Low Power

Applications and Technical Data Book

POWEREX

A Guide to Using the Data Book

1.0 Numbering System

Example:

BCR 10 C M – 8 L

(1) (2) (3) (4) (5) (6)

BCR10CM-8L is a 10 Ampere, 400V, Lead Mount, Inductive Load Triac

(1) Type of Device
- BCR : Triac
- CR : Thyristor

(2) Current Ratings
- 10 : I_C = 10 Amperes

(3) Auxiliary Number
- G, H : Isolated
- P : Isolated (full-molded type)
- Others : Non-Isolated

(4) Package
- M : Lead Mounted Type
- S : Surface Mounted Type

(5) Voltage Class
- V_{DRM} = Voltage Class x 50V

(6) Communication Characteristics
- L : For Inductive Loads

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2.0 Symbols and Definitions of Major Parameters

2.1 Power Semiconductor Devices, General Use

JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
R_θ	R_{th}	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.
$R_{\theta(j\text{-}a)}$	$R_{th(j\text{-}a)}$	Junction-to-Ambient Thermal Resistance	The steady state thermal resistance between the junction and ambient.
$R_{\theta(j\text{-}c)}$	$R_{th(j\text{-}c)}$	Junction-to-Case Thermal Resistance	The steady state thermal resistance between the junction and surface of the case.
$R_{\theta(j\text{-}s)}$	$R_{th(j\text{-}f)}$	Junction-to-Sink (Fin) Thermal Resistance	The steady state thermal resistance between the junction and the heatsink (fin) mounting surface.
$R_{\theta(c\text{-}s)}$	$R_{th(c\text{-}f)}$	Contact Thermal Resistance	The steady state thermal resistance between the surface of the case and the heatsink (fin) mounting surface.
Z_θ	Z_{th}	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 time interval causing the change of temperature difference.
$Z_{\theta(j\text{-}a)}$	$Z_{th(j\text{-}a)}$	Junction-to-Ambient Transient Thermal Impedance	The transient thermal impedance between the junction and ambient.
$Z_{\theta(j\text{-}c)}$	$Z_{th(j\text{-}c)}$	Junction-to-Case Transient Thermal Impedance	The transient thermal impedance between the junction and surface of the case.
$Z_{\theta(j\text{-}s)}$	$Z_{th(j\text{-}f)}$	Junction-to-Sink (Fin) Transient Thermal Impedance	The transient thermal impedance between the junction and the mounting surface.
T_a	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	T_f	Sink (Fin) Temperature	The temperature at a specified point on the device heatsink.
T_c	T_c	Case Temperature	The temperature at a specified point of the device case.
T_j	T_j	Junction Temperature Rating	The device junction temperature rating. Indicates the maximum and minimum allowable operation temperatures.
T_{stg}	T_{stg}	Storage Temperature Rating	The device storage temperature (with no electrical connection). Indicates the maximum and minimum allowable temperatures.

2.2 Phase Control SCRs

JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
V_{RRM}	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}	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.
$V_{R(DC)}$	$V_{R(DC)}$	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 anode to cathode voltage applicable in the reverse direction.

2.2 Phase Control SCRs (continued)

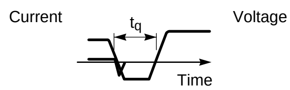
JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
V_{DRM}	V_{DRM}	Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and cathode, specifies the repetitive peak off-state anode to cathode voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive transient off-state voltage, but excludes non-repetitive transient off-state voltage.
V_{DSM}	V_{DSM}	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.
$V_{D(DC)}$	$V_{D(DC)}$	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	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 to an on-state when an exponential off-state voltage of specified amplitude is applied to the device. $\frac{dv}{dt} = \frac{0.632\,V_D}{r}$ V_D : Specified off-state voltage r : Time constant for exponential waveform
V_{TM}	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.
$I_{T(RMS)}$	$I_{T(RMS)}$	RMS On-state Current	At specified case temperature, indicates the RMS value for on-state current that can be continuously applied to the device.
$I_{T(avg)}$	$I_{T(avg)}$	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}	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.
I^2t	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.*
$I_{T(OV)}$	$I_{T(OV)}$	Average Overload On-state Current	Tested under specified cooling conditions, and after the device is continuously conducting an on-state current of specified value, but less than that of the average on-state current rating. The value indicated is the average overload on-state current (commercial frequency, sine half wave) conducted for a specified time immediately after attaining the above conditions, when the test current is removed, and the device is allowed to regain thermal balance, with rated operating voltage applied, it should again conduct the overload current.
di/dt	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 60 Hz, 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.

2.2 Phase Control SCRs (continued)

JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
I_H	I_H	Holding Current	At specified junction temperature, gate conditions and off-state voltage, indicates the minimum anode current required to hold the thyristor in an on-state.
I_L	I_L	Latching Current	At specified junction temperature, off-state voltage and gate conditions, and when the gate trigger current is lifted immediately following switching from an off- to on-state, indicates the minimum anode current required to hold the thyristor in an on-state.
I_{RRM}	I_{RRM}	Reverse Leakage Current, Peak	At maximum rated junction temperature, indicated 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}	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.
P_{GM}	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.
$P_{G(avg)}$	$P_{G(avg)}$	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.
I_{GFM}	I_{FGM}	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}	V_{RGM}	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}	V_{FGM}	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}	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}	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 thyristor from an off-state to an on-state.
V_{GDM}	V_{GD}	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.
$P_{T(avg)}$	$P_{T(avg)}$	On-state Power Dissipation	At a specified conducting angle, and with on-state current of specified waveform applied to the device, indicates the average value for internal power dissipation occurring over a one cycle interval.
t_{on}	t_{gt}	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 of these defines turn-on time.

2.2 Phase Control SCRs (continued)

JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
t_q	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.
Q_{rr}	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.



2.3 Triacs

JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
V_{DRM}	V_{DRM}	Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is a specified reverse voltage between the gate and T_1 terminal, specifies the repetitive peak off-state voltage applicable for each cycle. Includes the maximum instantaneous value for repetitive transient off-state voltage, but excludes non-repetitive transient off-state voltage.
V_{DSM}	V_{DSM}	Transient Peak Forward Blocking Voltage	Within the rated junction temperature range, and when there is no signal between the gate and T1 terminal, specifies the peak non-repetitive off-state voltage applicable for a time width equivalent to less than 5 ms. Indicates the maximum instantaneous value for non-repetitive transient off-state voltage.
V_{TM}	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.
$I_{T(RMS)}$	$I_{T(RMS)}$	RMS On-state Current	At specified case temperature, indicates the RMS value for on-state current that can be continuously applied to the device.
$I_{T(avg)}$	$I_{T(avg)}$	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}	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.
I^2t	I^2t	Current Squared Time	The maximum, on-state, non-repetitive short time thermal capacity of the device is helpful in selecting a fuse or providing a coordinated protection scheme of the device in the equipment. The rating is intended specifically for operation less than one half cycle of a 180° (degree) conduction angle sinusoidal waveform. *NOTE: The off-state blocking capability cannot be guaranteed at values near the maximum* I^2t.
di/dt	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 60 Hz, indicates the maximum rate-of-rise for on-state current which the thyristor will withstand after switching from an off-state to an on-state, when using recommended gate drive.
dv/dt	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 to an on-state when an exponential off-state voltage of specified amplitude is applied to the device. $$\frac{dv}{dt} = \frac{0.632\ V_D}{r}$$ V_D : Specified off-state voltage r : Time constant for exponential waveform

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2.3 Triacs (continued)

JEDEC Symbol	IEC Symbol	Parameter	Definition/Description
I_O	I_O	Average Output Rectified Current	At specified cooling conditions, and with the device connected to a resistive or inductive load, indicates the average value for the output current that can be continuously applied to the device.
I_{DRM}	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.
P_{GM}	P_{GM}	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 in forward conduction between the gate and cathode.
$P_{G(avg)}$	$P_{G(avg)}$	Average Gate Forward Power Dissipation	Within the rated junction temperature range, indicates the average value for maximum allowable power dissipation when the device is in forward conduction between the gate and cathode.
I_{GFM}	I_{FGM}	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}	V_{RGM}	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}	V_{FGM}	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}	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}	V_{GT}	Gate Voltage 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 voltage required to switch the thyristor from an off-state to an on-state.
V_{GDM}	V_{GD}	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.
$P_{T(avg)}$	$P_{T(avg)}$	On-state Power Dissipation	With an on-state current sine wave of specified conducting angle, specifies the average value for internal power dissipation occurring over one cycle.
$(dv/dt)_c$	$(dv/dt)_c$	Critical Rate-of-rise of Off-state Voltage at Commutation	At maximum rated junction temperature, and when conducting a specified on-state current, followed by reversing the current at a specified rate-of-fall, indicates the maximum rate-of-rise of off-state voltage which will not cause the device to conduct in the opposite direction when a specified voltage is applied to the opposite of the previously conducting direction. Specifies the smaller value for the two conducting directions.

3.0 Powerex Quality Assurance Program

One of the basic goals of Powerex is to offer our customers quality products. As a consequence, product quality, price, timely delivery, and service are equally important aspects deserving an equal amount of attention. Still, product quality must stand above all others from a standpoint of customer confidence.

Quality standards in the semiconductor industry are extremely high; production of wafers is carefully controlled, precision process, and assembly processes are done under microscopes to assure that there are no sacrifices made in technology or in quality.

3.1 The Path to a Mass-production Device

From research prototype through mass production, a series of tests are run at each stage to assure performance and reliability of the ultimate product. At the same time, the design drawings are also closely checked. The path from the research stage to mass production is shown in the flow chart of Figure 3.1. The information that follows briefly describes the reliability tests used to check for device reliability.

3.2 Environmental Controls

The semiconductor industry as a whole recognizes the effect environmental factors have on product quality. Rigorous standards have been established regarding the control of dust, humidity, and temperature in manufacturing facilities. The same level of standards are also used for various gases and the water used in the manufacturing process.

3.3 Periodic Inspection and Maintenance of Manufacturing Equipment and Instrumentation

The various equipment and measuring instruments in semiconductor production are an extremely important element of the total process. It is therefore imperative that a periodic program be implemented to inspect and adjust these components so that optimum precision standards are maintained and to forestall any interruptions in the production process.

3.4 Quality Control of Materials

Materials are subjected to rigorous acceptance tests using equipment such as spectrometers, and helium leak detectors. Before placing orders, thorough sample testing is done and all problem areas are worked out before making a final decision. Quality control procedures at the supplier's plant are also considered in any procurement decision.

3.5 Control of the Manufacturing Process

Various measures have been taken to control the elements that have a decisive influence on the quality of the product. Measuring instruments are used to monitor water purity, atmospheric conditions, furnace temperatures, gas flow, and other factors. Check sheet inspections are made and recorders keep automatic records. These records are carefully correlated with the records kept on matters such as diffusion depth and surface density to establish proper working conditions. Strength of the bonded leads is continually monitored. Thorough education programs have been implemented to assure that the personnel who perform these precision mechanical procedures are properly trained.

3.6 In-process and Final Inspections

The goals of the in-process and final inspections are two fold. The first is to assure product quality from the standpoint of outer appearance, dimensions, structural integrity, and mechanical and electrical characteristics. The second is to feed this information back up-line to improve quality and to reduce variations in future runs.

In-process inspections are intended to check the wafer and assembly processes. It also serves two purposes: as a self imposed check on the production process and as a quality control tool. As its name implies, the self imposed check is used by production personnel to correct deficiencies they clearly recognize and emphasis is placed on points that are difficult to detect in completed devices. After the device is completed, it is subjected to the final inspection and the quality assurance inspection. The final inspection is run on all devices and consists of testing electrical characteristics and outer appearance. Quality assurance personnel assume the role of the end user and inspect samples for correct electrical characteristics, outer appearance, and reliability before devices are packed in storage. The flow chart for the quality assurance program covered in the above is noted in Figure 3.2.

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Figure 3.1 Path from Research to Mass Production (Plastic Molded Types Only)

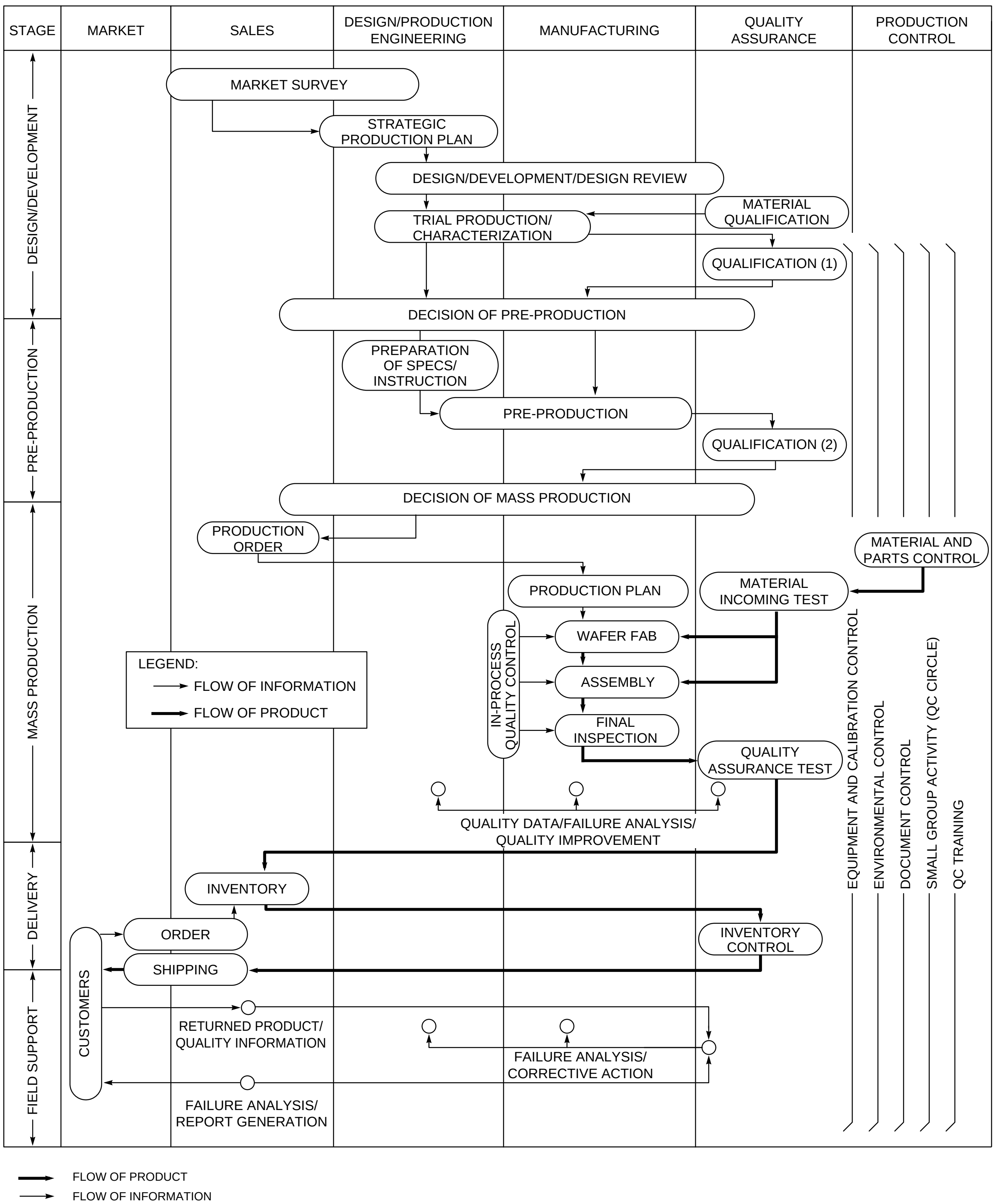
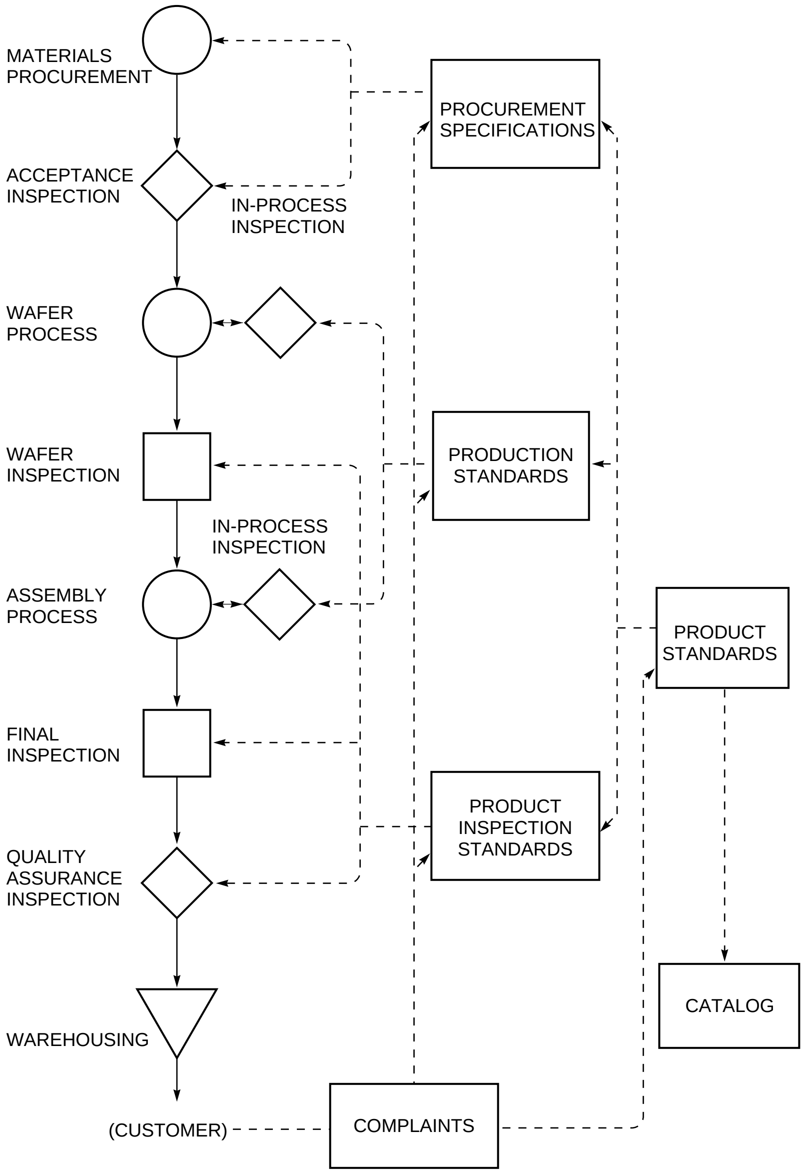


Figure 3.2 Semiconductor Device Quality Assurance Flowchart



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4.0 Semiconductor Device Reliability

It has only been somewhat over 30 years since semiconductor devices such as rectifier diodes, thyristors, and transistors gained widespread acceptance for use in industrial machinery and consumer appliances. During that period, the reliability standards for these devices have made rapid advances.

In equipment where high reliability is a must, failure rate of the semiconductor devices must range from 10 to 100 FIT (Failure-in-time) (1 FIT = 10^{-9}/hours). Of course, to achieve such reliability in the equipment itself, not only must each individual device be reliable, but it is also extremely important to match the specific characteristics of the device with its application within the piece of equipment. In fact, information obtained in field studies show that for semiconductor devices manufactured using identical procedures, failure rates in the field can vary by a factor of 10 depending simply on how the device was used.

The following information covers device reliability with regards to how a device is used. An introductory discussion is also presented on quality control procedures with some examples of reliability testing data given.

4.1 Basic Concepts of Semiconductor Device Reliability

The failure rate of devices used in an average piece of equipment can be expressed by using the bathtub curve shown in Figure 4.1, line (a). Taken from the standpoint of time, device failures can be classified as an early failure, random failure, and wear out failure period. Two points must be considered regarding the service life of a device; early and random failure rates, and lifetime before wear out. The failure rate of semiconductors is illustrated by line (b) in Figure 4.1, where failure rate is shown to gradually diminish as a factor of time. In other words, a notable gesture of semiconductor devices is that the longer a particular device has been used the more stable it will be. Viewed from a different perspective, even though random failure rate has been reduced to virtual stability, the failure distribution pattern shows early failure to still be prevalent. As shown in Figure 4.2 where failure rate versus time is given for an actual device, the highest failure rate occurs immediately after manufacture, where as the process of aging and debugging gradually lowers the failure rate.

The next step is with the user who assembles, adjusts, and takes the device aging. Failure rates continue to decline during this period also. Generally, the rate for major defect during this period drops to less than 0.1%. If this rate is exceeded by a substantial margin, one must look for a fault in the circuit design, assembly procedure, or the device itself. Unless the problem is found and corrected, frequent field failures will be the likely result. In most cases the field failure rate can be correlated to major defect during the period, so this is an important aspect of device reliability.

Upon transferring the equipment to field service, the stress level is reduced further with a corresponding drop in failure rates. Failure rates normally range from several FIT to several hundred FIT during this period.

Another typical characteristic of semiconductor devices is their long service lives. Generally the devices can be expected to far outlast the equipment that they are installed in.

Figure 4.1 Failure Rate vs. Time

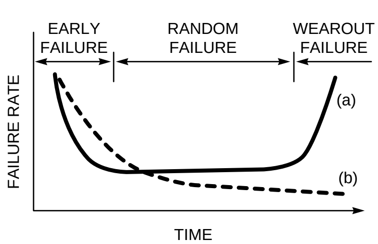
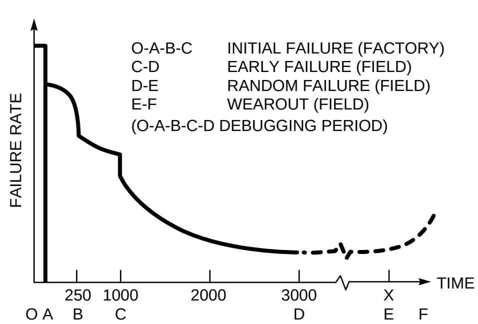


Figure 4.2 Semiconductor Device Failure Rate vs. Time



As noted by the failure rate curve in Figure 4.2, after the semiconductor device has been in service for several thousand hours, failure rates show a slight tendency to further decrease and parameter “m” on the Weibul distribution scale is usually 0.3 to 0.6. Presently, devices contained in hermetically sealed metal packages have not yet reached the wear out phase while in practical use, but the probable cause for eventual failure will be corrosion of the package pins or similar environmental causes.

The normal procedure for evaluating device reliability is to use various means to accelerate testing or to life test over a relatively short period ranging from 200 to 1000 hours. The first of these methods is intended mainly to check for device wearout failure mode, while the second method is used to detect sudden and catastrophic failures occurring in the early and random failure period of the distribution curve.

After a piece of equipment has been assembled and adjusted or has been placed in field service, failed devices that are returned to the factory are analyzed to determine the cause of failure. This procedure is intended to determine whether the problem lies with the device itself or the manner in which it was used. For devices that prove good, the usual reason given for returning it is unsuitability from the standpoint of rating or characteristics or that it does not work properly in combination with other devices. However, in most cases these has been a mistake in judgement on the part of the user. In analyzing failed devices where usage conditions were suspected to be the cause, the problem in nearly all cases was determined to be due to electrical stress such as caused by surge current or voltage or by exceeding di/dt of maximum rating specifications. In very few cases was the cause determined to be due to mechanical stress, such as excessive vibrations or shock.

In analyzing the most common type of failure, which was found to be with the device itself with low and medium power thyristors, the problem was determined to be either defective surface treatment of the silicon or a defect in the structure of the device. The first cause was a defect in the manufacturing process that left ion impurities in the vicinity of the silicon junction there by degrading device performance. The latter occurs in the process from metallization to bonding, i.e., in the process of installing electrodes, due to defects of mechanical structure in the manufacturing process. It has the distribution pattern of initial stage failure. These failed devices are found by magnifying the defective spots up to several thousand times using a microscope. The defect in the electrode installation process can be minimized by controlling the assembly facility or by testing by a high magnification microscope.

Products manufactured under the severest and most minutely controlled manufacturing process, however, are not free from defect. Defective products should be eliminated by debugging to increase reliability. High temperature aging and power aging are effective methods of debugging. Severest debugging methods mean higher device reliability. Compared to thyristors for consumer use, thyristors for industrial use are more expensive not only because of the higher cost of parts, materials used, and the control cost but also because of the elaborate work or debugging involved in the production.

