Fundamental Characteristics of Thyristors

Introduction

The Thyristor family of semiconductors consists of several very useful devices. The most widely used of this family are silicon controlled rectifiers (SCRs), Triacs, SIDACs, and DIACs. In many applications these devices perform key functions and are real assets in meeting environmental, speed, and reliability specifications which their electro-mechanical counterparts cannot fulfill.

This application note presents the basic fundamentals of SCR, Triac, SIDAC, and DIAC Thyristors so the user understands how they differ in characteristics and parameters from their electro-mechanical counterparts. Also, Thyristor terminology is defined.

SCR

Basic Operation

Figure AN1001.1 shows the simple block construction of an SCR.

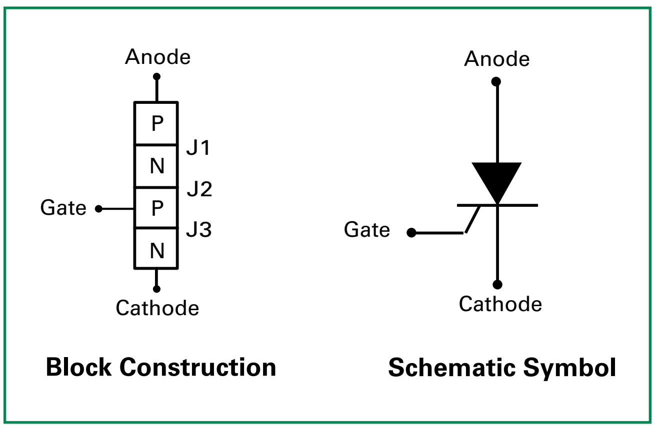

Figure AN1001.1 SCR Block Construction

The operation of a PNPN device can best be visualized as a specially coupled pair of transistors as shown in Figure AN1001.2.

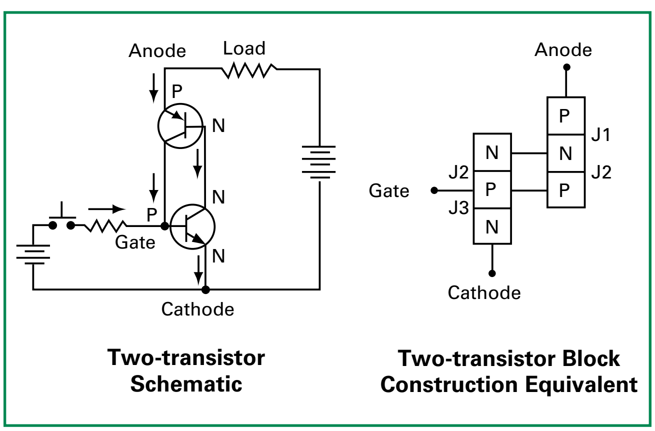

Figure AN1001.2 Coupled Pair of Transistors as a SCR

The connections between the two transistors trigger the occurrence of regenerative action when a proper gate signal is applied to the base of the NPN transistor. Normal leakage current is so low that the combined h_{FE} of the specially coupled two-transistor feedback amplifier is less than unity, thus keeping the circuit in an off-state condition. A momentary positive pulse applied to the gate biases the NPN transistor into conduction which, in turn, biases the PNP transistor into conduction. The effective h_{FE} momentarily becomes greater than unity so that the specially coupled transistors saturate. Once saturated, current through the transistors is enough to keep the combined h_{FE} greater than unity. The circuit remains "on" until it is "turned off" by reducing the anode-to-cathode current (I_T) so that the combined h_{FE} is less than unity and regeneration ceases. This threshold anode current is the holding current of the SCR.

Geometric Construction

Figure AN1001.3 shows cross-sectional views of an SCR chip and illustrations of current flow and junction biasing in both the blocking and triggering modes.

