PHOTOTRIAC Design Solutions

Basic TRIAC Characteristics

A TRIAC is a subset of a family of semiconductors referred to as thyristors. These are all four-layer bipolar devices with various triggering configurations. Regardless of the specific flavor of thyristor used, they all are built on the basic thyristor structure illustrated below in Figure 1.

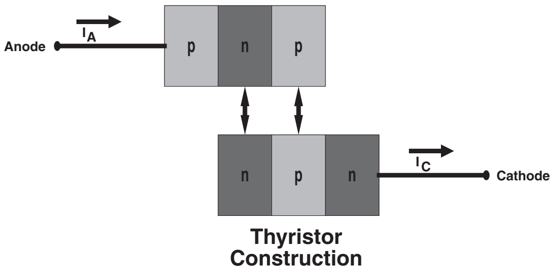


Figure 1.

Figure 2 is the VI curve most commonly associated with thyristor components. Note that the curve of a thyristor is actually quite similar to the characteristic curve of a standard diode, with the notable exception that the current increases slowly with voltage until a maximum point—commonly referred to as the “snapback” voltage—is reached. Having reached this point, the voltage across the thyristor drops sharply and the current begins to increase in a highly exponential function, as would be expected in a standard diode. Figure 2 illustrates this behavior using a “typical” VI curve for a s classic silicon controlled rectifier (SCR).

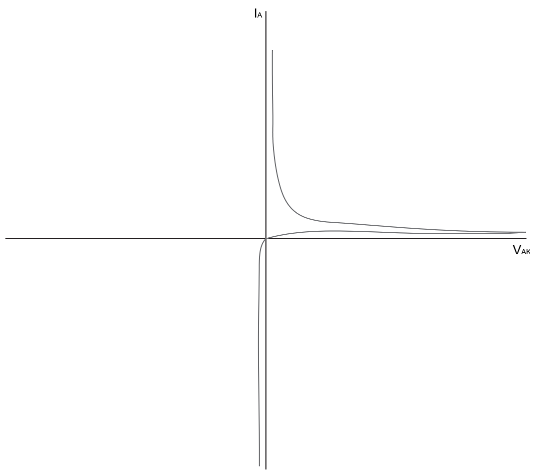


Figure 2. Typical SCR Curve.

The functionality of a thyristor is most easily understood if one thinks of the device as two bipolar transistors where the collector of one transistor drives the base of the other, as illustrated in Figure 3. This is a simplified view of TRIAC performance, however, and ignores some second-order effects that are key to successful TRIAC designs.

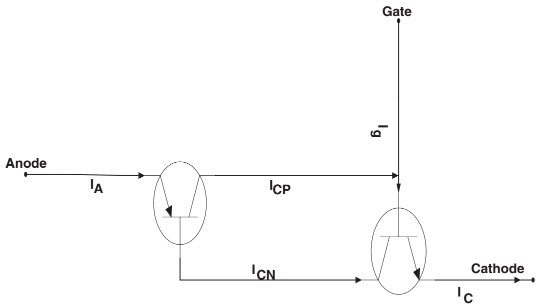


Figure 3. SCR Functional Schematic

A thyristor can be triggered by applying a voltage across its output terminals of sufficient amplitude to exceed its breakdown or snapback voltage. This type of triggering method is quite common and is used in thyristor devices referred to as DIACs; however, conduction can also be achieved in a more controllable fashion by connecting a triggering gate that allows for the injection of minority carriers into the gate region. In this way, a TRIAC can be triggered in much the same way as a bipolar transistor. This type of thyristor configuration is known as an SCR (Silicon Controlled Rectifier). Its schematic symbol and internal construction are illustrated in figure 4.

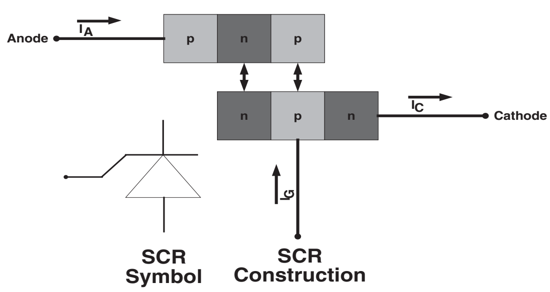


Figure 4.

The final configuration that needs to be considered for this document's brief overview of thyristor basics is the TRIAC. If one understands the characteristics and functionality of an SCR, a TRIAC can be thought of as two back-to-back SCRs with a common gate. This structure allows current to flow in both polarities and thereby constitutes a highly effective AC switch.

Figure 5 illustrates the schematic symbol and the V-I characteristic curves of a typical TRIAC. Note that the snapback voltage decreases as the gate current increases from an initial 0 point value.

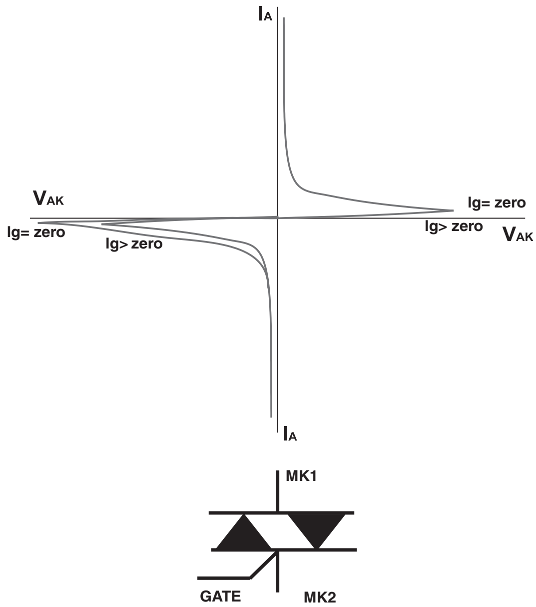


Figure 5. TRIAC

Finally, an PHOTOTRIAC can be implemented in two different ways, with the main differentiation being on the detector portion of the device. In one case the TRIAC itself can be designed such that it has a photosensitive gate region, in a way analogous to the base region of a phototransistor. This is the preferred detector configuration for inexpensive devices. Higher-performing devices usually employ a detector configuration similar to the one illustrated in Figure 6. This detector configuration does not employ a simple TRIAC with a photosensitive region; Its more sophisticated and complex approach consists of a power stage made up of a TRIAC, or two SCRs driven by a driver stage, which is in turn triggered by a photosensitive device such as a photodiode or phototransistor. This approach has the advantage of giving the designer the flexibility of adding circuitry to the driver stage to increase parametric performance. Moreover, the physical separation of the power stage from the driver and trigger sections of the device has an inherent benefit in terms of noise immunity. The physical isolation of the separate stages of the device decreases coupling due to parasitic impedances between the output circuit and the drive and trigger circuitry.