In the device failure rate curve shown in Figure 4.2, it is apparent that equipment reliability can be increased by extending the flat middle section of the curve to the left, and lowering early failure rates. On the other hand, greater margins must be designed by the user. For example, diodes and thyristors should be operated at 50 to 80% of their maximum voltage ratings, and junction temperatures should not exceed 70 to 80% of maximum rating. It is also important to remember that a device must be in working harmony with other components in the circuit for maximum reliability standards to be realized.

When designing a piece of equipment for reliable service, device selection must be considered from a standpoint of performance, reliability, and economy. Since it is not easy to achieve high performance, reliability, and economy at the same time, a balance must be struck on the side of practical value. In other words, device selection should be based on the user’s expectations for the machine to be designed.

4.2 Reliability Testing

4.2.1 Reliability Testing Procedures

High reliability standards are assured with Powerex semiconductor devices through the rigorous quality control inspections which the devices are subjected to in the design and manufacturing stages, and through the quality assurance inspections run on each production lot. Numerous reliability tests have been implemented in order to maintain the standards of reliability.

This section provides an overview of the reliability testing of thyristor devices. Test parameters are shown in Table 4.1, and as noted, conform to the procedures specified by the Japan Industrial Standards (JIS) handbook.

Explanation of JIS Reliability Test Methods follows this section.

4.2.2 Result of Reliability Test of Low Power Thyristor

The Powerex low power thyristor CR2AM is a plastic sealed reverse blocking 3-pin thyristor with 2A control current, widely used for consumer equipment. Employment of plastic sealing techniques allows the device to provide characteristics equal to those of metal sealed thyristors.

Table 4.2 shows the result of reliability test and Figure 4.3

Table 4.1 Semiconductor Device Reliability Testing Applies to BS08A, BCR, CR Types Only

Environmental Testing

Test Parameters	Test Method		Test Conditions		Notes
Soldering Heat	JIS C 7021*	A–1	260°C, 10 Sec.		
Solderability	JIS C 7021*	A–2	230°C, 5 Sec. Exist Flax		
Thermal Shock	JIS C 7021*	A–3	100°C, 15 sec. ~ 0°C, 5 Sec., 5 Cycles		
Temperature Cycling	JIS C 7021*	A–4	$T_{stg(max)}$, 30 Minutes ~ $T_{stg(min)}$, 30 Minutes, 5 Cycles		
Temperature Humidity Cycling	JIS C 7021*	A–5	Temperature Humidity Cycle, 10 Cycles		
Hermetic Seal	JIS C 7021*	A–6	Method I	Tracer Gas, Fine Leak	Using He Gas
			Method III	Bubble Testing for Gross Leaks	Using Fluorocarbon
Mechanical Shock	JIS C 7021*	A–7	100 ~ 1500G, Five Times in Each Direction		
Free Drop	JIS C 7021*	A–8	On a 75cm Wooden Plate, Three Times		
Vibration	JIS C 7021*	A–10	Method A	10 ~ 55Hz, 1.5mm, 6 Hours	
			Method D	100 ~ 2000Hz, 20G, 48 Minutes	
Lead Strength	JIS C 7021*	A–11	Method I	Tension, Specified Load Applied, 30 Sec.	
			Method III	Bending, Specified Load Applied, Bending of 90° Once in the Left and Right Directions	
			Method IV	Torque, Specified Torque Applied, 1 ~ 5 sec.	Applicable to Devices with Threaded Pins

Life Testing

Test Parameters	Test Method		Test Conditions		Notes
Continuous Operation	JIS C 7021*	B–13	$I_F = I_{F(max)}$, $T_j \le T_{j(max)}$, $V_{AK} = V_{RRM}$, 1000 Hours		Using Rectifier Diode
		B–14	$I_T = I_{T(max)}$, $T_j \le T_{j(max)}$, $V_{AK} = V_{DRM}$, V_{RRM}, 1000 Hours		Using Thyristor
High Temperature Voltage	JIS C 7021*	B–19	$T_j \le T_{j(max)}$, $V_{AK} = V_{RRM}$ or 70%, 1000 Hours		Using Rectifier Diode
		B–20	$T_j \le T_{j(max)}$, $V_{AK} = V_{DRM}$, V_{RRM} or 70%, 1000 Hours		Using Thyristor
High Temperature Stg.	JIS C 7021*	B–10	$T_a = T_{stg(max)}$, 1000 Hours		
Humidity	JIS C 7021*	B–11	Method A	T_a = 40°C, RH = 90%, 1000 Hours	
			Method B	T_a = 60°C, RH = 90%, 1000 Hours	

*Environmental and resistance conforms to standards specfied in JIS C 7021 for discrete semiconductor devices.

illustrates the results of high temperature voltage test as typical changes as a factor of time. Table 4.3 shows the failure criterion.

4.2.3 Result of Reliability Test of Medium Power Triac

Table 4.4 shows the result of reliability test of typical plastic sealed triac BCR10CM with a 10A control current. Figure 4.4 shows the result of interruptive conducting test, illustrating the typical changes as a factor of time. Table 4.5 shows the failure criterion.

4.3 Failure Analysis

Failure analysis is one of the sources of information used in maintaining and making improvements in standards of quality and reliability. Failure analysis procedures are performed on failed devices at all stages of their life cycle, ranging from the development state to failure while in use.

Failure analysis procedures are generally divided into the areas of external inspections, electrical testing, internal inspections, and chip analysis. The flow chart for these procedures is shown in Figure 4.5, while Table 4.6 lists the nature of the tests.

The results of the various reliability and failure analysis tests reveal the failure mode and mechanism. This information is fed back to the process technology and manufacturing personnel so that they can take the appropriate measures to improve the final product.

Table 4.2 CR2AM Reliability Test Results

Environmental Testing

Test Parameters	Test Method		Test Conditions		No. of Samples	No. of Failures
Soldering Heat	JIS C 7021	A–1	260°C, 10 Sec., Lead Wire Dipping		40	0
Solderability	JIS C 7021	A–2	230°C, 5 Sec., 95% Minumum		40	0
Thermal Shock	JIS C 7021	A–3	0 ~ 100°C, 5 Cycles		40	0
Temperature Cycling	JIS C 7021	A–4	-40°C, +125°C, 5 Cycles		40	0
Lead Strength	JIS C 7021	A–11	Method I	1.0kg	40	0
			Method III	0.5kg	40	0

Life Testing

Test Parameters	Test Method		Test Conditions	No. of Samples	No. of Failures
Continuous Operation	JIS C 7021	B–16	$I_{T(avg)}$ = 2A, T_j = 125°C, 1000 Hours	40	0
High Temp. Voltage	JIS C 7021	B–20	V_{AK} = 600V_P, R_{GK} = 1kΩ, T_j = 125°C, 1000 Hours	40	0
High Temp. Storage	JIS C 7021	B–10	T_a = 125°C, 1000 Hours	40	0
Humidity	JIS C 7021	B–11	T_a = 60°C, RH = 90%, 1000 Hours	40	0

Table 4.3 CR2AM Failure Criterion

Test Parameter	Test Conditions	Rating	
		Low Limit	High Limit
V_T	T_j = 25°C, I_{TM} = 4A	–	U.S.L. X 1.2*
I_{GT}	T_j = 25°C, V_D = 6V	–	U.S.L. X 1.2
V_{GT}	I_T = 0.1A	–	U.S.L. X 1.2
I_{DRM}, I_{RRM}	T_j = 25°C, $T_{j(max)}$ V_D, V_R = Class Voltage	–	U.S.L. X 2

*U.S.L. – Upper Specification Limit

Table 4.4 BCR10CM Reliability Test Results

Environmental Testing

Test Parameters	Test Method		Test Conditions		No. of Samples	No. of Failures
Soldering Heat	JIS C 7021	A–1	260°C, 10 Sec., Lead Wire Dipping		20	0
Solderability	JIS C 7021	A–2	230°C, 5 Sec., 95% Minumum		20	0
Thermal Shock	JIS C 7021	A–3	0 ~ 100°C, 5 Cycles		20	0
Temperature Cycling	JIS C 7021	A–4	-40°C, +125°C, 5 Cycles		20	0
Lead Strength	JIS C 7021	A–11	Method I	1.0kg	20	0
			Method III	0.5kg	20	0

Life Testing

Test Parameters	Test Method		Test Conditions	No. of Samples	No. of Failures
Intermittent Operation	JIS C 7021	B–18	I_T = 10A, T_j = 125°C ↔ 50°C, 15000 Cycles	20	0
High Temp. Voltage	JIS C 7021	B–20	V_D = 600V (AC Peak Value), T_j = 125°C, 1000 Hours	20	0
High Temp. Storage	JIS C 7021	B–10	T_a = 125°C, 1000 Hours	20	0
Humidity	JIS C 7021	B–11	T_a = 60°C, RH = 90%, 1000 Hours	20	0

Figure 4.3 Typical Changes as a Factor of Time of CR2AM High Temperature Voltage Test

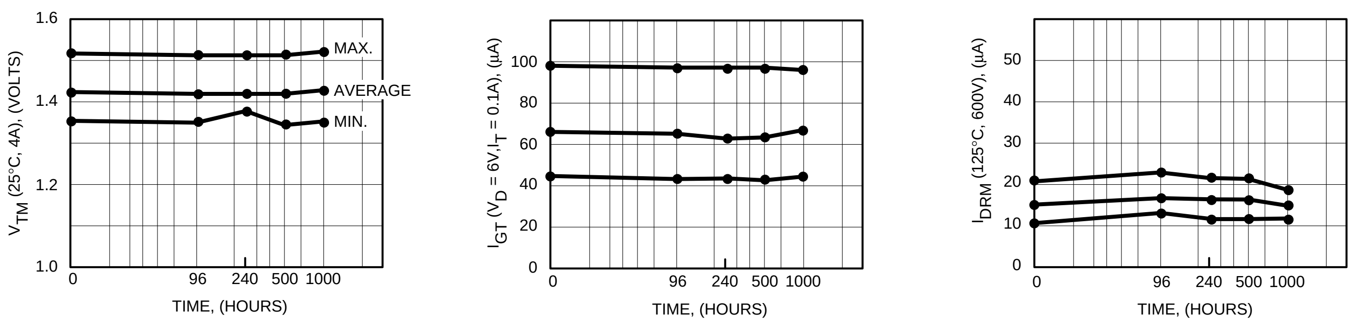


Figure 4.4 BCR10CM Typical Changes as a Factor of Time in Intermittent Operation Load

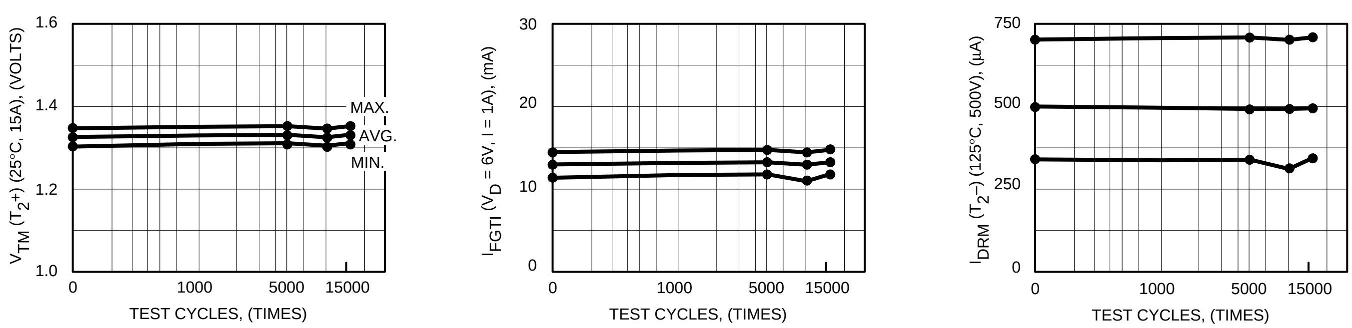
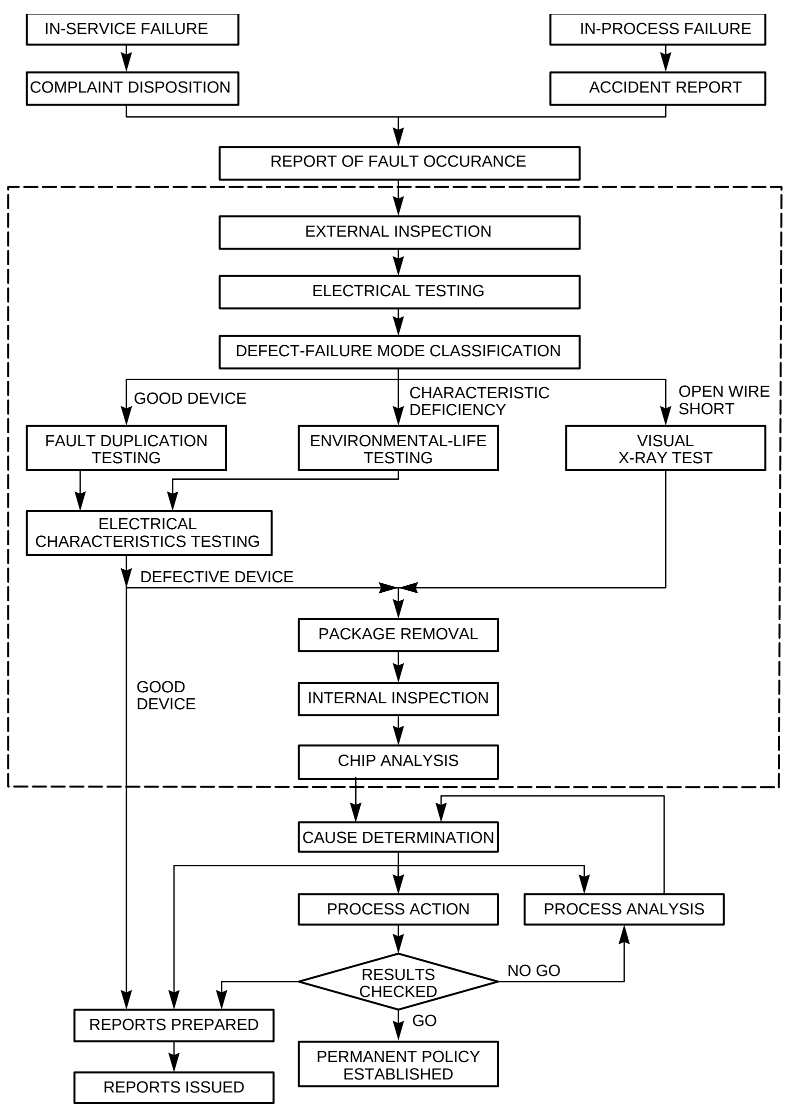


Table 4.5 BCR10 Failure Criterion

Test Parameter	Test Conditions	Rating	
		Low Limit	High Limit
V_{TM}	T_j = 52°C, I_{TM} = 15A	–	U.S.L. X 1.2*
I_{GT}	T_j = 25°C, V_D = 6V	–	U.S.L. X 1.2
V_{GT}	I_T = 1A	–	U.S.L. X 1.2
I_{DRM}, I_{RRM}	T_j = 25°C, $T_{j(max)}$ V_D = Class Voltage	–	U.S.L. X 2

*U.S.L. – Upper Specification Limit

Figure 4.5 Fault Analysis Procedure



4.4 Derating and Reliability Projections

The degree of reliability for a semiconductor device varies considerably depending on usage and environmental conditions. Design standards, the method of manufacture, and quality control procedures also play a role in establishing the intrinsic reliability for semiconductors. Correlating device derating with reliability is also not an easy task. However, in this section some methods will be introduced for projecting the reliability of diodes, and thyristors.

4.4.1 Reliability Projection Methods

The methods for projecting reliability of devices meeting U.S. Military standards are described in MIL-HDBK-217D. Since this handbook covers acceptance standards for parts used by the U.S. Military, it also contains a lot of good reference material for the average user. The information presented here has been taken from the portions of that manual that covers discrete semiconductor diodes and thyristors.

According to MIL-HDBK-217D, model λ_P for projected failure rate in discrete semiconductor device on derating is calculated according to the following equation based on Reliability Prediction of Electronic Equipment.

$$\lambda_P = \lambda_b(\pi_E \times \pi_Q \times \pi_A \times \pi_{S2} \times \pi_R \times \pi_C)$$

Where:

- λ_b : Basic failure rate
- π_E : Environmental factor
- π_Q : Quality factor
- π_A : Circuit factor
- π_{S2} : Voltage stress factor
- π_R : Rating factor
- π_C : Construction factor

Table 4.6 Fault Analysis Inspections and Equipment Used

Category	Inspection Items	Equipment
External Inspection	Condition of leads, plating, soldering, and welds. Marking Packaging Defect Solderability Hermetic Seal	Stereoscopic Microscope Metallurgy Microscope Leak Detector
Electrical Characteristics Testing	Static electrical characteristics, voltage and temperature margins, checking for broken bond wire, wire bond shorts, and degradation through operational testing Internal Wiring	Osciloscope Curve Tracer Characteristics Tester X-ray Equipment
Internal Inspection	Device removed from package and chip surface observed for defects Electrical characteristics check using microprobe Check for hot spots and other abnormalities	Metallurgy Microscope Microprobe Scanning Electron Microscope X-ray Microanalyzer Infared Microscanner Spectrum Analyzer
Chip Analysis	Analysis techniques used to supplement chip surface observation in internal inspection Cross section of chip observed for analysing oxide film, diffusion and metallizing	

Basic failure rate λ_b is determined by power dissipation or current stress ratio S and operating temperature T. In other words, this value depends on the amount of derating and applies in principle to all devices. Expected device reliability under actual usage conditions can be projected by multiplying λ_b by the factors that define design and manufacturing parameters (π_C, π_Q, π_R), environmental conditions under which the device will be used (π_E), and circuit conditions (π_A, π_{S2}). Of the factors used to modify λ_b, π_E and π_Q are common factors used in the λ_P calculation for all device types, but other factors can be omitted or used depending on the device. For example, in common diodes and transistors, all factors are used as illustrated in the basic equation, but in the equation for thyristor ($\lambda_P = \lambda_b \times \pi_E \times \pi_Q \times \pi_R \times \pi_T \times \pi_S$), serve as modifiers.

Tables 4.7 through 4.14 are excerpts taken from MIL-HDBK-217D, and list λ_b and the various modifying factors for diodes and thyristors. Table 4.7 and 4.8 shows basic failure rate λ_b, stress ratio S is calculated as follows:

Diode, thyristor (silicon):

$$S = \frac{I_{OP}}{I_{max}} \text{ (C.F.)}$$

I_{max} represents current and power dissipation ratings and I_{OP} is the value for operating current and power dissipation. C.F. is a correction factor that is determined by the temperature at which reduction in current and power dissipation starts (T_S), and the value for maximum junction temperature ($T_{j(max)}$). The equations are as follows:

$$\text{C.F.} = 1$$

When:
$T_S = 25°C$ and
$T_{j(max)} = 175$ to $200°C$.

$$\text{C.F.} = \frac{175 - T_S}{150}$$

When:
C.F. = $T_S \neq 25°C$, and
$T_{j(max)} = 175$ to $200°C$

$$\text{C.F.} = \frac{T_{j(max)} - 25}{150}$$

When:
$T_S = 25°C$, and
$T_{j(max)} < 175°C$

$$\text{C.F.} = \frac{T_{j(max)} - T_S}{150}$$

When:
$T_S \neq 25°C$, and
$T_{j(max)} < 175°C$

Also, when $T_{j(max)} < 175°C$, operating temperature (T) must be corrected by the following equation:

$$T = T_a \text{ (or } T_c) + (175 - T_{j(max)})$$

Failure rate λ_P in the actual application is calculated as follows, using basic failure rate λ_b and various other factors.

Example:

Suppose a JAN-type silicon rectifier diode is provided with the maximum rate current 1.0A(T_a = 30°C, T_S = 30°C) $T_{j(max)}$ = 150°C.

Obtain the estimated failure rate λ_P when the device is used in the rectifier operation with a current of 0.5A and at 40% of the rated voltage on the ground (fixed) under the ambient temperature.

Calculation:

Stress ratio S is obtained by:

$$S = \frac{I_{OP}}{I_{max}} \text{ (C.F.)}$$

$$= 0.5 \times 0.8 = 0.4$$

Application temperature:

$$T = T_a + (175 - T_{j(max)})$$

$$= 35 + (175 - 150) = 60$$

We obtain $\lambda_b = 0.00085/10^6$ hours when T = 60°C and S = 0.4 from Table 4.7, π_E = 3.9 when on the ground (fixed) from Table 4.9, π_Q = 1.5 when JAN-type device is used from Table 4.10, π_A = 1.5 when used in the rectifier operation from Table 4.11, π_{S2} = 0.70 at 40% of the rated voltage from Table 4.12, π_R = 1 from Table 4.13, and π_C = 1.0 (Table 4.14) when the diode is metallurgically bonded. Using the above values, λ_P is calculated as follows:

$$\lambda_P = 0.00085 \; (3.9 \times 1.5 \times 0.70 \times 1 \times 1.0)$$

$$= 0.0052/10^6 \text{ hours}$$

$$= 5.2\text{FIT}$$

Table 4.7 MIL-S-19500 Thyristor Basic Failure Rate λ_b (Failure/10^6 Hours)

Temp.	S									
(°C)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	.0006	.0009	.0013	.0018	.0024	.0033	.0044	.0059	.0081	.011
10	.0008	.0012	.0016	.0022	.0030	.0039	.0053	.0072	.010	.014
20	.0010	.0015	.0020	.0027	.0036	.0048	.0065	.0090	.012	.019
25	.0012	.0016	.0022	.0030	.0039	.0053	.0072	.010	.014	.022
30	.0013	.0018	.0024	.0033	.0044	.0059	.0081	.011	.017	
40	.0016	.0022	.0030	.0039	.0053	.0072	.010	.014	.022	
50	.0020	.0027	.0036	.0048	.0065	.0090	.012	.019		
55	.0022	.0030	.0039	.0053	.0072	.010	.014	.022		
60	.0024	.0033	.0044	.0059	.0081	.011	.017			
65	.0027	.0036	.0048	.0065	.0090	.012	.019			
70	.0030	.0039	.0053	.0072	.010	.014	.022			
75	.0033	.0044	.0059	.0081	.011	.017				
80	.0036	.0048	.0065	.0090	.012	.019				
85	.0039	.0053	.0072	.010	.014	.022				
90	.0044	.0059	.0081	.011	.017					
95	.0048	.0065	.0090	.012	.019					
100	.0053	.0072	.010	.014	.022					
105	.0059	.0081	.011	.017						
110	.0065	.0090	.012	.019						
115	.0072	.010	.014	.022						
120	.0081	.011	.017							
125	.0090	.012	.019							
130	.010	.014	.022							
135	.011	.017								
140	.012	.019								
145	.014	.022								
150	.017									
155	.019									
160	.022									

The previous discussion described the outline of the general concept of reliability, reliability tests, and derating and reliability prediction.

To increase the reliability of semiconductor devices, it is essential to select the devices that match the equipment or sets and to design reliable equipment with due consideration given to derating under the conditions of utilization and the environment as well as to fully understand the characteristics of semiconductor devices. It is also an important practice to conduct debugging of equipment or sets and to analyze the process data or field data to feed them back to the design or manufacturing stages. Various items must be considered for reliable design and care should be taken in the use of semiconductor devices, with overall consideration given to product quality, reliability, and economy.

