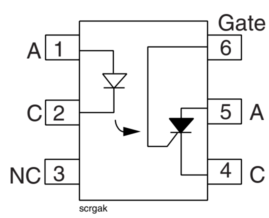
TRIAC Coupler

INTRODUCTION

As is the case for TRIACs in general, OPTO-TRIACs have traditionally been used as solid state AC switches. As a matter of fact, in many industries such as industrial and process control, it is not uncommon to use the terms solid state relay and OPTO-TRIAC synonymously.

TABLE 1 - OPTO-SCRs

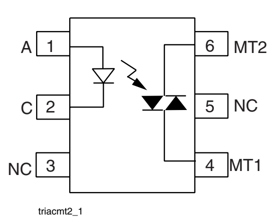


PART #	CURRENT	ISOLATION VOLTAGE	PEAK ANODE VOLTAGE	TOTAL POWER DISSIPATION AT 25 °C
H11C4	11 mA	5300 V_{RMS}	400 V	400 mW
H11C5	11 mA		400 V	400 mW
H11C6	14 mA		400 V	400 mW
IL400	10 mA		400 V	250 mW
4N39	14 mA		200 V	450 mW

Vishay's OPTO-TRIACs vary, in terms of breakdown voltage, power rating, and a parameter which is most important when designing with OPTO-TRIACs and TRIACs in general: dV/dt. Most of the applications for OPTO-TRIACs involve their use as AC switches; however, they can also be used as simple DC latches in unique applications. The possibilities are only limited by the designer's imagination.

OPTO-TRIACs and OPTO-SCRs are used where electrical isolation is required from driving source to load. This isolation requirement can be driven by electrical safety as well as other requirements. These include ground-loop mitigation, EMI mitigation, etc. All Vishay couplers meet UL safety agency standards, and can meet VDE requirements when ordered with option 1 (please refer to Vishay's Safety Agency Guidelines app-note). Vishay's selection of OPTO-TRIACs is listed in table 2.

TABLE 2 - OPTO-TRIACs



PART #	TRIGGER CURRENT	ISOLATION VOLTAGE	V_{drm}	dV/dt	TOTAL POWER DISSIPATION AT 25 °C
IL410	2.0 mA	5300 V_{RMS}	600 V	10 kV/µs	500 mW
IL4108	2.0 mA		800 V		
IL4116	1.3 mA		600 V		
IL4117	1.3 mA		700 V		
IL4118	1.3 mA		800 V		
IL420	2.0 mA		600 V		
IL4208	2.0 mA		800 V		
IL4216	1.3 mA		600 V		
IL4217	1.3 mA		700 V		
IL4218	1.3 mA		800 V		
IL440-1	15 mA		600 V	50 V/µs	300 mW
IL440-2	10 mA				
IL440-3	5.0 mA				
IL440-4	15 mA		400 V		
IL440-5	10 mA				
IL440-6	5.0 mA				
K3010P(G) series	5.0 mA to 15 mA		250 V	10 V/µs	350 mW
K3020P(G) series	5.0 mA to 30 mA		400 V		

INPUT (EMITTER SIDE)

Vishay's OPTO-TRIACs are driven by a GaAs LED, which in turn generates optical energy that is collected by a photo-SCR. As is the case for standard optocoupler products, it is important to perform a worst case analysis when determining the optimum driving current. This will allow the designer to choose the correct I_{FT} under the worst case temperature and component variance conditions.

The first thing to determine is the required turn-on time for the switch in question. The faster the desired turn-on time, the more current is required to turn on the device. This is intuitive for those used to working with MOS devices such as solid state relays, which likewise require increased LED current with increasingly faster tun-on times. figure 1 is an excellent graphical presentation of this parametric trend. It clearly demonstrates two important trends: trigger delay increases with increasing temperature and decreasing I_{FT}.