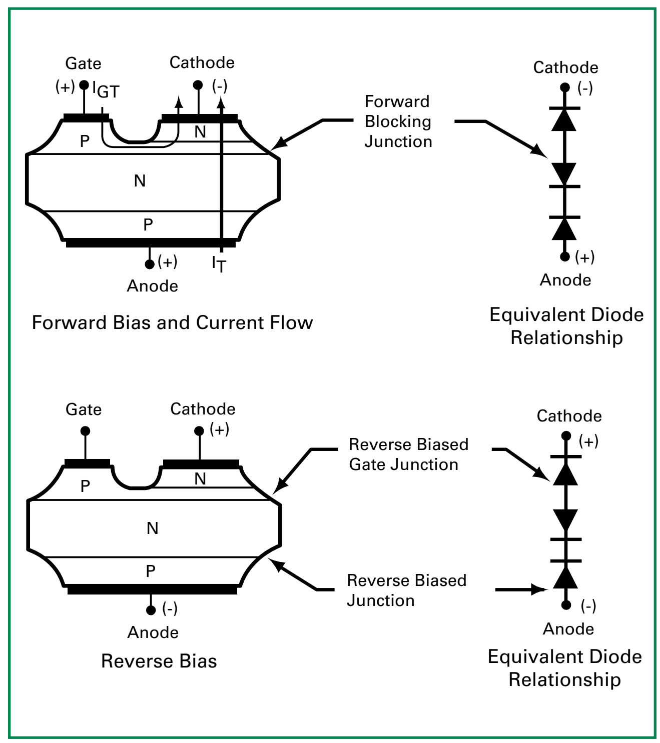

Figure AN1001.3 Cross-sectional View of SCR Chip

Triac

Basic Operation

Figure AN1001.4 shows the simple block construction of a Triac. Its primary function is to control power bilaterally in an AC circuit.

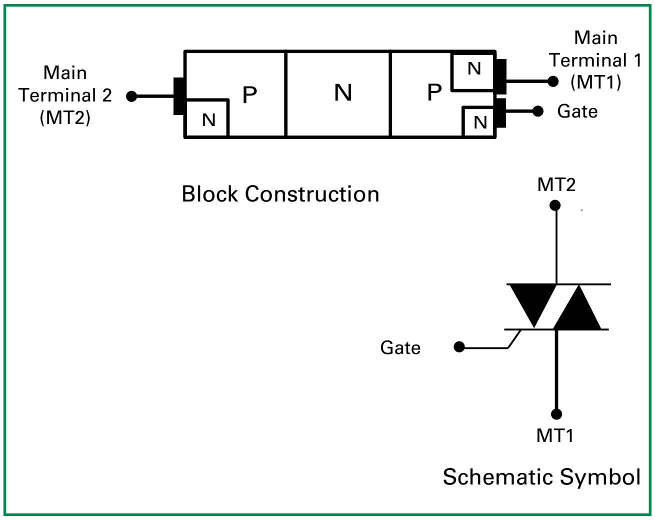

Figure AN1001.4 Triac Block Construction

Operation of a Triac can be related to two SCRs connected in parallel in opposite directions as shown in Figure AN1001.5.

Although the gates are shown separately for each SCR, a Triac has a single gate and can be triggered by either polarity.

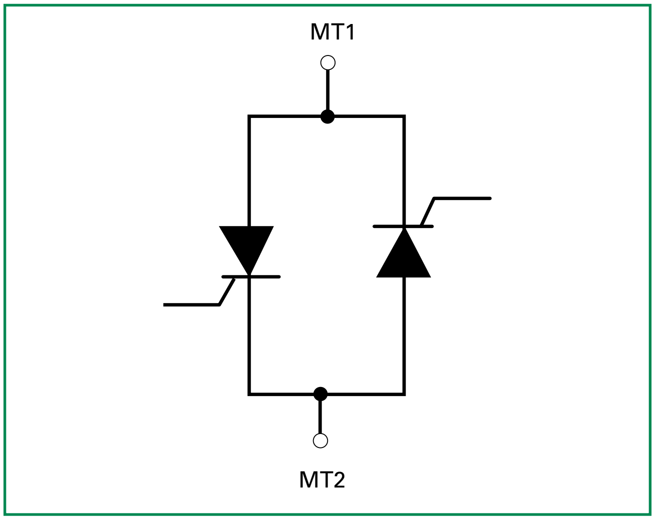

Figure AN1001.5 SCRs Connected as a Triac

Since a Triac operates in both directions, it behaves essentially the same in either direction as an SCR would behave in the forward direction (blocking or operating).