Table 4.8 MIL-S-19500 Rectifier Diode Basic Failure Rate λ_b (Failure/10^6 Hours)

Temp.	S									
(°C)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	.00010	.00014	.00020	.00027	.00037	.00049	.00065	.00085	.0011	.0016
10	.00012	.00018	.00025	.00033	.00045	.00059	.00076	.0010	.0014	.0022
20	.00016	.00023	.00031	.00041	.00053	.00070	.00092	.0013	.0019	.0031
25	.00018	.00025	.00033	.00045	.00059	.00076	.0010	.0014	.0022	.0039
30	.00020	.00027	.00037	.00049	.00065	.00085	.0017	.0016	.0025	
40	.00025	.00033	.00045	.00059	.00076	.0010	.0014	.0022	.0039	
50	.00031	.00041	.00053	.00070	.00092	.0013	.0019	.0031		
55	.00033	.00045	.00059	.00076	.0010	.0014	.0022	.0039		
60	.00037	.00049	.00065	.00085	.0011	.0016	.0025			
65	.00041	.00053	.00070	.00092	.0013	.0019	.0031			
70	.00045	.00059	.00076	.0010	.0014	.0022	.0039			
75	.00049	.00065	.00085	.0011	.0016	.0025				
80	.00053	.00070	.00092	.0013	.0019	.0031				
85	.00059	.00076	.0010	.0014	.0022	.0039				
90	.00065	.00085	.0011	.0016	.0025					
95	.00070	.00092	.0013	.0019	.0031					
100	.00075	.0010	.0014	.0022	.0039					
105	.00085	.0011	.0016	.0025						
110	.00092	.0013	.0019	.0031						
115	.0010	.0014	.0022	.0039						
120	.0011	.0016	.0025							
125	.0013	.0019	.0031							
130	.0014	.0022	.0039							
135	.0016	.0025								
140	.0019	.0031								
145	.0022	.0039								
150	.0025									
155	.0031									
160	.0039									

Table 4.9 Environmental Factor π_E (Diode, Thyristor)

Environment	Symbol	Diode	Thyristor
Ground (Temperate)	G_B	1	1
Ground (Fixed)	G_F	3.9	3.9
Ground (Vehicle Mounted, Portable)	G_M	18	18
Shipboard (Covered)	N_S	4.8	8.7
Shipboard (Open)	N_U	21	21
Aircraft (Transport, Habitat)	A_{IT}	11	12
Aircraft (Fighter, Habitat)	A_{IF}	25	25
Aircraft (Transport, Non-habitat)	A_{UT}	20	20
Aircraft (Fighter, Non-habitat)	A_{UF}	40	40

Table 4.10 Quality Factor π_Q

	Device	
Quality Standard	**Diode**	**Thyristor**
JANTXV	0.15	0.5
JANTX	0.3	1.0
JAN	1.5	5.0
Lower	7.5	25.0
Plastic	15.0	50.0

Table 4.11 Circuit Factor π_Q (Diode)

Application	π_A
Analog Circuit (< 500mA)	1.0
Switching (< 500mA)	0.6
Power Rectifier (> 500mA)	1.5
Power Rectifier (High Voltage Stak) V_{max} > 600V	2.5/ Junction

Table 4.12 Voltage Stress Factor π_{S2} (Diode)

S_2(%)*	π_{S2}
0 ~ 60	0.70
70	0.75
80	0.80
90	0.90
100	1.0

$$*S_2 = \frac{\text{Applied Voltage}}{\text{Rated Voltage}} \times 100$$

Table 4.13 Rating Factor π_R

Diode (Si, Ge, Common)		Thyristor	
Current Rating* (A)	π_R	**Current Rating* (A)**	π_R
≤1	1	≤1	1
From 1 to 3	1.5	From 1 to 5	3
From 3 to 10	2.0	From 5 to 25	10
From 10 to 20	4.0	From 25 to 50	15
From 20 to 50	10.0		

* Average Current

Table 4.14 Construction Factor π_C

Diode (Si, Ge, Common)	
Construction	π_C
Metallurgically Bonded	1.0
Non-metallurgically Bonded (Compression Bonded, Spot Contact, etc.)	2.0

5.0 Reliability Test Methods

5.1 Reliability Test Methods

The Japan Industrial Standards (JIS) have been established since reliability tests are to be performed under known conditions of stress. Following are tables indicating the related International Electro-technical Commission (IEC) Standards and U.S. Military Standards (MIL). While these standards differ slightly from one another their purpose is the same. Supplemental Tables 5.1 and 5.2 show the JIS C 7021 Standard “Environmental Test Methods and Endurance Test Methods for Discrete Semiconductor Devices” showing the various test categories, purposes, and conditions.

The test time and test conditions are determined by the quality level of the design or by the quality level required by the customer in the same manner as the number of samples is determined, but at the same time consideration should be given to mounting conditions, operating period, and acceleration of tests in order to choose the most effective and efficient conditions.

Table 5.1 Reliability Test of Discrete Semiconductor Devices (Test Categories and Conditions of Environmental Test - Supplemental)

Test Category	Discrete Semiconductor Devices (JIS C 7021) No.	Discrete Semiconductor Devices (JIS C 7021) Conditions	Purpose of Test	Related Standards IEC Pub. 68	Related Standards MIL-STD -750	Related Standards MIL-STD -883
Soldering Heat	A-1	**Condition / Solder Temperature (°C) / Immersion Time (Sec.)** A / 260 / 10 B / 350 / 3 Leads immersed up to within 11.5mm of the device seat plane	To evaluate whether the device will be damaged during soldering	T (2-20A)	2031.1	–
Solderability	A-2	**Solder Temperature (°C) / Immersion Time (Sec.)** 230 / 5 Using a Rosin-type flux, leads immersed up to within 1-1.5mm of the device seat plane	To determine the adherence of solder to leads which must be soldered for connections	T (2-20)	2026.2 MIL-STD -202 208	2003.1
Thermal Shock	A-3	**High Temp. (°C) / Low Temp. (°C) / Test Liquid** 100 / 0 / Fresh Tap Water **(Method I)** 15 Sec., Minimum at the High Temp. 5 Sec., Minimum at the Low Temp., 3 Sec., Maximum Transition Time 5 Cycles **(Method II)** 5 Min., Minimum at the High Temp. 5 Min., Minimum at the Low Temp. 10 Sec., Maximum Transition Time 5 Cycles	To determine the device durability to severe changes in temperature	N (2-14)	1056.1	1011.1

Table 5.1 Reliability Test of Discrete Semiconductor Devices (Test Categories and Conditions of Environmental Test - Supplemental) (continued)

Test Category	Discrete Semiconductor Devices (JIS C 7021) No.	Conditions	Purpose of Test	Related Standards IEC Pub. 68	MIL-STD -750	MIL-STD -883
Temperature Cycling	A-4	See conditions for A-4 below	To determine whether the device can withstand the sudden changes in temperature it might be subjected to in storage or in use	N (2-14)	1051.1 MIL-STD -202 107	1010.1
Temperature and Humidity Cycling	A-5	See conditions for A-5 below	To evaluate the device durability to temperature change under high humidity exposure	Da (2-4)	1021.1 MIL-STD -202 106	1004.1

Conditions for A-4

Step	Temperature	Time
1	-65, -55, -40, -25, -10°C (One Condition)	According to Table No. A-5
2	5 ~ 35°C	According to Table No. A-5
3	70, 85, 100, 125, 150, 175, 200°C (One Condition)	According to Table No. A-5
4	5 ~ 35°C	

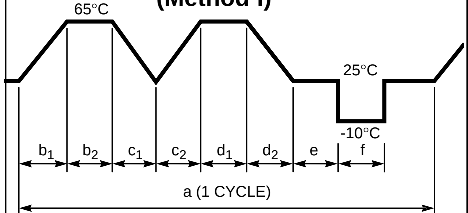
5 Cycles of Steps 1-4 are repeated

Table A

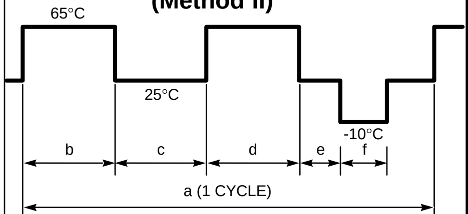
Weight of a Device (Gram)	Steps 2, 4 (Min.)	Steps 1, 3 (Min.)
1.5 Max.	2 ~ 5	30 Min.
1.5 ~ 15	5 ~ 15	30 Min.
15 ~ 150	15 ~ 30	30 Min.
150 ~ 1500	30 ~ 60	60 Min.

Conditions for A-5

(Method I)



(Method II)



Step	b_1	b_2	c_1	c_2	d_1	d_2	e	f	a
	b		c		d				
Time (h)	2.5	3.0	2.5	2.5	3.0	2.5	1~ 4	3	24
	5.5		5		5.5				

90 ~ 98% R.H.
(f is Arbitrary, c_1 and d_2 are in the Range 80 ~ 98% R.H.)
10 Cycles are Performed
(Only 5 Cycles of e and f)

Table 5.1 Reliability Test of Discrete Semiconductor Devices
(Test Categories and Conditions of Environmental Test - Supplemental) (continued)

<table>
<tr><th rowspan="3">Test Category</th><th colspan="2">Discrete Semiconductor Devices
(JIS C 7021)</th><th rowspan="3">Purpose of Test</th><th colspan="3">Related Standards</th></tr>
<tr><th rowspan="2">No.</th><th rowspan="2">Conditions</th><th>IEC</th><th>MIL-STD</th><th>MIL-STD</th></tr>
<tr><th>Pub. 68</th><th>-750</th><th>-883</th></tr>
<tr><td>Seal</td><td>A-6</td><td>Fine leak by helium gas leak test (Method I) (The sample device is placed in a pressurized helium atmosphere, after which a mass spectrometer type leak detector is used to make measurements)

Fine leak by radioisotope leak test (Method II) (The sample device is placed in a pressurized atmosphere of K_1^{85} and N_2 mixed gas, after which a scintillation counter is used to perform measurements)

Gross leaks by bubble test (Method III) (At room temperature the sample device is placed in a bath of liquid of viscosity less than 22mm^2/Sec. such as fluoro-carbon. The temperature is raised to 125°C and a check is made for the presence of bubbles)</td><td>To evaluate the hermeticitly of the cavity devices</td><td>Q
(2-17)</td><td>1071.1</td><td>1014.1</td></tr>
<tr><td>Shock</td><td>A-7</td><td><table>
<tr><th>Condi-tion</th><th>Maximum Accelera-tion, (G)</th><th>Pulse Width (msec.)</th><th>Direction and No. of Times</th></tr>
<tr><td>C</td><td>100</td><td>6</td><td rowspan="4">X_1, (X_2)
Y_1, Y_2
Z_1, (Z_2)
3 Times in Each Direction</td></tr>
<tr><td>D</td><td>500</td><td>1</td></tr>
<tr><td>E</td><td>1000</td><td>0.5</td></tr>
<tr><td>F</td><td>1500</td><td>0.5</td></tr>
<tr><td colspan="4">Shock Waveform: Half-sine Wave</td></tr>
</table></td><td>To evaluate the mechanical and structural integrity of the device to the severe shock to which it could be subjected by rough handling or during transport or use</td><td>Ea
(2-27)</td><td>2016.2</td><td>2002.1</td></tr>
<tr><td>Free Fall</td><td>A-8</td><td><table>
<tr><th>Height</th><th>75cm</th></tr>
<tr><td>Number of Times</td><td>3</td></tr>
<tr><td colspan="2">Dropped in the specified direction onto a maple wood board</td></tr>
</table></td><td>To evaluate the mechanical and structural integrity of the device to the irregular repeated shocks to which it could be subjected during handling, transport, or use</td><td>Ed
(2-32)</td><td></td><td></td></tr>
</table>

Table 5.1 Reliability Test of Discrete Semiconductor Devices
(Test Categories and Conditions of Environmental Test - Supplemental) (continued)

<table>
<tr><th rowspan="3">Test Category</th><th colspan="2">Discrete Semiconductor Devices (JIS C 7021)</th><th rowspan="3">Purpose of Test</th><th colspan="3">Related Standards</th></tr>
<tr><th colspan="2"></th><th rowspan="2">IEC Pub. 68</th><th rowspan="2">MIL-STD -750</th><th rowspan="2">MIL-STD -883</th></tr>
<tr><th>No.</th><th>Conditions</th></tr>
<tr><td>Constant Acceleration</td><td>A-9</td><td><table>
<tr><th>Condition</th><th>Acceleration (G)</th></tr>
<tr><td>A</td><td>5000</td></tr>
<tr><td>B</td><td>10000</td></tr>
<tr><td>C</td><td>20000</td></tr>
</table>In the X_1, X_2, Y_2, Z_1, and Z_2 Directions for 1 Minute Each</td><td>To evaluate the device integrity to constant acceleration</td><td>Ga
(2-7)</td><td>2006</td><td>2001.1</td></tr>
<tr><td>Vibration</td><td>A-10</td><td><table>
<tr><th>Condi-tion</th><th>Fre-quency, (Hz)</th><th>Peak-to-Peak Acceleration</th><th>Sweep (Two-way) (Min.)</th><th>Total Test Time (h)</th></tr>
<tr><td>A</td><td>10~55</td><td>1.5mm</td><td>1</td><td>6</td></tr>
<tr><td>B</td><td>10
~55
~500</td><td>1.5mm
10G</td><td>15</td><td>6</td></tr>
<tr><td>C</td><td>100
~2000</td><td>10G</td><td>20</td><td>6</td></tr>
<tr><td>D</td><td>100
~2000</td><td>20G</td><td>4</td><td>0.8</td></tr>
<tr><td>E</td><td>60</td><td>20G</td><td>—</td><td>96</td></tr>
</table>The Test Time is the Same for the X, Y, and Z Directions</td><td>To evaluate the device integrity to the vibration to which it could be subjected in transport or use</td><td>F_c
(2-6)</td><td>2046.1
2056</td><td>2005
2007</td></tr>
<tr><td>Lead Integrity</td><td>A-11</td><td>Tension (Method I)<table>
<tr><th>Condition</th><th>Time Load is Maintained</th></tr>
<tr><td>A</td><td>5 Seconds</td></tr>
<tr><td>B</td><td>30 Seconds</td></tr>
</table>Loads are given in Table B

Lead Torque (Method II)
2 Turns, 360°
1 Turn 2 Turns 3 Turns

Bending (Method III)
Loads are applied to the lead ends as specified in Table C. Bending to 90° is done 2 times

Stud Torque (Method IV)
Lefthand and righthand torque is applied to the stud as specified in Table D for 1 to 5 seconds</td><td>To evaluate the device integrity to the forces encountered during mounting or in use

(Pulling)
To evaluate the device integrity to the tension of the leads encountered in normal handling

(Lead Torque)
To evaluate the device integrity to the twisting forces to which it is likely to be subjected during mounting after post-soldering inspections or during use

(Bending)
To evaluate the device integrity to the bending to which it could be subjected during normal assembly operations</td><td>U
(2-21)

(Tension)
Ua

(Torque)
Uc

(Bending)
Ub</td><td>2036.3

(Tension)
(A)

(Torque)
(D_1)

(Bending)
(E)</td><td>2004.1

(Tension)
(A)

(Torque)
(C_1)

(Bending)
(B_2)</td></tr>
</table>

Table 5.1 Reliability Test of Discrete Semiconductor Devices
(Test Categories and Conditions of Environmental Test - Supplemental) (continued)

<table>
<tr><th rowspan="3">Test Category</th><th colspan="2">Discrete Semiconductor Devices (JIS C 7021)</th><th rowspan="3">Purpose of Test</th><th colspan="3">Related Standards</th></tr>
<tr><th rowspan="2">No.</th><th rowspan="2">Conditions</th><th>IEC</th><th>MIL-STD</th><th>MIL-STD</th></tr>
<tr><th>Pub. 68</th><th>-750</th><th>-883</th></tr>
<tr><td>Lead Integrity</td><td>A-11</td><td>
Table B / Table C
<table>
<tr><th>Cross Sectional Area (mm²)</th><th>Lead Diameter (mm)</th><th>Tension load (kgf)</th><th>Bending Load (kgf)</th></tr>
<tr><td>~ 0.07</td><td>~ 0.3</td><td>0.3</td><td>0.1</td></tr>
<tr><td>0.07 ~ 0.2</td><td>0.3 ~ 0.5</td><td>0.5</td><td>0.25</td></tr>
<tr><td>0.2 ~ 0.5</td><td>0.5 ~ 0.8</td><td>1</td><td>0.5</td></tr>
<tr><td>0.5 ~ 1</td><td>0.8 ~ 1.2</td><td>2.5</td><td>1</td></tr>
<tr><td>1~</td><td>1.2~</td><td>4.5</td><td>1.5</td></tr>
</table>
Table D
<table>
<tr><th>Screw Diameter (mm)</th><th>Torque (kgf-m)</th></tr>
<tr><td>2 ~ 2.6</td><td>0.3</td></tr>
<tr><td>2.6 ~ 3</td><td>0.04</td></tr>
<tr><td>3 ~ 3.5</td><td>0.06</td></tr>
<tr><td>3.5 ~ 4</td><td>0.08</td></tr>
<tr><td>4 ~ 5</td><td>0.1</td></tr>
<tr><td>5 ~ 5.5</td><td>0.15</td></tr>
<tr><td>5.5 ~ 6</td><td>0.2</td></tr>
<tr><td>6 ~</td><td>0.25</td></tr>
</table>
</td><td>(Torque)
To evaluate the device integrity to the torquing of stud which could occur during normal assembly operations</td><td>(Torque)
Ud</td><td>(Torque)
(D2)</td><td>(Torque)
(C2)</td></tr>
<tr><td>Salt Atmosphere</td><td>A-12</td><td>
35°C, 0.5 ~ 3ml/80cm²/Hr. Spray
Salt Content 5 ± 1%
<table>
<tr><th>Condition</th><th>Test Time (h)</th><th>Condition</th><th>Test Time (h)</th></tr>
<tr><td>A</td><td>16</td><td>C</td><td>48</td></tr>
<tr><td>B</td><td>24</td><td>D</td><td>96</td></tr>
</table>
</td><td>To evaluate the device tolerance to salt atmosphere</td><td>Ka
(2-11)</td><td>1046.2
MIL-STD
-202 101</td><td>1009.1</td></tr>
</table>

Table 5.2 Reliability Test of Discrete Semiconductor Devices (Test Categories and Conditions of Endurance Test - Supplemental)

<table>
<tr><th rowspan="2">Appl-icable Device</th><th rowspan="2">JIS Standard</th><th rowspan="2">No.</th><th rowspan="2">Test Category</th><th rowspan="2">Conditions</th><th rowspan="2">Purpose of Test</th><th colspan="3">Related Standards</th></tr>
<tr><th>IEC Pub. 68</th><th>MIL-STD -750 B</th><th>MIL-STD -883 C</th></tr>
<tr><td rowspan="3">All Devices</td><td rowspan="3">JIS C 7021</td><td>B-10</td><td>High-Temp. Storage</td><td>1000 Hours at $T_{stg(max)}$</td><td>To evaluate the device durability to storage for long periods at high temperature</td><td>B (2-2)</td><td></td><td>1008.2</td></tr>
<tr><td>B-12</td><td>Low-Temp. Storage</td><td>1000 Hours at $T_{stg(min)}$</td><td>To evaluate the device durability to storage at low temperature</td><td>A (2-1)</td><td></td><td></td></tr>
<tr><td>B-11</td><td>Temp. Humidity</td><td><table><tr><th>Test Condition</th><th>T_a (°C)</th><th>RH (%)</th></tr><tr><td>A</td><td>40</td><td>90</td></tr><tr><td>B</td><td>60</td><td>90</td></tr><tr><td>C</td><td>85</td><td>85</td></tr></table>1000 Hours</td><td>To evaluate the device durability to operation and storage at high humidity</td><td>Ca (2-3)</td><td></td><td></td></tr>
<tr><td rowspan="4">Rectifier Diodes</td><td rowspan="4">JIS C 7021</td><td>B-13</td><td>Steady-state Operation Life</td><td>T_a or $T_c \le T_{stg(max)}$
$I_F = I_{F(avg)}$, 50 ~ 60 Hz,
$V_R = V_{RRM}$ for
1000 Hours</td><td>To evaluate the device durability to electrical stress (voltage and current) as well as thermal stress for long periods of time</td><td>IEC Pub. 147-4</td><td></td><td></td></tr>
<tr><td>B-15</td><td>Steady-state Operation Life</td><td>T_a or $T_c \le T_{stg(max)}$
$I_F = I_{F(avg)}$, 50 ~ 60 Hz,
for 1000 Hours</td><td>To evaluate the device durability for long periods of time</td><td></td><td></td><td></td></tr>
<tr><td>B-17</td><td>Intermittent Operation Life</td><td>T_a or $T_c \le T_{stg(max)}$
$I_F = I_{F(avg)}$, 50 ~ 60 Hz,
on/off Times are Specified in Detail Specification
5000 Cycles</td><td>To evaluate the electrical and mechanical durability of the device over long periods of time by intermittently turning the device on and off, causing the temperature of the device to rise and fall, applying a thermal stress on the device</td><td></td><td></td><td></td></tr>
<tr><td>B-19</td><td>High-Temp. Reverse Bias</td><td>$T_a = T_{j(max)}$
V_R = 0.7 or
1.0 X V_{RRM} for
1000 Hours</td><td>To evaluate the device durability to voltage and thermal stresses applied under reverse biased condition</td><td>IEC Pub. 147-4</td><td></td><td></td></tr>
</table>

Table 5.2 Reliability Test of Discrete Semiconductor Devices (Test Categories and Conditions of Endurance Test - Supplemental) (continued)

Applicable Device	JIS Standard	No.	Test Category	Conditions	Purpose of Test	Related Standards: IEC Pub. 68	Related Standards: MIL-STD -750 B	Related Standards: MIL-STD -883 C
Thyristors	JIS C 7021	B-14	Steady-state Operation Life	T_a or $T_c \le T_{stg(max)}$ $I_F = I_{F(avg)}$, 50 ~ 60 Hz, $V_D = V_{DRM}$, $V_R = V_{RRM}$ for 1000 Hours	To evaluate the device durability to electrical stress (voltage and current) as well as thermal stress for long periods of time	IEC Pub. 147-4		
		B-16	Steady-state Operation Life	T_a or $T_c \le T_{stg(max)}$ $I_F = I_{F(avg)}$, 50 ~ 60 Hz, for 1000 Hours	To evaluate the device durability for long periods of time			
		B-18	Intermittent Operation Life	T_a or $T_c \le T_{stg(max)}$ $I_F = I_{F(avg)}$, 50 ~ 60 Hz, on/off Times are Specified in Detail Specification 5000 Cycles	To evaluate the electrical and mechanical durability of the device over long periods of time by intermittently turning the device on and off, causing the temperature of the device to rise and fall, applying a thermal stress on the device			
		B-20	High-Temp. Reverse Bias	$T_a = T_{j(max)}$ $V_D = 0.7 \times V_{DRM}$, $V_D = 0.7 \times V_{RRM}$ or $V_D = 1.0 \times V_{DRM}$, $V_D = 1.0 \times V_{RRM}$ for 1000 Hours	To evaluate the device durability to voltage and thermal stresses applied under reverse bias condition	IEC Pub. 147-4		

6.0 Designing Trigger Circuits for Thyristors

Following is a discussion of thyristor-gate circuits, including the determination of circuit time constants, methods of preventing erroneous operation, and precautionary measures for circuits with a high rate-of-rise di/dt of on-state current.

6.1 Determining Thyristor-gate Circuit Time Constants

When designing trigger circuits using thyristors, one of the first concerns is to assure that the device to be triggered is triggered completely, each time the control signal is applied to the gate. However, attempts to achieve this are hindered by gate losses (peak value, average value), and restrictions in peak gate forward current and voltage, as well as varying values in gate input resistance (gate-to-cathode resistance) that range from a few 10ohms to a few kilohms. Thus determining circuit time constants become an important task.

A graph similar to the one shown in Figure 6.1 can be used to help determine time constants. Here, the gate forward current is shown on the horizontal axis, and the gate forward voltage on the vertical axis. These two points are connected by a hyperbolic curve that represents allowable gate losses with respect to the range of trigger variations and gate duty interval. In all areas above and to the right of the shaded box, the device will always trigger. The boundary represents the maximum gate trigger current and voltage for the operating temperature image (minimum junction temperature). By contrast, in all areas below and to the left of the shaded box, the device will not trigger. Here the boundary represents the minimum gate non-triggering current and voltage for the operating temperature range (maximum junction temperature).

