

Thyristors Used as AC Static Switches and Relays

Introduction

Since the SCR and the Triac are bistable devices, one of their broad areas of application is in the realm of signal and power switching. This application note describes circuits in which these Thyristors are used to perform simple switching functions of a general type that might also be performed non-statically by various mechanical and electromechanical switches. In these applications, the Thyristors are used to open or close a circuit completely, as opposed to applications in which they are used to control the magnitude of average voltage or energy being delivered to a load. These latter types of applications are described in detail in "Phase Control Using Thyristors" (AN1003).

Static AC Switches

Normally Open Circuit

The circuit shown in Figure AN1007.1 provides random (anywhere in half-cycle), fast turn-on ($<10 \mu\text{s}$) of AC power loads and is ideal for applications with a high-duty cycle. It eliminates completely the contact sticking, bounce, and wear associated with conventional electromechanical relays, contactors, and so on. As a substitute for control relays, Thyristors can overcome the differential problem; that is, the spread in current or voltage between pickup and dropout because Thyristors effectively drop out every half cycle. Also, providing resistor R_1 is chosen correctly, the circuits are operable over a much wider voltage range than is a comparable relay. Resistor R_1 is provided to limit gate current (I_{GTM}) peaks. Its resistance plus any contact resistance (R_c) of the control device and load resistance (R_L) should be just greater than the peak supply voltage divided by the peak gate current rating of the Triac. If R_1 is set too high, the Triacs may not trigger at the beginning of each cycle, and phase control of the load will result with consequent loss of load voltage and waveform distortion. For inductive loads, an RC snubber circuit, as shown in Figure AN1007.1, is required. However, a snubber circuit is not required when an alternistor Triac is used.

Figure AN1007.2 illustrates an analysis to better understand a typical static switch circuit. The circuit operation occurs when switch S_1 is closed, since the Triac Q_1 will initially be in the blocking condition. Current flow will be through load R_L , S_1 , R_1 , and gate to MT1 junction of the Thyristor. When this current reaches the required value of I_{GT} the MT2 to MT1 junctions will switch to the conduction state and the voltage from MT2 to MT1 will be V_T . As the current approaches the zero crossing, the load current will fall below holding current turning the Triac Q_1 device off until it is re-fired in the next half cycle. Figure AN1007.3 illustrates the voltage waveform appearing across the MT2 to MT1 terminals of Q_1 . Note that the maximum peak value of current which S_1 will carry would be 25 mA since Q_1 has a 25 mA maximum I_{GT} rating. Additionally, no arcing of a

current value greater than 25 mA when opening S_1 will occur when controlling an inductive load. It is important also to note that the Triac Q_1 is operating in Quadrants I and III, the more sensitive and most suitable gating modes for Triacs. The voltage rating of S_1 (mechanical switch or reed switch) must be equivalent to or greater than line voltage applied.

