SCR/GTO/Diode POW-R-BLOK™ Modules Ratings and Characteristics

1.0 POW-R-BLOK™ Module Construction

Powerex POW-R-BLOK™ modules are hybrid assemblies consisting of various combinations of diodes and Silicon Controlled Rectifiers (SCRs). The metal baseplate of a POW-R-BLOK™ module is electrically isolated from the power devices. The isolated baseplate construction allows a number of POW-R-BLOK™ modules to be mounted on a common heatsink, greatly simplifying equipment assembly.

Chips are mounted to the baseplate within the package in two different ways. In lower power modules, the power chip is soldered to molybdenum discs. The molybdenum discs alleviate thermal stress on the chip due to the nearly equivalent thermal expansion coefficients of molybdenum and silicon. Both surfaces of this assembly are next soldered to the power terminals. The higher power modules use a pressure contact system to hold the chip against the power terminals.

Isolation of the power chips from the baseplate is achieved with various materials. The lower power modules typically utilize aluminum oxide, while the higher power modules utilize beryllium oxide (BeO). BeO has superior thermal conductivity, but it is more expensive and can be a personal health hazard. POW-R-BLOK™ modules which may contain BeO have the following caution printed on their data sheet:

WARNING:
Internal insulation used is Beryllium Oxide. User should avoid grinding, crushing or abrading these portions. Care must be exercised in properly disposing of unwanted modules.

The isolation materials used are selected to withstand 2000 to 2500 volts from live parts to the baseplate without significantly adding to the device's thermal resistance.

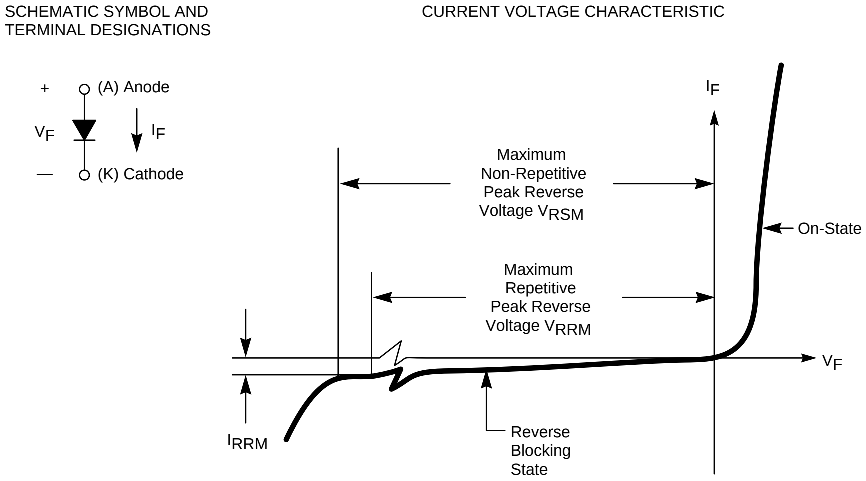
Many of the POW-R-BLOK™ modules have been tested and recognized by Underwriters Laboratories (QQQX2 Power Switching Semiconductors). UL Recognition is an on-going process for POW-R-BLOK™ modules. Please contact your local Powerex sales representative for the latest information on UL Recognition of POW-R-BLOK™ modules.

SCR/GTO/Diode
POW-R-BLOK™ Modules
Ratings and Characteristics

1.1 SCR/GTO/Diode POW-R-BLOK™ Module Configurations

The schematic symbol, terminal designations, and output current-voltage characteristic for diodes and SCRs are shown in Figures 1.1 and 1.2 respectively. The GTO is a special case of the SCR which can be turned off with a sufficiently high pulse of reverse gate current. Diodes are often also called rectifiers. Either term may be used interchangeably. SCRs are a member of the thyristor family of devices. The term thyristor defines any semiconductor switch whose bistable action depends upon p-n-p-n regenerative feedback. The SCR is classified as a reverse blocking triode thyristor.

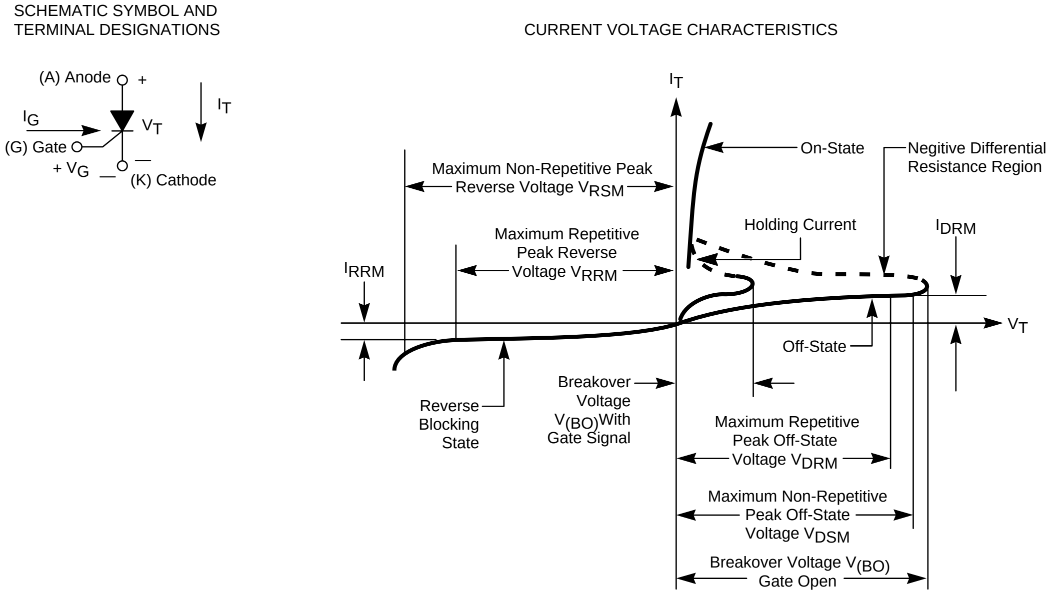
Figure 1.1 Schematic Symbol, Terminal Designations and Current Voltage Characteristics of a Diode (Rectifier).



SCHEMATIC SYMBOL AND TERMINAL DESIGNATIONS

CURRENT VOLTAGE CHARACTERISTIC

Figure 1.2 Schematic Symbol, Terminal Designations and Current Voltage Characteristics of an SCR.