A basic triggering circuit is shown in Figure 6.2. Here, the gate circuit can be considered as a series connected constant voltage power supply, current limiting resistor, and gate. The main concerns in designing a trigger circuit center around determining proper values for power supply voltage, power supply internal resistance, and current limiting resistors. However, these can be determined using the graph in Figure 6.1, by marking the triggering source voltage value for an open output terminal on the vertical axis, and the value for short circuit current, when the output terminal is closed on the horizontal axis, and then connecting the two points. This straight line is called the “gate load line,” and no matter how much gate input resistance varies, the voltage and current applied to the gate will not influence formation of this gate load line. Consequently, as long as this line does not cross into the shaded box and remains below the rated gate loss curve, all devices will trigger regularly and safely. If the shaded box is entered, some devices may not always trigger, and if the rated gate loss curve is crossed, power dissipation at the gate of some devices will be exceeded.

6.2 Methods of Preventing Erroneous Operation

Gate control gain values are high in thyristors, with small current values (at highest, not more than several hundred milliamperes) capable of turning on devices that conduct current values ranging from a few amperes to several kiloamperes. On the other hand, these gates are extremely sensitive and occasionally electrical noise will inadvertently open them. This is one cause of such spurious triggers in circuits

Figure 6.1 Gate Triggering Conditions

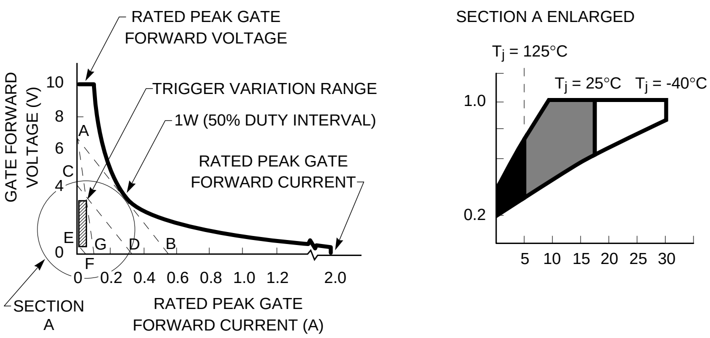
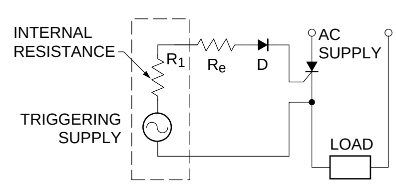


Figure 6.2 Basic Trigger Circuit



located near a gate circuit carrying high current. The electromagnetic effect tends to induce voltage into the gate line and the resultant noise voltage triggers the thyristor to conducting state. This problem is particularly prevalent with multiple phase circuits, so extra caution is advised. The following methods are recommended for preventing erroneous operation:

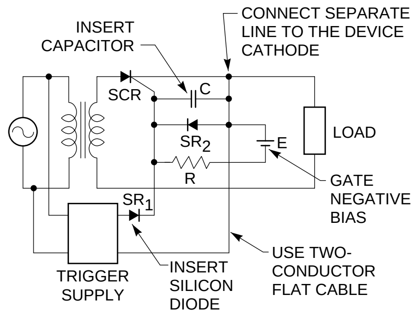
1. Keep gate lead lines far enough away from the main circuit conductors to prevent voltage induction.
2. Insert a capacitor (0.047 to 0.1μF) between the gate and cathode to absorb noise voltage.
3. Avoid using common lines to main circuit cathodes and gate circuit cathodes. Take the extra time to connect a separate line to the device cathode.
4. Use shielded wires for gate lines or use two conductor flat cables to inhibit the electro-magnetic induction effect.
5. Connect a silicon diode in series with the gate and use the voltage rise (approximately 0.7V) to block the noise voltage.
6. Apply bias to the gate, negative with respect to the cathode to block noise voltage.

These six points summarize the various methods available. Figure 6.3 shows these points diagrammatically.

6.3 Gate Circuit Design Example

The trigger circuit described here is illustrated in Figure 6.4. The voltage used to trigger the thyristor

Figure 6.3 Trigger Circuit



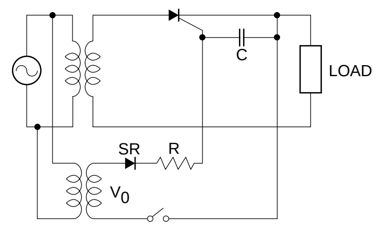
CR8AM is synchronized with the main circuit. The silicon diode (SR) shown in the circuit functions to block the negative cycle of the trigger supply. Unlike germanium diodes, silicon diodes have a voltage rise of 0.7V, and so this diode helps prevent unwanted triggering. The trigger voltage supply is also halfwave rectified by the silicon diode SR, so the duty period of the gate is 50%. Referring back to Figure 6.1 and drawing the allowable power dissipation curve for a gate load line with a duty interval of 50%, and the average gate power dissipation for CR8AM is 0.5W, and the resultant curve for a 50% duty interval will correspond to the 1W line. In other words, the value for

$$\text{Avg. Gate Input} \times \frac{100}{\text{Duty Interval (\%)}}$$

is used. When this value exceeds peak gate power loss (5W with CR8AM), use 5W.

For example, when the RMS value for trigger supply voltage is 7V, drawing the gate load line $\overline{AB}$ down from 7V on the vertical axis as a tangent to the allowable

Figure 6.4 Trigger Circuit Wiring Diagram



power dissipation curve (for 50% duty interval), it will intersect the horizontal axis at 0.56. Thus, 0.56A is the short circuit current. The gradient of this line (7V/0.56A) indicates that the resistance value must be over 12.5Ω. Therefore, assuming a resistance value of 12.5Ω, we draw another line representing the gate load for another trigger supply voltage parallel with the line $\overline{AB}$, but outside of the hatched box. As trigger supply voltage rises from zero any device will fire as long as its gate load line lies along this line, and does not encroach into the hatched box. This line is marked $\overline{CD}$ on the graph, indicating a trigger supply voltage of 1V. However, line $\overline{EF}$ indicates that in some case, some devices will trigger at a voltage of 0.5V.

The triggering voltage used here is a sine wave and depending on the individual characteristics of the device, the firing angle can vary between 1.5° and 24°. Using a voltage with a fast rate-of-rise reduces these variations, so normally a higher trigger voltage is used, with a Zener diode used to clip it below 10V.

When a magnetic amplifier or similar device is used as the trigger supply, the voltage waveform applied to the gate is close to a square wave in shape, so differences in firing angles become quite small. When these types of waveforms are used their peak values are used to construct the gate load line.

Circuit constants are determined by using the above procedures. Inserting a capacitor (approximately 0.047 μF) between the gate and cathode will prevent spurious triggers. Since the trigger supply voltage for this circuit is half-wave rectified, use of a silicon diode helps suppress noise voltage that could also cause unwanted triggering. The gate line should be either a two conductor flat cable or shielded cable and the gate and cathode terminal of device should have separate lines to minimize the electromagnetic induction effect.

6.4 Designing Gate Circuits for High Rate-of-rise of On-state Current Values

In this section, gate circuit design will be covered for thyristors requiring high load current and high rate-of-rise of current (di/dt). Such characteristics are typical in motor controllers inverters and DC choppers and triggering is generally followed by large rush currents.

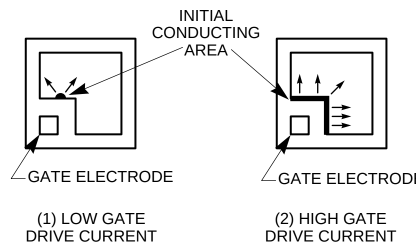
Thyristor turn-on time is a factor in the amount of current flow and width at the gate, on-current, anode-to-cathode voltage level of the thyristor and the characteristics of the load. However, a thyristor will always trigger if the current and voltage applied exceed the gate trigger current rating and voltage. The problem lies with the fact that since a high di/dt is accompanied by a large current flow, local heating will occur at turn-on. This tends to cause unstable characteristics and in some cases can even result in performance deterioration. However, these problems can be solved through trigger circuit design and reliable operation can still be achieved.

6.5 Current Concentration at Turn-on

When the events occurring at thyristor turn-on are considered, the time required for conduction to spread across all junctions from the point that the signal enters the gate is considerably longer than turn-on time. During the process of initial spreading, carriers are injected into the gate from the immediately surrounding areas and the local portions of the gate start the turn-on process.
At this time, the current will concentrate in these small spots, resulting in localized heating. The effects of this can degrade the characteristics of the device. The solution is to prevent localized current concentrations by holding load current rate-of-rise below a certain value.

In applications where load current rate-of-rise di/dt is low, local hot spots are not a problem. In applications where the rate-of-rise di/dt is high, for example, with motor control, inverter and DC choppers during triggering of the device, the hot spots become a problem. Extra care should be taken to solve high di/dt problems during turn-on, when using devices designed to handle large switching currents.

Figure 6.5 Turn-on Area Spreading



6.6 Gate Construction and Spreading from the Initial Turn-on Area

The speed of conduction spread from the initial turn-on area is generally considered to be approximately 0.1mm/μs. However, the amount of time required for spreading to cover the full effective conducting area depends on the gate electrode construction and the level of gate drive current as shown in Figure 6.5.

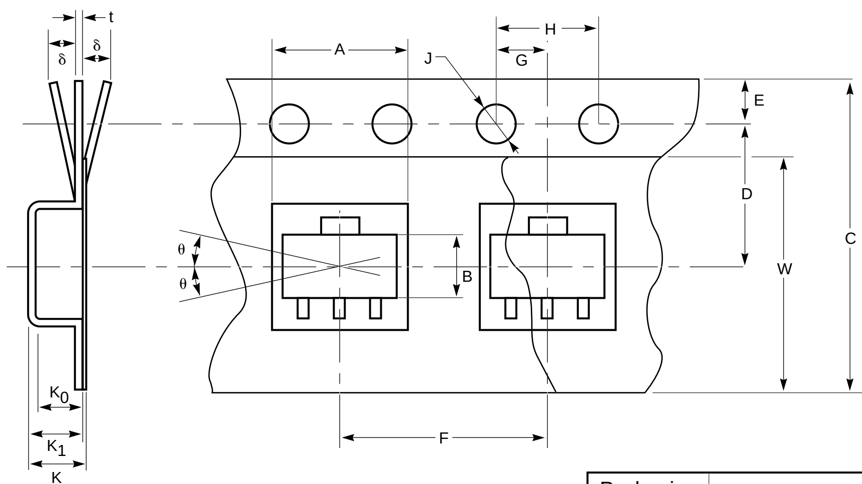
The turn-on of thyristor starts at a junction where it is most easily triggered.

Where gate drive currents are small, there is little difference in the two types concerning the area occupied by initial turn-on, but for large gate drive currents, this difference increases significantly. It is obvious that for large gate drive currents, the conducting area for a center gate becomes a circle around that gate, so not only is the initial conduction area increased, but spreading is also much more rapid than the corner gates. An obvious advantage is that there are fewer problems with localized heating at the junction. Consequently, using center gate thyristors with high gate drive currents will take care of most di/dt problems and dramatically improve conduction spreading from the initial turn-on area as well.

In general, applying a current or voltage that exceeds gate trigger values to the thyristor gate will turn the device on and unless di/dt is a particular problem, the device will continue to operate stably under these conditions alone. However, when the temperature dependency characteristics on the gate and current concentration at gate turn-on are considered, from the standpoint of device reliability, it is better to reduce turn-on time by increasing gate drive current on a slightly excess level than to extend turn-on time with the minimum required current or voltage level.

Figure 7.2 SOT-89 Package
Thyristor (CR08AS)

TAPING DIMENSIONS



Packaging Number	1000 PCS / REEL

Description of Symbol		Symbol	Dimensions (Unit : mm)	Remarks
Parts Insertion Concave Square Hole	Height	A	5.0 ± 0.1	Cross section of the Surface 0.5mm above the Inner Bottom
	Width	B	4.6 ± 0.1	
	Depth	K_0	1.8 ± 0.1	Inner Space
	Pitch	F	8.0 ± 0.1	Cumulative Error + 0.1/- 0.3 Max./10 Pitches
Round Feed Hole	Diameter	J	ϕ1.5 +0.1/-0.05	
	Pitch	H	4.0 ± 0.1	Cumulative Error +0.1/-0.3 Max./10 Pitches
	Position	E	1.5 ± 0.1	Distance Between the Tape Edge and the Hole Center
Distance Between Center Lines	Vertical	G	2.0 ± 0.5	Center Line of Concave Square Hole and Round Feed Hole
	Horizontal	D	5.65 ± 0.05	
Cover Tape	Width	W	9.5 +0.3/-0	Thickness: 0.1 Max.
Carrier Tape	Width	C	12 ± 0.2	Warp δ0.3 Max.
	Thickness	t	0.3 ± 0.05	
	Package Hole Depth	K_1	2.1 ± 0.1	
Device	Package Dimensions	–	–	As Shown in (e)
	Inclination	θ	30° Max.	
Total Thickness		K	2.3 ± 0.1	Total Thickness Including Cover and Carrier Tapes

8.0 Heatsinks

8.1 Designing Heatsinks for Rectifier Devices

Due to the heat generated internally in semiconductor power devices, special methods must be used to cool them. Natural heat radiation from the case of the device is insufficient, and so junction temperatures will exceed their allowable limits. Normal methods of cooling are self-cooling, air-cooling, water-cooling, oil-cooling, and boiling-condensing cooling. However, the problems of thermal cooling are akin to those in an electrical circuit, and the resistance to the flow of heat (thermal resistance must be considered). An analogy between an electrical circuit and a thermal radiation circuit is given in Table 8.1.

If the problem of heat radiation is considered analogous to an electrical circuit, then the heat radiation circuit can be illustrated as shown in Figure 8.1. This equivalent circuit shows that the heat generated at the device junction meets thermal resistance between the junction and case, between the case and heatsink, and between the heatsink fins and ambient, before being radiated into the atmosphere or surrounding substance.

Table 8.1 Comparing an Electrical Circuit and a Thermal Radiation Circuit.

Electrical Circuit	Thermal Radiation Circuit
Voltage (V)	Temperature (°C)
Current (A)	Power Dissipation (W)
Resistance (Ω)	Thermal Resistance (°C/W)

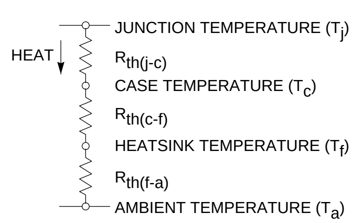
Considering P(W) to be the heat generated at the junction, the following equation can be derived.

$$T_j - T_a = P(R_{th(j\text{-}c)} + R_{th(c\text{-}f)} + R_{th(f\text{-}a)})$$

T_j : Junction Temperature (°C)
T_a : Ambient Temperature (°C)
P : Power Dissipation Within the Device (W)
$R_{th(j\text{-}c)}$: Junction-to-case Thermal Resistance (°C/W)
$R_{th(c\text{-}f)}$: Case-to-heatsink Thermal Resistance (°C/W)
Rth(f-a) : Heatsink-to-ambient Thermal Resistance (°C/W)

In designing the method of heatsinking, first the rectifier circuit must be designed, and then devices must be selected based on the various electrical conditions that must be met. At that point, maximum junction temperature, junction-to-case thermal resistance and internal power dissipation can be determined, along with an approximate idea of the case-to-heatsink thermal resistance. And since maximum ambient temperature $T_{a(max)}$ will be determined by other factors, the only variable free to work with is heatsink-to-ambient thermal resistance. This value is determined by the amount of heatsink fin surface exposed to ambient, hence the size of the heatsink itself. Consequently, if the heatsink size is insufficient, the only alternative is to use a device with a different current capacity rating, of to use a different method of heatsinking.

Figure 8.1 Equivalent Circuit for Thermal Radiation



8.2 Heatsink Thermal Resistance

The thermal resistance of a heatsink depends not only on its size, but also on shape, material, surface configuration (surface finish, painted or bare, etc.) and orientation. Other factors such as the difference between heatsink and ambient temperature, the speed of the air striking the heatsink surface, air-current conditions and the temperature of surrounding objects also influence thermal resistance. Normally, heatsinks are constructed from brass or aluminum plates having thickness ranging from 0.8 to 6mm. Thermal resistance values for several types of aluminum plate heatsinks are illustrated in Figure 8.2.

8.3 Device Setting

The thermal resistance $R_{\theta(c\text{-}s)}$ between the device and heatsink (contact thermal resistance) depends heavily on factors such as the type of material used, contact surface finish, area of contact, nature of any material interposed at the contact surface, and contact pressure. Minimizing $R_{\theta(c\text{-}s)}$ should thus be the primary consideration whenever mounting a device. The area of contact should be as large as possible, and the mounting hole should be no more than 0.5mm larger than the thread diameter. Also, chamfering of the hole should occupy no more than 1% of hole diameter. Finishing of the contact surface should be 6S or better (∇∇∇ Finishing), since that is the precision to which contact surfaces on the case of the device are finished. In general, rolled sheet, machine-finished brass or aluminum plate can be used in their original state, provided there are no deep scratches or noticeable warps in the plate. The contact surface of cast materials must be machined to a smooth finish.

When mounting the device to the heatsink, applying grease to the contact surfaces not only reduces contact thermal resistance, but also retards the growth of corrosion at the joint as well. However, note that the grease selected must not break down at device operation temperature and it should be resistant to chemical changes occurring over time. Silicon grease (Dow Corning DC200 or DC340) or carbon grease should be suitable for this application. Also, ALCOA No. 2 or Pentrox A is recommended for aluminum plate heatsinks.

When using an aluminum heatsink, the oxidation layer should be knocked off of the contact surface using a wire brush. Grease should normally be applied only to the contact surfaces, not the device threads.

A torque wrench must be used to mount the device tightening the nut to proper torque specifications. Brass is used for the thread of the device due to its good heat conducting properties. However, since the tensile strength of brass threads is less than that of steel, overtorquing can damage the threads, or can deform the case, resulting in a change in device characteristics. On the other hand, insufficient torque increases contact thermal resistance, and the threaded joint may loosen during use.

A cone shaped disc spring is normally used under the nut to maintain contact pressure (and thus contact thermal resistance) at a uniform value over the full range of operating temperatures. Using insulating type washers between the device and heatsink can increase contact thermal resistance dramatically (up to 10 times), and thus should be avoided if at all possible. If insulation is required, the heatsink should be supported with an insulating material. This is particularly true with high power devices, because, if the insulation in an insulating washer should break down, large overcurrents could destroy the device. Additional mounting information for various device models is given in Table 8.2.

Figure 8.2 Transient Thermal Impedance for Aluminum Plate Heatsinks (Single Plate Mounted Perpendicular, Painted Black, Self-cooling, Temperature in Center of Fin 60°C) (Actual Measurements)

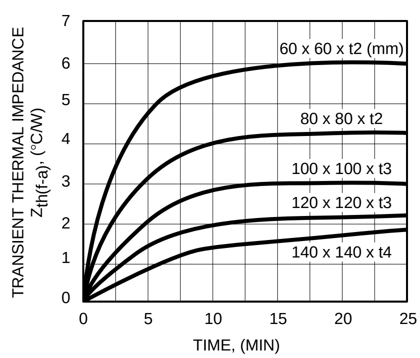


Table 8.2 Contact Thermal Resistance Information

Package Type	Device Model	Distance Across Hex Flats (mm)	Thread Dia.	Recom-mended Torque (kg/cm)	Contact Thermal Resistance (°C/W)
TO-220	CR6CM, CR8AM BCR5AM, BCR6AM BCR8CM, BCR10CM BCR12CM, BCR16CM	—	M 3	5	1
TO-202	CR2AM, CR3CM BCR3AM	—	M 3	5	4
Flat Base Type	BCR16HM, BCR30GM	—	M 4	12	0.5

Note: Values for contact thermal resistance applicable for mounting, using joint compound and torqued to recommended values.

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9.0 Cautions for Mounting

9.1 Tips for Mounting

- The heatsink surface should be smooth without burrs or metal chips (6S: ∇∇∇ finishing) when mounting heatsink fins to the flat-base and TO-202 and TO-220 package thyristors and triacs.

- A torque wrench, torque driver or box spanner must be used to mount the device, tightening the nuts to the proper torque specifications.

	Thread Dia.	Recom-mended Value	Max.
TO-202 (BCR3AM, CR2AM, etc) TO-220 (BCR10CM, CR6CM etc.)	M3	5kg•cm	10kg•cm
Flat Base Type (BCR16HM etc.)	M4	12kg•cm	15kg•cm

(Care should be taken to tighten both nuts of the device through the two mounting holes when mounting the device such as BCR16HM.)

- Apply silicon grease to the contact surface to improve heat conductivity from the device to heatsink fin. (DC200 and DC340 of Dow Corning, or ALCOA No. 2 or Pentrox A can be recommended for aluminum plate heatsinks.)

- Lead terminals of lead-mounted thyristors and triacs should be soldered according to the following conditions.
  – Soldering should be completed at a location more than 4mm away from the molded part.
  – Soldering should be made within 5 seconds, using a soldering iron of less than 80W.
  Recommended solder and flux are as follows:

  Solder: PbSn (4:6) solder (Melting Point 180°C)
  Example: H63A
  Flux: Solderite

- The mounting hole diameter of the heatsink fin should be smaller than ϕ3.2 or ϕ3.8 when the heatsink fin is mounted to TO-220 non-isolated thyristors or triacs by the conducting method, or when mounting the insulating type triacs.

9.2 Mounting the Stud Type SCR

The stud-mounted SCR is a particularly flexible component and has wide acceptance. This type of SCR uses a copper or aluminum stud with a machine thread for making mechanical, electrical and thermal contact to a heat exchanger of the user's choosing.

If the hole is punched, the fin should be subsequently blanked. If the hole is drilled, the burr should be carefully removed. The hole size should be between 0.005 and 0.015 inch larger than the stud outside diameter. If the stud has a fillet where the thread meets the flat surface of the hex, the fin hole should be chamfered to prevent the stud from hanging up on this fillet.

Mounting straight-threaded copper studs into a threaded hole in an aluminum fin is not recommended. Unequal temperature coefficients of expansion of aluminum and copper cause “thermal ratcheting.” This tends to unscrew the copper stud from the threaded hole as the temperature cycles. The result is higher stud-fin contact thermal resistance.

Where a copper stud is screwed into a tapped hole in a copper heat exchanger, extreme care must be taken to ensure that drilling and tapping are at right angles with the heat exchanger surface.

When mounting studs to a fin through a clearance hole by means of a nut on the backside, relaxation and metal creep may cause the mounting to gradually loosen. This condition is accelerated by temperature cycling and is dependent upon the magnitude of the time-temperature relation. Consequently, the stud-fin contact thermal resistance will increase with time-at-temperature because of a loss of contact pressure. Tests have shown that after 1000 hours of operation, the stud-fin contact thermal resistance can increase as much as three times the initial value.

To minimize the effect of relaxation, which is common in any fastener under torque, it is recommended that a belleville spring washer be used between the nut and fin. A commercially available nut-belleville washer assembly, made by Shakeproof Corp., Elgin, Illinois, has been found to be satisfactory for maintaining the initial stud-fin contact thermal resistance. Tests using the 3/8, 1.2 and 3/4 inch nut-washer assembly, Shakeproof numbers ND16470, ND16105, and ND16501 respectively, showed

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an 11% maximum increase in the initial stud-fin contact thermal resistance after 1000 hours at 150°C.

Good thermal contact between the semiconductor stud and the heat exchanger requires adequate pressure between these two surfaces as applied by torque on the threads of the device. However, torque beyond a certain point no longer improves the thermal contact and may mechanically stress the SCR junction and materials soldered or brazed to the stud inside the housing. Permanent damage to the device characteristics may result. For this reason, precise adherence to the manufacturer's torque recommendations is necessary, and a torque wrench should *always* be used in mounting this type of semiconductor.

Data sheets list recommended torque values for clean, dry threads. On devices with a 3/8-24 stud or larger, the torque is applied on the nut while holding the semiconductor stationary.

10.0 Selections of Devices and Cautions for Use

10.1 Use of Thyristors

10.1.1 Determination of the Current

The permissible currents for thyristors is shown by the average value.

- When no rush current flows (heater, solenoid load) Load current x 1.3 to 1.5 ⩽ permissible current for thyristor

  Example:
  1A x 1.5 → Applicable to 2A type thyristors. Determine the size of heatsink fin from the catalog. See Figure 10.1.

- When the rush current flows (lamp, transformer, motor load), the rush current should be measured and a detailed heat calculation should be made. The current is roughly estimated to be twice the calculated value when no rush current flows.