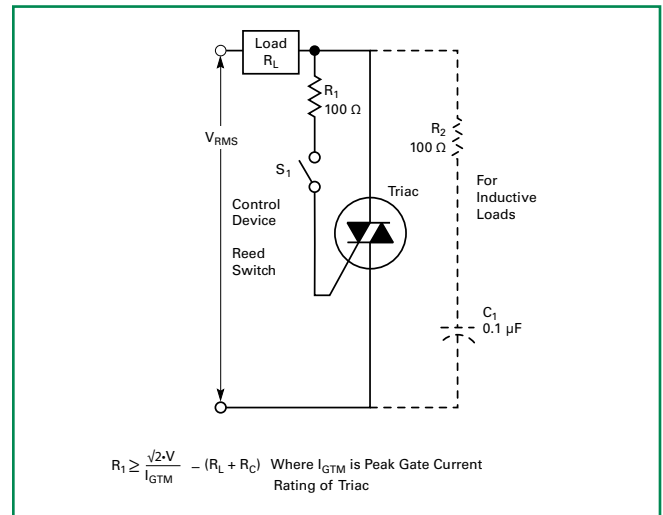


Figure AN1007.1 Basic Triac Static Switch

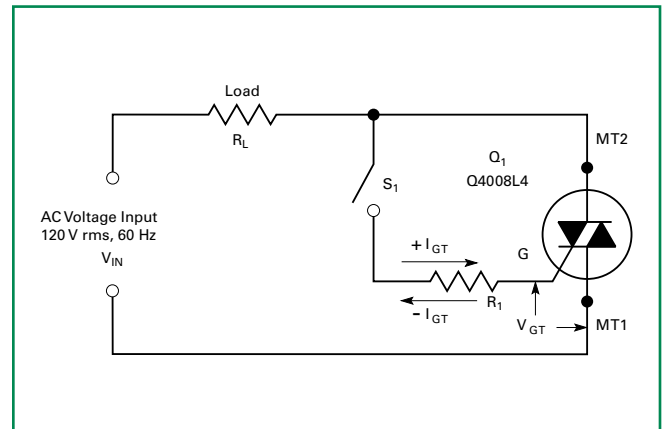


Figure AN1007.2 Analysis of Static Switch

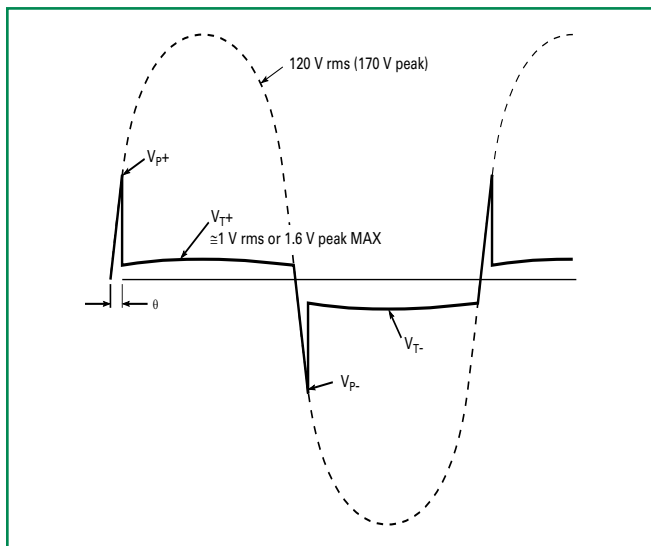


Figure AN1007.3 Waveform Across Static Switch

A typical example would be in the application of this type circuit for the control of 5 A resistive load with 120 V rms input voltage. Choosing a value of 100 Ω for R₁ and assuming a typical value of 1 V for the gate to MT1 (V_{GT}) voltage, we can solve for V_p by the following:

$$V_p = I_{GT} (R_L + R_1) + V_{GT}$$

Note: R_c is not included since it is negligible.

$$V_p = 0.025 (24 + 100) + 1.0 = 4.1 \text{ V}$$

Additionally the turn-on angle is

$$\theta = \sin^{-1} \frac{4.1}{170V_{PK}} = 1.4^\circ$$

The power lost by the turn-on angle is essentially zero. The power dissipation in the gate resistor is very minute. A 100 Ω, 0.25 W rated resistor may safely be used. The small turn-on angle also ensures that no appreciable RFI is generated.

The relay circuit shown in Figure AN1007.1 and Figure AN1007.2 has several advantages in that it eliminates contact bounce, noise, and additional power consumption by an energizing coil and can carry an in-rush current of many times its steady state rating.

The control device S₁ indicated can be either electrical or mechanical in nature. Light-dependent resistors and light-activated semiconductors, optocoupler, magnetic cores, and magnetic reed switches are all suitable control elements. Regardless of the switch type chosen, it must have a voltage rating equal to or greater than the peak line voltage applied. In particular, the use of hermetically sealed reed switches as control elements in combination with Triacs offers many advantages. The reed switch can be actuated by passing DC current through a small coiled wire or by the proximity of a small magnet. In either case, complete electrical isolation exists between the control signal input, which may be derived from many sources,

and the switched power output. Long life of the Triac/reed switch combination is ensured by the minimal volt-ampere switching load placed on the reed switch by the Triac triggering requirements. The Thyristor ratings determine the amount of load power that can be switched.

Normally Closed Circuit

With a few additional components, the Thyristor can provide a normally closed static switch function. The critical design portion of this static switch is a clamping device to turn off/eliminate gate drive and maintain very low power dissipation through the clamping component plus have low by-pass leakage around the power Thyristor device. In selecting the power Thyristor for load requirements, gate sensitivity becomes critical to maintain low power requirements. Either sensitive SCRs or sensitive logic Triacs must be considered, which limits the load in current capacity and type. However, this can be broader if an extra stage of circuitry for gating is permitted.

Figure AN1007.4 illustrates an application using a normally closed circuit driving a sensitive SCR for a simple but precise temperature controller. The same basic principle could be applied to a water level controller for a motor or solenoid. Of course, SCR and diode selection would be changed depending on load current requirements.

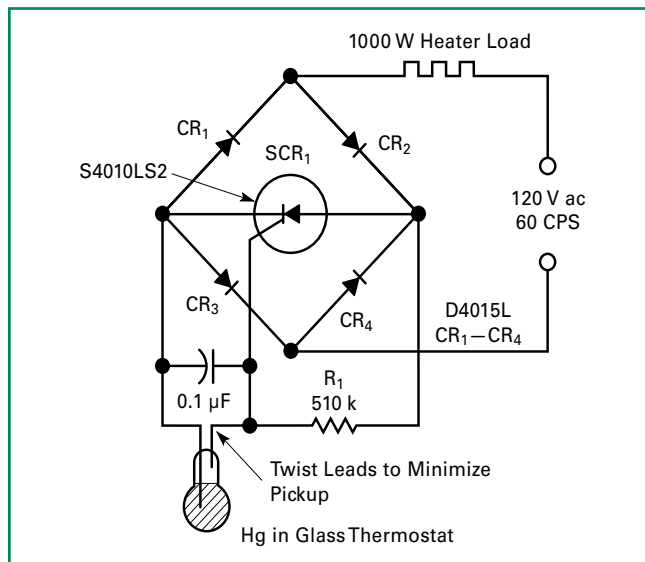


Figure AN1007.4 Normally Closed Temperature Controller

A mercury-in-glass thermostat is an extremely sensitive measuring instrument, capable of sensing changes in temperature as small as 0.1 °C. Its major limitation lies in its very low current-handling capability for reliability and long life, and contact current should be held below 1 mA. In the circuit of Figure AN1007.4, the S2010LS2 SCR serves as both current amplifier for the Hg thermostat and as the main load switching element.