Geometric Construction

Figure AN1001.6 show simplified cross-sectional views of a Triac chip in various gating quadrants and blocking modes.

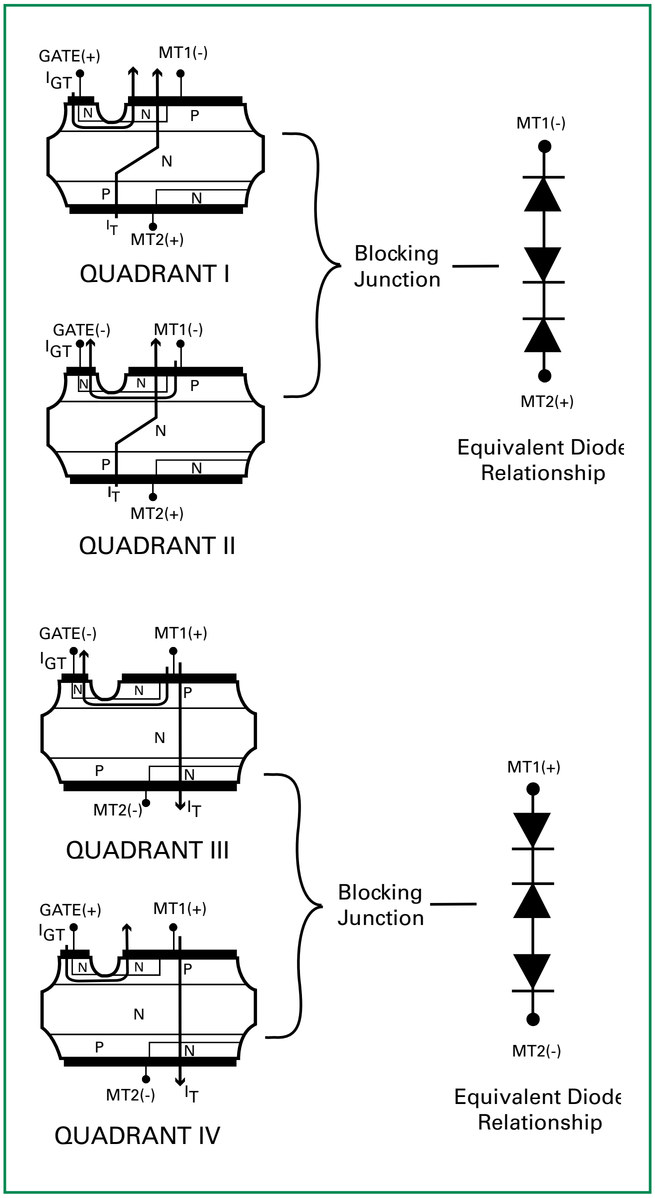

Figure AN1001.6 Simplified Cross-sectional of Triac Chip

SIDAC

Basic Operation

The SIDAC is a multi-layer silicon semiconductor switch. Figure AN1001.7 illustrates its equivalent block construction using two Shockley diodes connected inverse parallel. Figure AN1001.7 also shows the schematic symbol for the SIDAC.