Figure 10.1

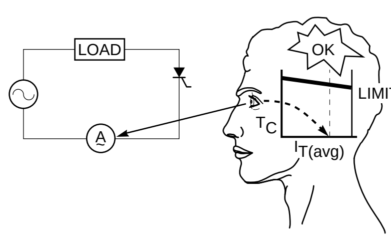
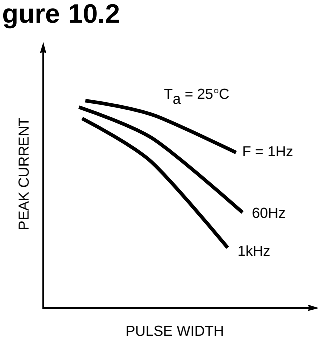


Figure 10.2



- When pulses are used (capacitor discharge, LC oscillation, short-duration application) (less than 10 seconds). See Figure 10.2.

10.1.2 Selection of Withstanding Voltage Class

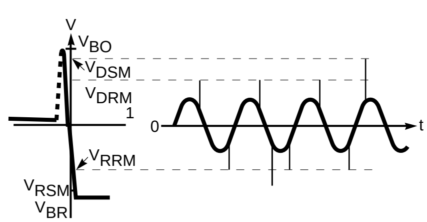
Withstanding voltage of thyristor (V_{DRM}) = Supply Voltage x 2.5 to 3

See Figure 10.3.

10.1.3 Selection of Voltage Items

Supply Voltage	Location of Use	Withstanding Voltage Class	V_{DRM} (V)	V_{DSM} (V)
100V Line	Japan (Home Use)	8	400	—
120V Line	USA			
100V Line	Earth Leakage Breaker	8	400	500
200V Line	Japan	12	600	—
230V, 240V Line	Europe			
200V Line (240V)	Leakage Protector	12	600	800

Figure 10.3



Measures for dv/dt

When large voltage dv/dt is applied to thyristors, CR absorbers should be connected in parallel to the thyristors to lighten the dv/dt applied to the device.

A capacitor of 0.047μF and a resistor of 33Ω are generally used for low power thyristors.

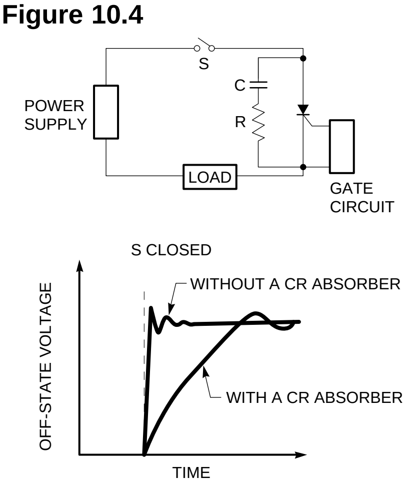
It is generally recommended to insert a resistor of 1kΩ between the gate and cathode for high-sensitivity low-current thyristors to lighten the dv/dt.

Figure 10.4 shows how to lighten the dv/dt with a CR absorber.

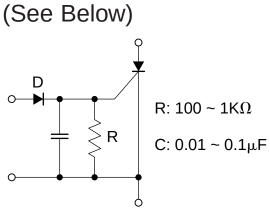
Cautions on the di/dt

If the current rate-of-rise di/dt exceeds the limit when a thyristor is turned on, the device may be damaged. In applications for inverters and choppers which discharge large currents when the thyristor is turned on, the di/dt causes a problem and, therefore, should be lightened by connecting an anode reactor.

Figure 10.4



Measures for Error Prevention
The cause and preventive measures of errors in the trigger circuit are shown in the following table.

Cause	Preventative Measures
Noise to Trigger Circuit	1. Stabilize the supply voltage. 2. Insert a surge voltage abosrber. 3. Avoid the use of a differentiation circuit which can be easily affected by the noise votltage resulting from the design of trigger circuits. 4. Provide electromagnetic shields to avoid external noise from the chassis.
Noise Voltage (Induced in relation to the trigger circuit to the gate of the thyristor.)	1. Use shielded wires to transmit the trigger signals. 2. Keep the wires as far apart as possible from the main circuit wires to avoid electromagnetic complications.
Feedback Noise from the Main Circuit	1. Insert an abosrber at the gate. (See Below) 2. Insert a diode (See Below)  ABSORBER FOR THE GATE

10.2 Use of Triacs

10.2.1 Determination of the Current

The permissible currents for triacs are shown by the effective values. See Figure 10.5.

The indicator values of AC ammeter are important.

- When no rush current flows (heater load) Load current x 1.3 to 1.5 ⩽ permissible current for triacs

  Example:
  6A x 1.5 → Applicable to 10A class thyristors

  Determine the size of heatsink fin from the catalog.

- When the rush current flows (lamp, transformer, motor load) The rush current should be measured and a detailed heat calculation should be made.

  Provide us with the following values and Powerex will do the calculation for you.

  Ambient Temperature:
  T_a = ____°C

  Peak Value of Rush Current:
  I_P = ____A
  Waveform if available.

  Constant Current Value:
  $I_{T(RMS)}$ = ____A

  Operation Sequence:
  ____ Seconds during ON
  ____ Seconds during OFF

  Heatsink fin Material, size, painting, heat resistance $R_{th(f\text{-}a)}$ if available.

The following triacs are applicable to the loads when the rush current flows (see following table).

Load	Rush Current	Applicable Triacs
Incadescent Lamp		
100V - 800W	80A	BCR16CM
100V - 600W	60A	BCR12CM
100V - 500W	50A	BCR10CM
Halogen Lamp		
100V - 600W	72A	BCR16CM
Microwave Oven		
100V - 600W	80A	BCR16CM
General Use – 3 Phase Induction Motor	40A-45A	
0.75kW - 200V		BCR16CM

Section of Withstanding Voltage Class as shown in Figure 10.6.

Withstanding voltage of triacs:

V_{DRM} = Two or three times the supply voltage

Figure 10.5

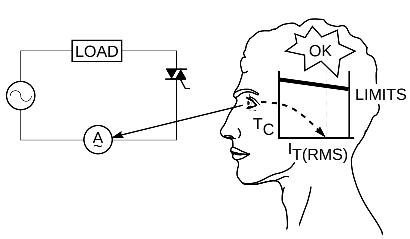
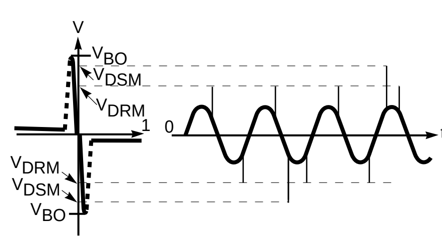


Figure 10.6



Section of Withstanding Voltage Items

100V to 120V Line System

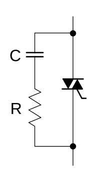
Supply Voltage	Location of Use	Withstanding Voltage Item	V_{DRM} (V)	V_{DSM} (V)
100V Line	Japan (Home Use)	8	400	600
120V Line	USA	8	400	600
100V Line 120V Line	Reversing Operation of Capacitor Motor	8	400	600

200V to 240V Line System

Supply Voltage	Location of Use	Withstanding Voltage Item	V_{DRM} (V)	V_{DSM} (V)
200V Line	Japan (Factory Use)	12	600	800
230V, 240V Line	Europe	12	600	800

Selection of CR Absorber

In general, CR absorbers should be connected to suppress the $(dv/dt)_C$ value applied to the device when controlling the inductive load by triacs as shown here.



The values for CR absorbers vary in accordance with the circuit conditions and sometimes they have to be determined by experimentation. In most cases, the $(dv/dt)_C$ value can be controlled to be less than 2.5V/μs (supply voltage 100V) and 5V/μs (supply voltage 200V) when C is 0.1μF and R is 100Ω.

Recommended Values for C and R

	100V ~ 120V	200V ~ 240V
C	0.1μF, 400WV	0.1μF, 600WV
R	100Ω, 0.5W	100Ω, 1W

10.3 Gate Circuit and Gate Trigger Current

10.3.1 Gate Circuit

As stated earlier, triacs have four trigger modes and can be used in the combinations shown in Figure 10.7.

10.3.2 Inductive and Resistive Load

The commutation characteristics of triacs should be considered according to the load. Commutating characteristics $(di/dt)_C$ and $(dv/dt)_C$ shift to on-state without the gate signal and become uncontrollable as shown in Figure 10.8, if they exceed certain values during commutation through the effect of current delay when the inductive load (L load) is controlled by triacs (commutation failure). See Figure 10.9

To turn off the triacs, the appropriate device should be selected in accordance with the load. Also, C and R should be connected in series to the device to control the rise in voltage during commutation.

	Example of Load
L Load (Inductive Load)	Motors, Electromagnetic Valves, Transformers, Solenoids
R Load (Resistive Load)	Heaters, Lamps

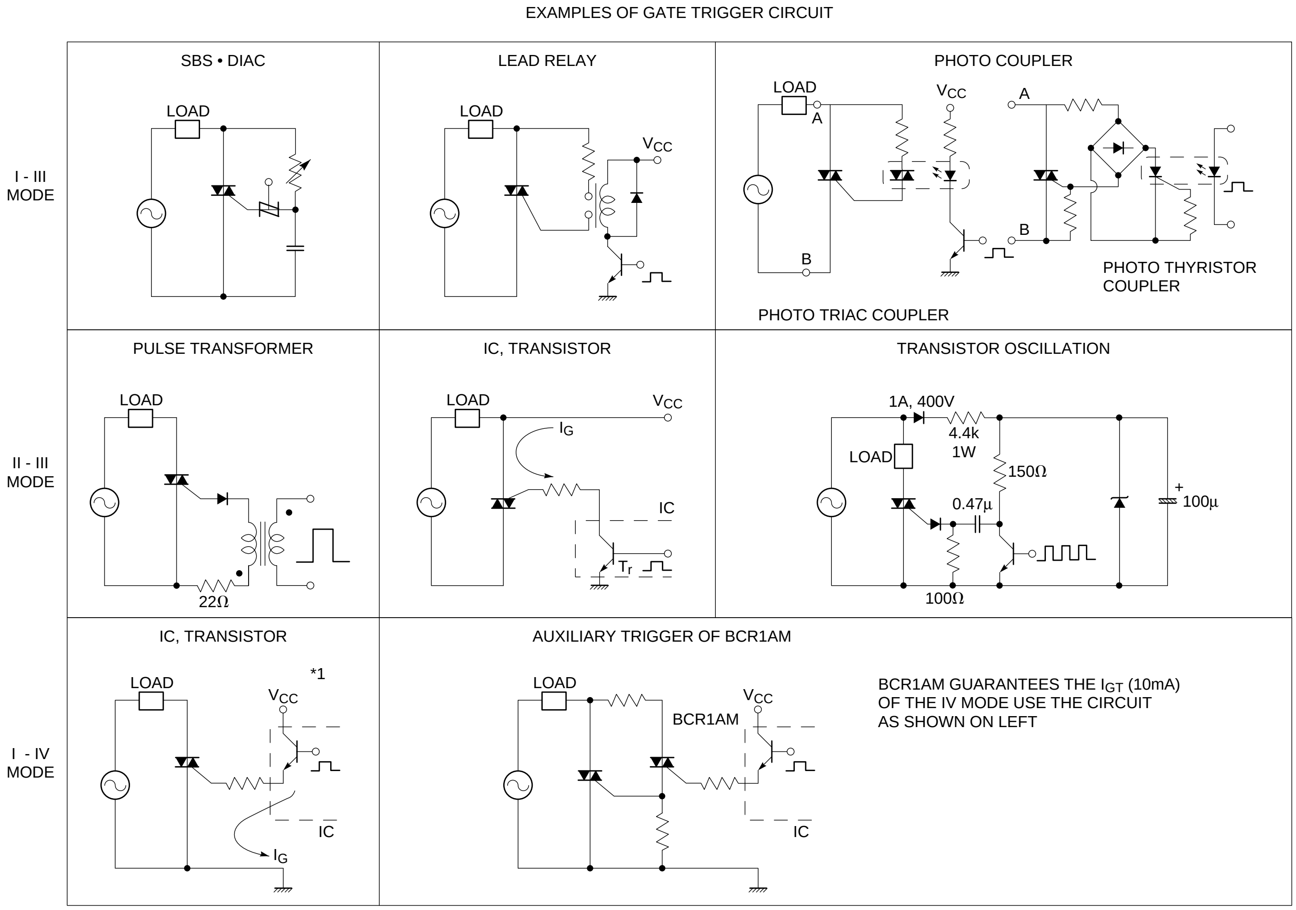
Trigger Mode of Triacs

Triacs are turned on by applying either positive or negative gate signals. Thyristors are turned on by the gate signal when either forward or reverse voltages are applied. See Figure 10.10.

Triacs can be triggered by the gate signal in the following four modes as shown in Figure 10.10. However, the IV mode is guaranteed only by the BCR1AM.

10.4 Determination of Gate Current (See Figure 10.11)

Figure 10.7



*1 THE IV MODE (G + T_2 –) IS NOT GENERALLY GUARANTEED EXCEPT THOSE OF BCR1AM. IF THIS TRIGGER MODE IS USED, SELECTION MUST BE MADE. SET THE SELECTION VALUS AT MORE THAN 80 ~ 100mA. (BCR3AM, BCR16HM)

Figure 10.8 Waveforms During Commutation

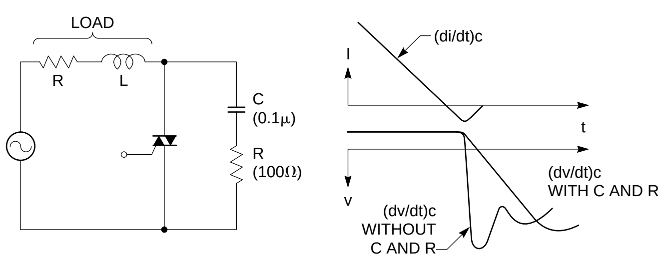
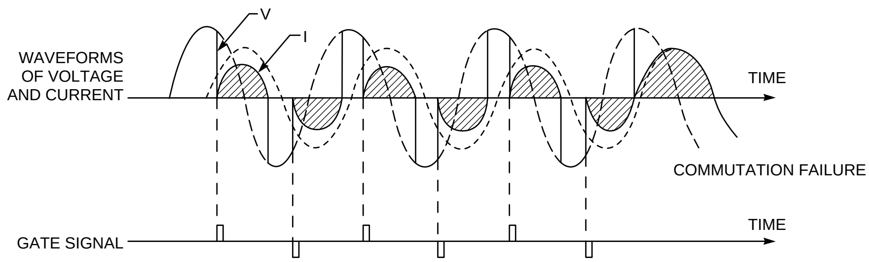


Figure 10.9 Waveforms of Voltage and Current Applied to Triacs During L Load



WAVEFORMS OF VOLTAGE AND CURRENT APPLIED TO TRIACS WHEN L LOAD IS USED AND WHEN COMMUTATION FAILS.

Figure 10.10 Trigger Mode for Triacs

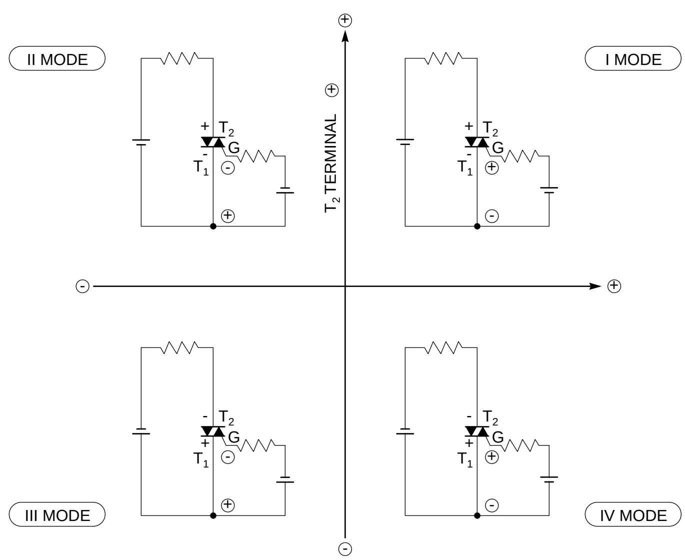


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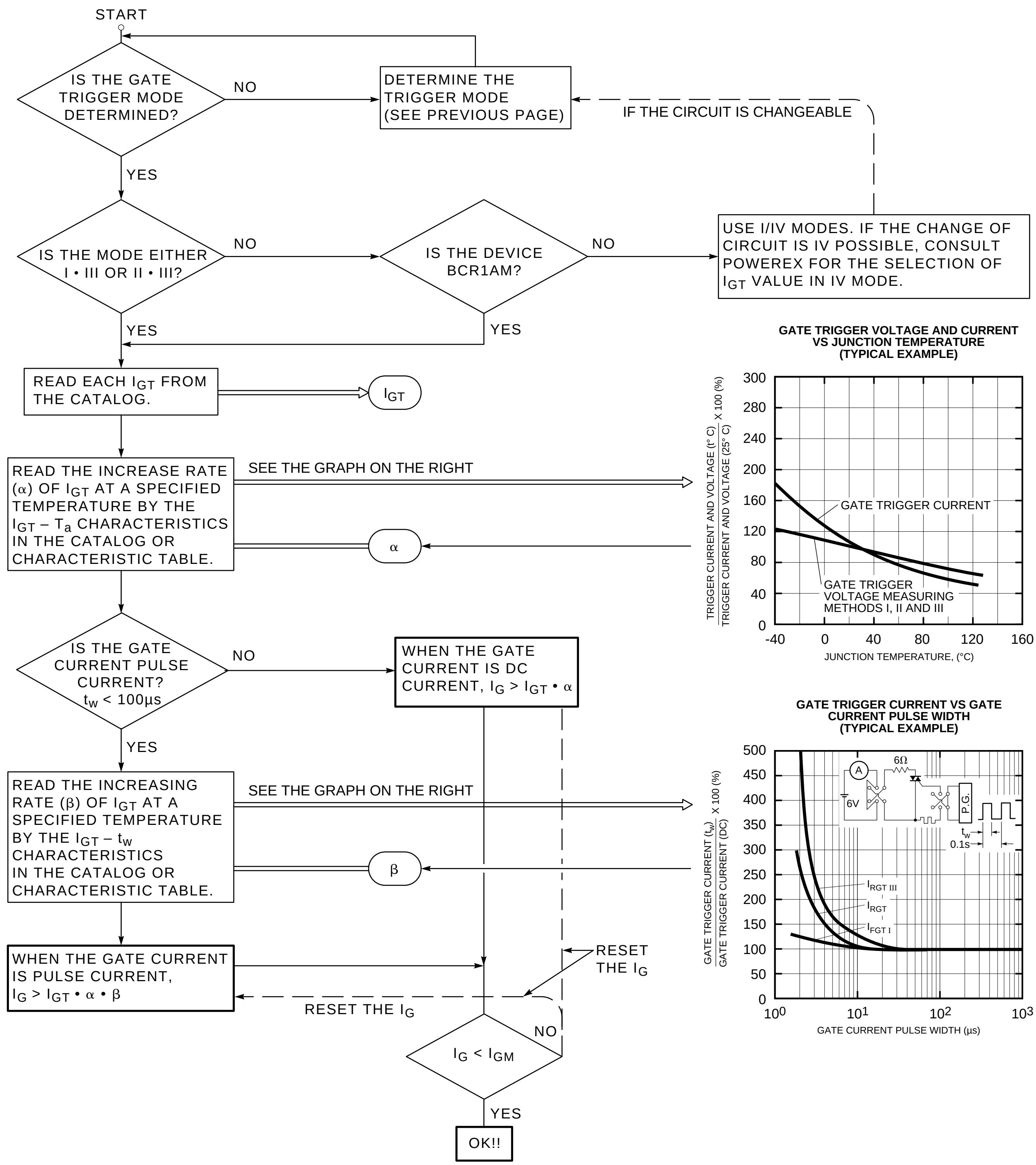
Figure 10.11 Determination of Gate Current



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11.0 Application Information

11.1 Radio Frequency Interference

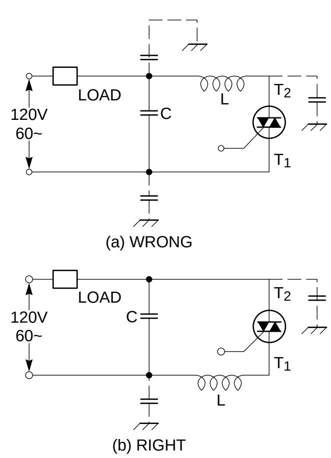
Each time a triac fires in a resistive circuit, the load current goes from zero to the load limited current value in less than a few microseconds. A frequency analysis of such a step function of current would show an infinite spectrum of energy, with an amplitude inversely proportional to frequency. With full wave phase control, there is a pulse of this noise 120 times a second. In applications where phase control is used in the home, such as light dimming, this can be extremely annoying, for while the frequencies generated would not interfere with television or FM radio reception, the broadcast band of AM radio would suffer interference. In such cases and others, RF filtering is required.

The simplest type of RF filter is a single L-C low pass filter. If an L-C resonant frequency of 50kc is chosen, this type of filter will give about 40 dB of noise suppression at the bottom of the broadcast band. As shown in Figure 11.1, the inductor should be placed in series with the terminal 1 connection to the Triac, since the capacitance to ground of the terminal 2 (case) by way of the heatsink, and the capacitance of the line to ground, would shunt the coil if it were in series with terminal 2.

If you look at the circuits of Figure 11.1, you can see the L-C, and triac form a resonant discharge circuit, which depends on the load impedance for damping. For circuit Q's of greater than approximately 2.5, the current through the triac will reverse, as shown in Figure 11.2(a), and a specific triac might turn off if it is a relatively fast device. This condition is worse for light loads, in this case about 100 watts of less, or somewhat inductive loads, which contribute little damping to the circuit. The simple L-C circuit does behave properly however with heavier resistive loads, as shown in Figure 11.2(b). To obtain proper operation under light load conditions, for instance the lamp dimmer with a 60 watt lamp, it is necessary to build in the damping required in the filter. This can be done by adding another resistor and capacitor as shown in the lamp dimmer circuit of Figure 11.3. The component values are chosen to give about the same filtering effect as the L-C filter of Figure 11.1.

Due to the subtle nature of the filter ringing problem, it is often not recognized as such. Since few triacs can turn off during this rapid oscillation, and most triacs seem to work, it sometimes is thought that the triacs are not triggering. Since some diac pulses are longer than others, and with some diacs gate current may still be flowing when the current reverses, changing the diacs appears to solve the problem and therefore some diacs may be thought to be “bad”. It is however important to note that even when the devices sometimes

Figure 11.1 Simple L-C Filter



FOR LOAD	>150 WATTS <1000 WATTS
LET	L = 100µH C = 0.1µF

Figure 11.2 Triac Current for the Circuit of Figure 11.1(b)

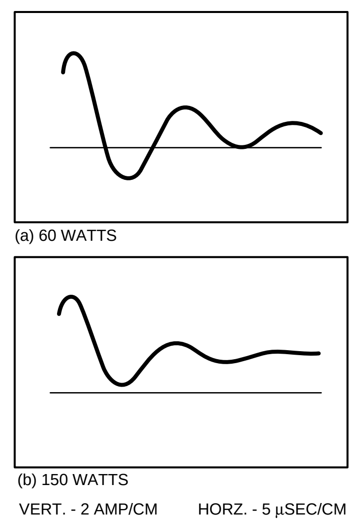
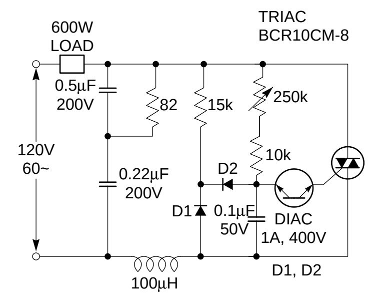


Figure 11.3 Complete Incandescent Lamp Dimmer with R-F Filter



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appear to work properly, i.e. they don't turn off or "flicker," the fact that the triacs may start to turn off, and then retrigger, introduces several noise pulses instead of one, and the filter effectiveness is drastically reduced. Use of the damped R-F filter of Figure 11.3 will however cure this problem.