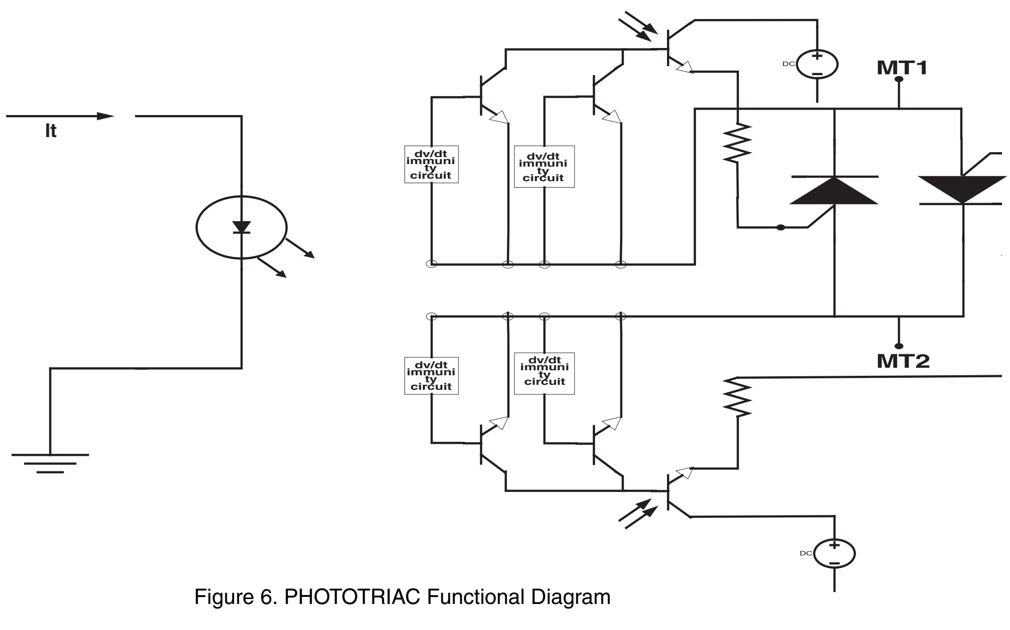
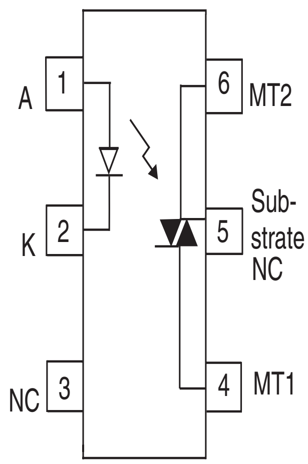


Figure 6. PHOTOTRIAC Functional Diagram

Vishay PHOTOTRIAC Selection Table



PART#	Trigger Current	Zero-voltage switching	Isolation Voltage	Vdrm	dv/dt	Total Power Dessipation @25C
IL410	2.0mA	yes	5300Vms	600V	10KVus	500mW
IL4108	2.0mA	yes		800V		
IL4116	1.3mA	yes		600V		
IL4117	1.3mA	yes		700V		
IL4118	1.3mA	yes		800V		
IL420	2.0mA	no		600V		
IL4208	2.0mA	no		800V		
IL4216	1.3mA	no		600V		
IL4217	1.3mA	no		700V		
IL4218	1.3mA	no		800V		
IL440-1	15.0mA	no		600V	50Vus	300mW
IL440-2	10.0mA	no				
IL440-3	5.0mA	no				
IL440-4	15.0mA	no		400V		
IL440-5	10.0mA	no				
IL440-6	5.0mA	no				
K3010P	5.0mA to 15mA	no		250V	10Vus	350mW
K3020P	5.0mA to 30mA	no		400V		

This is as far as this document's scope justifies discussing the basic features and characteristics of TRIACs and PHOTOTRIACs. If the reader is interested in delving more deeply into PHOTOTRIAC characteristics, please refer to the Vishay apnote on PHOTOTRIAC characteristics.

http://www.vishay.com/docs/80053/80053.pdf

TRIAC dv/dt Concerns

One set of parameters which deserves special attention when discussing the design of solutions using thyristors, and TRIACs in particular, is output dv/dt. This parameter falls into two different categories: static output dv/dt and commutating dv/dt. Each of these output load dv/dt parameters is governed by a different cause and effect.

Static dv/dt is the behavior by which a thyristor can be triggered as a result of a high slew rate transient on the output load, even without any triggering signal on the input. The mechanism by which this type of false triggering takes place is a coupling of the high-frequency transient output noise back to the gate by means of parasitic coupling capacitances, as illustrated in Figure 7. The measurement technique for measurement of static dv/dt is illustrated in figure 8.

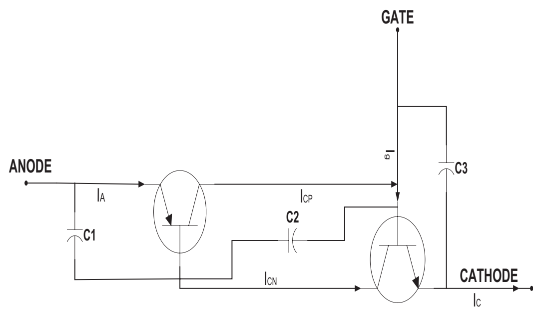


Figure 7. SCR Parasitic Capacitance

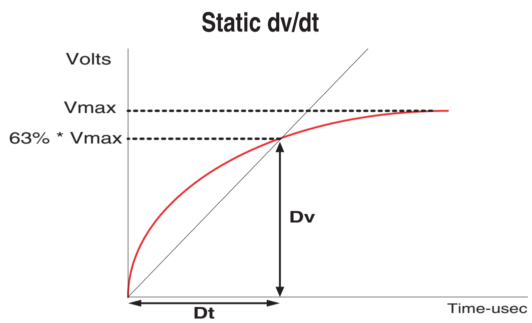


Figure 8. dv/dt Test Techniques

Manufacturers normally give typical static dv/dt numbers in datasheets and specify them in V/µsec. They can range from tens of volts/µsec up to 10 kV/µsec, as in the case of the IL410 or IL420. The IL410 (zero-crossing) and IL420 (non-zero crossing) TRIACs offer the highest dv/dt performance in the industry at 10 kV/µsec.

Commutating dv/dt is not a design parameter that comes into play in inadvertent turn-on. Instead it prevents the TRIAC from turning off.

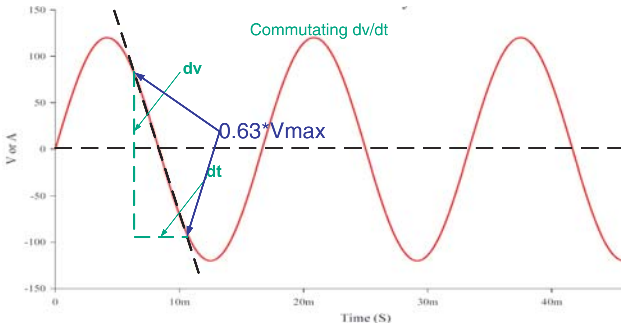
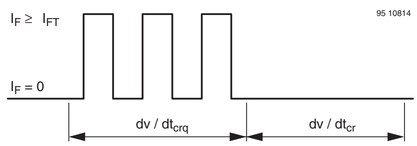


Figure 9-b. dv/dt Test Techniques



dv/dt_{cr} Highest value of the "rate of rise of off-state voltage" which does not cause any switching from the off-state to the on-state

dv/dt_{crq} Highest value of the "rate of rise of communicating voltage" which does not switch on the device again, after the voltage has decreased to zero and the trigger current is switched from I_{FT} to zero

Figure 9-a. Static and commutating dv/dt

Figure 9a shows one way to look at the difference between commutating and static dv/dt. The left-hand portion of the waveform in Figure 8 labeled dv/dtcrq refers to the static dv/dt or the maximum pulse rise time required to turn a TRIAC on from an off-state. The right-hand part of Figure 8 illustrates commutating dv/dt, labeled dv/dtcr. This describes how long the TRIAC has to be off to ensure that the device will stay off.

