient:

In the case of phrase control, or when there are no difficulties due to interference from the environment, proceed to a starting up at progressively increasing conduction angle. Figure 20 illustrates the example of a simple controller. Progressive energization is achieved at the opening of switch S through the charge of capacitor C (2 to 10 µF, 100 V), potentiometer P is used for ower adjustment in normal operation.

For on-off control at the zero voltage point, carry out the first firing of the triac at the beginning of a half wave whose polarity is opposite that of the half wave at the end of which the triac has ceased conducting.

In any case, these cares will be illusory if no precautions (as described in sub-section 2.4) are taken against untimely triac firing on violent interference or mains overvoltages occuring at any instant.
Anyway, it is recommended, for these applictions, to use preferably "alternistors" of a rating overdimensioned with respect to the continuous-duty nominal current, and to protect the circuit by means of fast-acting fuses (refer to sub-section 2.2).

Figure 19 : Switching with Triacs on the Primary (a), or Secondary (b) of a Transformer.

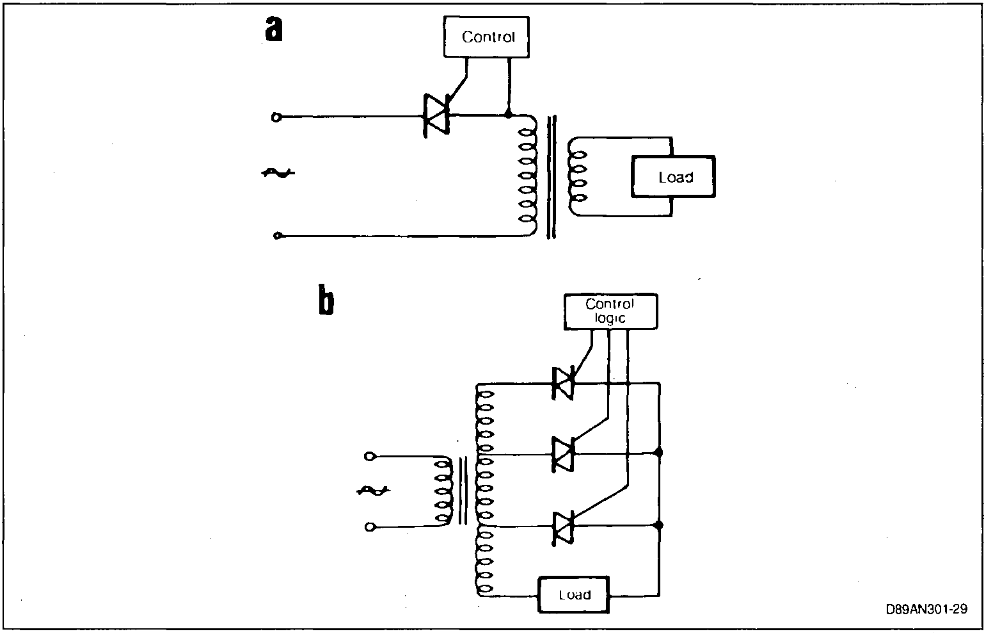
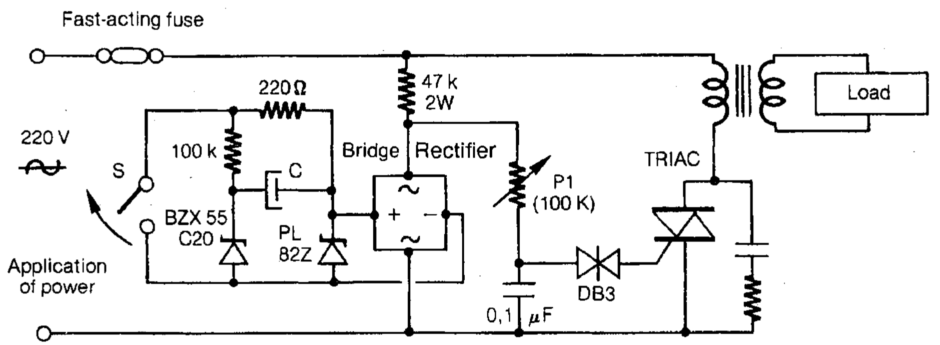


Figure 20 : Diac Controller with Progressive Energization of the Transformer.