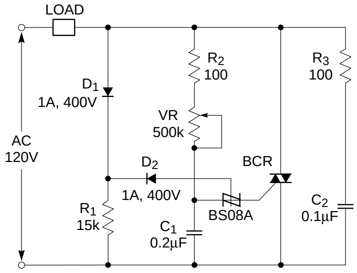
Following are examples of standard application circuits. Basic phase control circuits using thyristors (CR), triacs (BCR) and bi-directional switching devices, motor speed control circuits, and temperature control circuits are described.

Features are given followed by the operating principles.

Basic Phase Control Circuit using Silicon Bilateral Switch (BS08A), Triac (BCR), or SCR (CR).

Example A

- Smooth control is possible in the range of 5 to 90% of load power supply for AC input voltage.
- Suitable for resistive load.
- Phase control range is 10 to 150°



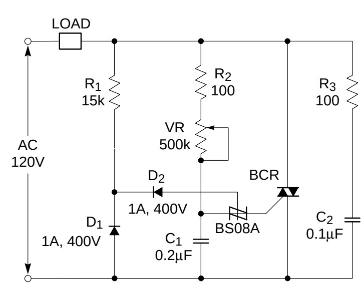
BCR: TRIACS OF 1A TO 30A CLASS CAN BE USED.

The triac BCR trigger phase is controlled by the CR phase-shifting circuit consisting of VR and C_1 and hysteresis is reduced by D_1, D_2, R_1 and the gate of BS08A.

Example B

- Smooth control is possible in the range of 5 to 99% of the load power supply for AC input voltage.
- Suitable for resistive load.
- Phase control range is 10 to 150°.

The triac BCR trigger phase is controlled by the CR phase-shifting circuit consisting of VR and C_1 and hysteresis is reduced by D_1, D_2, R_1 and the gate of BS08A.

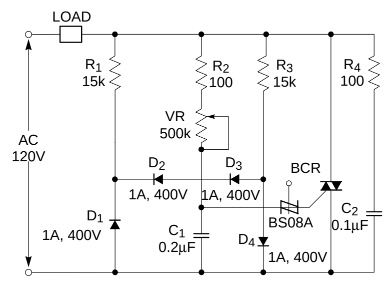


BCR: TRIACS OF 1A TO 30A CLASS CAN BE USED.

Example C

- Smooth control is possible in the range of 5 to 99% of the load power supply for AC input voltage.
- Suitable for inductive load.
- Phase control range is 10 to 150°C.

The triac BCR trigger phase is controlled by the CR phase-shifting circuit consisting of VR and C_1 and hysteresis is reduced by D_1, D_2, D_3, D_4, R_1, R_3.

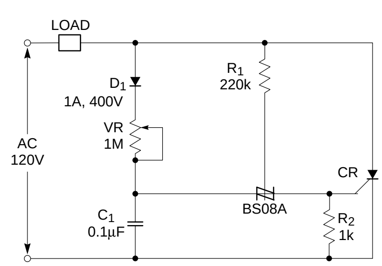


BCR: TRIACS OF 1A TO 30A CLASS CAN BE USED.

Example D

- Smooth control is possible in the range of 1 to 99% of the load power supply for AC input voltage.
- Suitable for both resistive and inductive loads.
- Phase control range is 10 to 170°.

The thyristor CR trigger phase is controlled by the CR phase-shifting circuit consisting of VR and C_1. The voltage of C_1 is reset and hysteresis is reduced by applying the gate current of BS08A to C_1, and by switching the BS08A, applying the gate, R_1, load, power supply and circuit C_1.



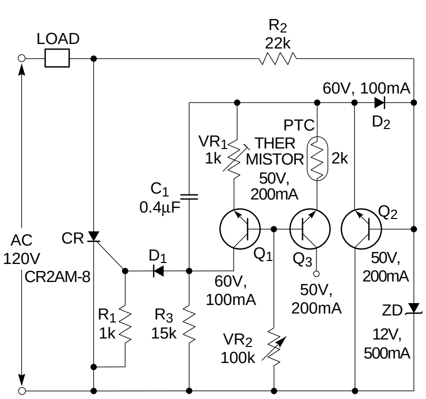
CR: THYRISTORS OF 0.3A TO 20A CLASS CAN BE USED.

11.2 Temperature Control Circuit of an Electric Blanket using a Thyristor

- Electric blankets of up to approximately 100W can be controlled by a thyristor.
- Control by the zero volt switch prevents interference to radio or TV equipment.

By the zero-volt switch control method, trigger voltage of the thyristor CR is set at around zero volt, and the on-off of the device is controlled by the temperature detected by the PTC thermistor. If the temperature of the blanket is lower than a specified value, C_1 is charged up to ZD voltage during the negative cycle of the power supply. When the supply voltage changes to a positive cycle, C_1 discharges through Q_2 and the current flows to the gate of CR. On the other hand, if the temperature rises, resistance of PTC thermistor increases and Q_1 is turned on during the negative cycle of the supply voltage and C_1 is not charged and thus CR is not triggered. Q_3 is inserted for temperature compensation. See Figure 11.4. (Patented by Mitsubishi Electric)

Figure 11.4

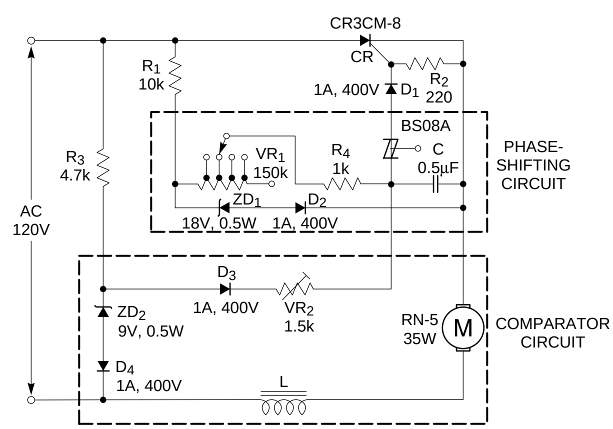


11.3 Constant-speed Control Circuit of a Universal Motor

- The feedback amount is automatically controlled by the motor speed for easy constant-speed operation.
- The feedback amount required for each motor type can be adjusted by resistor VR_2, thus enabling control of various types of motors.

The speed of motor is adjusted by VR1 in the phase-shifting circuit. In the comparison circuit, the reference voltage supplied by the Zener diode and the armature voltage are compared, and C in the phase-shifting circuit is charged by the difference of voltages. The effect of feedback is negligible as the sum of VR_1 and C is small during high-speed operation, but during low-speed operation, when the sum of CR_1 and C is large, even a small feedback is effective and constant operation is improved at low-speed operation. See Figure 11.5. (Patented by Mitsubishi Electric)

Figure 11.5



11.4 Speed Control Circuit of a Juice Mixer

- This circuit allows non-stage speed control by the half wave phase control.
- Timer circuit allows automatic repetition of running and stopping.

If SW_1 is turned on, Q_1 is always turned off and Q_2 is always turned on, and the thyristor CR is triggered by the phase angle set by VR_1 to control motor speed. If SW_2 is turned on, the self-running multi-vibrator consisting of Q_1, Q_2 and C_1, C_2, R_1 and R_2 is activated and the on-off operation of Q_2 is repeated. When Q_2 is turned on, the phase of CR is controlled by VR_1 and the motor operates, and speed control is enabled. But when Q_2 is turned off, CR is not triggered and the motor stops. See Figure 11.6.

11.5 Earth Leakage Breaker

- Electric shock or fire caused by earth leakage can be prevented by detecting earth leakage and tripping the breaker.

- The circuit can protect equipment from damage due to overload or short-circuit.

If the circuit is normal,

$$I_1 + I_2 = I_{01} = 0,$$

and the voltage is not induced on the secondary coil of zero-phase rectifier (ZCT). But, if earth leakage occurs, the sum of currents flowing through ZCT, I_{01} does not equal 0, and the voltage is induced on the secondary coil. The inductive signal is converted into a proper thyristor trigger signal by IC M54122 and enters the thyristor gate circuit driving the thyristor and tripping the breaker. See Figure 11.7.

11.6 Gas/Petroleum Ignition Circuit

- When the power supply is in the negative half cycle, spark discharge occurs. Compact and small-capacity resistor R_1 and a thyristor can be used as the current does not flow from the power supply of the thyristor.

- High-voltage pulses of more than 14kV are output to cause ignition of gas of kerosene.

Capacitor C_1 is charged through R_1 and D_1 during the half cycle of positive power supply and C_2 is charged through R_2 using the reverse voltage applied to D_1. In this case, R_1, R_2, C_1 and C_2 should be selected to make R_1C_1 << R_2C_2, SBS is turned on as C_2 reaches the switching voltage after C_1 is fully charged, and the gate current flows to the thyristor CR. The electric charge charged in C_1 is instantly discharged through CR, and after C_1 is charged with the reverse polarity, it is discharged again through D_2 and the coil, and then it is charged again with the original polarity. Thus high voltage is generated (more than 14kV) on the secondary side of the coil by the current flowing through the coil to produce spark discharge at the discharge gap. See Figure 11.8

Figure 11.6

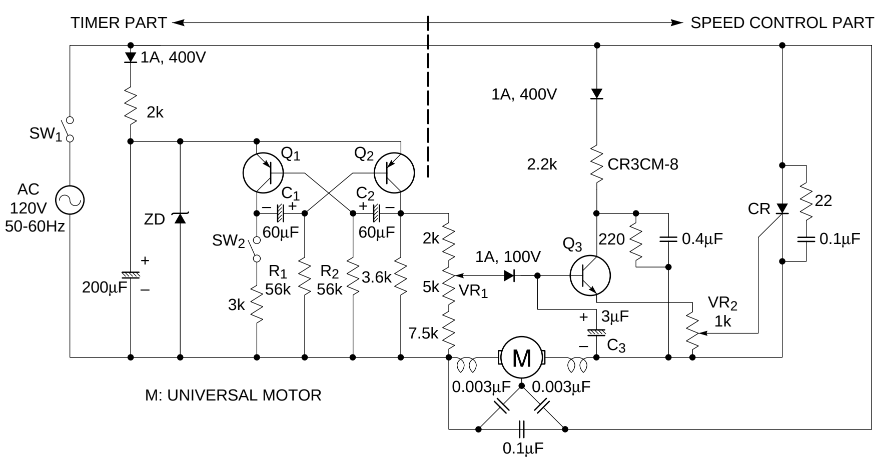
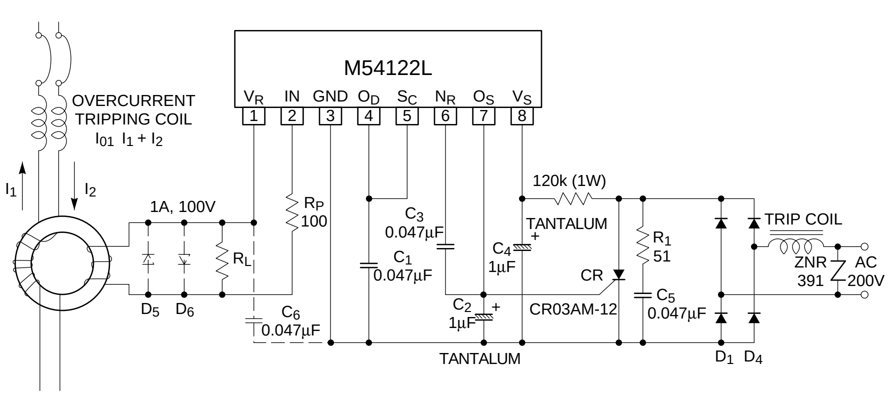


Figure 11.7



CR: CR2AM-12 CAN BE USED AS WELL AS CR03AM-12
D_5,D_6: NOT REQUIRED IF ZCT INCLUDES PROPER MEASURES TO COPE WITH LEAKAGE
M54122L: MITSUBISHI ELECTRIC

Powerex, Inc., 200 Hillis Street, Youngwood, Pennsylvania 15697-1800 (412) 925-7272

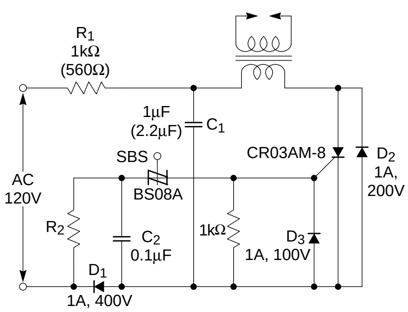
11.7 Ignition Circuit Used Internal-combustion Engine

- Use of contactless contact breaker and electronic advancers reduces the number of deteriorating parts to ensure high reliability and performance.

- Suitable for the ignition unit of small engines used in motor cycles, outboard motors, or snow mobiles.

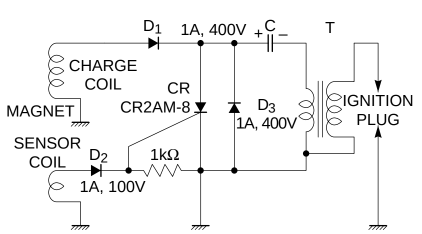
Rotation of the rotor of the magnet induces voltage in the charge coil and the sensor coil. Capacitor C is charged, with polarity as illustrated in Figure 11.9, through diode D_1 by the voltage induced in the charge coil. If the signal voltage for ignition control generated in the sensor coil is applied to the gate of thyristor CR through D_2 the CR is set on and the electric charge of capacitor C_3 is discharged through the primary coil of the ignition coil. The ignition coil is excited by this current, and high voltage is generated in the secondary coil to produce sparks at the ignition plug.

Figure 11.8



GAS IGNITION UNIT ....R_1 = 1kΩ, C_1 = 1µF
PETROLEUM IGNITION UNIT ....R_1 = 560kΩ, C_1 = 2.2µF

Figure 11.9



CR: CR3CM-8, CR03AM-8 CAN BE USED AS WELL AS CR2AM-8 AS SHOWN ABOVE

11.8 Strobe Circuit with Serial-type Automatic Dimmer

- The circuit reduces waste of discharge energy of CM by stopping the discharge current.

- Continuous flashes at short intervals can be generated.

After F.T. is triggered and conducted by closing the switch SW, synchronized with the shutter of a camera, the thyristor CR_1 is triggered to produce a flash. When a flash is emitted to the field object and the reflected light reaches the required intensity, the thyristor CR_2 is triggered. When the C_C voltage, charged with the polarity as shown in the Figure, is applied to CR_1 as reverse voltage, CR_1 is turned off and the flash of F.T. stops. See Figure 11.10.

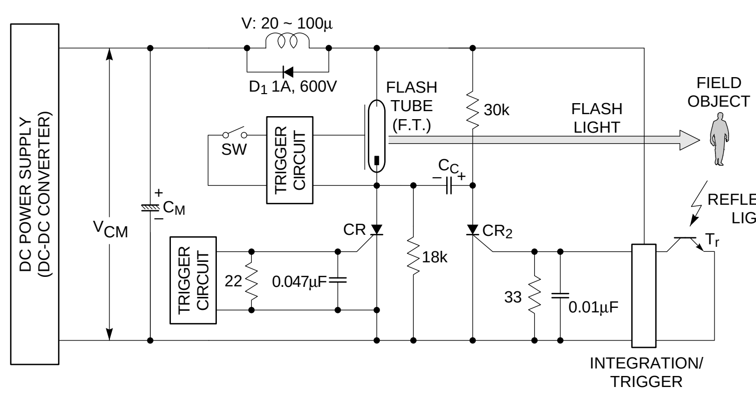
11.9 Thyristor-type Ring Counter

- With a built-in starter circuit 1, starter capacitor charge circuit 2 and starter capacitor charge circuit 3 housed in a conventional ring counter circuit, the ring counter starts immediately if the input signal is applied.

- Thyristor-driven anode-connected ternary counter.

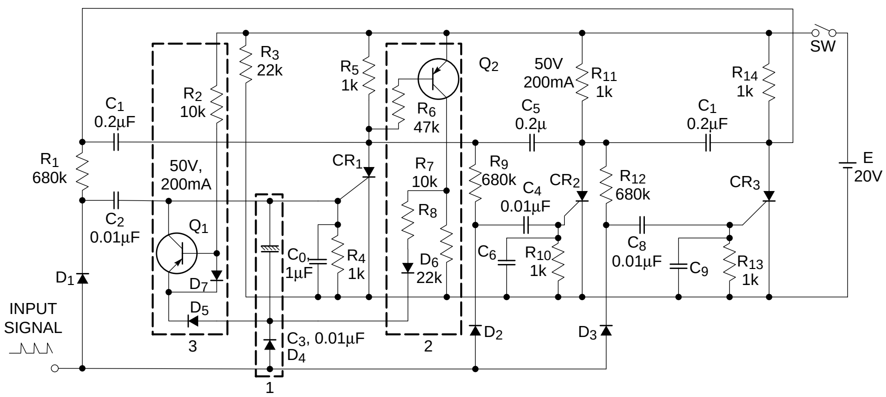
As the input signal is applied to the gate of thyristor CR_1 through C_0, CR_1 is turned on first. If CR_1 is turned on, then Q_2 is turned on and C_0 is charged up to the supply voltage through R_7 and D_6. As the starter circuit 1 has nothing to do with the next input signal, ring counter operation is enabled. If SW is turned off, Q_1 is turned on and the charge of C_0 is discharged immediately, making the circuit suitable for repetitive operation. See Figure 11.11. (Patented by Mitsubishi Electric)

Figure 11.10



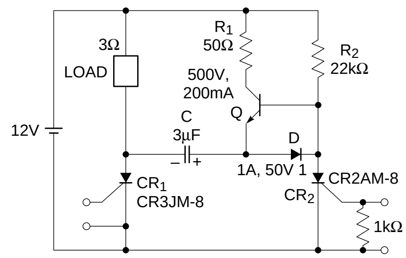
CR_1: CR3AMZ-8 – CR3JM-8
CR_2: CR3EM-8

Figure 11.11



C_1~D_7: 1A, 100V
CR_1~CR_3: CR02AM-4

Figure 11.12



11.10 DC Static Switch

- The DC static switch returns to normal by applying the off signal again if commutation fails.
- The fast response ensures high-speed switching.
- Low power dissipation during the off-state period.

If the input signal is applied to the gate of thyristor CR_1, as illustrated in Figure 11.12, CR_1 enters on state, and current flows to the load. As the base current flows to the transistor Q through resistor R_2 and capacitor C, Q enters an on state and C is charged with the polarity as shown in Figure 11.12. If the signal enters the gate of auxiliary thyristor CR_2, CR_2 enters an on state and the discharge current flows from C through diode D, CR_2 and CR_1, and CR_1 enters an off state. Then C is charged with the reverse polarity as illustrated. During this period, Q enters an off state as the voltage of D falls. When C is completely discharged, CR_2 returns to off state. If CR_2 returns to an off state, C is discharged through Q in preparation for the next operation.

If commutation fails during this commutation period, both CR_1 and CR_2 enter an on-state, but CR_2 returns to an off-state and C is discharged with the polarity as illustrated in Figure 11.12 because the value of R_2 is large, only a small amount of current flows to CR_2, and the current bypass circuit is provided, consisting of R_1, Q base and C. Therefore, CR_1 can be placed off state again by applying the off-state pulse signal to the gate of CR_2.

11.11 Electric Foot Warmer

- Non-stage and wide-range control of the temperature of an electric foot warmer is possible.

The temperature is controlled by trigger pulses generated by VR, PTh, R_1, BM, R_3 and C_4 and by the control of the trigger phase of triac BCR. If the temperature exceeds a specified value after the temperature is set by VR, the resistive value of positive-type thermistor PTh increases and the conductive angle of BCR becomes smaller and so the temperature falls. If the value decreases, the conductive angle becomes larger and the temperature rises.

The bimetal switch BM detects sudden temperature rises and turns the BCR to an off state and stops the power supply. R_2 is provided to prevent retriggering of SBS.

As the charge current of C is the current flowing through resistor R_2 multiplied by h_{EE} of transistor Q, C can be charged quickly and a large resistive value of R_2 can be set so that the current is less than the holding current of CR_1. Thus, power dissipation is minimized during the off state of DC static switch.

Proper selection of h_{FE} of transistor Q and resistive value of R_2 enables normal operation at repetitive frequency of 1kHz. See Figure 11.13. (Patented by Mitsubishi Electric)

11.12 Zero-volt Switch using Triacs

- A heater of 1 to 1.6kW can be controlled in a range of 40 to 160°C.

- A zero-volt switch does not counter problems due to high-frequency noise.

The saw-toothed wave voltage generated in a saw-toothed wave oscillator is superimposed between the base and emitter of Q_1 in the Schmidt circuit, and is used to repeat the on-off operation of the Schmidt circuit. The duty cycle of on-off operation is determined by VR and Th. Q_4 is turned off only during a short period near the phase of 0 to 180 degrees of the power supply by Q_3 and Q_5, and the current flows to the gate of the triac through C_4 and R_{22} in the pulse generating circuit of the final stage. During other periods, Q_4 enters an on state, and the current does not flow to the gate. But if Q_1 enters an off state in the Schmidt circuit, Q_4 is always placed in an on state and the triac is not triggered. See Figure 11.14. (Patented by Mitsubishi Electric)

11.13 Zero-Volt Switch of Triac and Thermo IC M54101P (For use of Heater Control)

- Control of the zero-volt switch does not cause interference to radio or TV equipment.
- High reliability is ensured by the small number of parts in the control circuit.