With the thermostat open, the SCR will trigger each half cycle and deliver power to the heater load. When the thermostat closes, the SCR can no longer trigger and the heater shuts off. Maximum current through the thermostat

in the closed position is less than 250 μA rms.

Figure AN1007.5 shows an all solid state, optocoupled, normally closed switch circuit. By using a low voltage SBS triggering device, this circuit can turn on with only a small delay in each half cycle and also keep gating power low. When the optocoupled transistor is turned on, the gate drive is removed with only a few milliamps of bypass current around the Triac power device. Also, by use of the BS08D and 0.1 μF , less sensitive Triacs and alternistors can be used to control various types of high current loads.

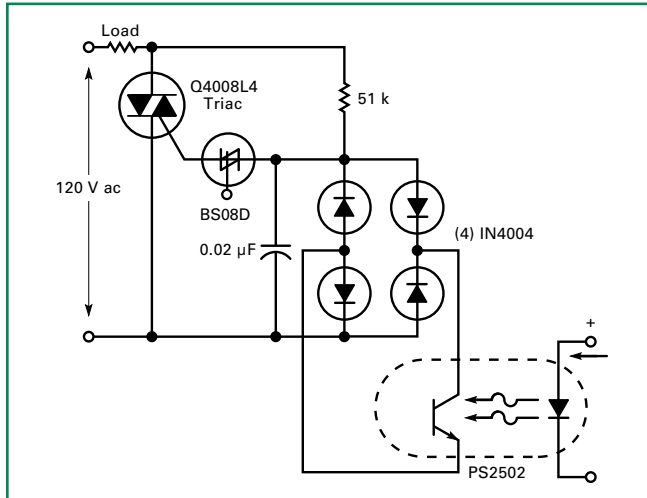


Figure AN1007.5 Normally Closed Switch Circuit

A common mistake in this circuit is to make the series gate resistor too large in value. A value of 180 Ω is shown in a typical application circuit by optocoupler manufacturers. The 180 Ω is based on limiting the current to 1 A peak at the peak of a 120 V line input for Fairchild and Toshiba optocoupler I_{TSM} rating. This is good for protection of the optocoupler output Triac, as well as the gate of the power Triac on a 120 V line; however, it must be lowered if a 24 V line is being controlled, or if the R_L (resistive load) is 200 W or less. This resistor limits current for worst case turn-on at the peak line voltage, but it also sets turn-on point (conduction angle) in the sine wave, since Triac gate current is determined by this resistor and produced from the sine wave voltage as illustrated in Figure AN1007.2. The load resistance is also important, since it can also limit the amount of available Triac gate current. A 100 Ω gate resistor would be a better choice in most 120 V applications with loads greater than 200 W and optocouplers from Quality Technologies or Vishay with optocoupler output Triacs that can handle 1.7 A_{PK} (I_{TSM} rating) for a few microseconds at the peak of the line. For loads less than 200 W, the resistor can be dropped to 22 Ω . Remember that if the gate resistor is too large in value, the Triac will not turn on at all or not turn on fully, which can cause excessive power dissipation in the gate resistor, causing it to burn out. Also, the voltage and dv/dt rating of the optocoupler's output device must be equal to or greater than the voltage and dv/dt rating of the Triac or alternistor it is driving.

Figure AN1007.7 illustrates a circuit with a dv/dt snubber network included. This is a typical circuit presented by optocoupler manufacturers.

Optocoupled Driver Circuits

Random Turn-on, Normally Open

Many applications use optocouplers to drive Thyristors. The combination of a good optocoupler and a Triac or alternistor makes an excellent, inexpensive solid state relay. Application information provided by the optocoupler manufacturers is not always best for application of the power Thyristor. Figure AN1007.6 shows a standard circuit for a resistive load.