Figure 9b describes a very practical approach to measuring the commutating dv/dt parameter. In other words, what is the maximum sinusoidal frequency that a TRIAC can see before it no longer can be turned off once it is triggered. In practice this is probably the easiest way to measure commutating dv/dt. The only thing required is an AC source of sufficient voltage and frequency range.

In the case of inductive loads, dv/dt is of primary importance, because the effective commutating dv/dt is very tightly related to the power factor of the load. This is illustrated in Figure 21, and understanding it simply requires the reader to go back to the "ELI the ICE man" rule of basic electronics. If the current lags the voltage, such as is the case in an inductive load, by the time the current crosses zero and the TRIAC turns off, there is already a significant voltage across the device, and it is immediately time to turn on again. Therefore the device never has enough time to clear out the charge in the gate region and simply stays on cycle after cycle. This phenomenon manifests itself in the load device turning on and failing to turn off for one or more cycles after the first zero crossing after the gate signal is removed.

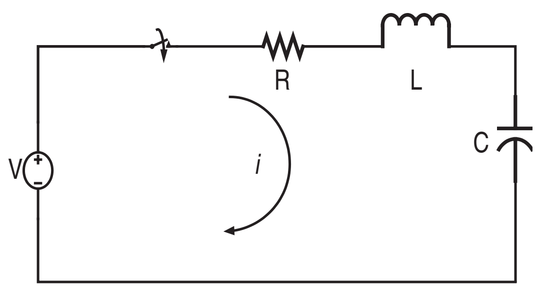
Solutions to dV/dT Triggering

Whether the effects are due to static dv/dt triggering or commutating dv/dt, as described above, and though the results are different, the possible solutions are similar. The options are to either reduce the effective dv/dt experienced across the TRIAC or to utilize a TRIAC that is capable of withstanding high dv/dt transitions. As we will see, the choice between these approaches depends largely on economics and available board real estate.

The first approach is to reduce the dv/dt seen by the TRIAC. This involves implementing an RC snubber circuit across the load, such as the circuit illustrated in Figure 10.

The fundamental governing equation involved is as follows:

$$R_i + L\frac{d_i}{d_t} + \frac{1}{C}\int i d_t + V_0 = 0$$



This equation is derived from the governing differential equation describing an RLC series circuit, as illustrated above.

From this basic equation one can derive the equations required to calculate the desired snubber values.

$$C = \frac{1}{\omega_0^2 L}$$

$$R = \frac{\beta}{\omega_0 C}$$

$$\frac{dv}{dt} = \frac{VR}{L}$$

ß is the damping factor for the RLC resonant waveform, and 0.7 is a good rule of thumb number to use for this value; however, lower values can be used if more damping is required for the resonant peak. dv/dt refers to the maximum permissible load slew rate for a particular device.

The process of designing the snubber may be straightforward on the conceptual level, but in practice it turns out to be a somewhat empirical and iterative process, since design objectives always need to be reconciled with the capabilities of real off-the-shelf components.

The decrease in dv/dt through the use of a snubbing technique is illustrated in the example in Figure 10. The first circuit illustrates an inductive load lacking a snubber and possessing extreme dv/dt spikes, which are labeled “max dv/dt.” The second circuit demonstrates the dampening effect of introducing a snubber circuit at the output of the TRIAC device. The difference in the amplitude of the max dv/dt spikes is accounted for by the snubbing effect of the RC network, illustrated in the second schematic of Figure 10a.

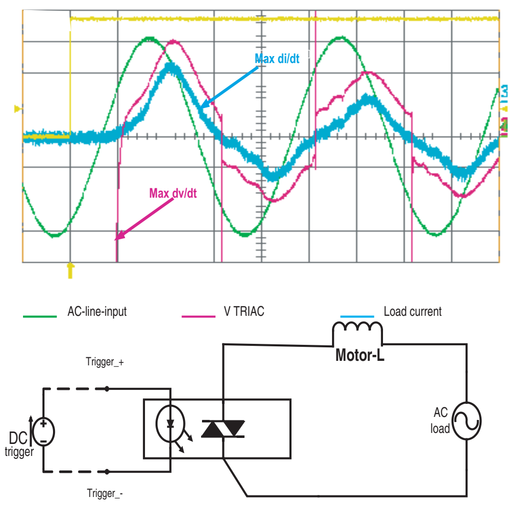


Figure 10-a. Inductive Load without snubber

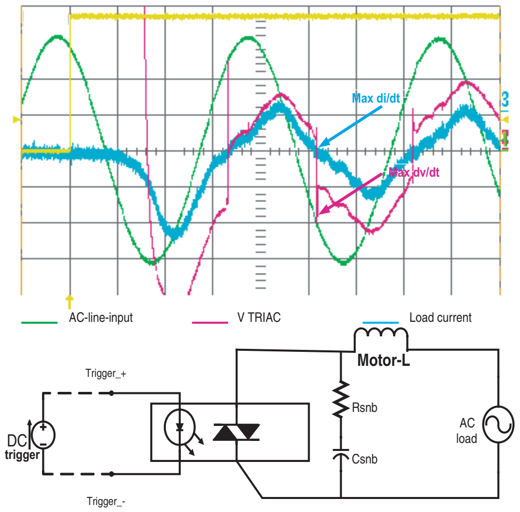


Figure 10-b. Inductive Load with snubber

Instead of resorting to a snubber and a low dv/dt TRIAC, another approach that offers the designer a compact, high-performance solution is a TRIAC driver with extremely large dv/dt immunity, such as a Vishay IL410, or IL420. This will allow the designer to create a TRIAC application while avoiding entirely the need for lossy,mn large, and possibly expensive snubber circuits. Vishay's high dv/dt PHOTOTRIACs come in both non-zero and zero-crossing configurations and have dv/dt ratings as high as 10000 V/µsec. These high dv/dt ratings eliminate the need for snubber circuits in most cases and greatly diminish the size of the required components that are needed except in the extreme cases involving poor power factor control. PHOTOTRIAC drivers enable a compact and elegant solution with improved performance, smaller PCB space, and often lower price.

PHOTOTRIAC Static Switches

Thyristors have been around longer than any other type of power semiconductor, and for many years they ruled the domain of solid-state power switching exclusively. Today, with the advances in power MOSFET technology, TRIACs are sometimes replaced by MOSFETs. Yet when it comes to low-cost AC switching applications, TRIACs still have a very important role.

Why use a TRIAC instead of a simple mechanical switch?

1.Solid state reliability
2.Elimination of contact bounce
3.Elimination of contact arcing
4.Small size to current handling capacity

Figure 11-a illustrates what is arguably the simplest TRIAC switch imaginable. Yet it provides all of the advantages listed above.