SCHEMATIC SYMBOL AND TERMINAL DESIGNATIONS

CURRENT VOLTAGE CHARACTERISTICS

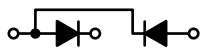
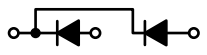
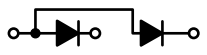
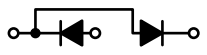
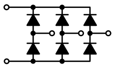
SCR/GTO/Diode
POW-R-BLOK™ Modules
Ratings and Characteristics

1.2 Typical Applications

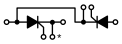
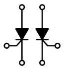
Some of the typical applications for POW-R-BLOK™ modules are: UPS, inverters, lighting controls, induction heating, ultrasonic cleaning, battery chargers, AC and DC motor control, high frequency welding, and power supplies. To meet such a diverse range of applications, POW-R-BLOK™ modules are available in a wide range of circuit configurations, as illustrated by Table 1.1.

Table 1.1 POW-R-BLOK™ Module Circuit Configurations.

DIODE MODULES

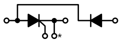
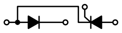
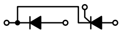
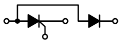
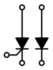
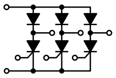
	Single	CS Series
	Dual	CD_1 Series ED_1 Series
	Common Anode	CC Series EC Series
	Common Cathode	CN Series EN Series
	Reverse Dual	CD_9 Series
	Three Phase Bridge	ME Series

DUAL SCR (FULL CONTROL) MODULES

	Dual SCR	CM_3 Series CD_3 Series ED_3 Series CD_A Series
	Split Dual SCR	CT_3 Series

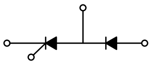
*Auxiliary Cathode Terminal Not Available On All Module Types

SCR/DIODE (HALF CONTROL) MODULES

	SCR/Diode	CM_2 Series CD_2 Series ED_2 Series CD_B Series
	Diode/SCR	CD_7 Series ED_7 Series CD_C Series
	Diode/SCR Center Tap	CC_2 Series EC_2 Series
	SCR/Diode Center Tap	CN_7 Series EN_7 Series
	Split SCR/Diode	CT_2 Series
	SCR/Diode Three-Phase Bridge	CE_2 Series

*Auxiliary Cathode Terminal Not Available On All Module Types

GTO BRIK



SCR/GTO/Diode
POW-R-BLOK™ Modules
Ratings and Characteristics

1.3 The Device Data Sheet

The proper application of power semiconductors requires an understanding of their maximum ratings and electrical characteristics, information which is presented within the device data sheet. Good design practice employs data sheet limits and not information obtained from small sample lots.

A *rating* is a maximum or minimum value that sets a limit on device capability. Operation in excess of a rating can result in irreversible degration or device failure. Maximum ratings represent extreme capabilities of a device. They are not to be used as design conditions.

A *characteristic* is a measure of device performance under specified operating conditions expressed by minimum, typical, and/or maximum values, or shown graphically.

Table 1.2 Major Ratings and Characteristics of a Typical POW-R-BLOK™ Module.

Absolute Maximum Ratings

Characteristics	Symbol	CM421290	CM421690	Units
Peak Forward Blocking Voltage	V_{DRM}	1200	1600	Volts
Transient Peak Forward Blocking Voltage (Non-Repetitive), t < 5ms	V_{DSM}	1350	1700	Volts
DC Forward Blocking Voltage	$V_{D(DC)}$	960	1280	Volts
Peak Reverse Blocking Voltage	V_{RRM}	1200	1600	Volts
Transient Peak Reverse Blocking Voltage (Non-Repetitive), t < 5ms	V_{RSM}	1350	1700	Volts
DC Reverse Blocking Voltage	$V_{R(DC)}$	960	1280	Volts
RMS On-State Current	$I_{T(RMS)}$, $I_{F(RMS)}$	140	190	Amperes
Average On-State Current, T_C = 82°C	$I_{T(AV)}$, $I_{F(AV)}$	90	90	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (60Hz)	I_{TSM}, $I_{F(TSM)}$	1800	1800	Amperes
Peak One-Cycle Surge (Non-Repetitive) On-State Current (50Hz)	I_{TSM}, $I_{F(TSM)}$	1730	1730	Amperes
I^2t (for Fusing), 8.3 milliseconds	I^2t	15000	15000	A^2sec
Critical Rate-of-Rise of On-State Current*	di/dt	100	100	Amperes/μs
Peak Gate Power Dissipation	P_{GM}	5.0	5.0	Watts
Average Gate Power Dissipation	$P_{G(AV)}$	0.5	0.5	Watts
Peak Forward Gate Voltage	V_{GFM}	10	10	Volts
Peak Reverse Gate Voltage	V_{GRM}	5.0	5.0	Volts
Peak Forward Gate Current	I_{GFM}	2.0	2.0	Amperes
Storage Temperature	T_{STG}	-40 to 125	-40 to 125	°C
Operating Temperature	T_j	-40 to 125	-40 to 125	°C
Maximum Mounting Torque M6 Mounting Screw	—	26	26	lb.-in.
Maximum Mounting Torque M5 Terminal Screw	—	17	17	lb.-in.
Module Weight (Typical)	—	160	160	Grams
V Isolation	V_{RMS}	2500	2500	Volts

*T_j = 125°C, I_G = 1.0A, V_D = 1/2 V_{DRM}

Table 1.2 illustrates the major ratings and characteristics of a typical Powerex POW-R- BLOK™ SCR/Diode Module. Table 1.3 lists the symbols and definitions of the major device parameters for diodes, SCRs, and GTOs.

The remainder of this section on ratings and characteristics will be specific to SCRs. However, much of the material is also applicable to diodes and GTOs.