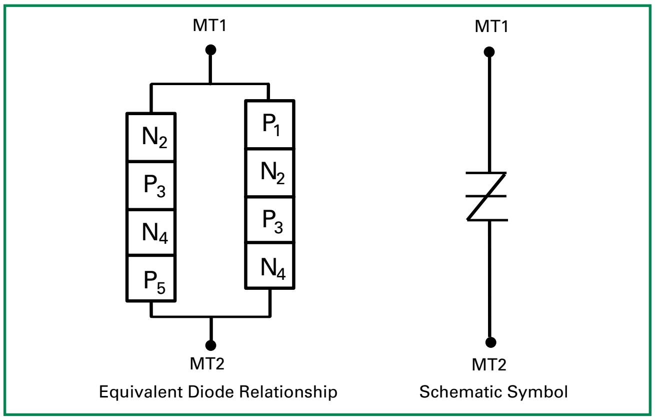

Figure AN1001.7 SIDAC Block Construction

The SIDAC operates as a bidirectional switch activated by voltage. In the off state, the SIDAC exhibits leakage currents (I_{DRM}) less than 5 µA. As applied voltage exceeds the SIDAC V_{BO}, the device begins to enter a negative resistance switching mode with characteristics similar to an avalanche diode. When supplied with enough current (I_S), the SIDAC switches to an on state, allowing high current to flow. When it switches to on state, the voltage across the device drops to less than 5 V, depending on magnitude of the current flow. When the SIDAC switches on and drops into regeneration, it remains on as long as holding current is less than maximum value (150 mA, typical value of 30 mA to 65 mA). The switching current (I_S) is very near the holding current (I_H) value. When the SIDAC switches, currents of 10 A to 100 A are easily developed by discharging small capacitor into primary or small, very high-voltage transformers for 10 µs to 20 µs.

The main application for SIDACs is ignition circuits or inexpensive high voltage power supplies.

Geometric Construction

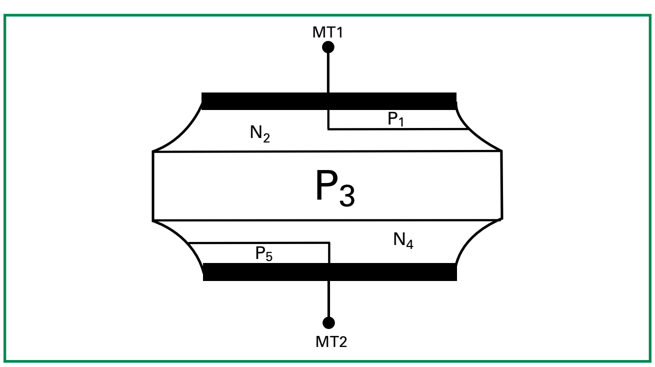

Figure AN1001.8 Cross-sectional View of a Bidirectional SIDAC Chip with Multi-layer Construction

DIAC

Basic Operation

The construction of a DIAC is similar to an open base NPN transistor. Figure AN1001.9 shows a simple block construction of a DIAC and its schematic symbol.

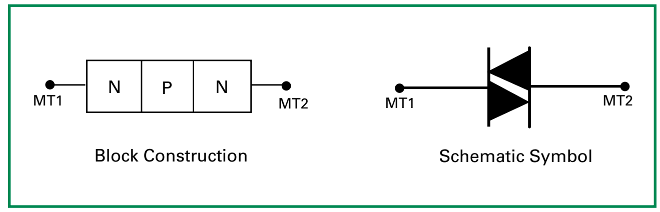

Figure AN1001.9 DIAC Block Construction

The bidirectional transistor-like structure exhibits a high-impedance blocking state up to a voltage breakover point (V_{BO}) above which the device enters a negative-resistance region. These basic DIAC characteristics produce a bidirectional pulsing oscillator in a resistor-capacitor AC circuit. Since the DIAC is a bidirectional device, it makes a good economical trigger for firing Triacs in phase control circuits such as light dimmers and motor speed controls. Figure AN1001.10 shows a simplified AC circuit using a DIAC and a Triac in a phase control application.