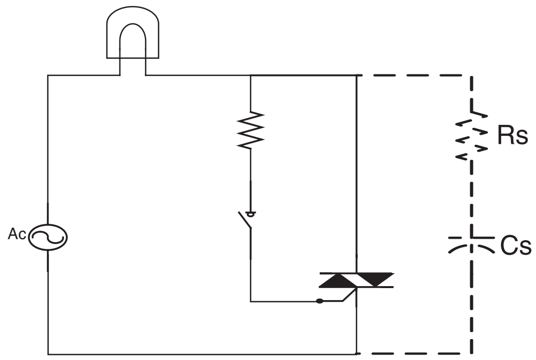


Figure 11-a. Simple static switch application

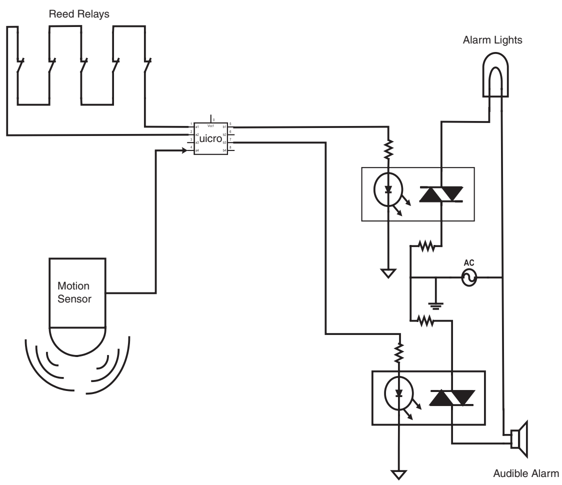


Figure 11-b Alarm switch application

Replacing the TRIAC with the an PHOTOTRIAC would provide the further advantage of safety isolation from the high-voltage output to the triggering switch. This is of vital importance if the low-voltage triggering circuit is accessible to the operator or devices are susceptible to noise. This type of application refinement is illustrated in Figure 11-b.

Another common use of a static TRIAC switch is as “crowbar” protection on the output of power supplies. This TRIAC solution is illustrated in Figure 12. Here the TRIAC is used as a DC latch rather than in its conventional role as an AC switch. It works like any other type of overvoltage sensing scheme. A comparator senses the output voltage and triggers an alarm based on some predetermined trip point. A crowbar circuit has the added feature of tying a power TRIAC across the output of the supply and having this TRIAC triggered by the output voltage comparator circuit. Consequently, when the TRIAC is triggered into its conduction mode by an overvoltage condition, it latches into a conduction mode, due to the fact that the TRIAC will not turn off until a zero current crossing turns off the TRIAC. Thus, the crowbar overvoltage protection scheme protects any output load from any possible overvoltage condition by forcing the output low by “shorting” the output.

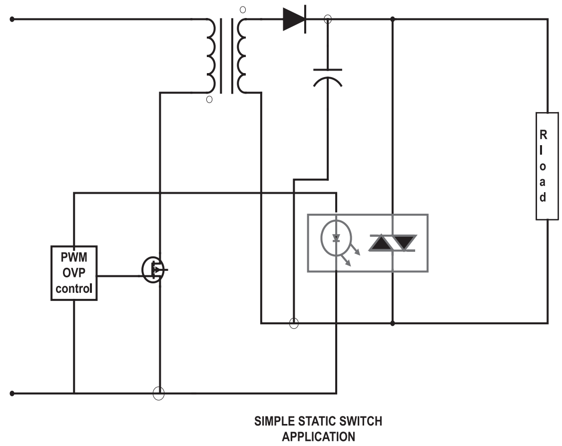


Figure 12. Simple static switch application

An additional power supply application is the use of a TRIAC as an AC switch to bypass the inrush limiting element in a power supply. In most cases this function is accomplished by the use of a mechanical relay; however, an PHOTOTRIAC or PHOTOTRIAC/ power-TRIAC combination can often perform this function with the added advantage of solid state reliability, as illustrated in Figure 13

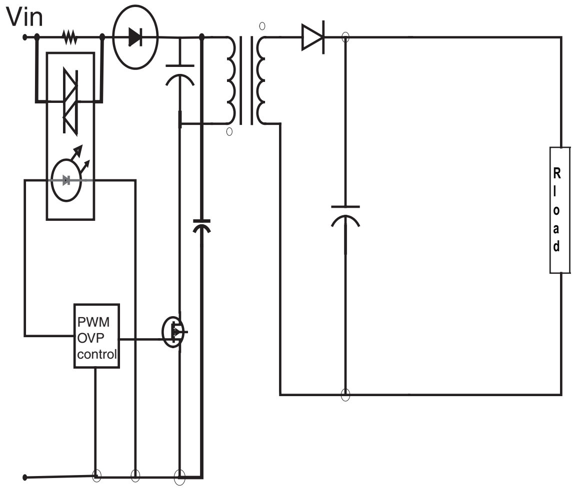


Figure 13. Inrush limit bypass application

Solid State Relays

Solid State Relays (SSRs) were once the exclusive realm of thyristor devices, but since the advent of power MOSFETs this is no longer the case. Today thyristors still comprise a large share of the devices that are commonly referred to as SSRs. Many high power industrial SSRs, such as the representative samples shown in Figure 14, are actually optically isolated TRIACs. These can range from devices that have load current ratings of a few hundred milliamps to hundreds of amps. For strictly AC environments, thyristor devices still enjoy a wide acceptability in many commercial and industrial applications. They offer operation at high power ranges with acceptably low on-state voltage drops.

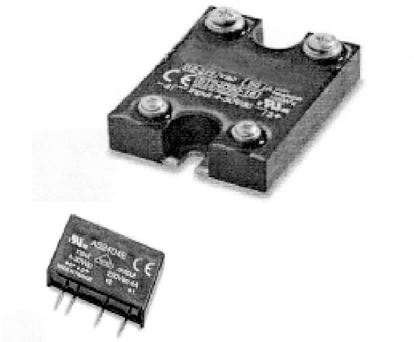


Figure 14. Commercial high-power SSRs

Vishay offers PHOTOTRIAC modules, and an extremely broad range of PHOTOTRIAC drivers. These provide designers with flexible, and economic alternative to more expensive “hockey puck” solutions. Figure 15a and b illustrates an alternative to using a commercial solution in a high-power AC switching application. Many commercially available high power SSRs employ lower power PHOTOTRIAC drivers in their designs. If cost is a primary concern, this alternative can offer high power performance for the price of an off-the-shelf power TRIAC and an PHOTOTRIAC IC driver.