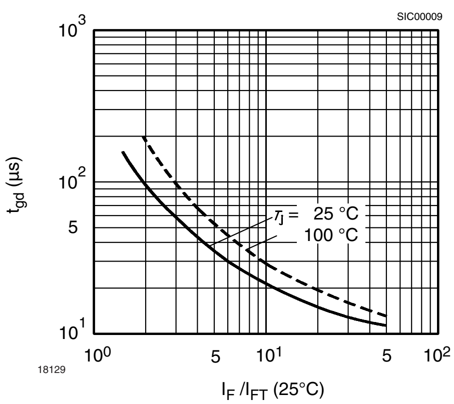


Fig. 1

In addition to the affects of temperature and switching time, one needs to take into account the power dissipated in the optocoupler as a whole, and the LED in particular. Vishay data sheets document limits for both. When attempting to calculate the maximum permissible LED current, it is important to accurately establish the forward voltage drop across the LED. This is well illustrated in figure 2, with figure 3 providing the maximum allowable power dissipation at various ambient temperatures.

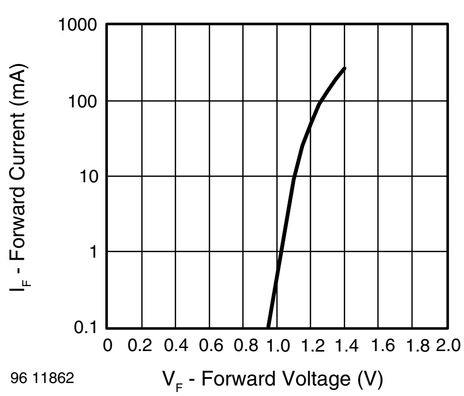


Fig. 2

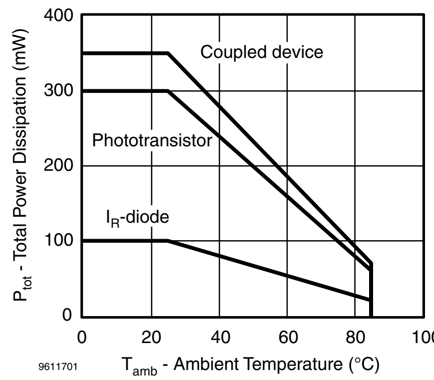


Fig. 3

Finally, when discussing LED drive design it is important to take into account one last consideration: LED "aging". This is a well-known phenomena, but unfortunately one that is highly exaggerated and not well understood. It is true that GaAs LEDs degrade over time; however, the amount of degradation is usually not something that limits the performance of most endproducts given normal operating conditions and equipment life cycles.

The parameters that affect LED aging are temperature and LED drive current. As the temperature and LED current increase, the aging process of the LED increases. This process is only significant under the most extreme examples of temperature and current. Under most conditions, it can be expected that the optocoupler will outlast the expected operational life of most products.

OUTPUT (DETECTOR SIDE)

As mentioned previously, an OPTO-TRIAC is basically a photo-TRIAC driven by an LED, similar to the way that an LED would drive any "standard" transistor output optocoupler. Therefore, it is imperative to have a basic understanding of TRIAC and SCR operation before one can understand the functionality of an OPTO-TRIAC or an OPTO-SCR.

SCRs and TRIACs fall into the family of electronic components commonly referred to as thyristor, which include DIACs, SCRs, and TRIACs. All of these devices originate from the four-layer diode (also known as the Shockley diode). The four-layer diode is represented in figure 5 symbolically, and more importantly, functionally.