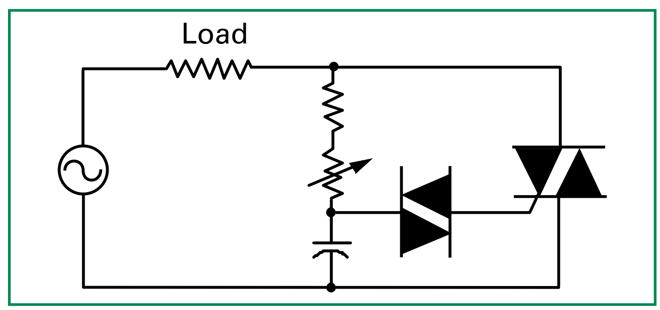

Figure AN1001.10 AC Phase Control Circuit

Geometric Construction

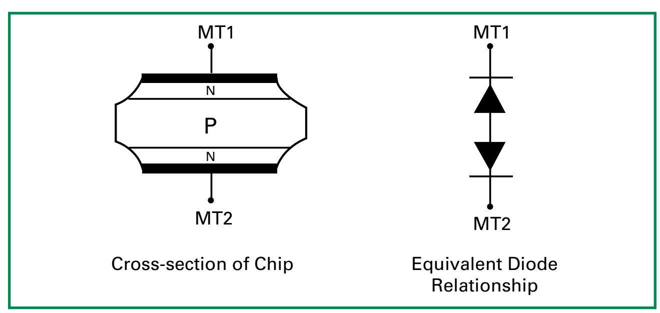

Figure AN1001.11 Cross-sectional View of DIAC Chip

Electrical Characteristic Curves of Thyristors

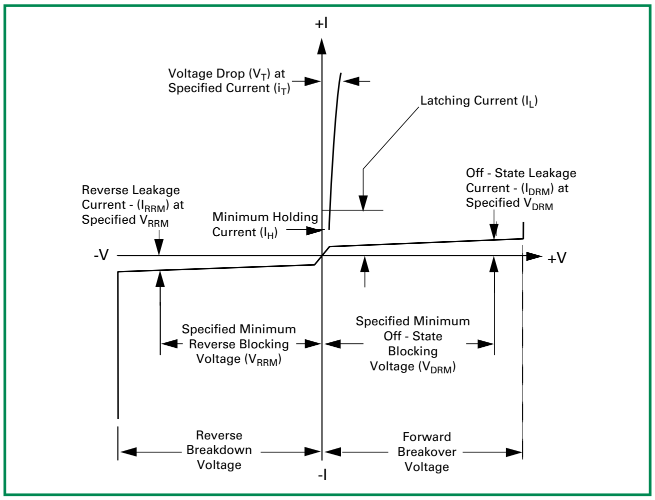

Figure AN1001.12 V-I Characteristics of SCR Device

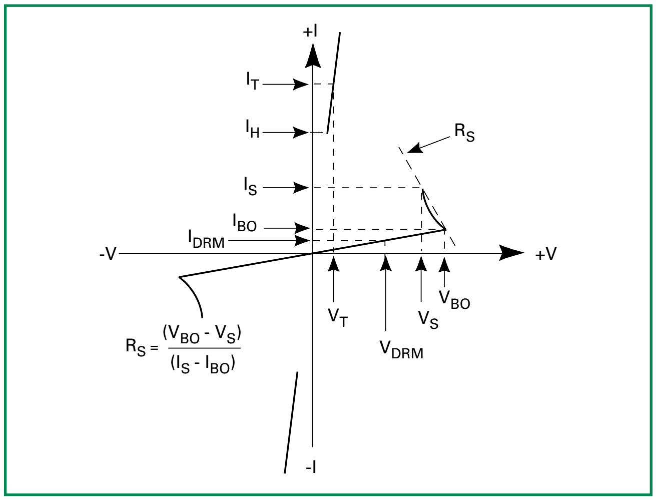

Figure AN1001.15 V-I Characteristics of a SIDAC Chip

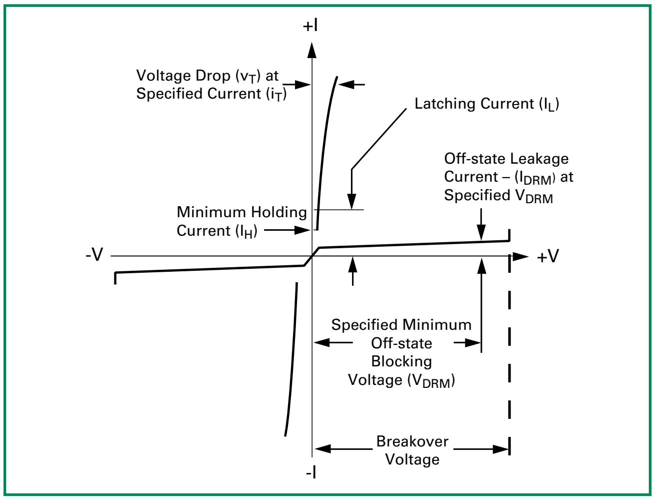

Figure AN1001.13 V-I Characteristics of Triac Device

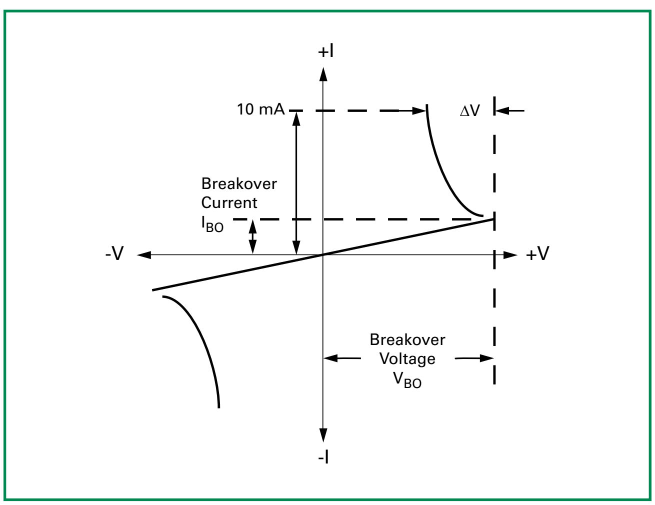

Figure AN1001.14 V-I Characteristics of Bilateral Trigger DIAC

Methods of Switching on Thyristors

Three general methods are available for switching Thyristors to on-state condition:

- Application of gate signal
- Static dv/dt turn-on
- Voltage breakover turn-on

Application Of Gate Signal

Gate signal must exceed I_{GT} and V_{GT} requirements of the Thyristor used. For an SCR (unilateral device), this signal must be positive with respect to the cathode polarity. A Triac (bilateral device) can be turned on with