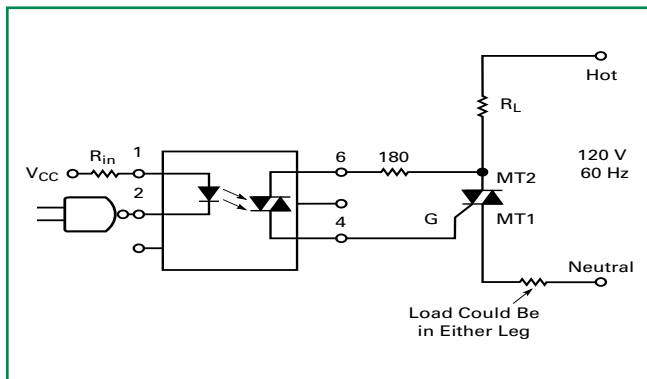


Figure AN1007.6 Optocoupled Circuit for Resistive Loads (Triac or Alternistor Triac)

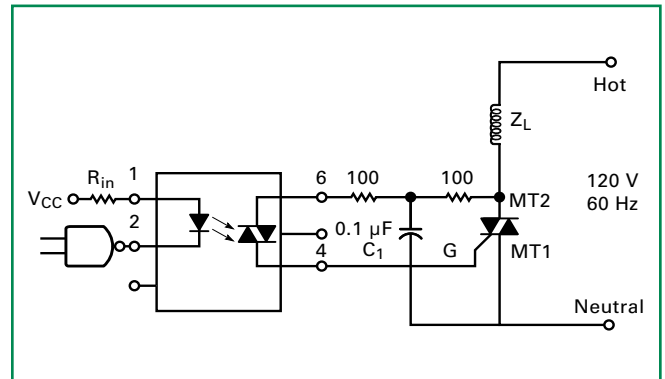


Figure AN1007.7 Optocoupler Circuit for Inductive Loads (Triac or Alternistor Triac)

This "T" circuit hinges around one capacitor to increase dv/dt capability to either the optocoupler output Triac or the power Triac. The sum of the two resistors then forms the Triac gate resistor.

Both resistors should then be standardized and lowered to 100 Ω . Again, this sum resistance needs to be low, allowing as much gate current as possible without exceeding the instantaneous current rating of the opto output Triac or Triac gate junction. By having 100 Ω for current limit in either direction from the capacitor, the optocoupler output Triac and power Triac can be protected

against di/dt produced by the capacitor. Of course, it is most important that the capacitor be connected between proper terminals of Triac. For example, if the capacitor and series resistor are accidentally connected between the gate and MT2, the Triac will turn on from current produced by the capacitor, resulting in loss of control.

For low current (mA) and/or highly inductive loads, it may be necessary to have a latching network ($3.3\text{ k}\Omega + 0.047\text{ }\mu\text{F}$) connected directly across the power Triac. The circuit shown in Figure AN1007.8 illustrates the additional latching network.

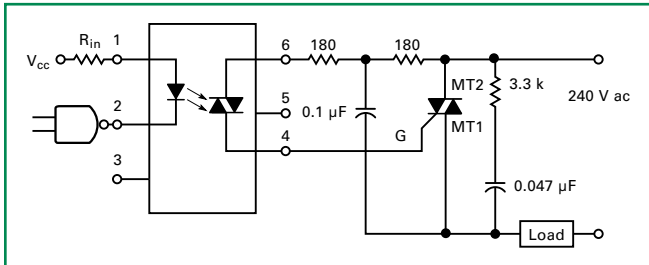


Figure AN1007.8 Optocoupler Circuit for Lower Current Inductive Loads (Triac or Alternistor Triac)

In this circuit, the series gate resistors are increased to $180\text{ }\Omega$ each, since a 240 V line is applied. Note that the load is placed on the MT1 side of the power Triac to illustrate that load placement is **not** important for the circuit to function properly.

Also note that with standard U.S. residential 240 V home wiring, both sides of the line are hot with respect to ground (no neutral). Therefore, for some 240 V line applications, it will be necessary to have a Triac switch circuit in both sides of the 240 V line input.

If an application requires back-to-back SCRs instead of a Triac or alternistor, the circuit shown in Figure AN1007.9 may be used.

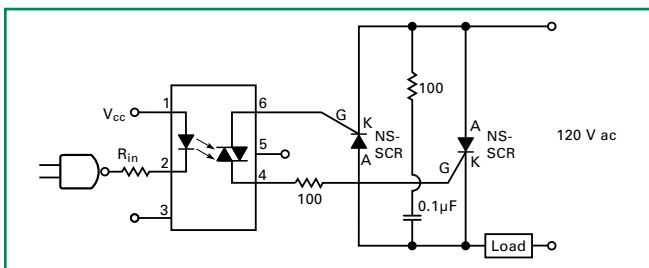


Figure AN1007.9 Optocoupled Circuit for Heavy-duty Inductive Loads

All application comments and recommendations for optocoupled switches apply to this circuit. However, the snubber network can be applied only across the SCRs as shown in the illustration. The optocoupler should be chosen for best noise immunity. Also, the voltage rating of the optocoupler output Triac must be equal to or greater than the voltage rating of SCRs.

Summary of Random Turn-on Relays

As shown in Figure AN1007.10, if the voltage across the load is to be phase controlled, the input control circuitry must be synchronized to the line frequency and the trigger pulses delayed from zero crossing every half cycle. If the series gate resistor is chosen to limit the peak current through the opto-driver to less than 1 A, then on a 120 V ac line the peak voltage is 170 V; therefore, the resistor is $180\text{ }\Omega$. On a 240 V ac line the peak voltage is 340 V; therefore, the resistor should be $360\text{ }\Omega$. These gate pulses are only as long as the device takes to turn on (typically, 5 μs to 6 μs); therefore, 0.25 W resistor is adequate.