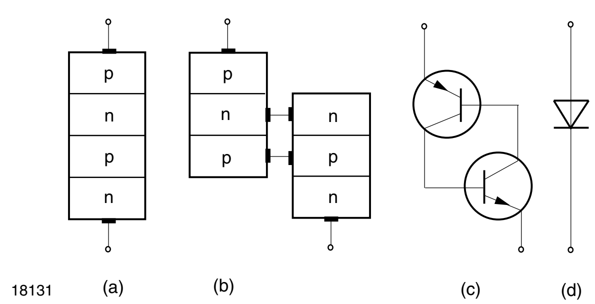


Fig. 4 - Four-Layer Diode (Shockley Diode)

The most important portion of figure 5 is part (c). This is key to understanding the functionality of all thyristors. As can be seen in the above figure, the top transistor drives the base of the lower transistor. Thus, when this device is turned on it will remain on until the current through the device drops to zero. Turning on the device can be accomplished by exceeding the forward blocking voltage; however, in most cases it is accomplished by providing an external trigger current to the gate of one of the transistors, as shown in figure 6 (c).
In such cases, the devices are described as silicon controlled rectifiers, SCRs.

Such devices act as unidirectional AC switches. Unidirectional, because current is allowed to flow in only one direction, and AC switch because it relies on the zero current crossing of the AC waveform to turn off the switch once it has been triggered.

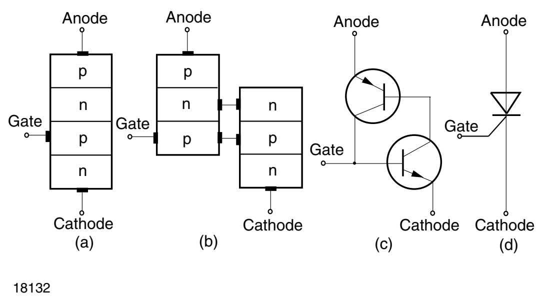


Fig. 5 - Silicon Controlled Rectifier (SCR)

The next logical step in the development of an AC switch is to create a bi-directional, as opposed to the unidirectional, switch. This is conceptually accomplished by connecting two SCRs in parallel and with opposite polarities. As a matter of fact, most of Vishay's OPTO-TRIACS are created in this fashion. Instead of producing a monolithic TRIAC device, they are actually two separate SCRs back to back. Such a device is illustrated schematically in the figure bellow, and functionally describes the detector portion of an OPTO-TRIAC.

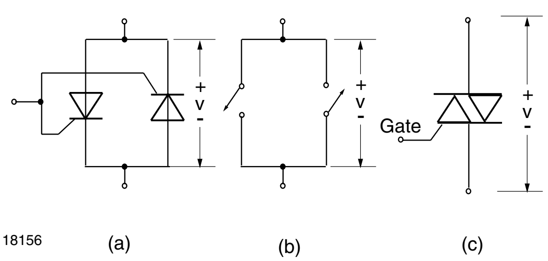


Fig. 6 - TRIAC

CRITICAL DESIGN PARAMETERS

From a designer's point of view, understanding the key parametric characteristics of an OPTO-TRIAC is very similar to understanding an ordinary TRIAC. The main difference rests with the way in which the trigger current is supplied to the TRIAC. Unlike a standard TRIAC, where the trigger current is supplied directly, the trigger current for an OPTO-TRIAC is supplied indirectly by means of a photocurrent generator on the detector side; however, the designer can treat this current just the same as the trigger current for any standard TRIAC. This has to be qualified with the caveat that when calculating the worst case I_{FT}, one has to go through a worst case analysis similar to that described in the beginning section of this document.
The next crucial parameters to be considered are V_{DRM} and $V_{D(RMS)}$. These parameters describe what is commonly referred to in the TRIAC world as the breakover voltage. In Vishay's datasheets, these two parameters are referred to respectively as off-state voltage and repetitive peak off-state voltage. It describes the maximum voltage that can be placed across the anode-cathode terminals of an OPTO-TRIAC, without "turning on" the device. In some thyristor devices, such as DIACs, this is the normal operating mode; however, when it comes to OPTO-TRIACs and OPTO-SCRs, this maximum voltage value should never be exceeded to avoid permanent damage to the part. In conjunction with the off-state- voltage and repetitive peak off-state voltage, it is sometimes necessary to take into account the off-state current $I_{D(RMS)}$. This parameter denotes the OPTO-TRIAC's leakage current, or the current that the device will pass in its off state. An occasion where this may be critical is when an OPTO-TRIAC is being used as a "TRIACdriver", and driving a TRIAC with a particularly low trigger current. In its continuous operating region, it is also important to know what the expected voltage across the device will be when the device is turned on. This parameter is referred to as the on-state voltage or V_{TM}. This parameter, in conjunction with the on-state current I_{TM}, is most often used to determine the maximum operating point of the device at any particular ambient temperature.
As mentioned earlier, thyristors are latching devices when used in DC mode. That is to say that once triggered, they will conduct even if the triggering signal is henceforth removed. These devices are turned off by lowering the current through the device to a very low value, close to zero. Exactly how much current through the TRIAC is required to keep it in conduction mode is referred to as holding current or I_H.
Most of the important DC characteristics that must be considered when designing with OPTO-TRIACs can be graphically measured using a standard curve tracer. This instrument will produce a set of curves such as the one in figure 8.