gate signal of either polarity; however, different polarities have different requirements of I_{GT} and V_{GT} which must be satisfied. Since DIACs and SIDACs do not have a gate, this method of turn-on is not applicable. In fact, the single major application of DIACs is to switch on Triacs.

Static dv/dt Turn-on

Static dv/dt turn-on comes from a fast-rising voltage applied across the anode and cathode terminals of an SCR or the main terminals of a Triac. Due to the nature of Thyristor construction, a small junction capacitor is formed across each PN junction. Figure AN1001.16 shows how typical internal capacitors are linked in gated Thyristors.

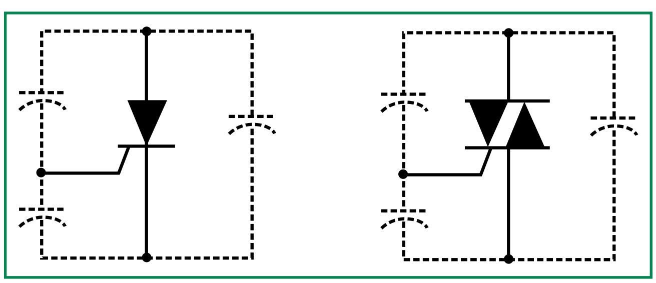

Figure AN1001.16 Internal Capacitors Linked in Gated Thyristors

When voltage is impressed suddenly across a PN junction, a charging current flows, equal to:

$$i = C\left(\frac{dv}{dt}\right)$$

When $C\left(\frac{dv}{dt}\right)$ becomes greater or equal to Thyristor I_{GT},

the Thyristor switches on. Normally, this type of turn-on does not damage the device, providing the surge current is limited.