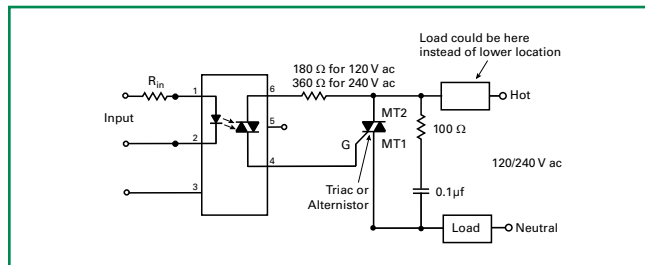


Figure AN1007.10 Random Turn-on Triac Driver

Select the Triac for the voltage of the line being used, the current through the load, and the type of load. Since the Gpeak voltage of a 120 V ac line is 170 V, you would choose a 200 V (MIN) device. If the application is used in an electrically noisy industrial environment, a 400 V device should be used. If the line voltage to be controlled is 240 V ac with a peak voltage of 340 V, then use at least a 400 V rated part or 600 V for more design margin. Selection of the voltage rating of the opto-driver must be the same or higher than the rating of the power Triac. In electrically noisy industrial locations, the dv/dt rating of the opto-driver and the Triac must be considered.

The RMS current through the load and main terminals of the Triac should be approximately 70% of the maximum rating of the device. However, a 40 A Triac should not be chosen to control a 1 A load due to low latching and holding current requirements. Remember that the case temperature of the Triac must be maintained at or below the current versus temperature curve specified on its data sheet. As with all semiconductors the lower the case temperature the better the reliability. Opto-driven gates normally do not use a sensitive gate Triac. The opto-driver can supply up to 1 A gate pulses and less sensitive gate Triacs have better dv/dt capability. If the load is resistive, it is acceptable to use a standard Triac. However, if the load is a heavy inductive type, then an alternistor Triac, or back-to-back SCRs as shown in Figure AN1007.9, is recommended. A series RC snubber network may or may not be necessary when using an alternistor Triac. Normally a snubber network is not needed when using an alternistor because of its high dv/dt and dv/dt(c) capabilities. However, latching network as described in Figure AN1007.8 may be needed for low current load variations.

Zero Crossing Turn-on, Normally Open Relay Circuits

When a power circuit is mechanically switched on and off mechanically, generated high-frequency components are generated that can cause interference problems such as RFI. When power is initially applied, a step function of voltage is applied to the circuit which causes a shock excitation. Random switch opening stops current off, again generating high frequencies. In addition, abrupt current interruption in an inductive circuit can lead to high induced-voltage transients.

The latching characteristics of Thyristors are ideal for eliminating interference problems due to current interruption since these devices can only turn off when the on-state current approaches zero, regardless of load power factor.

On the other hand, interference-free turn-on with Thyristors requires special trigger circuits. It has been proven experimentally that general purpose AC circuits will generate minimum electromagnetic interference (EMI) if energized at zero voltage.

The ideal AC circuit switch, therefore, consists of a contact which closes at the instant when voltage across it is zero and opens at the instant when current through it is zero. This has become known as “zero-voltage switching.”

For applications that require synchronized zero-crossing turn-on, the illustration in Figure AN1007.11 shows a circuit which incorporates an optocoupler with a built-in zero-crossing detector

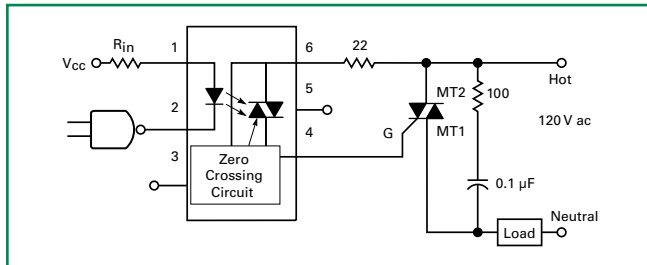


Figure AN1007.11 Optocoupled Circuit with Zero-crossing Turn-on (Triac or Alternistor Triac)

Also, this circuit includes a dv/dt snubber network connected across the power Triac. This typical circuit illustrates switching the hot line; however, the load may be connected to either the hot or neutral line. Also, note that the series gate resistor is low in value (22 Ω), which is possible on a 120 V line and above, since zero-crossing turn-on is ensured in any initial half cycle.

Zero Voltage Switch Power Controller

The UAA2016 (at www.onsemi.com) is designed to drive Triacs with the Zero Voltage technique which allows RFI-free power regulation of resistive loads. Operating directly on the AC power line, its main application is the precision regulation of electrical heating systems such as panel heaters or irons. It is available in eight-pin I.C. package variations.