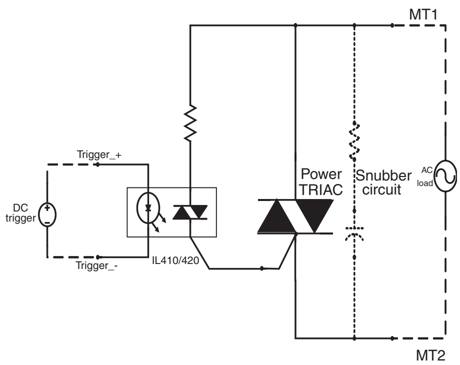


Figure 15-a. TRIAC driver basic SSR

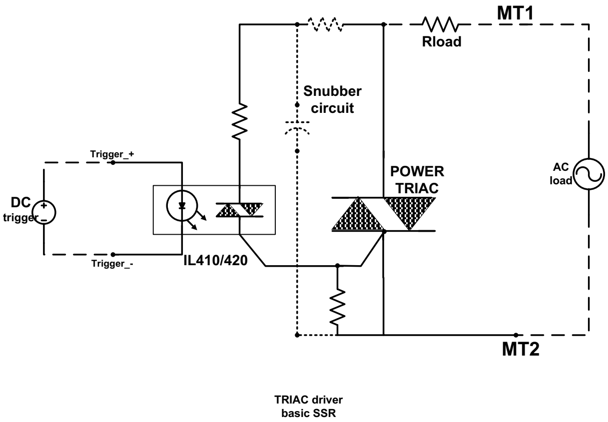


Figure 15-b. TRIAC driver basic SSR

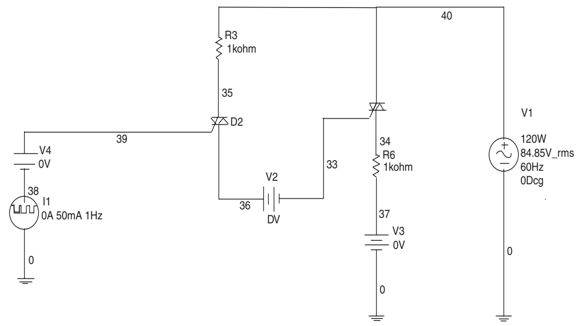


Figure 15-c. TRIAC driver SPICE MODEL

In applications where an PHOTOTRIAC works as a driver, commutating dv/dt is less of an issue when a narrow pulse is used to trigger the drive TRIAC than when an PHOTOTRIAC is used to drive a load directly. This is because in the case of a driver circuit the PHOTOTRIAC immediately turns off when the main TRIAC turns on; therefore the driver PHOTOTRIAC has an entire half-cycle in which to discharge its gate charge. This concept is illustrated in the SPICE simulation on Figure 16.

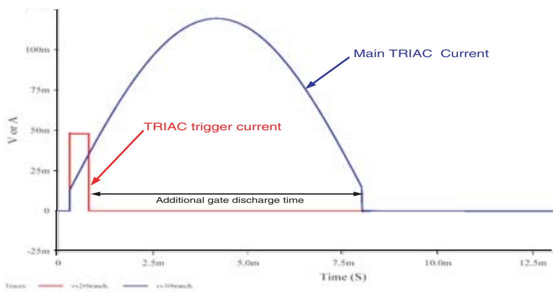


Figure 16. TRIAC driver Waveforms

Zero-voltage Switching

Figure 17 shows the result of two types of AC relay implementations. The first is a zero-voltage crossing (ZVC) implementation and the second is a non-zero-voltage crossing (NZVC) implementation. There are several advantages to the zero-voltage crossing approach to TRIAC control, but the suitable applications for this method of TRIAC triggering are limited to ones where the control time constant is significantly large, such as heater controls and solenoid drivers. Devices that require fine control involving shorter time constants are not suitable for ZVC applications. Examples of such applications are light dimmers, where coarse control would produce annoying flickering, and motor control. Phase control is more suitable for such applications, where, as we shall discuss in a subsequent paragraph, an NZVC would be appropriate.

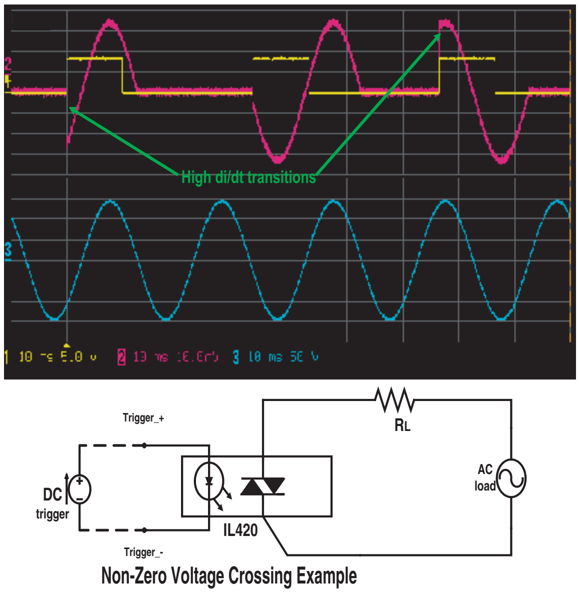


Figure 17-b. NZC TRIAC Waveforms

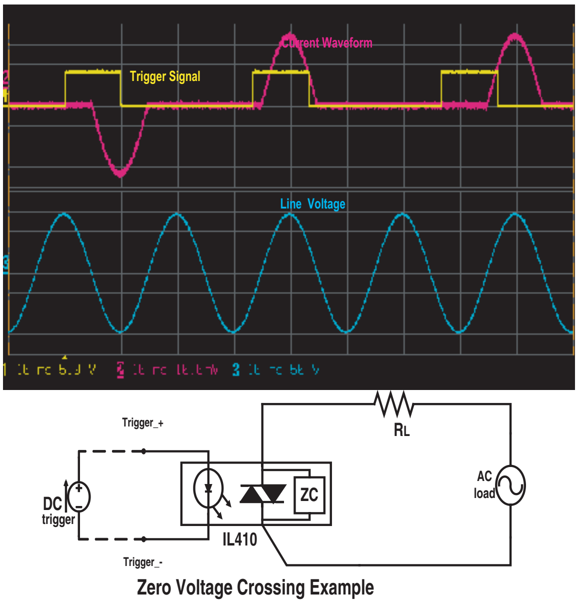


Figure 17-a. ZC TRIAC Waveforms

As can be seen from the second plot on Figure 17, a non-zero-crossing implementation produces very sharp di/dt transitions across the TRIAC, with resulting detrimental outcomes. One of these results is that the sharp di/dt transitions generate a harmonic rich power spectrum.

Today, controlling for radio frequency interference (RFI) and electronic magnetic compliance (EMC) is of increasing concern in most product designs. The high-frequency harmonics generated by the sharp di/dt transitions make themselves known by radiating directly out into space as RFI and by propagating down the power lines, which in turn also radiate the lower frequency harmonics that would not otherwise be radiated directly. The first case of direct RFI is addressed as radiated emissions RFI in FCC emissions compliance criteria as well as in EN55022 A and B. The RFI generated from the power lines is addressed in the “conducted emissions” portion of these standards.

The reduction of RFI is often the critical reason for going to a ZVC. Anyone that has ever dimmed their lights and seen “snow” on a television screen has witnessed the effects of RFI. The main idea behind this effect is derived from Fourier Signal analysis, which states that all signals can be generated by a sum of a series of one or more sinusoidal functions. Conversely, any signal that is not a sinusoidal function is made up of a fundamental frequency and an infinite series of harmonics of decreasing amplitude. The higher the frequency of the harmonics generated, the easier it is to effectively propagate it into free space with an antenna of small dimensions. Without going any further into RF theory, suffice it to say that if you don’t want to generate noise, make your waveforms as close to a sinusoidal waveforms as possible. Figure 18 graphically illustrates this point.