Table 1.2 Major Ratings and Characteristics of a Typical POW-R-BLOK™ Module. (Continued)

Electrical and Thermal Characteristics, T_j = 25°C unless otherwise specified

Characteristics	Symbol	Test Conditions	CM421290/CM421690	Units
Blocking State Maximums				
Forward Leakage Current, Peak	I_{DRM}	T_j = 125°C, V_{DRM} = Rated	15	mA
Reverse Leakage Current, Peak	I_{RRM}	T_j = 125°C, V_{RRM} = Rated	15	mA
Conducting State Maximums				
Peak On-State Voltage	V_{FM}	I_{FM} = 270A, I_{TM} = 270A	1.4	Volts
Switching Minimums				
Critical Rate-of-Rise of Off-State Voltage	dv/dt	T_j = 125°C, V_D = 2/3 V_{DRM}	500	Volts/µs
Thermal Maximums				
Thermal Resistance, Junction-to-Case	$R_{\theta(J-C)}$	Per Module	0.3	°C/Watt
Thermal Resistance, Case-to-Sink (Lubricated)	$R_{\theta(C-S)}$	Per Module	0.2	°C/Watt
Gate Parameters Maximums				
Gate Current-to-Trigger	I_{GT}	V_D = 6V, R_L = 2Ω	100	mA
Gate Voltage-to-Trigger	V_{GT}	V_D = 6V, R_L = 2Ω	2.0	Volts
Non-Triggering Gate Voltage	V_{GDM}	T_j = 125°C, V_D = 1/2 V_{DRM}	0.25	Volts

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters

Power Semiconductor Devices, General Use

Symbol	Parameter	Definition/Description
R_{θ}	Thermal Resistance	Defined when junction power dissipation results in a balanced state of thermal flow. Specifies the degree of temperature rise per unit of power, measuring junction temperature from a specified external point.
$R_{\theta(J-A)}$	Junction-to-Ambient Thermal Resistance	The steady state thermal resistance between the junction and ambient.
$R_{\theta(J-C)}$	Junction-to-Case Thermal Resistance	The steady state thermal resistance between the junction and surface of the case.
$R_{\theta(J-S)}$	Junction-to-Sink Thermal Resistance	The steady state thermal resistance between the junction and the heatsink mounting surface.
$R_{\theta(C-S)}$	Contact Thermal Resistance	The steady state thermal resistance between the surface of the case and the heatsink mounting surface.
Z_{θ}	Transient Thermal Impedance	The change of temperature difference between two specified points or regions at the end of a time interval divided by the step function change in power dissipation at the beginning of the same interval causing the change of temperature difference.
$Z_{\theta(J-A)}$	Junction-to-Ambient Transient Thermal Impedance	The transient thermal impedance between the junction and ambient.
$Z_{\theta(J-C)}$	Junction-to-Case Transient Thermal Impedance	The transient thermal impedance between the junction and the surface of the case.
$Z_{\theta(J-S)}$	Junction-to-Sink Transient Thermal Impedance	The transient thermal impedance between the junction and the heatsink mounting surface.
T_A	Ambient Temperature	When used in the natural cooling or forced-air cooling it is the temperature of the surrounding atmosphere of a device which is dependent on geographical location and season, and is not influenced by heat dissipation of the device.
T_S	Sink Temperature	The temperature at a specified point on the device heatsink.
T_C	Case Temperature	The temperature at a specified point on the device case.
T_j	Junction Temperature Rating	The device junction temperature rating. Indicates the maximum and minimum allowable operation temperatures.
T_{STG}	Storage Temperature Rating	The device storage temperature (with no electrical connection). Indicates the maximum and minimum allowable temperatures.
—	Mounting Torque Mounting Screw	The maximum allowable torque specification for mounting a device to a heatsink with the specified mounting screw.
—	Mounting Torque Terminal Screw	The maximum allowable torque specification for tightening the specified electrical terminal screws.

SCR Modules

Symbol	Parameter	Definition/Description
V_{RRM}	Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the repetitive peak reverse anode to cathode voltage applicable on each cycle.
V_{RSM}	Transient Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the non-repetitive peak reverse anode to cathode voltage applicable for time width equivalent to less than 5ms.
$V_{R(DC)}$	DC Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the maximum value for DC anore to cathode voltage applicable in the reverse direction.

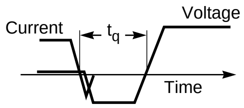
Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

SCR Modules (continued)

Symbol	Parameter	Definition/Description
V_{DRM}	Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the repetitive peak off-state anode to cathode voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive off-state voltage, but excludes non-repetitive transient off-state voltage.
V_{DSM}	Transient Peak Forward Blocking Voltage	Within the rated junction temperature range and when there is no signal between the gate and cathode, specifies the peak non-repetitive off-state anode to cathode voltage applicable for a time width equivalent to less than 5ms. Indicates the maximum instantaneous value for non-repetitive transient off-state voltage.
$V_{D(DC)}$	DC Forward Blocking Voltage	Within the rated junction temperature range and when there is no signal between the gate and cathode, specifies maximum value for DC anode to cathode voltage applicable in the forward direction.
dv/dt	Critical Rate-of-Rise of Off-State Voltage	At maximum rated junction temperature, and when there is no signal between the gate and cathode, specifies the maximum rate-of-rise of off-state voltage that will not drive the device from an off-state when an exponential off-state voltage of specified amplitude is applied to the device. $\frac{dv}{dt} = \frac{0.632V_D}{r}$ V_D: Specified Off-State Voltage r: Time constant for exponential waveform
V_{TM}	Peak On-State Voltage	At specified junction temperature, and when on-state current (commercial frequency, half sine wave of specified peak amplitude) is applied to the device, indicates peak-value for the resulting voltage drop.
$I_{T(RMS)}$	RMS On-State Current	At specified case temperature, indicates the RMS value for on-state current that can be continuously applied to the device.
$I_{T(AV)}$	Average On-State Current	At specified case temperature, and with the device connected to a resistive or inductive load, indicates the average value for forward-current (sine half wave, commercial frequency) that can be continuously applied to the device.
I_{TSM}	Peak On-State Current	Within the rated junction temperature range, indicates the peak-value for non-repetitive on-state current (sine half wave, commercial frequency). This value indicated for one cycle, or as a function of a number of cycles.
I^2t	Current-Squared Time	The maximum, on-state, non-repetitive short time-thermal capacity of the device and is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. This rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal wave form. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
di/dt	Critical Rate-of-Rise of On-State Current	At specified case (or point) temperature, specified off-state voltage, specified gate conditions, and at a frequency of less than 60Hz, indicates the maximum rate-of-rise of on-state current which the thyristor will withstand after switching from an off-state to an on-state, when using recommended gate drive.
I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for reverse-current flow when a voltage (sine half wave, commercial frequency, and having a peak value as specified for repetitive peak reverse-voltage rating) is applied in a reverse direction to the device.
I_{DRM}	Forward Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for off-state-current flow when a voltage (sine half wave, commercial frequency, and having a peak value for repetitive off-state voltage rating) is applied in a forward direction to the device.
P_{GM}	Peak Gate Power Dissipation	Within the rated junction temperature range, indicates the peak-value for maximum allowable power dissipation over a specified time period, when the device is in forward conduction between the gate and cathode.
$P_{G(AV)}$	Average Gate Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation when the device is forward-conducting between the gate and cathode.