A built-in digital sawtooth waveform permits proportional temperature regulation action over a ±1 °C band around the set point. For energy savings there is a programmable temperature reduction function, and for security a sensor failsafe inhibits output pulses when the sensor connection is broken. Preset temperature (in other words, defrost) application is also possible. In applications where high hysteresis is needed, its value can be adjusted up to 5 °C around the set point. All these features are implemented with a very low external component count.

Triac Choice and R_{out} Determination

The power switching Triac is chosen depending on power through load and adequate peak gate trigger current. The illustration in Figure AN1007.12 shows a typical heating control.

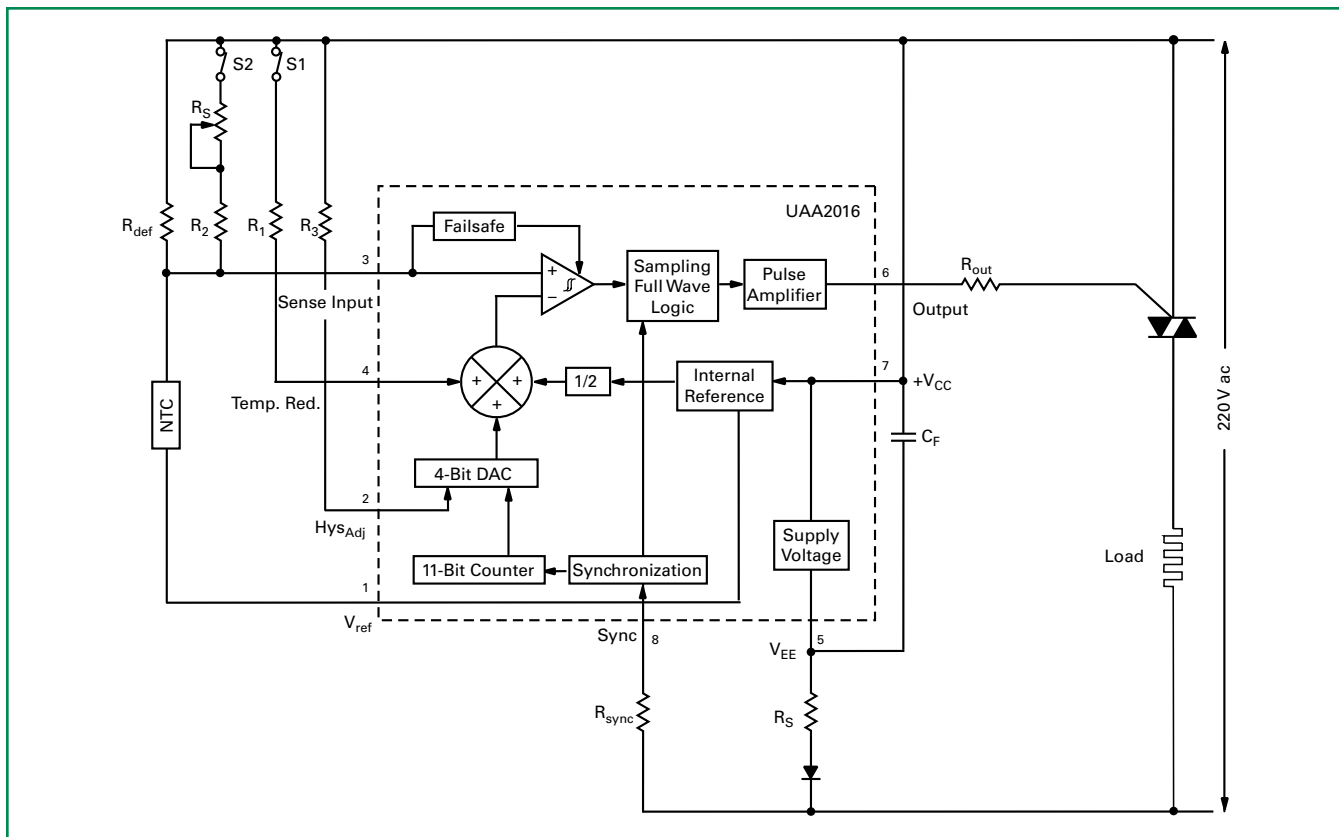


Figure AN1007.12 Heater Control Schematic

R_{out} limits the output current from UAA2016. Determine R_{out} according to the Triac maximum gate current (I_{GT}) and the application low temperature limit. For a 2 kw load at 220 V rms, a good Triac choice is Q6012LH5. Its maximum peak gate trigger current at 25 °C is 50 mA.

For an application to work down to -20 °C, R_{out} should be 68 Ω . since I_{GT} Q6012LH5 can typically be 80 mA and minimum current output from UAA2016 pin 6 is -90 mA at -8 V, -20 °C.

Output Pulse Width, R_{sync}

Figure AN1007.13 shows the output pulse width T_p determined by the Triac's I_H , I_L together with the load value, characteristics, and working conditions (frequency and voltage).