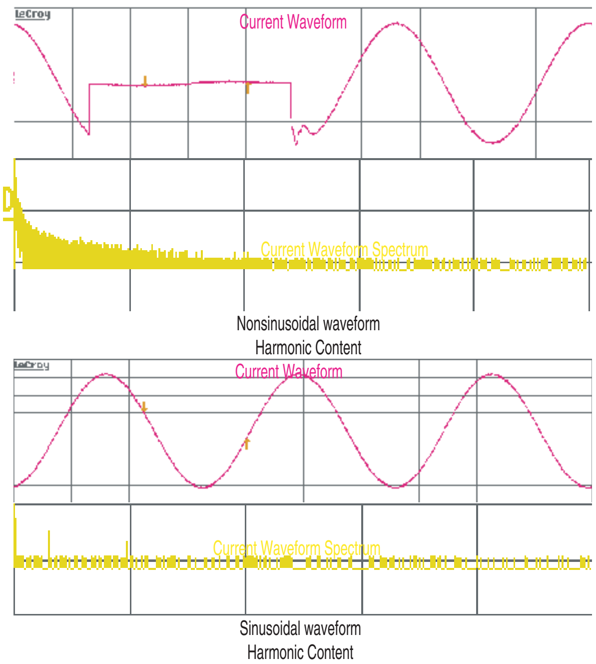


Figure 18. Harmonic content of non-sinusoidal current wave-forms

Another advantage of a zero-voltage triggering PHOTOTRIAC is the fact that since the trigger always occurs at the zero crossing point, it allows the maximum amount of time for current to build up across an inductive load. This is illustrated by the fundamental equation:

$I=Ldv/dt$

and the waveforms in Figure 19.

In the first case of Figure 19 a motor contactor was first triggered with a non-zero crossing TRIAC, with the result that there was not enough time for current to build up to a sufficient magnitude to activate the contactor armature. While in the second case, current was given the full half cycle, thus resulting in a larger peak current build up, and thus contactor closure. The longer the current is allowed to build up in a motor, or a solenoid’s windings, the higher will be the peak I.

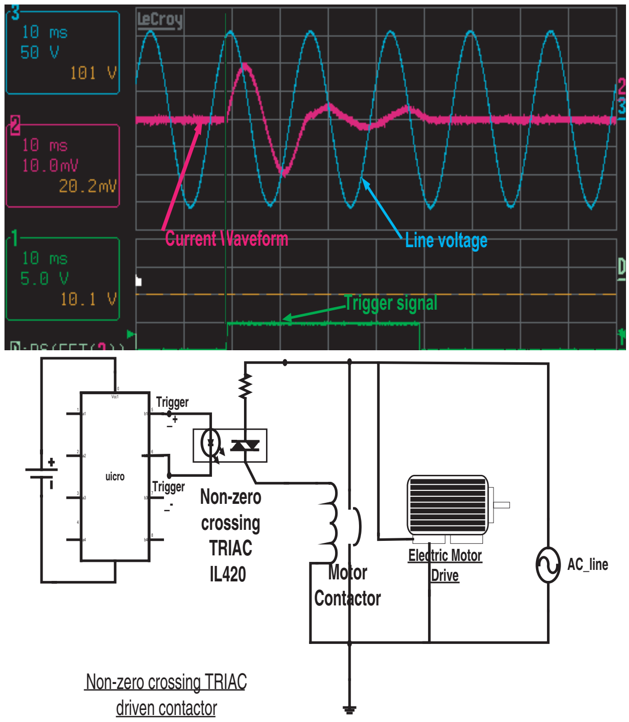


Figure 19-a. non zero crossing TRIAC - lower peak I

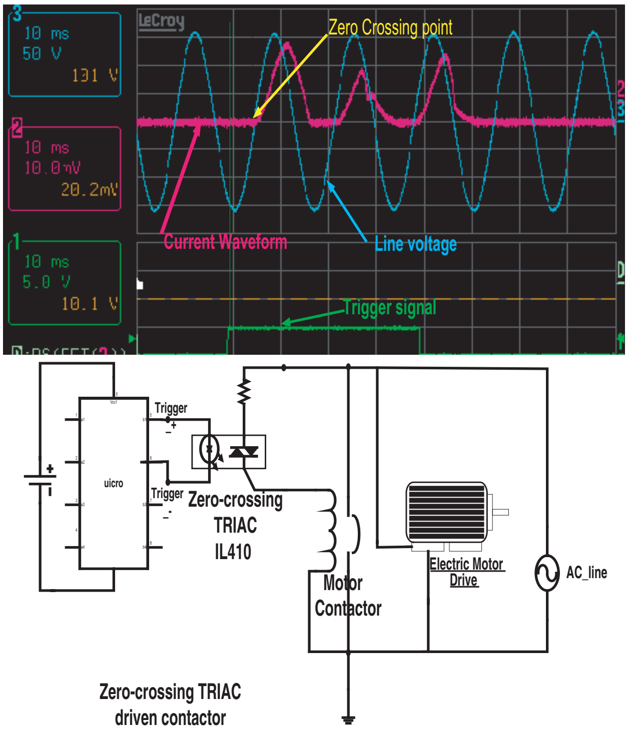


Figure 19-b. Zero-crossing TRIAC - higher peak I

Finally, it is true that a zero-crossing implementation does not necessarily mandate the use of a zero-crossing PHOTOTRIAC. A zero-crossing detector can be implemented using various approaches ranging from IC comparators and op amp circuits to simple discrete devices. Yet, when one takes into account the increase in circuit complexity, added component cost, and the requirement for galvanic isolation between the TRIAC output and input driving LED, and the need to reduce board real estate, a simple IC ZC PHOTOTRIAC looks very attractive as illustrated in the two schematics on the in Figure 20.

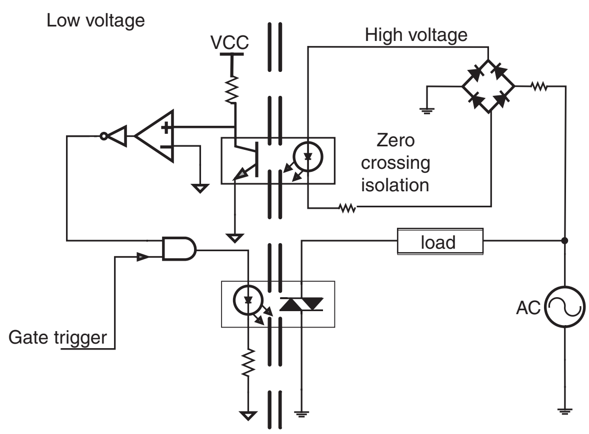


Figure 20-a. Discrete Zero Crossing Solution

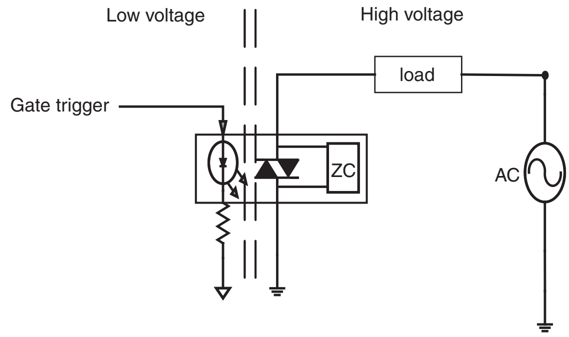


Figure 20-b.ZC TRIAC Solution

Basic inductive load applications

In cases where simple non-inductive resistive loads are controlled, the dv/dt and di/dt of the load is not usually a major concern; however, many loads that utilize TRIAC control are inductive loads where high rates of dv/dt and di/dt require design control schemes that can contend with these high slew rate conditions.