The M54101 is a digital integrated circuit for thermal control such as heaters. Load temperature is detected by temperature detector PTC and if the temperature is lower than a specified value, an output pulse in the vicinity of zero volt of the supply voltage is generated by transistor Q to trigger a triac. The load temperature can be

Figure 11.13

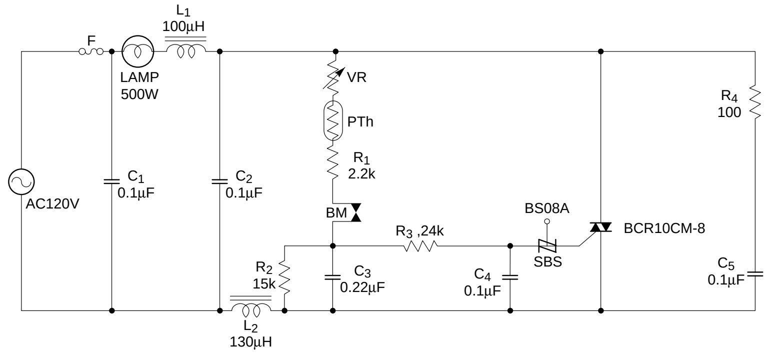
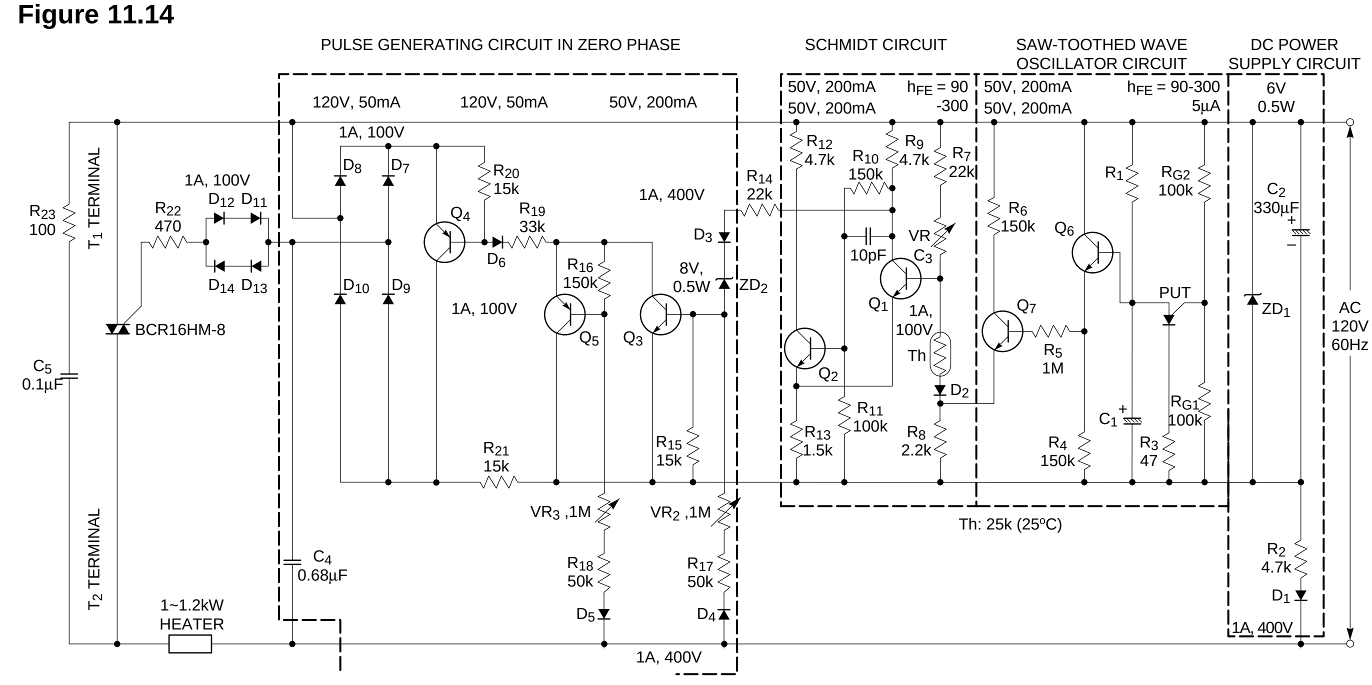


Figure 11.14



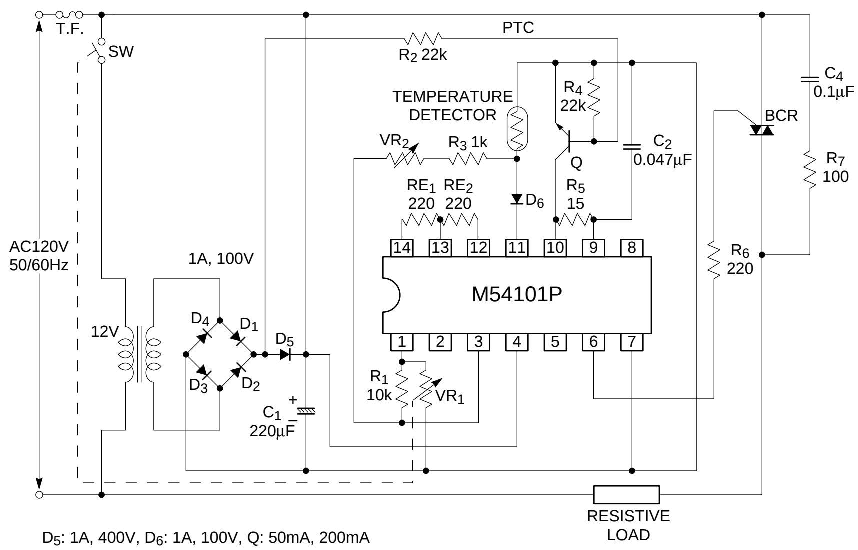
EXAMPLE: CYCLE IS 100 SEC WHEN R_1 IS 1M AND C_1 IS 100µF specified at any value by changing VR_1. See Figure 11.15

11.14 Zero-volt Switch Using a Triac and Zero-volt Control IC M5172L (Water Heater)

- Control of zero-volt switch causes no radiowave interference.
- High reliability is ensured by the small number of parts.
- Used for resistive load.

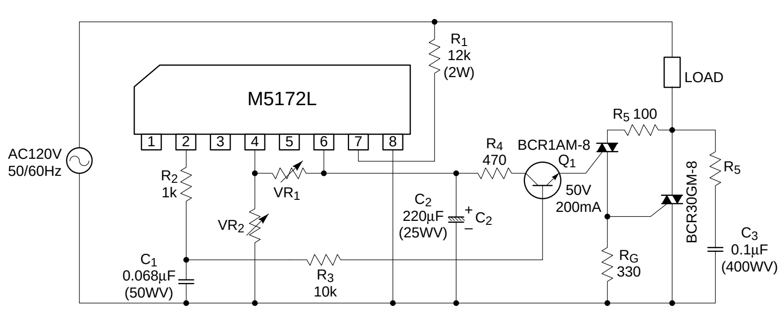
The M5172L is a linear semiconductor integrated circuit for zero-volt control of a thyristor, and by delaying the output pulse, zero-volt control of a triac is enabled. If the temperature of water is lower than a specified value, pulses are generated in the vicinity of zero-volt. The pulse width of this output is enlarged by the delay circuit, consisting of C_1 and R_2 and amplified by transistor Q_2. By applying this output to the gate of the triac and using a thermistor for VR_1, the temperature can be automatically controlled. See Figure 11.16.

Figure 11.15



D5: 1A, 400V, D6: 1A, 100V, Q: 50mA, 200mA
BCR: BCR3AM-8, BCR10CM-8, BCR16HM-8, BCR30GM-8, ETC.
M54101P: MITSUBISHI ELECTRIC

Figure 11.16



M5172L: MITSUBISHI ELECTRIC

11.15 Temperature Control Circuit by Zero-volt Switch

- Control of the zero-volt switch and the use of general use comparator IC dispenses with radiowave interference.
- Used for resistive load.
- Figure 11.17 shows a zero-volt switch circuit suitable for temperature control of heaters used in home electric appliances for heating and cooking equipment.

This circuit employs an NTC thermistor for the temperature detector device. One of the two IC M51207 comparators is used for the temperature comparator and the other is used for zero-volt detector of AC power supply. The temperature detector unit and AC power supply unit are electrically insulated by a photo-coupler. When switch SW is turned on, and if the detector temperature is lower than a specified value, the temperature detector comparator is set high. In this condition, the zero-volt detection comparator 2 enters a low state in the vicinity of zero-volt at both ends of all-wave rectifier circuit. The triac is triggered in the vicinity of zero-volt of AC supply voltage (II and III modes) and the power is supplied to the load of heater.

If the detected temperature exceeds a specified value as the temperature of the heater rises, comparator 2 of the temperature detector circuit is set low and the comparator is set high, irrespective of the state of input at pin ⑧, and the power supply is stopped. The Triac BCR10CM can control a heater with the wattage of more than 500W. The required size of a heatsink fin is 60 x 60 x t2.3mm. BCR10PM is an insulated type.

11.16 Single-phase Capacitor Motor Speed Control Circuit

- Negative feedback control allows large load variation and large start-up torque, making the device suitable for the speed controller of washing machines.
- Employment of BS08A for the trigger device of triac makes the control circuit comparatively cheap.

In general, wide-range speed control of a capacitor motor is not achieved simply by controlling the phase. In this circuit, the speed of a motor is detected by the pilot generator (PG) and by the voltage (terminal voltage of C_2) in proportion to the rotating speed. The specified voltage (determined by Zener diode ZD_1, ZD_2, resistor R_2, R'_2 and R''_2) are compared, and the charge current of capacitor C1 is controlled by applying the difference of the voltages between the gate and emitter of transistor (Q) and by amplifying it. The charge constants of capacitor C_1 varies according to this control, and therefore, the breakover phase of silicon bidirectional switching device (BS08A), i.e., trigger phase of triac (BCR10CM), changes and the power supply of the motor can be adjusted, enabling constant speed control. See Figure 11.18. (Patented by Mitsubishi Electric)

Figure 11.17

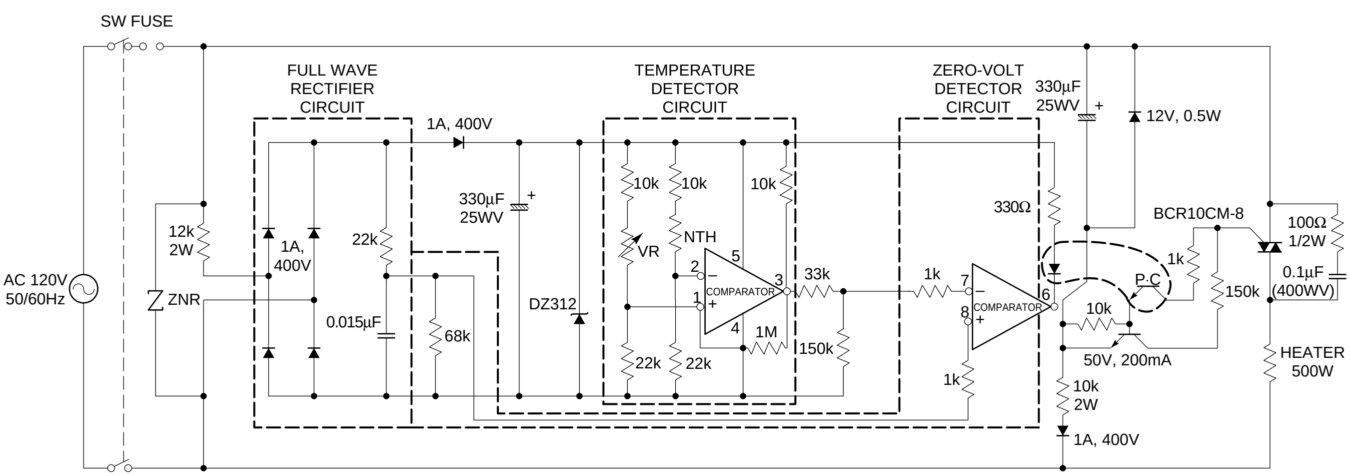
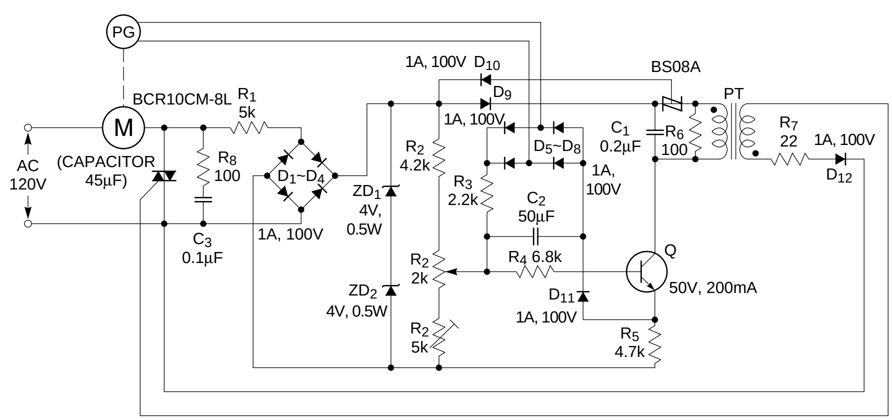


Figure 11.18



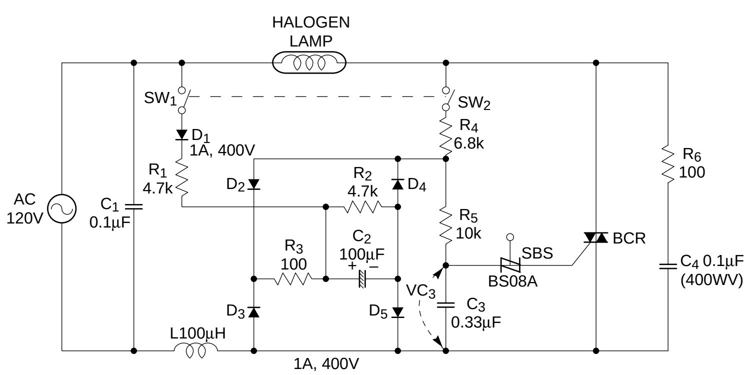
11.17 Rush Current Control Circuit of Halogen Lamp (Using Photocopiers)

- The rush current can be reduced by the soft-start drive.

- Reduction of rush current enables the use of cheap devices with low rated current, and thus more economical equipment design.

The soft-start is enabled by bypassing the charge current to C_3 at the early stage of switching. If the voltage VC_3 of C_3 reaches the switching voltage V_S of SBS, the SBS is set on and BCR is also set on. During the first several ten cycles after the power supply is turned on, the charge current for D_2, D_5, C_2 and C_3 are bypassed to delay the phase when VG_3 becomes Vs. If G_2 is charged, the bypass current does not flow and, in normal conditions, the switching phase is settled at a value determined by the charge constants of R_4, R_5 and C_3. Figure 11.19. (Patented by Mitsubishi Electric)

Figure 11.19



Capacity of Halogen Lamp	Rush Current (Peak Value)	Applicable Device	
		Without Soft Start	With Soft Start
500W/100V	68A	BCR10CM	BCR10CM
800W/100V	103A	BCR16CM, BCR16HM	BCR12CM
1000W/100V	130A	BCR30GM	BCR16HM, BCR16CM
1200W/100V	170A	BCR30GM	BCR30GM

11.18 On-off Operation Circuit for Rush Current Control of the Transformer

Reduction of rush current by the soft-start drive makes the device suitable for on-off control of transformers and motors.

A multi-vibrator consisting of Q_1 and Q_2 determines the on-off cycle of a triac. If Q_1 is conducted, the impedance of transistor Q_3 gradually decreases by the delay circuit consisting of a capacitor C_7 and a resistor R_6. The generated phase of trigger pulses for the triac BCR gradually advances to enable the soft-start. See Figure 11.20

11.19 Battery Charger (I)

- If the battery is connected in reverse direction, the circuit prevents the current flow and damage to the charger.

- The reverse connection is displayed by the display lamp.

The output voltage stepped down by a transformer of home-use AC power supply is rectified by the all-wave rectifier diode and is applied to the triac. If the battery is connected normally, the gate current flows to the triac BCR gate from the battery, and the triac is set on and the battery is charged. If the battery is connected in the reverse direction, the gate current of BCR is blocked by D_1, the battery is not discharged and no current flows to diodes from D_1 through D_4. As DC current is supplied to the light-emitting diode LED, it is illuminated to indicate the reverse connection. See Figure 11.21. (Patented by Mitsubishi Electric)

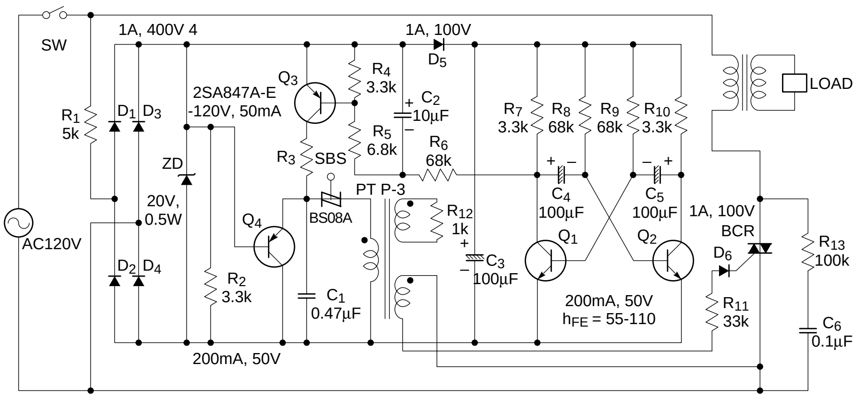
11.20 Battery Charger (II)

- The battery is charged by connecting it to the terminals of a charger. Polarity does not need to be matched.

- For safety measures, even if the input terminals are connected to AC power supply, the voltage appears to the output terminals only when a battery is connected.

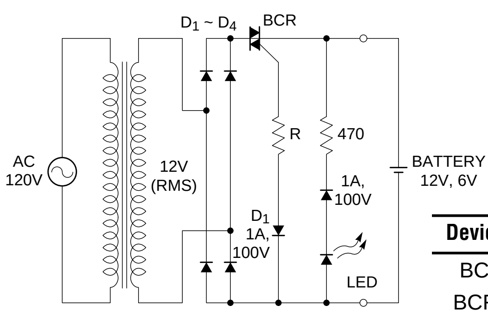
The circuit is operated by the trigger mode II (T_2 pin (+) gate (-)) and by the function of the circuit that triggers one of the two triacs in accordance with the polarity of the connected battery. As the gate

Figure 11.20



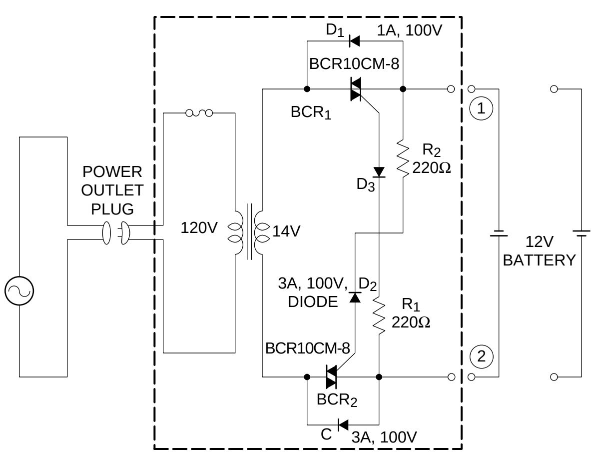
BCR: BCR3AM-8 ~ BCR30GM-8L, ETC.

Figure 11.21



Device Name	Register R
BCR3AM	47Ω/3W
BCR10CM	100Ω2W
BCR16CM	100Ω/2W

Figure 11.22



current is not applied to the triac when a battery is not connected to the charger, no voltage appears at the output terminals of the charger.

If the battery output terminal (1) is connected to the positive side of the battery, the gate current flows to BCR_1 in loop from the battery, T_1 terminal of triac BCR_1, diode D_3, resistor R_1 and to the battery by the residual voltage of the battery, and BCR_1 is set on. During the positive half cycle of AC power supply, the charge current flow from the secondary coil of a transformer, BCR_1, battery, diode D_3 to the secondary coil, and the battery is charged.

On the other hand, if the battery is connected to the charger with reverse polarity, exactly the reverse operation takes place, and during the negative half cycle of AC power supply, the charge current flows through triac BCR_2 and diode D_1, and the battery is charged. See Figure 11.22 (Patented by Mitsubishi Electric)

11.21 Battery Charger (III)

A battery is automatically charged if it is connected with the specified polarity. It does not operate if it is connected in reverse direction, shorted, or opened.

If a battery B is not connected between A and A' when the power supply E is turned on, as illustrated, the triac BCR is set off and no current flows in the secondary coil of transformer T.
If A and A' are shorted, no current flows in the secondary coil of transformer T. If a normal battery B is connected as illustrated, the

relaxation oscillator circuit of PUT, using the battery as its power supply, oscillates in a specified cycle determined by R_4 and C_1. Therefore, pulses are generated at both ends of resistor R_3 and are applied to the base of transistor Tr, and Tr is set on in accordance with the cycle of relaxation oscillator circuit. If Tr is set on, the pulse gate current flows to the gate of BCR in a loop from battery B, gate of BCR, resistor R_1, Tr and to battery B. By contrast, when the positive half cycle of sine wave voltage half-wave rectified by a rectifier diode is applied at terminal T_2 of triac BCR, BCR is set on and starts to charge automatically when the BCR gate current flows. The pulse current flows to the gate of BCR irrespective of the voltage phase, and if R_4 and C_1 are specified so that the pulse frequency is more than 1kHz, a triac can be triggered without making the conductive angle of BCR too small. If the terminal of battery B is accidentally connected in the reverse direction, the current to the gate of the triac is blocked by transistor Tr and the battery is not charged or discharged as the triac is set off. See Figure 11.23 (Patented by Mitsubishi Electric)

Figure 11.23

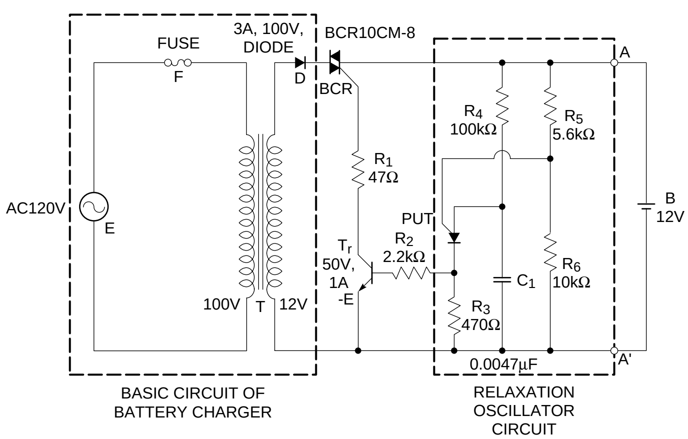
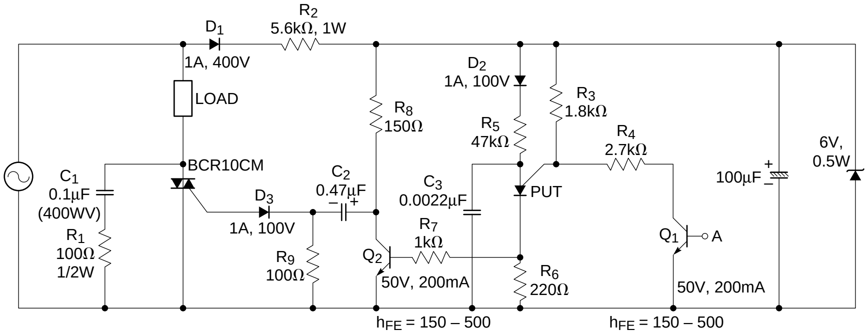


Figure 11.24



11.22 On-off Switch using a Triac

- A triac can be triggered using the output of an IC in modes II or III.
- A pulse transformer is not required.

The signal from the IC is applied to Q_1. If the signal is high, Q_1 is set on and the PUT oscillates approximately at 10kHz and Q_2 repeats on-off operation accordingly. On the other hand, C_2, R_3 and R_9 are charged as illustrated, the charge of C_2 is discharged from C_2, Q_2, triac BCR (T_1 to G) and D_3 whenever Q_2 is set on. The charge current of C_2 flows from the gate of a triac, the triac is triggered in modes II and III. As the oscillator frequency of PUT is set at 10kHz, occurrence of radio noise is suppressed. See Figure 11.24 (Patented by Mitsubishi Electric)

11.23 De-icing Timer Circuit for an Electric Oven

- Suitable for disconnection control of a magnetron.
- Half-wave conduction blocking circuit prevents the flow of excess current to the triac.

If switches SW_1 and SW_2 are turned on, an unstable multivibrator consisting of PUT_1 and PUT_2 function and transistor Q_1 repeats the on-off operation at a specified interval. The triac BCR is set on while Q_1 is off and the power is supplied to the magnetron. While Q_1 is on, the BCR gate is shorted, no gate current flows, and BCR is set off. In this way, the triac repeats on-off operation and the power is supplied to the magnetron intermittently.

If Zener diode ZD and transistor Q_2 prevent the flow of excess current by half-wave conduction, in which only the sensitive modes of the triac are triggered as the gate current decreases when the discharge voltage of capacitor C decreases, then only the SW_2 is turned off. If the charge voltage is less than the Zener voltage of ZD, transistor Q_2 is turned off and Q_1 is turned on and no current flows to the gate of a triac. Therefore, no current under a specified value flows to the gate of BCR. See Figure 11.25 (Patented by Mitsubishi Electric)

11.24 DC Power Supply Circuit for 100V and 200V

- A specified DC voltage is output from either 100V or 200V source without switching.

If the plug is inserted at a 100V power outlet, gate current flows to the gate of triac BCR through resistor R_3 during both positive and negative cycles, as the thyristor (Thy). Thy is set off if the ratio of resistors R_1 and R_2 are selected so that the charge voltage of C_1 is less than the Zener voltage of the Zener diode. As a result, BCR is set on during both half cycles and the amplifier circuit in the later stage provides DC voltage approximately two times larger than AC voltage.

If the plug is inserted at a 220V power outlet, the charge voltage of capacitor C_1 is larger than the Zener voltage and gate current flows to Thy. Thy is set on and BCR gate and terminal T_1 are shorted. Thus, BCR is set off during the negative half cycle, and capacitor C_2 is not charged. C_2 is charged only during the positive half cycle and functions as a half-wave rectifier. Therefore, the output DC voltage is equal to the input AC voltage.

As stated above, the same DC voltages are output by the selection of half wave and full wave for the AC supply voltages of 100V and 200V. See Figure 11.26. (Patented by Mitsubishi Electric)

11.25 Pulse Amplifier Circuit Using Thyristor

- High-frequency pulse of approximately 1kHz can be amplified.
- Small capacity required for thyristors and transistors reduces power dissipation.
- The circuit can be used to trigger thyristors of large capacity.