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

SCR Modules (continued)

Symbol	Parameter	Definition/Description
I_{GFM}	Peak Forward Gate Current	Within the rated junction temperature range, indicates the peak-value for forward-current flow between the gate and cathode.
V_{GRM}	Peak Reverse Gate Voltage	Within the rated junction temperature range, indicates the peak-value for reverse-voltage applied between the gate and cathode.
V_{GFM}	Peak Forward Gate Voltage	Within the rated junction temperature range, indicates the peak-value for forward-voltage applied between the gate and cathode.
I_{GT}	Gate Current-to-Trigger	At a junction temperature of 25°C, and with a specified off-voltage, and a specified load resistance, indicates the minimum gate DC current required to switch the thyristor from an off-state to an on-state.
V_{GT}	Gate Voltage-to-Trigger	At a junction temperature of 25°C, and with a specified off-state voltage, and a specified load resistance, indicates the minimum gate DC voltage required to switch the thyristor from an off-state to an on-state.
V_{GDM}	Non-Triggering Gate Voltage	At maximum rated junction temperature, and with a specified off-state voltage applied to the device, indicates the maximum gate DC voltage which will not switch the device from an off-state to an on-state.
t_{on}	Turn-On Time	At specified junction temperature, and with a peak repetitive off-state voltage of half rated value, followed by device turn-on using specified gate-current, when specified on-state current of specified di/dt flows, indicated as the time required for the applied off-state voltage to drop to 10% of its initial value after gate current application. "Delay time" is the term used to define the time required for applied voltage to drop to 90% of its initial value following gate-current application, and the time required for level to drop from 90% to 10% is referred to as "rise time". The sum of both these defines turn-on time.
t_q	Turn-Off Time 	Specified at maximum rated junction temperature. Device set up to conduct on-state current, followed by application of specified reverse-voltage to quench on-state current, and then increasing voltage at a specified rate-of-rise as determined by circuit conditions controlling the point where specified off-state voltage is reached. Turn-off time defines the minimum time which the device will hold its off-state, starting from the point on-state current reached zero, and after forward voltage is again applied.

Diode Modules

Symbol	Parameter	Definition/Description
V_{RRM}	Peak Reverse Blocking Voltage	Within the rated junction temperature range, specifies the repetitive peak reverse voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive transient reverse voltage, but excludes non-repetitive transient reverse-voltage.
V_{RSM}	Transient Peak Reverse Blocking Voltage	Within the rated junction temperature range, specifies the non-repetitive peak reverse voltage applicable for a time width equivalent to less than 5ms. Indicates the maximum instantaneous value for non-repetitive transient voltage.
$V_{R(DC)}$	DC Reverse Blocking Voltage	The maximum value for DC voltage applicable in the reverse direction, specified within the rated junction temperature range.
V_{FM}	Peak On-State Voltage	At specified junction temperature, and when forward-current (commercial frequency, sine wave of specified peak amplitude) is applied to the device, indicates peak-value for the resulting voltage drop.
$I_{F(RMS)}$	RMS On-State Current	At specified case temperature, indicates the RMS value for forward-current that can be continuously applied to the device.
$I_{F(AV)}$	Average On-State Current	At specified case temperature, and with the device connected to a resistive or inductive load, indicates the average value for forward-current (sine half wave, commercial frequency) that can be continuously applied to the device.
I_{FSM}	Peak Surge On-State Current	Within the rated junction temperature range, indicates the peak-value for non-repetitive forward-current (sine half wave, commercial frequency), this value is defined at one cycle or as a function of a number of cycles.

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

Diode Modules (continued)

Symbol	Parameter	Definition/Description
I^2t	Current-Squared Time	The maximum, on-state, non-repetitive short time-thermal capacity of the device and is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. This rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal wave form. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for reverse-current flow when a voltage (sine half wave, commercial frequency, and having a peak value as specified for repetitive peak reverse-voltage rating) is applied in a reverse direction to the device.
Q_{rr}	Reverse Recovery Charge	Indicates the total amount of reverse recovery charge. Specified at a certain junction temperature, and current which has decreased at a specified rate of decrease, from the forward state to reverse after a certain forward current was applied.

GTO Modules

V_{RRM}	Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the peak repetitive reverse-voltage applicable on each cycle.
V_{RSM}	Transient Peak Reverse Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the peak non-repetitive peak reverse voltage applicable for a time width equivalent to less than 5ms.
V_{DRM}	Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and cathode, specifies the peak repetitive off-state voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive transient off-state voltage, but excludes non-repetitive off-state voltage.
V_{DSM}	Transient Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and cathode, specifies the peak non-repetitive off-state voltage applicable for a time width equivalent to less than 5ms. Indicates the maximum instantaneous value for non-repetitive transient off-state voltage.
$V_{D(DC)}$	DC Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and cathode, specifies maximum value for DC voltage applicable in the forward direction.
dv/dt	Critical Rate-of-Rise of Off-State Voltage	At maximum rated junction temperature, and when there is a specified reverse voltage between the gate and cathode, specifies the maximum rate-of-rise of off-state voltage that will not drive the device from an off-state to an on-state when an exponential off-state voltage of specified amplitude is applied to the device. $\frac{dv}{dt} = \frac{0.632V_D}{r}$ V_D: Specified Off-State Voltage r: Time constant for exponential waveform
V_{TM}	Peak On-State Voltage	At specified junction temperature, and when on-state current (commercial frequency, half sine wave of specified peak amplitude) is applied to the device, indicates peak-value for the resulting voltage drop.
$I_{T(RMS)}$	RMS On-State Current	At specified case temperature, indicates the RMS value for on-state current that can be continuously applied to the device.
$I_{T(AV)}$	Average On-State Current	At specified case temperature, and with the device connected to a resistive or inductive load, indicates the average value for forward-current (sine half wave, commercial frequency) that can be continuously applied to the device.
I_{TSM}	Peak Surge On-State Current	Within the rated junction temperature range, indicates the peak-value for non-repetitive on-state current (sine half wave, commercial frequency). This value indicated for one cycle, or as a function of a number of cycles.