A perfect example of this is a TRIAC application where the load is an electric motor. Electric motors, like any inductive load, have lagging displacement power factors associated with them. This presents a unique problem with TRIAC circuits, in that there is a limitation to how fast the load voltage can change and still allow sufficient time for the TRIAC to turn off. This is not something that is encountered with simple SCRs, where the SCR has an entire half cycle to discharge the gate region; however, in the case of TRIACs the amount of time allowed for gate-region discharge is only a very small period around the zero-current crossing point.

In the case of an inductive load, the turn-off region of a TRIAC is pushed out beyond the zero-voltage crossing point of the TRIAC. Consequently, when the TRIAC finally turns off, the voltage is not at or near zero but something much higher. This leads to the dv/dt across the TRIAC being much higher than would be the case if the current and voltage were in phase. Both the resistive and inductive load cases are shown in Figure 21, which illustrates the detrimental affect of power factor on commutating dv/dt. Notice the difference in the magnitude of the dv/dt spikes between the inductive and resistive load applications. In the case of the inductive load, the voltage is already significantly higher than zero before the current even gets to the zero point. This results in even less than normal time being available for minority charge carriers to be cleared from the gate region.

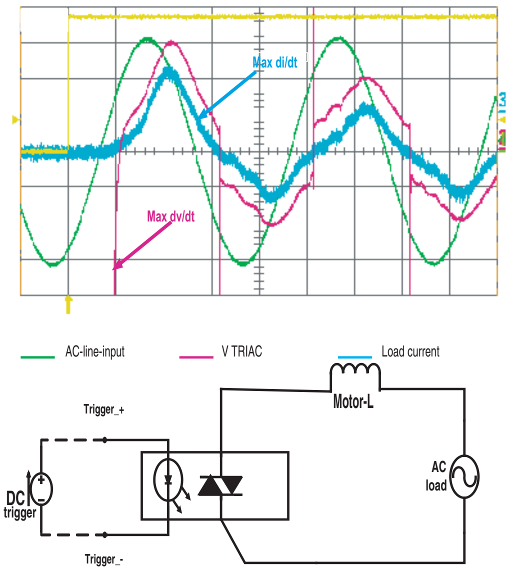


Figure 21-a. Inductive Load without snubber

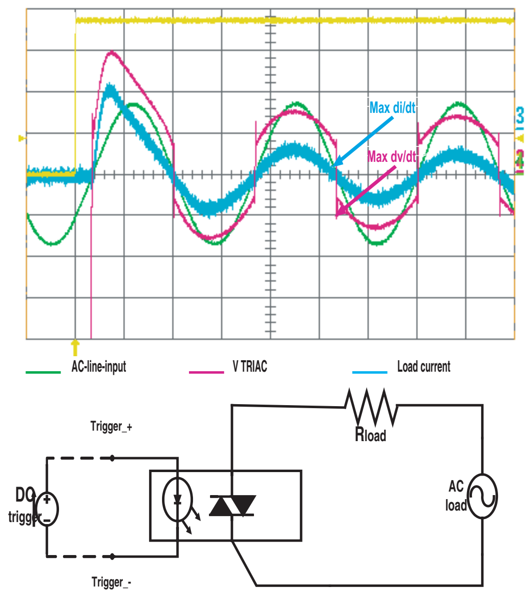


Figure 21-b. Resistive Load.

Phase Modulation Control

While zero-voltage crossing is desirable from an RF noise generation point of view, it is not possible for many AC switching applications. In general, when the switching time constants of the physical control phenomena involved are close to or less than the half cycle of the line voltage, zero-voltage switching is not effective because the control resolution is too "rough." For example if one is trying to control a light-bulb's output intensity, it is desirable to have continuous resolution over the entire range of operation. With zero-voltage switching, the smallest increment that could be achieved in terms of control resolution would be one half of the line frequency period. In the case of heater control, the time constant of the thermal phenomena to be controlled is so large that one half cycle of line voltage resolution would be adequate in most cases.

Applications that require a finer control resolution than is achievable with zero-voltage control can be met by using a technique known as phase modulation control. This technique requires the TRIAC to be fired anywhere along the line voltage conduction angle, with the operating principle being that the conduction angle is varied to increase or reduce the resulting overall RMS voltage at the output, as illustrated in Figure 22a./b.. The disadvantage of this technique is that there is an inherent increase in the level of RF that is generated. When fine resolution is required, however, this is a price that must be paid with greater effort being expended to achieve a low-EMI PCB layout, filtering, and, as a last resort, shielding.

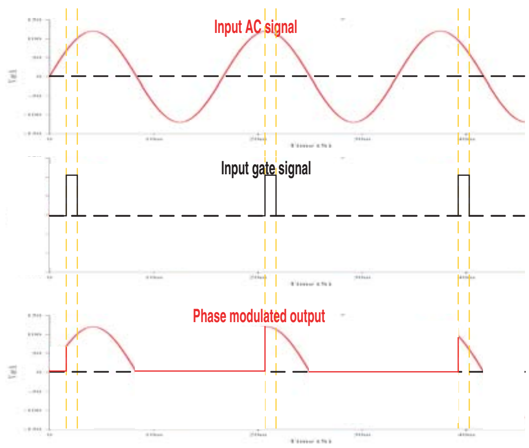


Figure 22-a. Phase modulation control

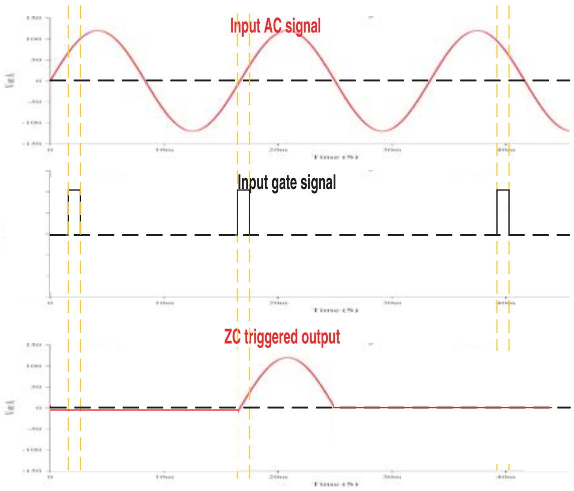


Figure 22-b. Zero voltage crossing modulation control

All applications that require fine resolution control are good candidates for PM control and can utilize the NZC family of PHOTOTRIACs. Good examples of applications requiring this type of solution would be lighting dimmers, universal motor controls where continuous speed control is required, SCR-based voltage regulators, and SCR-based welders. In all these examples, zero-voltage crossing would result in too coarse a solution in terms of output voltage control. An excellent choice for the ZC application would be an IL420, which has the superior performance of an IL410 ZC part but also allows for NZC operation.

