Application Note AN-3006
Optically Isolated Phase Controlling Circuit Solution

Introduction

Optocouplers simplify logic isolation from the ac line, power supply transformations, and the control of polyphase power systems. They help solve problems by keeping ac line noise and transients out of sensitive logic. Fairchild's 6–Pin Dip Optocoupler family, with high surge voltage capability (7500 volts peak ac, 60 Hz, 1 second duration), allows designers to achieve their goals. This paper presents a power triac phase control circuit and contrasts it with the traditional zero–crossing circuit. The example circuit isolates the low level control circuitry from the ac line. It is able to control the speed of a universal motor or brilliance of a lamp. The universal motor is capable of high starting torque and wide speed range — commonly used in mixers, blenders, floor polishers, electric hand and woodworking tools, etc.

Zero–Crossing and Random Phase Triac Drivers

The zero–crossing triac driver optocouplers are the MOC316X and MOC308X series. The random phase optocouplers are the MOC301X, MOC302X and MOC305X series. All families have the same type of aluminum gallium arsenide infrared light–emitting diode but optically couple to different monolithic silicon detector chips. The zero–cross family is designed for interface applications between control circuit and power loads. The advantage of using zero–crossing switching is less surge current and resulting electromagnetic interference (EMI). This reduces reliability problems in many applications such as solid–state relays, industrial controls, motors, solenoids and consumer appliances. The high– speed zero–crossing switch provides a minimum dv/dt

from 500 V/µs to 2000 V/µs, protecting the device from accidental triggering by ac power line transients.

The circuit in Figure 1 is the basic circuit for on–off power control. With a continuous forward current through the LED, the detector of the zero–crossing optocoupler switches to the conducting state only when the applied ac voltage passes through a point near zero. Phase control applications, such as controlling the speed of a motor or brilliance of a lamp, require triggering at points along the ac voltage wave. This necessitates a random phase triac driver optocoupler.

Phase Controlling a Power Triac Using MOC3023

Design Objective

The application circuit shown in figure 2 is an example of phase controlling a power triac. The random phase triac driver is Fairchild's MOC3023. It has an LED trigger current I_{FT} of 5 mA and off–state output terminal voltage V_{DRM} of 400 V. The power triac used in this example has an on–state (RMS) current of 15 Amps at $T_C = 80C$. The load is a 1/3 HP, single phase induction motor driving a fan with maximum speed of 1750 rpm. This circuit can be applied to different power triacs and loads with larger rating. The design objective is to phase control a power triac that drives a motor or a light dimmer powered from the 115 VAC line. This is accomplished by using a variable pulse width generated from an optically isolated logic system with a control voltage of 5 to 15 VDC.
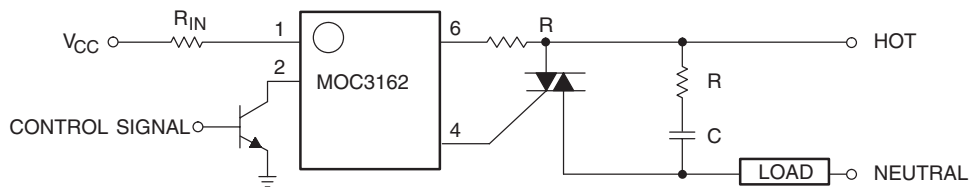
DESIGN RULE: V_{peak}/I_{peak} = 180 /1 amp = 180 ohms
(Assume the line voltage is 115 volts RMS)

Figure 1. Zero–Cross Switching Using MOC3061

System Block Diagram

The full wave zero–crossing sensor is connected to an optically isolated variable pulse width oscillator. The oscillator controls the conduction time of the optically isolated power triac, thus providing phase control to the load.
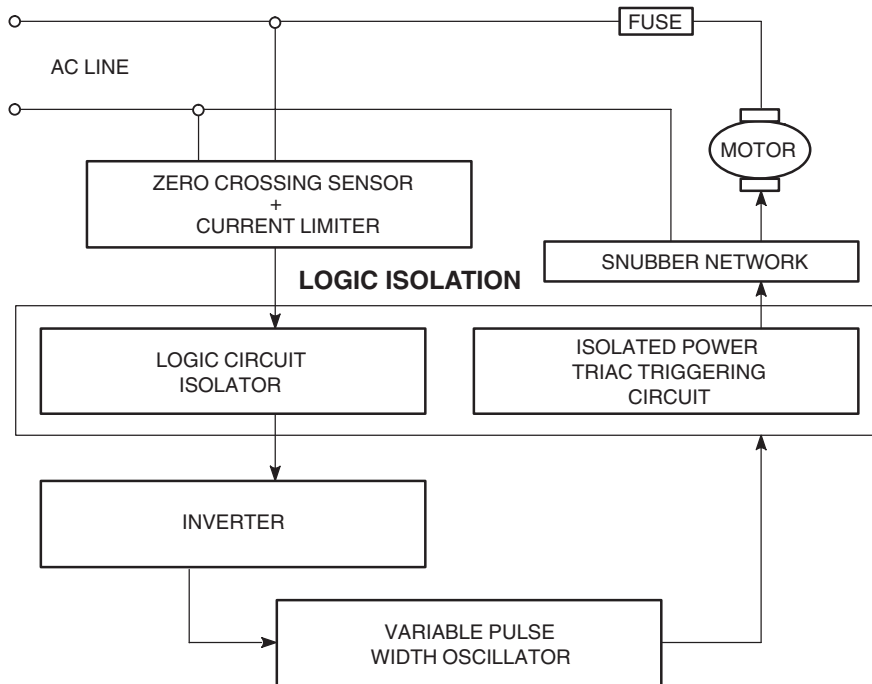