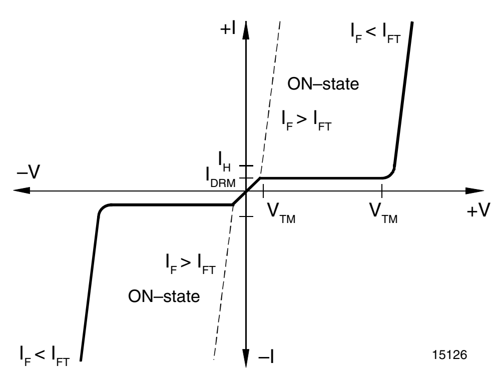
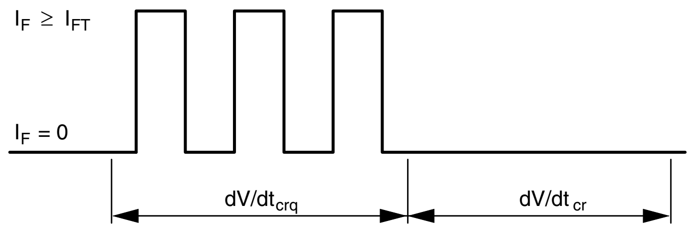


Fig. 7 - Characteristics Curve of an OPTO-TIRAC

In addition to the DC characteristics that need to be considered when designing with OPTO-TRIACs, there are some very important AC characteristics that need to be considered. One of the most important of these is the dV/dt of the output waveform. The output dV/dt parameters can be divided into two separate categories, and which of these we consider depends on the state of I_{FT}. If I_{FT} is changing, dV/dt_{crq} becomes the parameter of interest. If I_{FT} is continuously off, dV/dt_{cr} is the parameter that should be examined. The differences between these two dV/dt parameters are graphically explained in figure 9.



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

95 10814

Fig. 8 - dV/dt_{cr} and dV/dt_{crq}

The dV/dt_{cr} parameter refers to the situation where the output dV/dt is so fast that it actually triggers the TRIAC even though the input trigger voltage is held at zero. Such situations can arise either because the voltage and frequency of the output waveform are extremely high, or more commonly, because of fast transients such as those encountered with fast switching inductive loads, as in the case of motor switching. In such cases, a snubber across the load of some kind is required.

This slows down the dV/dt to an acceptable level; however, it also dissipates power, and increases component count, circuit size, and cost.

The dV/dt_{crq} parameter refers to the maximum change in the output change in voltage in the same way as dV/dt_{cr}. The difference being that instead of the condition I_{FT} being continuously off, it is on for one portion of the AC cycle then turns off for the second half. If the dV/dt of the output load is fast enough, it may not allow for the charge in the depletion region to dissipate fast enough, thereby allowing the second half of the AC waveform to also get through. In many applications, being off by half a cycle is not significant; however, in others it is critical. Thus, whether or not dV/dt_{crq} is important depends on the user's application.