Table 1.3 Symbols and Definitions of Major POW-R-BLOK™ Parameters (continued)

GTO Modules (continued)

Symbol	**Parameter**	**Definition/Description**
I^2t	Current-Squared Time	The maximum, on-state, non-repetitive short time-thermal capacity of the device and is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. This rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal wave form. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
di/dt	Critical Rate-of-Rise of On-State Current	At specified case (or point) temperature, specified off-state voltage, specified gate conditions, and at a frequency of less than 60Hz, indicates the maximum rate-of-rise of on-state current which the GTO will withstand after switching from an off-state to an on-state, when using recommended gate drive.
I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for reverse-current flow when a voltage (a half sine wave, commercial frequency, and having a peak value as specified for repetitive peak reverse-voltage rating) is applied in a reverse direction to the device.
I_{DRM}	Forward Leakage Current, Peak	At maximum rated junction temperature, indicates the peak-value for off-state-current flow when a voltage (sine half wave, commercial frequency, and having a peak value as specified for repetitive off-state voltage rating) is applied in a forward direction to the device. Tested with a specified reverse voltage between the gate and cathode.
P_{GFM}	Peak Gate Forward Power Dissipation	Within the rated junction temperature range, indicates the peak-value for maximum allowable power dissipation over a specified time period, when the device is forward conducting between the gate and cathode.
$P_{G(AV)}$	Average Gate Forward Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation when the device is forward-conducting between the gate and cathode.
I_{GFM}	Peak Forward Gate Current	Within the rated junction temperature range, indicates the peak-value for forward-current flow between the gate and cathode.
V_{GRM}	Peak Reverse Gate Voltage	Within the rated junction temperature range, indicates the peak-value for reverse-voltage applied between the gate and cathode.
V_{GFM}	Peak Forward Gate Voltage	Within the rated junction temperature range, indicates the peak-value for forward-voltage applied between the gate and cathode.
I_{GT}	Gate Current-to-Trigger	At a junction temperature of 25°C, and with a specified off-voltage, and a specified load resistance, indicates the minimum gate DC current required to switch the GTO from an off-state to an on-state.
V_{GT}	Gate Voltage-to-Trigger	At a junction temperature of 25°C, and with a specified off-state voltage, and a specified load resistance, indicates the minimum gate DC voltage required to switch the GTO from an off-state to an on-state.
P_{GRM}	Peak Gate Reverse Power Dissipation	Within the rated junction temperature range, indicates the peak-value for maximum allowable power dissipation in the reverse direction between the gate and cathode, over a specified time period.
$P_{GR(AV)}$	Average Gate Reverse Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation in the reverse direction between the gate and cathode.
I_{GRM}	Peak Reverse Gate Current	Within the rated junction temperature range, indicates peak-value for reverse-current that can be conducted between the gate and cathode.
I_{TGQ}	Gate Controlled Turn-off Current	Under specified conditions, indicates the instantaneous value for on-current usable in gate control, specified immediately prior to device turn-off.
t_{gt}	Turn-On Time	When applying forward-current to the gate, indicates the time required to switch the GTO from an off-state to an on-state.
t_{gq}	Turn-Off Time	When applying reverse-current to the gate, indicates the time required to switch the GTO from an on-state to an off-state.

1.4 Voltage Ratings

The specified voltages are defined by the maximum rating voltages which can be applied between anode and cathode in the forward, (anode positive with respect to the cathode), and the reverse directions. *The maximum voltage ratings should never be exceeded.* Exceeding the maximum voltage ratings can be detrimental to the device, resulting in instant failure or a decrease in the life of the device.

The repetitive peak sinusoidal forward voltage which can be applied to an SCR or a GTO in the off-state is specified by the Peak Forward Blocking Voltage, V_{DRM}. The forward voltage applicable for sine pulses of less than 5 milliseconds duration which can be applied on a non-repetitive basis to an SCR or a GTO in the off-state is specified by the Transient Peak Forward Blocking Voltage, V_{DSM}. The maximum forward DC voltage rating for an SCR or a GTO is specified by the DC Forward Blocking Voltage, $V_{D(DC)}$. Similar parameters exist with respect to the reverse direction, i.e. Peak Reverse Blocking Voltage, V_{RRM}; Transient Peak Reverse Blocking Voltage, V_{RSM}; and DC Reverse Blocking Voltage, $V_{R(DC)}$. The reverse parameters are applicable to diodes in addition to SCRs and GTOs.

Voltage ratings are specified at the maximum rated junction temperature and are applicable over the entire operating temperature range. For most SCRs, voltage ratings are specified with the gate terminal open. Of particular caution, users should avoid applying positive gate voltage during periods when an SCR is blocking reverse voltage. Positive gate bias during reverse anode to cathode voltage results in a significant increase in SCR power dissipation which must be accounted for to insure reliable operation. For GTOs, voltage ratings are specified with a stipulated value of reverse gate to cathode voltage. SCRs are normally assigned the same voltage rating in both the forward and reverse directions. In practice, most SCRs exhibit a slightly higher reverse breakdown voltage, and the forward breakdown voltage sets the device rating.

Leakage currents are specified at the device forward and reverse voltage ratings. Leakage currents are strongly temperature dependent. At high junction temperatures, it is possible to have regenerative thermal runaway of the device if the case to ambient thermal resistance is at or above a critical value. This potential high power dissipation, particularly with poor or no heatsinking is one reason why it is not recommended to measure blocking voltages of diodes, SCRs, or GTOs with DC tests.