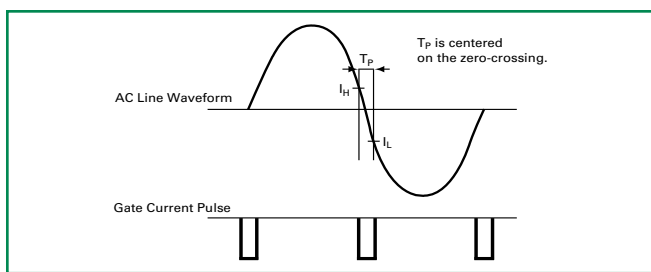


Figure AN1007.13 Zero Voltage Technique

To ensure best latching, T_p should be 200 μ s, which means R_{sync} will have typical value >390 k Ω .

To ensure best latching, T_p should be 200 μ s, which means R_{sync} will have typical value >390 k Ω .

R_S and Filter Capacitor (C_F)

For better UAA2016 power supply, typical value for R_S could be 27 k Ω , 2 W with C_F of 75 μ F to keep ripple <1 V.

Summary of Zero Crossing Turn-on Circuits

Zero voltage crossing turn-on opto-drivers are designed to limit turn-on voltage to less than 20 V. This reduces the amount of RFI and EMI generated when the Thyristor switches on. Because of this zero turn-on, these devices cannot be used to phase control loads. Therefore, speed control of a motor and dimming of a lamp cannot be accomplished with zero turn-on opto-couplers.

Since the voltage is limited to 20 V or less, the series gate resistor that limits the gate drive current has to be much lower with a zero crossing opto-driver. With typical inhibit voltage of 5 V, an alternistor Triac gate could require a 160 mA at -30 °C ($5\text{ V}/0.16\text{ A} = 31\ \Omega$ gate resistor). If the load has a high inrush current, then drive the gate of the Triac with as much current as reliably possible but stay under the I_{TSM} rating of the opto-driver. By using 22 Ω for the gate resistor, a current of at least 227 mA is supplied with only 5 V, but limited to 909 mA if the voltage goes to 20 V. As shown in Figure AN1007.14, Figure AN1007.15, and Figure AN1007.16, a 22 Ω gate resistor is a good choice for various zero crossing controllers.

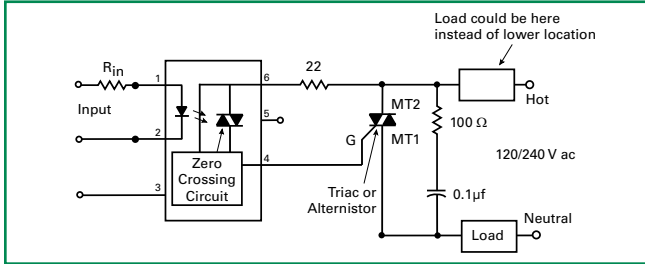


Figure AN1007.14 Zero Crossing Turn-on Opto Triac Driver

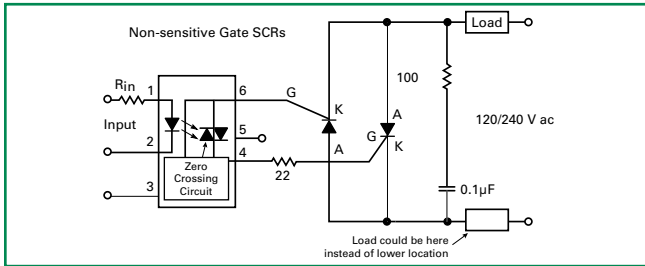


Figure AN1007.15 Zero Crossing Turn-on Non-sensitive SCR Driver

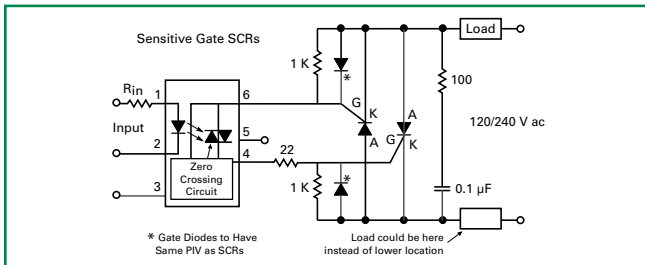


Figure AN1007.16 Zero Crossing Turn-on Opto-sensitive Gate SCR Driver

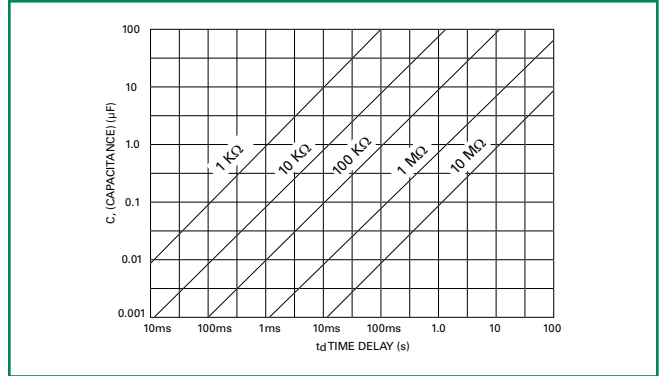


Figure AN1007.18 Resistor (R) and capacitor (C) combination curves

IR Motion Control

An example of a more complex Triac switch is an infrared (IR) motion detector controller circuit. Some applications for this circuit are alarm systems, automatic lighting, and auto doorbells.