When thyristor CR is set off, C is charged through Q. If CR is triggered by the external signal, the base-emitter of Q is reverse-biased by D_1 and Q is put in an off state. This state after C is discharged completely, Q turns to an on state again and starts to charge C. See Figure 11.27 (Patented by Mitsubishi Electric)

Figure 11.25

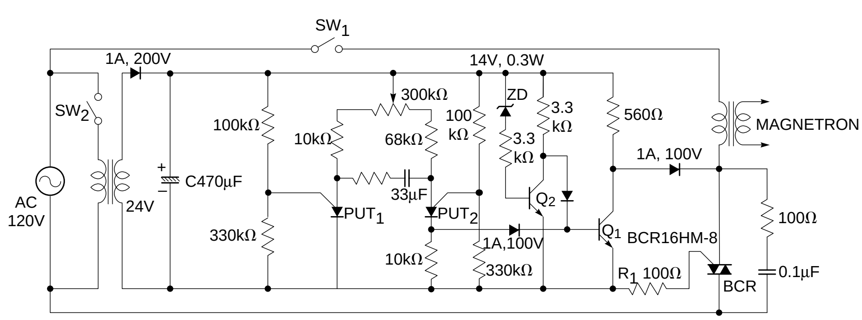


Figure 11.26

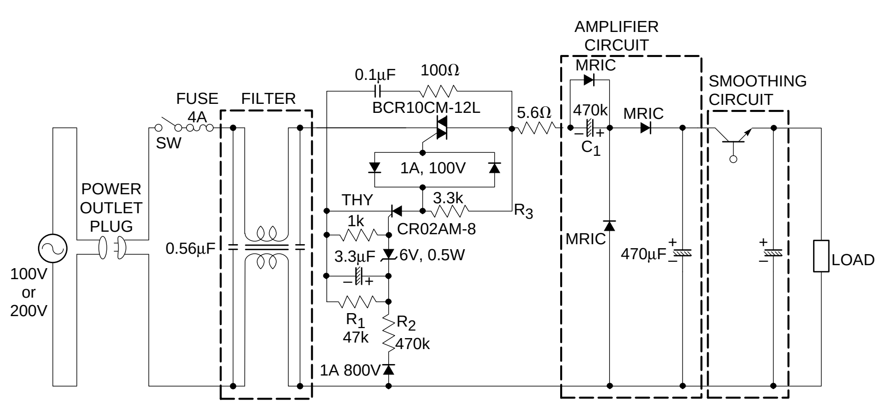


Figure 11.27

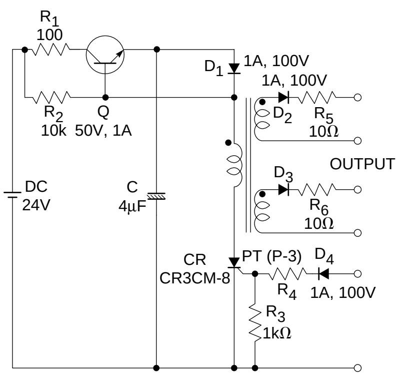
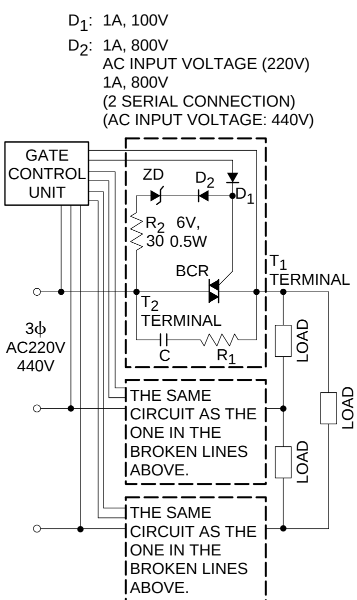


Figure 11.28



11.26 3-Phase AC Power Supply Control Circuit Using a Triac

To control the 3-phase AC power supply, the gate trigger signal should have an electrical angle of more than 60 degrees or double pulse with a distance of more than 60 degrees and the circuit becomes very complicated. But a control circuit with the same function is realized with this simple circuit as illustrated in Figure 11.28.

The flow of current in one direction from T_2 terminal to T_1 terminal of the triac is controlled by the gate control unit. The reverse current is controlled by triggering the triac with the gate current flowing from the load, T_1 terminal, gate terminal, diode D_1, Zener diode ZD and resistor R_2. The power is controlled from 0 to 100% by changing the ignition phase angle from 210 to 0 degrees. Zener diode ZD prevents mis-operation due to noise from the main circuit. (Patented by Mitsubishi Electric)

11.27 Electric Starter for Fluorescent Lamps

Employment of a non-linear saturable capacitor, triac and reverse-blocking two-terminal thyristor provides a cheap, compact and light-weight electric starter for fluorescent lamp with short turn-on time.

If the power supply switch is turned on, the bi-directional switching device is set on at a proper phase θ of the positive half cycle of the power supply at the early stage of startup, and triac Q_2 is triggered. If Q_2 is turned on, non-linear saturable capacitor C_1 with charge saturation characteristic under a specified charge voltage is charged quickly by the power supply through the stabilizer with polarity as illustrated.
C_1 enters quickly into the saturation area and the current flowing to the stabilizer decreases instantly, and the high-voltage pulses of $e = L\,(di/dt)$ are generated in the stabilizer. The reverse-blocking two-terminal thyristor Q_3 is triggered by this pulse and a pre-heating current flows to the filament of the fluorescent lamp. The conducting current of Q_3 becomes zero at the phase θ_2 of the negative half cycle of power supply and Q_3 is turned off. Then, the near-the-peak voltage of the negative half cycle of the supply voltage is suddenly applied at both ends of the fluorescent lamp, Q_1 and Q_2 are turned on again and C_1 is charged quickly, with the reverse polarity as illustrated. With the same mechanism, high-voltage pulses with the reverse polarity are generated in the stabilizer and the turn-on pulse is applied at both ends of the fluorescent lamp.

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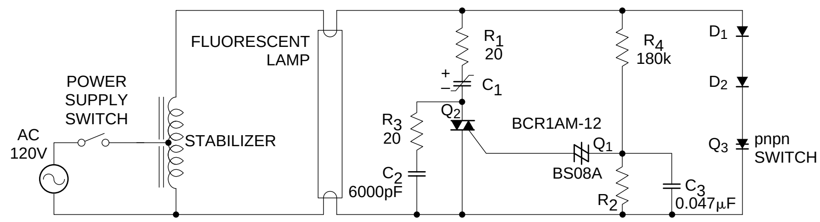
Then the same operation continues and the light is turned on if the filament is sufficiently heated. (Approximately 0.5 seconds after the power is supplied.) If the lamp is turned on, the voltage applied at both ends of the lamp decreases, and Q_1, Q_2 and Q_3 are set off. Then pre-heating and high voltage pulses are stopped.
See Figure 11.29.

Figure 11.29



(CIRCUIT CONSTANTS ARE USED FOR 32W TYPE.)

UNIT: Ω

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12.0 Application Chart for Plastics

APPLICATION		Home Applications																Camera Equipment	
		Air Conditioner	Microwave Oven	Electric Oven	Refrigerator	Washing Machine	Electric Blanket	Food Processor	Sewing Machine	Stereo	Television Set	Fan Heater	Electric Fan	Vacuum Cleaner	VCR	Light Dimmer	Gas Ignitor	Camera	Automatic Electronic Flash
LOAD		Motor	Transformer	Heater	Motor Heater & Lamp	Motor & Solenoid	Heater	Motor	Motor	Transformer & Solenoid	Crowbar Circuit	Heater	Motor	Motor	Crowbar Circuit	Lamp Starter	Induction Coil	Trigger Transformer	Xenon Tube
THYRISTORS General Use	CR02AM			○			●			○								●	●
	CR03AM																●		
	CR04AM						●			○							●	○	
	CR08AS						○											●	●
	CR2AM			○			●	○	●		○						○		
	CR3CM						●	●	●		○						○		○
	CR5AS							○	○		●								
	CR6CM							○		○	○				○		○		
	CR8AM									○					○				
THYRISTORS Pulse Applictions	CR3AMZ										○								●
	CR3JM																		●
	CR3EM																		●
TRIACS General Use	BCR1AM	●	○		●	●			○			○	●			●			
	BCR3AM	○	○		●	●			●				○			●			
	BCR5AS	○	○		●	○			○	○			○			●			
	BCR5AM	○			○	○			○	○						●			
	BCR6AM				○	●		○		○		○		○		●			
	BCR8CM				○	●		○		○		●		○		●			
	BCR10CM			●	○	●		●		○		○		●		●			
	BCR12CM			●	○	○		●						○		●			
	BCR16CM	○	○	●	●			○						○		●			
	BCR16HM	●	●	●	○											○			
	BCR30GM	●	●	●												○			
	BCR5PM					●										●			
	BCR8PM			○	○	○		●						○		●			
	BCR10PM	○	○	○	●			○						○		●			
	BCR12PM				○	●		○		○		○		○		●			
	BCR16PM			○	○	●		●		○		○		○		●			

● Most Preferred

○ May Be Used

POWEREX

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APPLICATION		Printer	CRT Monitor	Typewriter	Duplicator	(ECR) Electronic Cash Register	Capacitor Discharge Ignitor	Regulator	Timer	Touch Sensitive Switch	(SSR) Solid State Relay	Programmable Logic Control	Switch Mode Power Supply	Display Driver	Vending Machine	Fitness Equipment	Ground Fault Breaker	Power Tools	Automatic Door	Telephone
LOAD		Soft Start Circuit	Soft Start Circuit	Crowbar Circuit	Heater & Motor	Crowbar Circuit	Inductive Coil	Battery	Solenoid	Solenoid			Crowbar & Soft Start Circuit		Solenoid	Motor & Solenoid	Relay	Motor & Solenoid	Motor	Surge Current & Voltage Arrestor
THYRISTORS General Use	CR02AM								●	○	○		●	●	●			●		
	CR03AM						●		○								●			
	CR04AM								○	○	○		○	○	○			○		
	CR08AS						○		○	○	●		●	●	●			○		
	CR2AM	○					●			●	○		○			○		●	○	
	CR3CM	○		○		○	●			○			○			○		●	●	
	CR5AS	●		○		○	●	●		○			○					●	●	
	CR6CM	○		○		●	●	●		○			●					●		○
	CR8AM			●		○	○	●					○					○		○
THYRISTORS Pulse Applictions	CR3AMZ																			
	CR3JM																			
	CR3EM																			
TRIACS General Use	BCR1AM	○			○						●	○		○	●					
	BCR3AM	○	○		○						●				○	●		●	●	
	BCR5AS	○	○		○						●	●	○			○		●	○	
	BCR5AM	●	●		○						○	○	●			○		○	○	
	BCR6AM		○		○						●	○	○					○		
	BCR8CM				●						●	●	●							
	BCR10CM				○						●	●	●							
	BCR12CM				○						●	●	●		○					
	BCR16CM				○						●	●	○		○					
	BCR16HM				●						○		○		○					
	BCR30GM				○						○		○		○					
	BCR5PM	○	○		○						○	○	○					○	○	
	BCR8PM				●						○	○	○							
	BCR10PM				○						○	○	○							
	BCR12PM				○						○	○	○		○					
	BCR16PM				○						○	○	○		○					

● Most Preferred

○ May Be Used

13.0 Selector Guides

13.1 Phase Control SCRs

Type	V_{DRM} Volts	$I_{T(avg)}$ Amperes	@ T_C °C	I_{TSM} Amperes	I^2t A^2 sec	P_{GM} Watts	V_{FGM} Volts	I_{FGM} Amperes
General Purpose								
CR02AM-8	400	0.3	30	10	0.4	0.1	6	0.1
CR03AM-8	400	0.3	47	20	1.6	0.5	6	0.3
CR03AM-12	600	0.3	47	20	1.6	0.5	6	0.3
CR04AM-8	400	0.4	54	10	0.4	0.5	6	0.3
CR04AM-12	600	0.4	54	10	0.4	0.5	6	0.3
CR08AS-8	400	0.8	51	10	0.42	0.5	6	0.3
CR08AS-12	600	0.8	51	10	0.42	0.5	6	0.3
CR2AM-8	400	2.0	75	20	1.6	0.5	6	0.3
CR2AM-12	600	2.0	75	20	1.6	0.5	6	0.3
CR3CM-8	400	3.0	50	90	33	0.5	6	0.3
CR3CM-12	600	3.0	50	90	33	0.5	6	0.3
CR5AS-8	400	5.0	88	90	33	0.5	6	0.3
CR5AS-12	600	5.0	88	90	33	0.5	6	0.3
CR6CM-8	400	6.0	88	90	34	5	6	2
CR6CM-12	600	6.0	88	90	34	5	6	2
CR8AM-8	400	8.0	88	120	60	5	6	2
CR8AM-12	600	8.0	88	120	60	5	6	2

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V_{RGM} Volts	I_{DRM} / I_{RRM} mA	V_{TM} Volts	@ I_{TM} Amperes	I_H mA	I_{GT} mA	V_{GT} Volts	V_{GD} Volts	Operating Temperature (°C)	Package Outline
6	0.1	1.6	0.6	3	0.1	0.8	0.2	-40 to 125	TO-92
6	0.1	1.8	4	3	0.1	0.8	0.2	-40 to 110	TO-92
6	0.1	1.8	4	3	0.1	0.8	0.2	-40 to 110	TO-92
6	0.5	1.2	1.2	3	0.1	0.8	0.2	-40 to 125	TO-92
6	0.5	1.2	1.2	3	0.1	0.8	0.2	-40 to 125	TO-92
6	0.5	1.5	2.5	3	0.1	0.8	0.3	-40 to 125	SOT-89
6	0.5	1.5	2.5	3	0.1	0.8	0.3	-40 to 125	SOT-89
6	0.1	1.8	4	—	0.1	0.8	0.15	-40 to 125	TO-202
6	0.1	1.8	4	—	0.1	0.8	0.15	-40 to 125	TO-202
6	1	1.6	10	—	0.2	0.8	0.1	-40 to 110	TO-202
6	1	1.6	10	—	0.2	0.8	0.1	-40 to 110	TO-202
6	2	1.8	2.5	3.5	0.2	0.8	0.1	-40 to 125	MP-3
6	2	1.8	2.5	3.5	0.2	0.8	0.1	-40 to 125	MP-3
10	2	1.7	20	15	10	1	0.2	-40 to 125	TO-220
10	2	1.7	20	15	10	1	0.2	-40 to 125	TO-220
10	2	1.4	25	15	15	1	0.2	-40 to 125	TO-220
10	2	1.4	25	15	15	1	0.2	-40 to 125	TO-220

13.2 Non-Isolated Triacs

Type	V_{DRM} / V_{RRM} Volts	$I_{T(RMS)}$ @	T_C °C	I_{TSM} Amperes	I^2t A^2 sec	P_{GM} Watts	I_{GM} Amperes	V_{GM} Volts
Non-isolated								
BCR1AM-8	400	1	56	10	0.4	1	1	6
BCR1AM-12	600	1	56	10	0.4	1	1	6
BCR3AM-8	400	3	86	30	3.7	3	0.5	6
BCR3AM-12	600	3	86	30	3.7	3	0.5	6
BCR5AM-8	400	5	103	50	10.4	3	2	10
BCR5AM-8L	400	5	103	50	10.4	3	2	10
BCR5AM-12	600	5	103	50	10.4	3	2	10
BCR5AM-12L	600	5	103	50	10.4	3	2	10
BCR5AS-8L	400	5	103	50	10.4	3	2	10
BCR5AS-12L	600	5	103	50	10.4	3	2	10
BCR6AM-8	400	6	103	60	15	5	2	10
BCR6AM-8L	400	6	103	60	15	5	2	10
BCR6AM-12	600	6	103	60	15	5	2	10
BCR6AM-12L	600	6	103	60	15	5	2	10
BCR8CM-8L	400	8	105	80	26	5	2	10
BCR8CM-12	600	8	105	80	26	5	2	10
BCR8CM-12L	600	8	105	80	26	5	2	10
BCR10CM-8	400	10	103	100	41.6	5	2	10
BCR10CM-8L	400	10	103	100	41.6	5	2	10
BCR10CM-12	600	10	103	100	41.6	5	2	10
BCR10CM-12L	600	10	103	100	41.6	5	2	10
BCR12CM-8	400	12	98	120	60	5	2	10
BCR12CM-8L	400	12	98	120	60	5	2	10
BCR12CM-12	600	12	98	120	60	5	2	10
BCR12CM-12L	600	12	98	120	60	5	2	10
BCR16CM-8	400	16	100	170	121	5	2	10
BCR16CM-8L	400	16	100	170	121	5	2	10
BCR16CM-12	600	16	100	170	121	5	2	10
BCR16CM-12L	600	16	100	170	121	5	2	10
BCR20AM-8	400	20	105	200	167	5	2	10
BCR20AM-8L	400	20	105	200	167	5	2	10
BCR20AM-12	600	20	105	200	167	5	2	10
BCR20AM12L	600	20	105	200	167	5	2	10
BCR30AM-8	400	30	75	300	378	5	2	10
BCR30AM-8L	400	30	75	300	378	5	2	10
BCR30AM-12	600	30	75	300	378	5	2	10
BCR30AM12L	600	30	75	300	378	5	2	10

I_{DRM} mA	V_{TM} Volts	@ I_{TM} Amperes	I_{GT} mA	V_{GT} Volts	V_{GD} Volts	$(dv/dt)_c$ Volts/µs	Operating Temperature (°C)	Package Outline
1	1.6	1.5	5	2	0.1	2	-40 to 125	TO-92
1	1.6	1.5	5	2	0.1	2	-40 to 125	TO-92
2	1.5	4.5	30	1.5	0.2	5	-40 to 125	TO-202
2	1.5	4.5	30	1.5	0.2	5	-40 to 125	TO-202
2	1.8	7	20	1.5	0.2	—	-40 to 125	TO-220
2	1.8	7	20	1.5	0.2	5	-40 to 125	TO-220
2	1.8	7	20	1.5	0.2	—	-40 to 125	TO-220
2	1.8	7	20	1.5	0.2	5	-40 to 125	TO-220
2	1.8	7	30	1.5	0.2	5	-40 to 125	MP-3
2	1.8	7	30	1.5	0.2	5	-40 to 125	MP-3
2	1.7	9	30	1.5	0.2	—	-40 to 125	TO-220
2	1.7	9	30	1.5	0.2	10	-40 to 125	TO-220
2	1.7	9	30	1.5	0.2	—	-40 to 125	TO-220
2	1.7	9	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	12	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	12	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	12	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	15	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	15	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	15	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	15	30	1.5	0.2	10	-40 to 125	TO-220
2	1.6	20	30	1.5	0.2	—	-40 to 125	TO-220
2	1.6	20	30	1.5	0.2	10	-40 to 125	TO-220
2	1.6	20	30	1.5	0.2	—	-40 to 125	TO-220
2	1.6	20	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	25	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	25	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	25	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	25	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	30	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	30	30	1.5	0.2	10	-40 to 125	TO-220
2	1.5	30	30	1.5	0.2	—	-40 to 125	TO-220
2	1.5	30	30	1.5	0.2	10	-40 to 125	TO-220
3	1.6	45	50	2.5	0.02	—	-40 to 125	TO-3P
3	1.6	45	50	2.5	0.02	20	-40 to 125	TO-3P
3	1.6	45	50	2.5	0.02	—	-40 to 125	TO-3P
3	1.6	45	50	2.5	0.02	20	-40 to 125	TO-3P

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13.3 Isolated Triacs

Type	V_{DRM} / V_{RRM} Volts	$I_{T(RMS)}$ @	T_C °C	I_{TSM} Amperes	I^2t A^2 sec	P_{GM} Watts	I_{GM} Amperes	V_{GM} Volts
Isolated								
BCR5PM-8	400	5	95	50	10.4	3	2	10
BCR5PM-8L	400	5	95	50	10.4	3	2	10
BCR5PM-12	600	5	95	50	10.4	3	2	10
BCR5PM-12L	600	5	95	50	10.4	3	2	10
BCR8PM-8	400	8	88	80	26	5	2	10
BCR8PM-8L	400	8	88	80	26	5	2	10
BCR8PM-12	600	8	88	80	26	5	2	10
BCR8PM-12L	600	8	88	80	26	5	2	10
BCR10PM-8	400	10	85	100	41.6	5	2	10
BCR10PM-8L	400	10	85	100	41.6	5	2	10
BCR10PM-12	600	10	85	100	41.6	5	2	10
BCR10PM-12L	600	10	85	100	41.6	5	2	10
BCR12PM-8	400	12	74	120	60	5	2	10
BCR12PM-8L	400	12	74	120	60	5	2	10
BCR12PM-12	600	12	74	120	60	5	2	10
BCR12PM-12L	600	12	74	120	60	5	2	10
BCR16PM-8L	400	16	71	160	106.5	5	2	10
BCR16PM-12	600	16	71	160	106.5	5	2	10
BCR16PM-12L	600	16	71	160	106.5	5	2	10
BCR16HM-8	400	16	82	170	121	5	2	10
BCR16HM-8L	400	16	82	170	121	5	2	10
BCR16HM-12	600	16	82	170	121	5	2	10
BCR16HM-12L	600	16	82	170	121	5	2	10
BCR30GM-12	600	30	60	300	375	5	2	10
BCR30GM-12L	600	30	60	300	375	5	2	10

13.4 Thyristors for Strobe Flasher Applications

Type	V_{DRM} Volts	$I_{(avg)}$ @	T_C °C	I_{TSM} Amperes	I^2t A^2 sec	I_{TRM} Amperes	P_{GM} Watts	V_{FGM} Volts
CR3AMZ-8	400	0.4	—	—	—	200	0.5	6
CR3EM-8	400	0.6	65	70	20	—	2	6
CR3JM-8	400	0.8	37	—	—	240	3	6

V_{ISO} Volts	I_{DRM} mA	V_{TM} Volts @	I_{TM} Amperes	I_{GT} mA	V_{GT} Volts	V_{GD} Volts	$(dv/dt)_C$ Volts/µs	Operating Temperature (°C)	Package Outline
1500	2	1.8	7	20	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.8	7	20	1.5	0.2	5	-40 to 125	TO-220F
1500	2	1.8	7	20	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.8	7	20	1.5	0.2	5	-40 to 125	TO-220F
1500	2	1.6	12	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.6	12	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.6	12	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.6	12	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.5	15	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.5	15	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.5	15	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.5	15	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.6	20	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.6	20	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.6	20	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.6	20	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.6	25	30	1.5	0.2	10	-40 to 125	TO-220F
1500	2	1.6	25	30	1.5	0.2	—	-40 to 125	TO-220F
1500	2	1.6	25	30	1.5	0.2	10	-40 to 125	TO-220F
2200	3	1.6	25	30	1.5	0.2	—	-40 to 125	Flatbase
2200	3	1.6	25	30	1.5	0.2	10	-40 to 125	Flatbase
2200	3	1.6	25	30	1.5	0.2	—	-40 to 125	Flatbase
2200	3	1.6	25	30	1.5	0.2	10	-40 to 125	Flatbase
2200	3	1.6	45	50	2.5	0.2	—	-40 to 125	Flatbase
2200	3	1.6	45	50	2.5	0.2	20	-40 to 125	Flatbase

I_{FGM} Amperes	V_{RGM} Volts	I_{DRM}/I_{RRM} mA	V_{TM} Volts @	I_{TM} Amperes	I_{GT} mA	V_{GT} Volts	V_{GD} Volts	C_C µF	Operating Temperature	Package Outline
0.5	—	0.1	2.0	3	30	1.5	0.1	2.2	-40 to 125	TO-202B1
1	6	0.1	1.6	10	30	1.5	0.2	—	-40 to 125	TO-202B1
1	6	0.1	1.8	3	50	2	0.1	2.8	-40 to 125	TO-220

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13.5 Triac Trigger

Type	I_T mA	P_T mW	I_G mA	$V_{S(max)}$ Volts	I_S µA	$(V_{S1}-V_{S2})$ Volts	$(I_{S1}-I_{S2})$ µA	I_H mA	I_D µA	V_T Volts	I_{GT} µA	V_{GD} Volts	Operating Temperature (°C)	Package Outline
BS08A	175	250	5	9	200	0.5	100	1.5	1	1.4	200	0.2	-55 to 125	TO-92