CONCLUSION

The triac is a AC switch which changes from the blocked to the conducting state when a current or current pulses of any polarity are applied to the control electrode. Turn-on of the device can be achieved with precision in synchronism with the AC input voltage, while turn-off occurs when the current passes through zero following the control signal removal.

This permits setting up systems for the switching, variation or regulation of the power delivered to any load (lamp, resistor, transformer, motor). Provided an appropriate heat sink keeps the junction temperature below the specified maximum value, the service like of the triacs used in these systems is almost unlimited.

Owing to the remarkable overloads capabilities of the triacs, users will but exceptionally experience difficulties as regards the reliability of these devices. We have insisted on the various cases of applications requiring particular precautions, in order to give all the information necessary to solve possible problems in the best possible way. Appendix I sums up all useful instruction, in relation with the parameters specified by the individual datasheets.

APPENDIX

RELATIVE CONSIDERATIONS TO A FEW TRIAC UTILIZATION PARAMETERS

Parameters	To be Particularly Consideredfor	Precautions to be Taken (together or separately)
1) Thermal Stresse **I_{TRMS}: Triac Nominal Current** (rms current at 80 °C case temperature). **$R_{th(jc)}$: Junction/case Thermal Resistance;** see Sub-section 2.1	**Continuos Operational ITeff in High Ambient Temperature t_{amb}** **Permanent Operation at Small Conduction Angle, with High Peak Currents** **Operation with High-frequency ac Input Voltage**	**Suitable Heat Sink** Its thermal resistance with respect to t_{amb} should e at the most: $\frac{Tj - t_{amb}}{P} - R_{th(jc)} - R_{tj(cd)}$ With: P = Dissipated power : fig. 3, 4 Tj = max. permissible junction temperature : see Sub-section 2.1 and 4) below (untimely firing)
2) Current Stresse **I_{TSM}: non repetitive peak overload current** (peak current permissible during one period only) **di/dt: critical rate of rise of the current** at turn-on; see Sub-section 2.2	- **Capacitive Load** (or capacitor across the triac terminals) - **Utilization on Incandescent Lamps** (high current inc old condition) - **Windingson Saturable Core,, transformer primary** (magnetizing current) - **Risk of Short-circuit on Load** - **Risk of Untimely** firing occuring on overvoltages (see 4) below	- **Inductive Circuit** (addition of L higher than a few hundreds of µH); see figure 13 - **At least 30 Ω** in series with **possible capacitor** - **Triggering at zero voltage point** - **Triggering through gate pulse of steep leading edge,** with peak much higher than specified I_{GT} - **Non-delayed fuse** rated for less than 2/3 of triac I_{Teff}
3) Holding of Firing Instantaneous output value (current in load) below which the triac turns off (I_H) or does not steadily fire (I_L) after the removal of the gate current (see Sub-section 1.3) a) at End Conduction: holding Current I_H b) at Beginning of Conduction: Latching Current I_L	- **Highly Variable Loads** (low currents) - **Highly Inductive Loads** (see fig. 7) - **Presence of an LC Resonant Circuit** (for instance, underdamped interference filter)	- **Long trigger pulse** or long trains of closely spaced pulses - **RC network across triac terminal** (see fig. 15) - **Triac of Low IH** (sensitive series)
4) Untimely Firing **a) Firing through breakower** (through momentary over-shooting of the maximum specified voltage V_{DMW}; see sub-section 2.3) **b) Firing by dv/dt** (critical rate of rise of the voltage in the blocked state-parasitic triac firing, without gate signal, by a voltage wavefront acting on the triac terminals **c) Commutating dv/dt** (critical rate of rise of the voltage at commutation-see fig. 11); spontaneous triac re-firing through the voltage slope on inductive load at the end of a current half wave	- **High Mains Interference** - **Atmospheric Interference** - **Commutator-type Motors, intermittent contacts** - **Under-dimensioned heat sink** - **High Input Voltage Frequency** - **Forced commutation, rectifiers switch inductive load**	- Limit Junction Temperature (largely dimensioned heat sink); - **ALTERNISTOR** - **RC Network on Triac Terminals**