In either case of output voltage dV/dt, it is important to note that Vishay has OPTO-TRIACs available with the **highest dV/dt** ratings available in the industry. Some of these can go as high as 10 000 V/µs. Having such high dV/dt ratings allows for the design of TRIAC circuits that can handle very rapidly changing output voltages without the need for snubber circuits. This inherent dV/dt immunity reduces parts count, inefficiency, circuit size, and overall cost.

Getting an idea of how fast your load voltage changes is easy in the case of a simple sinusoidal output waveform. When the dV/dt waveform is a more complex function such as a transient produced by the "inductive kick back" of a highly inductive load, a measurement is worth a thousand impressive calculations. In the simple case of a sinusoidal output wave form, the analysis would flow as follows:

$V = V_{peak}\ SIN(\omega t)$

$dV/dt = V_{peak} \times \omega \times \cos(\omega t)$

given $\rightarrow V_{peak} = \sqrt{2} \times V_{rms}$

•

•

•

$dV/dt = 8.89 \times V_{rms} \times f$

where f = frequency.

THERMAL DESIGN PARAMETERS

The last set of parameters that should be considered are the thermal design parameters. Vishay OPTO-TRIACs are designed to operate at power dissipation levels as high as 0.5 W. When one is dealing with a DIP-6 package, this is not an insignificant amount of power. Moreover, TRIACs are often used in applications where the ambient temperature is different than standard roomtemperature. Such is the case in many industrial and process control applications.

There are three approaches to take in the case of thermal design. The first is to go simply by a component derating number given in power/degrees. This is the simplest and safest approach to take. Manufacturers are very conservative when deriving this number. Consequently, if a designer follows this criteria it is unlikely that yet will get in trouble. The second approach is very similar to this, but instead of a simple number, the designer follows a graph of allowable power vs. temperature similar to the one in figure 10. Again, this is a very conservative approach and should allow for a very reliable design.

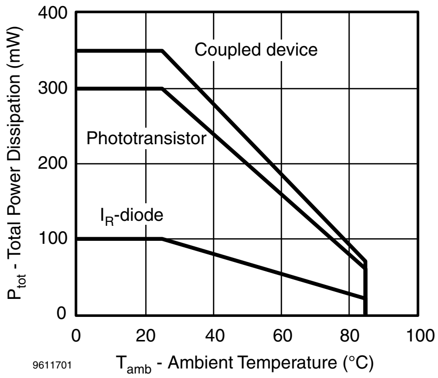


Fig. 9 - Allowable Dissipated Power

If the above two methods are not sufficient for the application, it is possible to calculate the thermal operating conditions based on the given thermal impedance data, when such data is available.

The fundamental formula to remember when performing thermal impedance is the following:

$\theta jx = \Delta T/\Delta P_{dis}$

P_{dis} is in Ws while ΔT can either be in Celsius or Kelvin. Since relative and not absolute temperature quantities are involved, Celsius of Kelvin can be used.

If someone requires convincing, they should try it both ways. The result will be the same.

The previous method is quite straight forward and simple; the complication comes in getting the appropriate θjx.

One can have the following forms of θjx, θjc (junction to case), θjb (junction to board), θjj (junction to junction, as can be found in hybrid circuits such as optocouplers), and θja (junction to ambient). As is the case for most low-power IC manufacturers, Vishay usually gives the θja values for most parts. In some occasions θja values are given for the LED and detector. In such cases, the conservative approach is to calculate both separately and take the worst case.

Finally, if nothing else is gained from this document, a designer should understand the following principle. Published junction temperatures are absolute maximums. They should not be designed to or even approached if it all possible. It is an established fact that reliability and operating temperature are closely linked and inversely proportional when dealing with semiconductor devices. In other words, if you run it hot, a part may still be under guarantee when it fails, but it will not last as long as if it were running cooler; therefore, thermal margin is crucial to reliable designs.