Figure AN1007.19 shows an easy-to-implement automatic lighting system using an infrared motion detector control circuit. A commercially available LSI circuit HT761XB, from *Holtek*, integrates most of the analog functions. This LSI chip, U2, contains the op amps, comparators, zero crossing detection, oscillators, and a Triac output trigger. An external RC that is connected to the OSCD pin determines the output trigger pulse width. (*Holtek Semiconductor Inc.* is located at No.3, Creation Road II, Science-Based Industrial Park, Hsinchu, Taiwan, R.O.C.) Device U1 provides the infrared sensing. Device R13 is a photo sensor that serves to prevent inadvertent triggering under daylight or other high light conditions.

Choosing the right Triac depends on the load characteristics. For example, an incandescent lamp operating at 110 V requires a 200 V, 8 A Triac. This gives sufficient margin to allow for the high current state during lamp burn out. U2 provides a minimum output Triac negative gate trigger current of 40 mA, thus operating in QII & QIII. This meets the requirements of a 25 mA gate Triac. Teccor also offers alternistor Triacs for inductive load conditions.

This circuit has three operating modes (ON, AUTO, OFF), which can be set through the mode pin. While the LSI chip is working in the auto mode, the user can override it and switch to the test mode, or manual on mode, or return to the auto mode by switching the power switch. More information on this circuit, such as mask options for the infrared trigger pulse and flash options, are available in the *Holtek* HT761X General Purpose PIR Controller specifications.

Time Delay Relay Circuit

By combining a 555 timer IC with a sensitive gate Triac, various time delays of several seconds can be achieved for delayed activation of solid state relays or switches. Figure AN1007.17 shows a solid state timer delay relay using a sensitive gate Triac and a 555 timer IC. The 555 timer precisely controls time delay of operation using an external resistor and capacitor, as illustrated by the resistor and capacitor combination curves. (Figure AN1007.18)

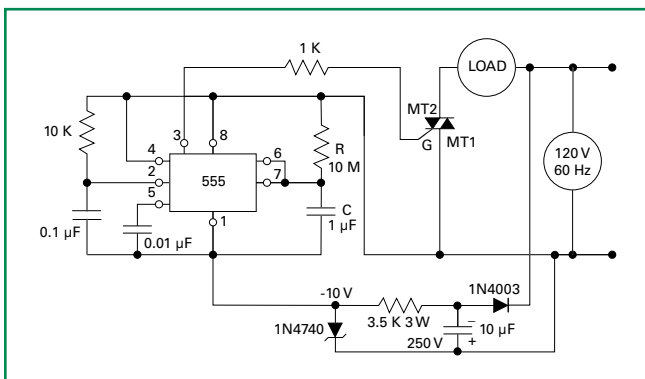


Figure AN1007.17 555 timer circuit with 10 second delay

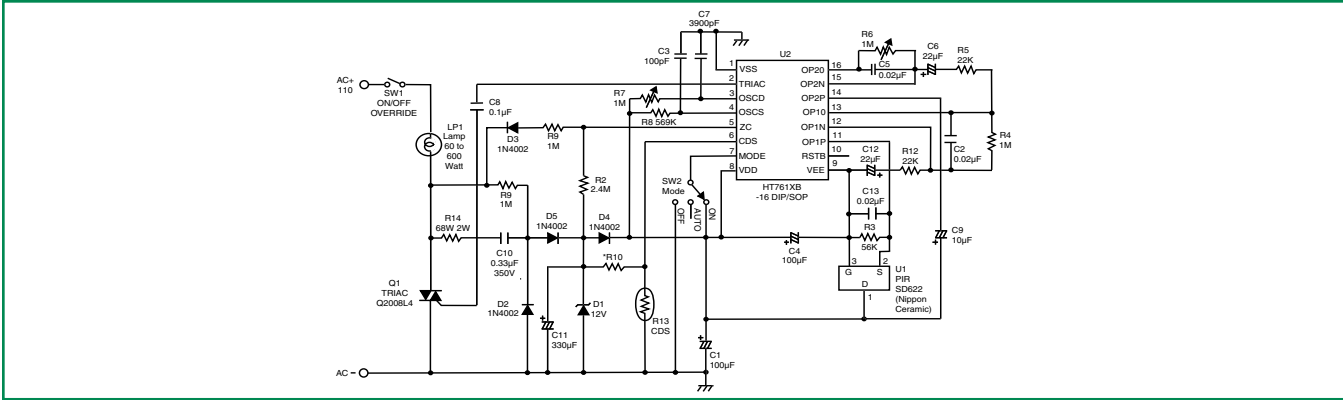


Figure AN1007.19 I R motion control circuit