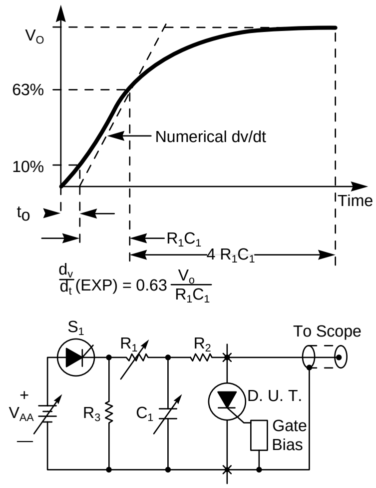
Exceeding the forward blocking voltage of an SCR will result in triggering the device into conduction. Voltage breakover is generally not damaging providing the allowable di/dt rating under this condition is not exceeded. The breakover voltage of an SCR is highly temperature dependent, decreasing rapidly above rated junction temperature. It is not recommended to trigger SCRs by voltage breakover, rather a zener diode or equivalent network should be connected from anode to gate so that the device is triggered by gate drive.

1.5 dv/dt Rating

A high rate of off-state anode-to-cathode voltage, dv/dt, may cause an SCR to turn-on. The static dv/dt test circuit and standard waveforms are shown in Figure 1.3.

Static dv/dt capability is an inverse function of junction temperature. Reverse biasing the gate with respect to the cathode may increase dv/dt withstand capability for medium and low current SCRs. Often the circuit designer will need to add a snubber network across the SCR to limit the maximum dv/dt applied to an SCR.

Figure 1.3 Exponential dv/dt Test Circuit and Waveform



S_1 = Mercury Wetted Reed Relay or SCR
R_1 = Noninducive Resistor
R_2 = Current Limiting Resistor

1.6 Power Dissipation

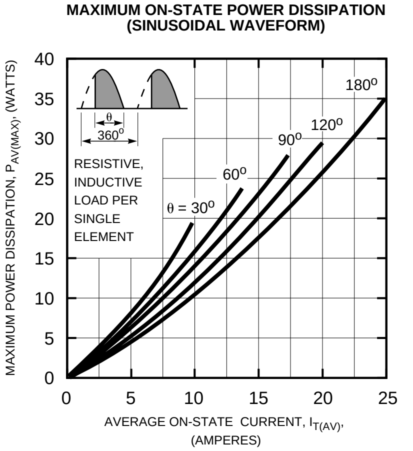
The power generated in an SCR consists of the following components:

1. Turn-on switching
2. Conduction
3. Turn-off switching or commutation
4. Blocking
5. Gate Circuit

On-state conduction losses are the major source of junction heating for normal duty cycles and power frequencies. For very high di/dt current waveforms or high operating frequencies, turn-on switching loss can become significant.

Figure 1.4 illustrates a typical curve of on-state power dissipation in average watts for an SCR as a function of average current in amperes for various conduction angles for operation up to 400 Hz. These curves are based on a current waveform which is the remainder of a half sine wave which results from delayed angle triggering in a single phase resistive load circuit. Similar curves are provided for rectangular current waveforms. These curves represent the integrated product of the instantaneous anode current and on-state voltage drop, and the integration of the appropriate reverse blocking losses. Pulse triggering is assumed and hence gate losses are neglected.

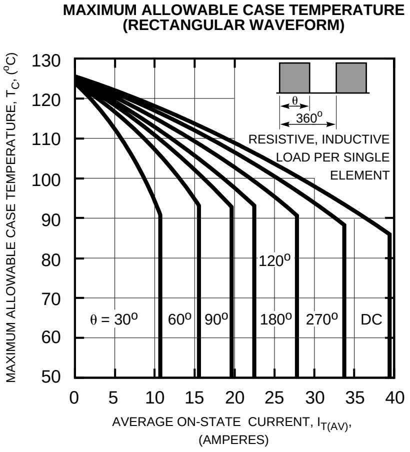
Figure 1.4 On-State Power Dissipation vs. Average Current Characteristic Curve



1.7 Average and RMS Current Ratings

Average current rating versus case temperature as it appears in a typical curve for an SCR is shown in Figure 1.5. These curves specify the maximum allowable average anode current ratings of the SCR as a function of case temperature and conduction angle for a resistive load operating up to 400 Hz. Points on this curve are selected so that the junction temperature does not exceed the maximum allowable value. These curves have definite end points for the various conduction angles. These end points represent the RMS rating of the device. The RMS current rating is necessary to prevent excessive heating of the resistive elements of the SCR, such as joints, leads, interfaces, etc. The relationship between the RMS value and the average value of a current waveform is dependent upon the wave shape. For the data sheet rating standard half wave sinusoidal waveform, the ratio of RMS to average values is 1.57. For low duty cycle waveforms, the average value can be well within device ratings but the high peak currents can result in the allowable RMS rating being exceeded. Similar curves are provided for rectangular current waveforms, typical highly inductive loads.

Figure 1.5 Average Current vs. Case Temperature Characteristic Curve

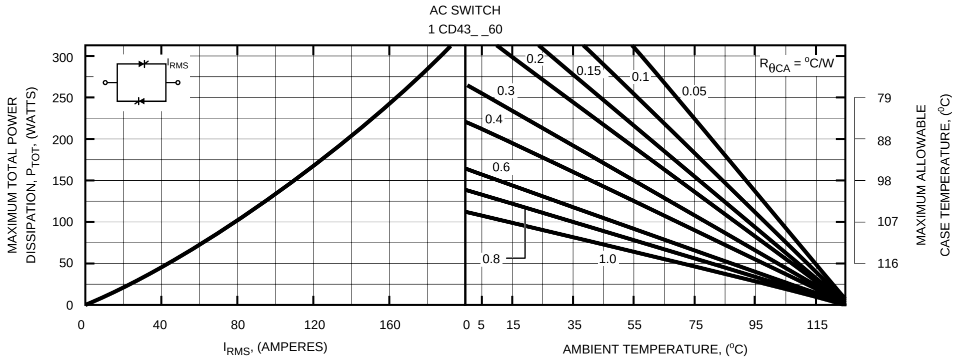


1.8 POW-R-BLOK™ Rating Curves

In addition to the standard sine and square wave information, there are also families of curves for assemblies of AC switches, single and three-phase bridges. This latter group takes the designer one step closer in selecting a heatsink to satisfy his systems needs.

The set of curves shown in Figure 1.6 for the single phase AC switch will be used to demonstrate how the curves were constructed. This set of curves is for one (1) CD43_ _60 module mounted on a heatsink. The left hand vertical axis is for total average power, the right hand vertical is for maximum allowable case temperature, the

Figure 1.6 Maximum Total Power Dissipation and Maximum Ambient Temperature Curve for AC Switch Application



horizontal axis is split between current and ambient temperature.