Sample Circuits:

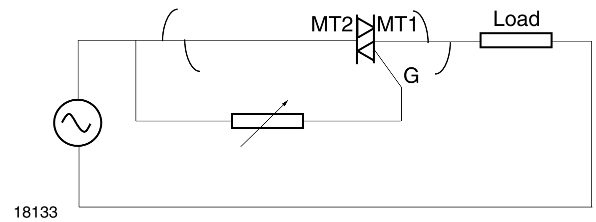


Fig. 10 - Phase-Shift Controller

Figure 11, in spite of its apparent simplicity, forms the basis of a great deal of practical TRIAC circuits. It is sometimes referred to as a "phase-shift controller". If the input to the above circuit is a sinusoidal waveform, the output will be some "chopped up" fraction of that waveform. This allows for the efficient and economical control of the rms AC voltage. Some variant of this type of control is often used in commercial/consumer applications such as light dimmers, and universal motors.

Vishay's OPTO-TRIACs can handle currents in the range of 100s of mA. However, many TRIAC applications require current handling capability of several amps. In such applications, discrete OPTO-TRIACs cannot be used directly, but can be used in conjunction with standard high-power TRIACs to yield simple, low-part-count, cost-effective solutions to higher-power AC switching applications. In this type of application, OPTO-TRIACs are used as "TRIAC drivers". In other words, they provide the gate current and isolation required to drive standard high-power TRIACS, as seen in the drawing of this page.

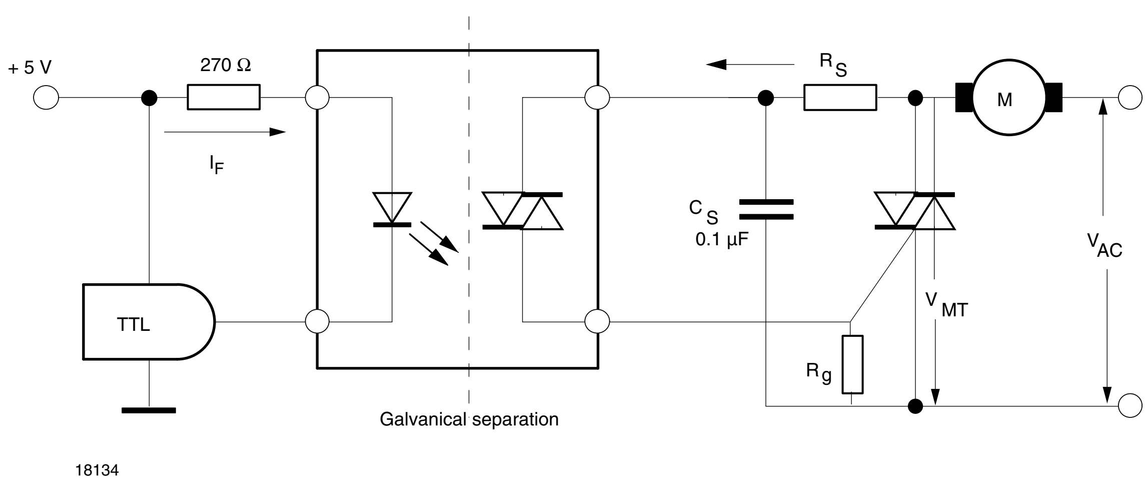


Fig. 11 - TRIAC Driver Example

In addition to providing an example of an application where an OPTO-TRIAC is used as a TRIAC driver, the above circuit also illustrates the concept of using a snubber circuit and one of the main advantages of Vishay's OPTO-TRIACs.

The circuit in figure 12 is driving an electric motor, which under most circumstances is a highly inductive load. This in turn leads to unique difficulties in terms of output dV/dt. When inductive loads are switched rapidly they generate high transient spikes quantified by V = L dI/dt. The L in the case of even small electric motors is comparatively large, thereby generating equivalently large values of dV/dt on the output. Such large skewing in output voltage could generate false triggering as described in previous sections.