Generally, Thyristor application circuits are designed with static dv/dt snubber networks if fast-rising voltages are anticipated.

Voltage Breakover Turn-on

This method is used to switch on SIDACs and DIACs. However, exceeding voltage breakover of SCRs and Triacs is definitely not recommended as a turn-on method.

In the case of SCRs and Triacs, leakage current increases until it exceeds the gate current required to turn on these gated Thyristors in a small localized point. When turn-on occurs by this method, localized heating in a small area may melt the silicon or damage the device if di/dt of the increasing current is not sufficiently limited.

DIACs used in typical phase control circuits are basically protected against excessive current at breakover as long as the firing capacitor is not excessively large. When DIACs are used in a zener function, current limiting is necessary.

SIDACs are typically pulse-firing, high-voltage transformers and are current limited by the transformer primary. The SIDAC should be operated so peak current amplitude, current duration, and di/dt limits are not exceeded.

Triac Gating Modes Of Operation

Triacs can be gated in four basic gating modes as shown in Figure AN1001.17.

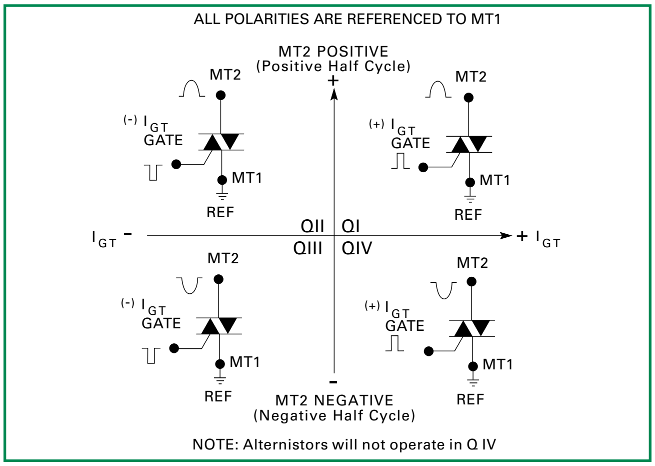

Figure AN1001.17 Gating Modes

The most common quadrants for Triac gating-on are Quadrants I and III, where the gate supply is synchronized with the main terminal supply (gate positive -- MT2 positive, gate negative -- MT2 negative). Gate sensitivity of Triacs is most optimum in Quadrants I and III due to the inherent Thyristor chip construction. If Quadrants I and III cannot be used, the next best operating modes are Quadrants II and III where the gate has a negative polarity supply with an AC main terminal supply. Typically, Quadrant II is approximately equal in gate sensitivity to Quadrant I; however, latching current sensitivity in Quadrant II is lowest. Therefore, it is difficult for Triacs to latch on in Quadrant II when the main terminal current supply is very low in value.

Special consideration should be given to gating circuit design when Quadrants I and IV are used in actual application, because Quadrant IV has the lowest gate sensitivity of all four operating quadrants.

General Terminology

The following definitions of the most widely-used Thyristor terms, symbols, and definitions conform to existing EIA-JEDEC standards:

Breakover Point – Any point on the principal voltage-current characteristic for which the differential resistance is zero and where the principal voltage reaches a maximum value

Principal Current – Generic term for the current through the collector junction (the current through main terminal 1 and main terminal 2 of a Triac or anode and cathode of an SCR)

Principal Voltage – Voltage between the main terminals:

(1) In the case of reverse blocking Thyristors, the principal voltage is called positive when the anode potential is higher than the cathode potential and negative when the anode potential is lower than the cathode potential.