Figure 2. System Block Diagram

Circuit Description

Full Wave AC to Logic Coupling

The circuit begins with the ac line input voltage. It is rectified by the 1N4001 diode bridge rectifier and connected to the gallium arsenide LED of the H11L1 logic output optocoupler. A forward current (set between 10 and 50 mA) flows through the optocoupler LED, generating infrared radiation that triggers the high speed Schmitt trigger output stage into conduction. This occurs every half ac cycle, near the line zero crossing, at a constant input voltage defined by the zener diode.

Current Limiters

R1 is the limiting resistor for both the zener diode and the input LED of the optocoupler. R2 provides a small bias current to ensure the zener operates on the linear portion of its characteristic above the knee. It facilitates on–off switching of the LED by providing a path for leakage currents.

R1 = (VIN – VF) / IF   where
VF = diode forward voltage
IF = diode forward current

Optically Isolated Triggering of the Variable Pulse Width Oscillator

A dc signal with a pulse width of 720μs is generated at the output detector of the H11L1. The purpose of the MPSA40 NPN transistor is to generate an inverted signal, which goes into the trigger pin 2 of the LM555 monolithic timing circuit. See Figure 4 for the input trigger pulse versus the line voltage.

The Variable Pulse Width Oscillator

At every falling edge of the input trigger signal, the LM555 monolithic timing circuit generates a positive going pulse with duty cycle controlled by C1, VR1 and R5. The pulse duration is measured in time constants of $t = 1.1 \times (VR1+R5) \times C1$. See Figure 5 for the voltage across capacitor C1 versus the input trigger signal of the LM555.