There are two options to deal with this problem. The first is to use Vishay's high dV/dt (10 000 V/μs) OPTO-TRIACs, and call it victory, because the inherent high dV/dt immunity will solve the problem.

The second is to add a snubber similar to the one included in the circuit shown above.

The basic design process for arriving at the most advantageous snubber possible is as follows:

1. What is the highest tolerable dV/dt that a particular OPTO-TRIAC can withstand?
2. Use dV/dt = V/(Rs x Cs) to come up with an appropriate RC combination.

In addition to having the highest dV/dt specifications in the industry, Vishay optocouplers are also available with internal zero-crossing features. This is to say that for the "zero-crossing" OPTO-TRIACs, they are designed such that they can be triggered only when the load voltage is nominally at zero volts. Incorporating this feature in various applications greatly decreases circuit complexity and reliability by reducing the number of parts required to implement this functionality.

Finally, as is the case for optocouplers in general, OPTO-TRIACs are well suited for the current trend towards increasing embedded intelligence and microprocessor control. By allowing the designer to separate the "power stage" from the controller/firmware portion of the system, it allows for simpler and lower-cost designs. This is true in industrial automation where microprocessor-based systems control large numbers of widely varying AC and DC loads.

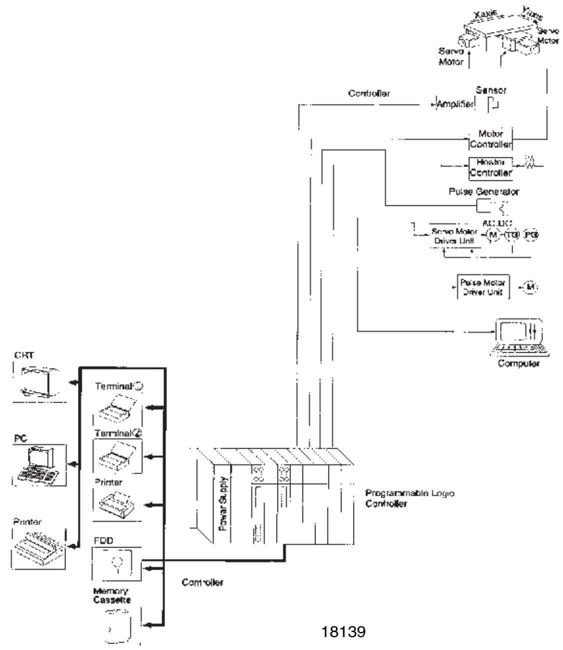


Fig. 12 - Industrial Programmable Logic Example

In addition to industrial process controls, there is an increasing trend to the use of solid state switches, to replace traditional EMRs (electro mechanical relays) in the consumer appliance market. Solid state switches such as TRIACs and SSRs offer highly reliable solutions that are well suited to the increasingly microcontroller-dominated consumer market place.