The first step is to plot the left hand half of the curve. This information is available from the more familiar average power versus average current curve. In this case, only the 180° sine data is plotted. First the average current is changed to RMS by the 2.22 factor. The 2.22 factor takes current rating from average SCR current to RMS switch current for 180° sine. Then the average power for the AC switch is plotted as a function of RMS switch current. The formula

$$T_C = T_j - P_{AVG} R_{\theta(J\text{-}C)}$$

is used to determine the maximum allowable case temperature while maintaining the junction temperature rating of 125°C. Three or four power levels were selected to do the calculations to determine case temperature limits. For instance, at 108A RMS, the power dissipation is 150 watts. $R_{\theta(J\text{-}C)}$ is determined again from average power and case temperature curves both a function of current. The value for the CD43_ _60 is 0.183°C/W, based on the complete module and 180° sine. This yields

$$T_C = 125°C - 150W \times 0.183°C/W$$

$$T_C = 98°C$$

A horizontal line is drawn from the 150 watt level and it intersects the right hand vertical axis at 98°C. This process is continued until the maximum allowable case temperature axis is sufficiently filled.

The next step is to label the right hand horizontal axis with ambient temperatures up to 125°C which corresponds to the maximum permitted junction temperature. The formula

$$T_A = T_C - P_{TOT} \times R_{\theta(C\text{-}A)}$$

is used to generate case-to-ambient thermal impedance lines where:

T_A = Ambient temperature

T_C = Maximum allowable case temperature from above

P_{TOT} = Total power dissipation

NOTE: If 3 modules were used as in three-phase AC switch, P_{TOT} would be the total power of all three modules.

and

$R_{\theta(C\text{-}A)}$ = Thermal impedance case-to-ambient.

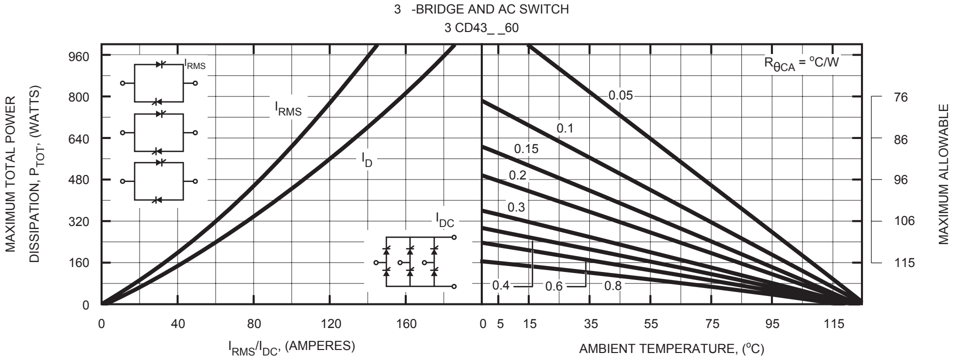
The procedure is to take an average power dissipation and its corresponding maximum allowable case temperature and arbitrarily select $R_{\theta(c\text{-}a)}$ values to calculate maximum ambients. For example

$$T_A = 98°C - 150W \times 0.1°C/W$$

$$T_A = 83°C$$

The intersection of the 83°C ambient and 98°C case temperature becomes a point on the 0.1°C/W $R_{\theta(C\text{-}A)}$ line. The line may be drawn through this point and the 125°C ambient which is a common point to all $R_{\theta(C\text{-}A)}$ lines. Another $R_{\theta(C\text{-}A)}$ is chosen and the procedure is repeated. If

Figure 1.7 Maximum Total Power Dissipation and Maximum Ambient Temperature Curve for Three-Phase Bridge Application.



negative ambients are found, choose other values of average power and case temperature and continue the process until sufficient $R_{\theta(c\text{-}a)}$ lines are drawn.

1.9 Sample Problem

Assume one is trying to select a device to use on a 50hp direct current machine. A current of 90 amperes is required from a three-phase 480 volt AC line with the motor running at base speed. This assumes a 90% efficiency. Figure 1.7 is very useful in determining what heatsink rating is required for a given ambient. A horizontal line can be drawn from the 90 amp point on the I_D curve. This line intersects with the case-to-heatsink curves on the right hand side of the illustration. Assuming a 40°C ambient then the 0.15°C/W line will be used. With three (3) POW-R BLOK's mounted on a common heatsink, the following formula may be used to determine the actual heatsink rating required.

$$R_{\theta(S\text{-}A)} = R_{\theta(C\text{-}A)} - \frac{R_{\theta(C\text{-}S)}}{N}$$

where

$R_{\theta(S\text{-}A)}$ = Sink-to-ambient thermal impedance

$R_{\theta(C\text{-}A)}$ = Case-to-ambient thermal impedance

$R_{\theta(C\text{-}S)}$ = Case-to-sink thermal impedance for a module, i.e. 0.1°C/W

and

N = The quantity of POW-R-BLOK's on the common sink.

The sink-to-ambient thermal impedance is

$$R_{\theta(S\text{-}A)} =$$

$$0.15°\text{C/W} - \frac{0.1°\text{C/W}}{3}$$

$$R_{\theta(S\text{-}A)} = 0.12°\text{C/W}$$

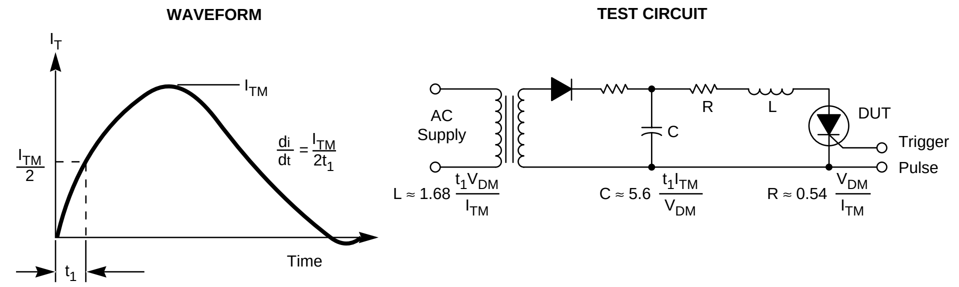
This value of thermal impedance, however, only guarantees the junction temperature will not exceed 125°C. This is not normally the approach taken by designers. A safety margin is normally applied to keep the junction to a lower value and provide added system reliability. A simple method to use with the curves at hand is to add the desired safety margin onto the actual maximum ambient. If 20° margin on junction temperature is desired in a 40°C ambient, extend the existing horizontal line so that it intersects with the vertical 60°C line. This intersection lies on another $R_{\theta(C\text{-}A)}$ line which is 0.1°C/W. This translates into a 0.07°C/W heatsink to ambient thermal impedance. This heatsink would guarantee that even with worst case device parameters, the peak junction temperature will not exceed 105°C.