(2) For bidirectional Thyristors, the principal voltage is called positive when the potential of main terminal 2 is higher than the potential of main terminal 1.

Off State – Condition of the Thyristor corresponding to the high-resistance, low-current portion of the principal voltage-current characteristic between the origin and the breakover point(s) in the switching quadrant(s)

On State – Condition of the Thyristor corresponding to the low-resistance, low-voltage portion of the principal voltage-current characteristic in the switching quadrant(s).

Specific Terminology

Average Gate Power Dissipation [$P_{G(AV)}$] – Value of gate power which may be dissipated between the gate and main terminal 1 (or cathode) averaged over a full cycle

Breakover Current (I_{BO}) – Principal current at the breakover point

Breakover Voltage (V_{BO}) – Principal voltage at the breakover point

Circuit-commutated Turn-off Time (t_q) – Time interval between the instant when the principal current has decreased to zero after external switching of the principal voltage circuit and the instant when the Thyristor is capable of supporting a specified principal voltage without turning on

Critical Rate-of-rise of Commutation Voltage of a Triac (Commutating dv/dt) – Minimum value of the rate-of-rise of principal voltage which will cause switching from the off state to the on state immediately following on-state current conduction in the opposite quadrant

Critical Rate-of-rise of Off-state Voltage or Static dv/dt (dv/dt) – Minimum value of the rate-of-rise of principal voltage which will cause switching from the off state to the on state

Critical Rate-of-rise of On-state Current (di/dt) – Maximum value of the rate-of-rise of on-state current that a Thyristor can withstand without harmful effect

Gate-controlled Turn-on Time (t_{gt}) – Time interval between a specified point at the beginning of the gate pulse and the instant when the principal voltage (current) has dropped to a specified low value (or risen to a specified high value) during switching of a Thyristor from off state to the on state by a gate pulse.

Gate Trigger Current (I_{GT}) – Minimum gate current required to maintain the Thyristor in the on state

Gate Trigger Voltage (V_{GT}) – Gate voltage required to produce the gate trigger current

Holding Current (I_H) – Minimum principal current required to maintain the Thyristor in the on state

Latching Current (I_L) – Minimum principal current required to maintain the Thyristor in the on state immediately after the switching from off state to on state has occurred and the triggering signal has been removed

On-state Current (I_T) – Principal current when the Thyristor is in the on state

On-state Voltage (V_T) – Principal voltage when the Thyristor is in the on state

Peak Gate Power Dissipation (P_{GM}) – Maximum power which may be dissipated between the gate and main terminal 1 (or cathode) for a specified time duration

Repetitive Peak Off-state Current (I_{DRM}) – Maximum instantaneous value of the off-state current that results from the application of repetitive peak off-state voltage

Repetitive Peak Off-state Voltage (V_{DRM}) – Maximum instantaneous value of the off-state voltage which occurs across a Thyristor, including all repetitive transient voltages and excluding all non-repetitive transient voltages

Repetitive Peak Reverse Current of an SCR (I_{RRM}) – Maximum instantaneous value of the reverse current resulting from the application of repetitive peak reverse voltage

Repetitive Peak Reverse Voltage of an SCR (V_{RRM})– Maximum instantaneous value of the reverse voltage which occurs across the Thyristor, including all repetitive transient voltages and excluding all non-repetitive transient voltages

Surge (Non-repetitive) On-state Current (I_{TSM}) – On-state current of short-time duration and specified waveshape

Thermal Resistance, Junction to Ambient ($R_{\theta JA}$)– Temperature difference between the Thyristor junction and ambient divided by the power dissipation causing the temperature difference under conditions of thermal equilibrium

Note: Ambient is the point at which temperature does not change as the result of dissipation.

Thermal Resistance, Junction to Case ($R_{\theta JC}$) – Temperature difference between the Thyristor junction and the Thyristor case divided by the power dissipation causing the temperature difference under conditions of thermal equilibrium