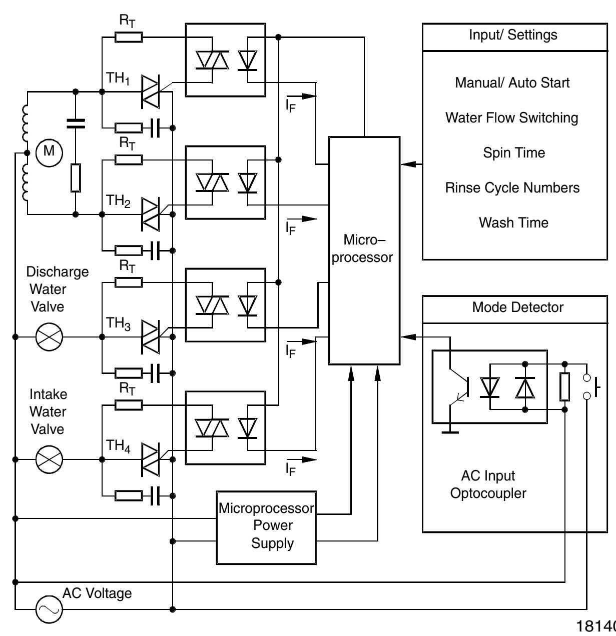


Fig. 13 - Consumer Appliance Example

Finally, it is important to emphasize that OPTO-TRIACs are not by any means limited to the above applications. The possible uses for OPTO-TRIACs are limited only by the designer's imagination. Should there be any questions regarding the efficacy of using these products to provide new and unique solutions, do not hesitate to contact VISHAY applications engineering for further support.

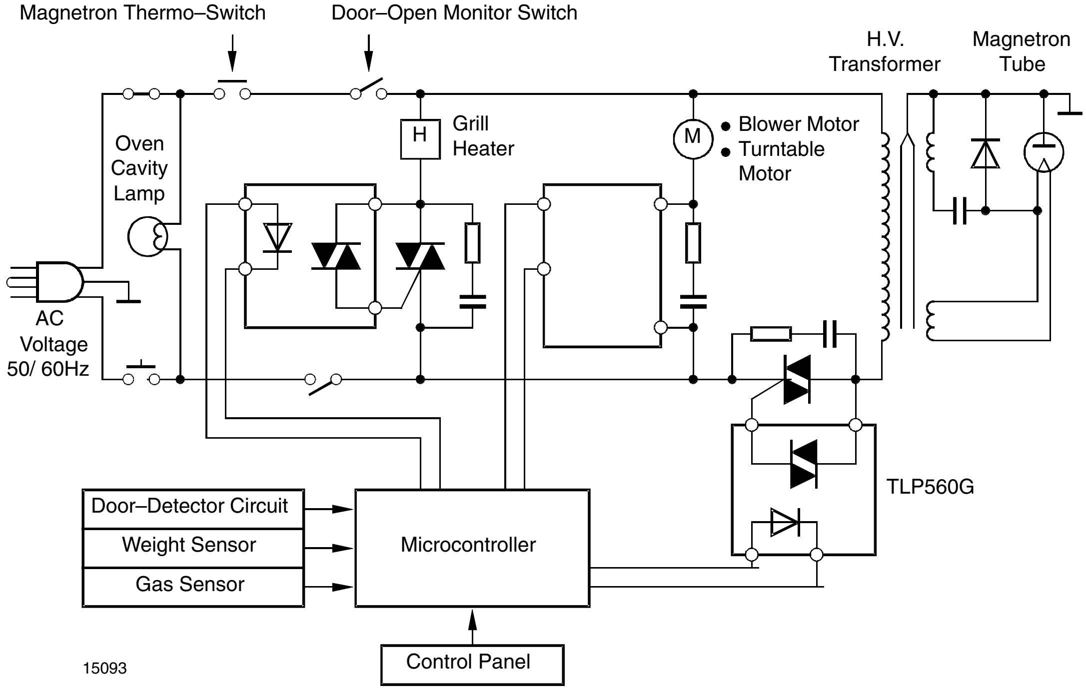


Fig. 14 - Microwave Oven with Grill Example

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Malvino Albert Paul, Electronic Principles, NY, McGraw Hill, 1983.

Mazur Glen & Rockis Gary, Elecrical Motor Controls,.Homewood Ill., American Technical Publishers Inc., 1997.

USEFUL WEB LINKS:

Vishay	http://www.vishay.com/optocouplers
UL	http://www.ul.com/
IEC	http://www.iec.ch/
FIMCO	http://www.sgsfimko.fi/index_en.html
BSI	http://www.bsi-global.com/index.xalter
CSA	http://www.csa-international.org/default.asp?language=english
VDE	http://www.vde.com/VDE/de/