Similar problems may be solved with any of the other sets of curves for AC switch or single phase bridge configurations.

1.10 Surge and I^2t Ratings

For non-recurrent current overloads, the rated junction

Figure 1.8 di/dt Test Circuit and Waveform



Test Parameter	Recommended Values
I_{TM}	≥ Twice Device Current Rating
t_1	≥ Iμs
Test REP Rate	≥ 60PPS
Test Temperature	Maximum Rated Value
Off-State Voltage	Rated Value
Gate Trigger Pulse	20V/20Ω, t_r = Iμs, t_r = 3μs
Test Duration	≥ 1000 Hours

temperature can be exceeded for a brief instant as indicated by the surge and I^2t ratings. Non-recurrent ratings apply only when they are not repeated before the peak junction temperature has returned to its maximum rated value or less. Non-recurrent ratings apply to situations that occur no more than a limited, typically 100, number of times over the life of the device. In determining the surge current rating, the device is assumed to be at its rated junction temperature prior to application of the overload. Many of the device parameters are not specified or guaranteed immediately following the surge current. Surge current ratings are provided for one, three, or ten half cycles of sinusoidal current at 60 Hz. The I^2t rating is derived from the single cycle surge current rating. The “I” in I^2t rating is the RMS value of the surge current, while it is a peak value in the surge current rating. The I^2t rating is useful in coordinating fuses to protect the SCR or diode.

1.11 di/dt Ratings

When the rate of rise of anode current (di/dt) is very rapid compared to the spreading velocity of the turn-on process across the junctions, local “hot spot” heating will occur. These “hot spots” may lead to localized excessive temperatures that can destroy the device.

The di/dt test circuit and standard waveform are shown in Figure 1.8. The di/dt rating guarantees that the device will block voltage but does not guarantee maintenance of device dynamic characteristics such as turn-off time and dv/dt capability.

The circuit designer must consider all current sources when assessing di/dt. In particular, the discharge current from a snubber network must be included in determining the application di/dt.

1.12 Reverse Recovery Characteristics

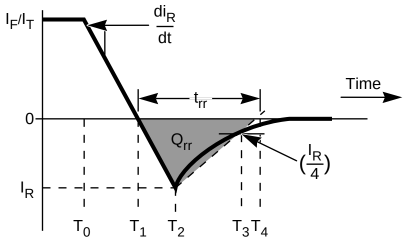
During commutation from forward conduction to the off-state, SCRs and diodes display a transient reverse current that far exceeds the maximum rated blocking current. This reverse current is called reverse recovery current and its time integral is the recovered charge, Q_{rr}. Figure 1.9 illustrates a typical reverse recovery waveform and includes the definition of reverse recovery time, t_{rr}.

Both Q_{rr} and t_{rr} are strongly circuit dependent as well as device dependent. The peak on-state forward current prior to commutation as well as the commutation di/dt are significant circuit variables. Recovered charge has a positive temperature coefficient. Diodes are available in power modules in standard, fast, and super fast recovery times. With the exception of the ED Series, POW-R-BRIK™ and OPEN-BRIK™ modules, the SCRs used in POW-R-BLOK™ modules have standard recovery times typical of power line frequency applications.

1.13 Thermal Resistance

Temperature calculations are simplified by using thermal resistance concepts. The flow of heat through a thermal path as a result of power dissipation is analogous to the flow of current through a conductive path as a

Figure 1.9 Reverse Recovery Waveform and Parameter Definitions



result of a voltage source. Hence, knowing the power being dissipated in a device, and the ambient temperature, the resulting junction temperature can be calculated using the total thermal resistance and the following equation.

$$T_j = T_A + PT^* R_{\theta(J-A)}$$

where:

$R_{\theta(J-A)}$ = Total thermal resistance junction-to-ambient (°C/W)

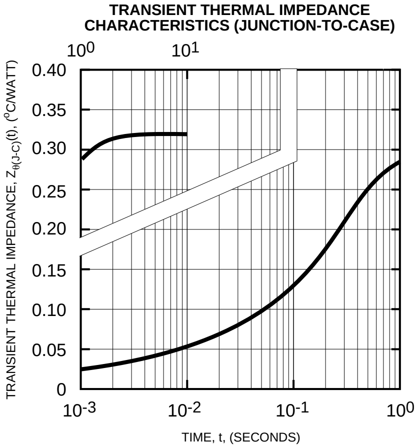
P_T = Total power dissipation (W)

T_j, T_A = Junction, ambient temperature

The total thermal resistance is given by:

$$R_{\theta(J-A)} = R_{\theta J-C)} + R_{\theta(C-S)} + R_{\theta(S-A)}$$

Figure 1.10 Transient Thermal Impedance Characteristic Curve



where:

$R_{\theta(J-C)}$ = Junction-to-case thermal resistance specified on data sheet (°C/W)

$R_{\theta(C-S)}$ = Lubricated case-to-sink thermal resistance specified on data sheet (°C/W)

$R_{\theta(S-A)}$ = Sink-to-ambient thermal resistance (°C/W)

The thermal resistance ($R_{\theta(J-C)}$) specified for a device is always a maximum value, with a safety margin included to allow for production variations from lot to lot. The interface case-to-sink thermal resistance ($R_{\theta(C-S)}$) can be significant and the data sheet value specified is for a baseplate properly lubricated with thermal compound.

1.14 Transient Thermal Impedance

For short or low duty cycle power pulses, using the steady state thermal resistance will give conservative junction temperatures. In addition, using the average value of power dissipation will underestimate the peak junction temperature. The solution is use of the transient thermal impedance curves (Figure 1.10 illustrates a typical transient thermal impedance curve). For a power device subjected to single or very low duty cycle, short duration power pulses, the maximum allowable power dissipation during the transient period can be substantially greater than the steady state dissipation capability.