Isolated Triac Triggering

The output signal (V_{td}) from the oscillator goes to the MOC3023 triac driver LED. When sufficient LED current (I_{FT}) passes through the LED, the triac driver latches on and generates a gate current in the power triac, triggering it into the conducting state.
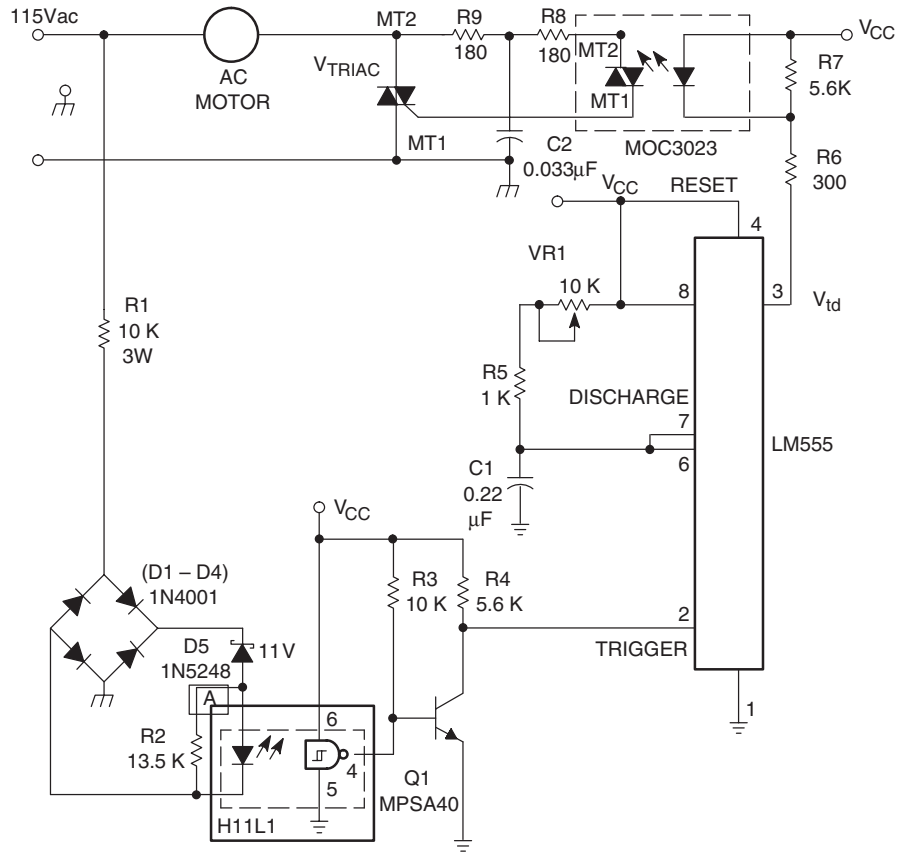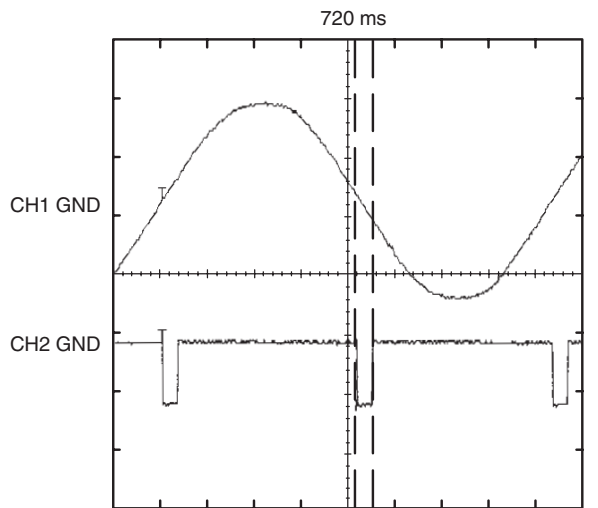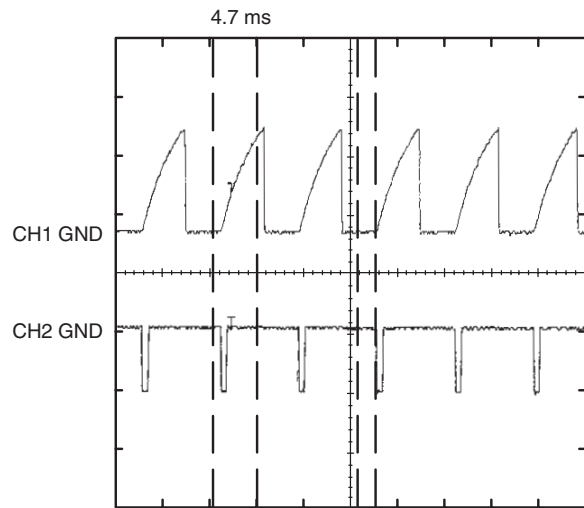
Figure 3. Schematic Diagram
Phase Controlling a Power Triac Using MOC3023

Time: 2 ms/div
CH1:   Line voltage waveform (100 V/div)
CH2:   Trigger signal measured at Pin 2 of the LM555

Figure 4. Zero Cross AC to Logic Coupling

Time: 5 ms/div
CH1:   Output voltage across C1 (2 V/div)
CH2:   Input trigger pulse to LM555 (5 V/div)

Figure 5. Capacitor C1 starts to charge up at the
falling edge of the input trigger pulse with a time
constant equal to 1.1*R5*C1

Once the power triac latches on, the triac driver will be forced into off–state even when I_{FT} is applied. The power triac MT2 to gate voltage falls to a low value below the opto-coupler's threshold voltage and cannot hold the optocoupler on. See Figure 8 for voltage across the power triac terminals (V_{TRIAC}) versus power triac gate trigger signal (V_{td}).

Minimum Load Power for Phase Control

The average power applied to the load is modulated by the duration of the waveform input to the triac driver. The longer the phase delay, the smaller the conduction angle and power delivered to the load. R5, VR1 and C1 set the minimum load power. This ensures power triac latching and optocoupler turn–off. This prevents optocoupler commutating dv/dt failure. The circuit in Figure 3 has a minimum conduction angle of 12 degrees. See Figure 9 for the voltage across the power triac terminals versus the input signal of the triac driver.

Snubber Network

The power triac can be switched on unintentionally if the rate of rise in applied voltage exceeds its dv/dt or the dv/dt of the triac driver. To prevent this false triggering, a single snubber limits the maximum dv/dt seen by the power triac and optocoupler. Snubber networks can be defined by assuming a power factor for the inductive load and modified later by measuring the actual dv/dt and adjusting the snubber as required. The snubber network used in Figure 3 results in a worst case dv/dt at the coupler of:

dv/dt $= Vto / (R9 * C2) = 180 / (180 * 0.033)$
        $= 30.3$ V/µs
V_{to} = instantaneous peak line voltage

The presence of load inductance (for example, when the load is a motor) results in significantly lower values of dv/dt. For details on designing the snubber network, refer to Fairchild application note AN3008.