Thermal Design Considerations

Though all of Vishay's line of PHOTOTRIACs don't fall into what many designers consider the "power device" category, care must be taken that the rated junction temperature of the devices is not exceeded. This is true for two main reasons.

The first is to increase the overall long-term reliability of the PHOTOTRIACs. The operating temperature of any solid-state device is inversely proportional to its long term viability. Consequently, it behooves any prudent designer to operate a device at the lowest practical operating junction temperature. Secondly, thyristor device performance parameters are very closely tied to the operating temperature of the device; these temperature-dependent parameters include, leakage current, trigger current, and snapback voltage.

The development of the thermal models involves experimental and numerical modeling techniques that are beyond the scope of this discussion. This document will work with a simplified thermal impedance model of our 6-pin TRIACs. If used correctly, this should give results that provide "engineering accuracy" for practical thermal calculations. As a thermal impedance model, the model is intuitive and simple to understand for most electrical engineers. The simplified electrical analogous model for the 6-pin DIP TRIACs is provided in Figure 23. The specific datasheet of each device should be consulted to obtain the thermal impedances and specified junction temperatures for a particular device.

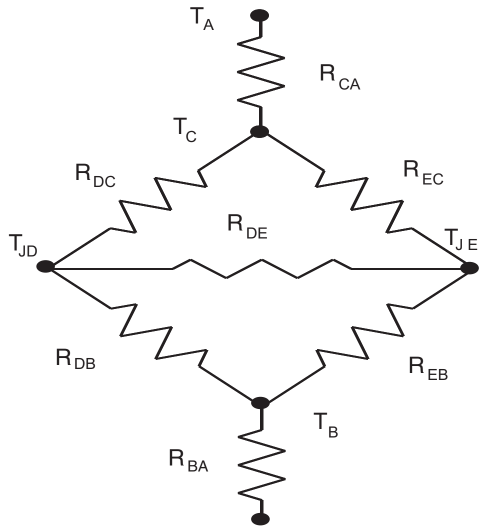


Figure 23. 6-pin DIP TRIAC Simplified Thermal Model

RCA – **Thermal Z case to ambient**
RDC – 103 C/W **Thermal Z detector to case**
REC – 139 C/W **Thermal Z emitter to case**
RDB – 78 C/W **Thermal Z detector to board**
RDE – 49.6 C/W **Thermal Z detector to emitter**
REB – 150 C/W **Thermal Z emitter to board**
TJE – **emitter junction temperature**
TJD – **detector junction temperature**
TC – **case temperature**
TA – **ambient temperature**
TB – **board temperature**

The first step is to perform any further simplifications that might be appropriate. These might include elimination of thermal impedances that could be deemed superfluous because they are much larger than the norm. Two such impedances are RDC and REC, detector to case and emitter to case. This is graphically illustrated in the heatflux diagrams in Figure 24 and Figure 25. In these diagrams it is obvious that the heat path for thermal dissipation is through the leadframe and not through the package itself; therefore, junction-to-package thermal impedances can be safely ignored.

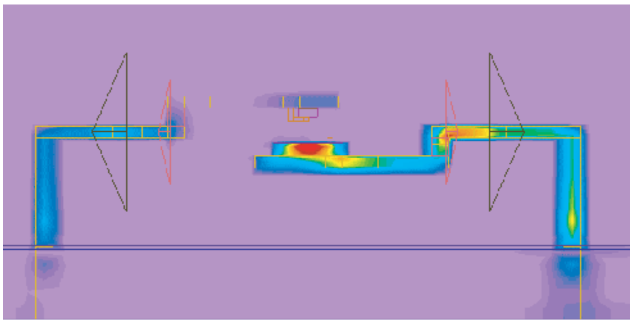


Figure 24. Heat flux - with TRIAC at full power

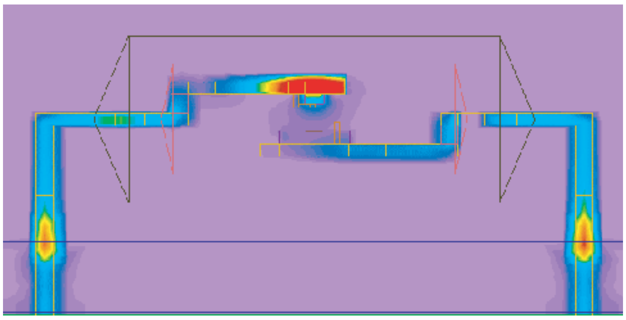


Figure 25. Heat flux - with LED full power

When the junction-to-case thermal impedances are removed, one ends up with the thermal model illustrated in Figure 26. This model is easily workable with even simple hand calculations. The equations that are required to solve this thermal model are identical to the equations that would be used to solve electrical network equations.

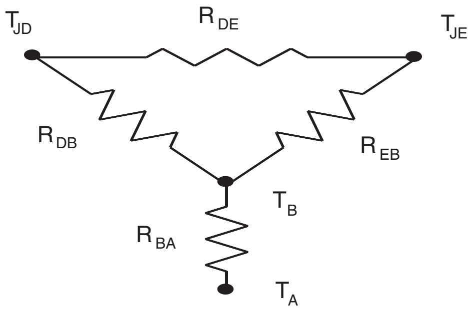


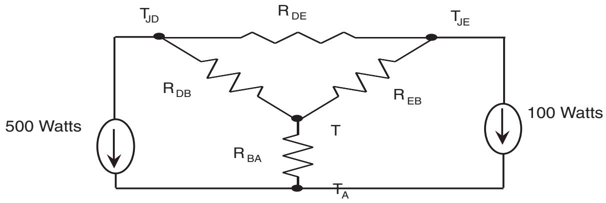
Figure 26. Reduced Simplified Thermal Model

Thus it is possible to relate thermal/electrical equivalent quantities as illustrated in the following table:

Electrical parameter	Thermal parameter
R (electrical resistance)	$R_{thermal}$
I (electrical current)	Power (watts)
V (electrical voltage)	Temperature

The formulae that govern these parameters are the same as would be used in solving for electrical lumped sum networks.

For example, to calculate the temperature at both detector and LED junctions given a set of thermal impedances at room temperature with 100 W and 500 W on the LED and detector respectively, the analogous electrical model would be the following:



Thermal to Electrical Analogy

All that is left is to solve the network equations, or even easier is to have SPICE solve them, and it is a simple matter to obtain any temperature at any junction in the network. The same steps could be used if one wishes to use the complete thermal impedance model. This approach would result in a more complex set of network equations, but SPICE does not mind the extra complexity and it would only take a couple of nanoseconds longer to extract a solution.

Whichever way one performs the analysis, the important thing to keep in mind is to 'perform' the analysis. It is not wise to become lulled into a false sense of security and ignore the thermal design of the DIP PHOTOTRIACs simply because they are small DIP packages. Exceeding the thermal parameters of these parts can have detrimental and sometimes even disastrous consequences.