R8 limits the peak capacitor discharge current through the triac driver. Its minimum value calculates as:

$R8 = V_{pk} / I_{max} = 180 / 1.2$ A $= 150$ ohm (1/2 W)
V_{pk} – gate trigger required voltage
I_{max} – rated surge current of the optocoupler

The author selected 180 ohms for the limiting resistor.

Conclusion

This application note demonstrates the use of triac drivers and power triacs in an ac logic isolation phase control application. The circuit designs are easily accomplished with relatively few components.
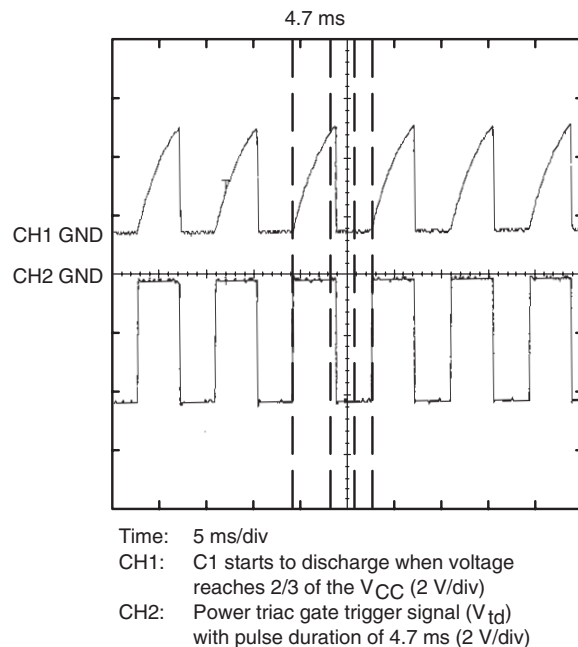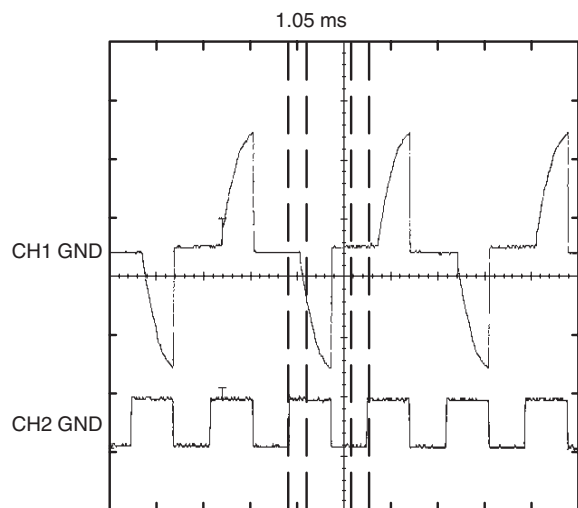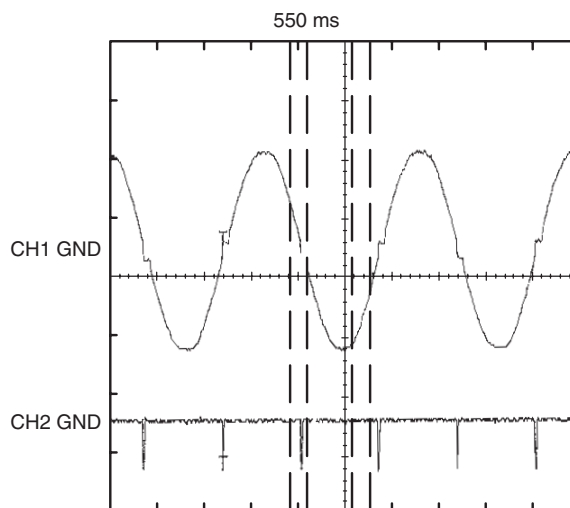
Time: 5 ms/div
CH1:   Output signal measured at Pin 3 of the MC1455 (2 V/div)
CH2:   Input trigger pulse to MC1455 (5 V/div)

Figure 6. Square Wave with Pulse Width of 4.2 ms Generated at Output Pin of the LM555

Time: 5 ms/div
CH1:   C1 starts to discharge when voltage reaches 2/3 of the V_{CC} (2 V/div)
CH2:   Power triac gate trigger signal (V_{td}) with pulse duration of 4.7 ms (2 V/div)

Figure 7. Capacitor Voltage versus Power Triac Gate Trigger Signal

1.05 ms

Time: 5 ms/div
CH1: Voltage across the power triac terminals (V_{TRIAC}) (100 V/div)
CH2: Power triac gate trigger signal, V_{td} (5 V/div)

Figure 8. Power Triac

550 ms

Time: 5 ms/div
CH1: Voltage across the power triac terminals (V_{TRIAC}) (100 V/div)
CH2: Power triac gate trigger, V_{td} (5 V/div)

Figure 9. Minimum Load Power

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