Evans Associates
Lafayette, California 94549
3149 Stanley Blvd.

Phone: (925) 947-5781
Cell: (925) 788-7736
E-mail: donevans@lazuli.com

ASIC/1-6000 DIAGNOSTIC RESULTS

Discussion of Triac driver malfunction with low-power Microprocessors

History of the evolution of the ASIC/1-6000

Many thousands of the ASIC/1-6000 have been manufactured by ASI Controls and shipped to customers all over the world. The manufacturer of the microprocessor utilized in the ASIC/1-6000 recently determined that the units they manufactured with a relatively small internal random access memory (RAM) should be superseded by units with a larger portion of internal RAM, probably because their manufacturing yield of the units allowed them to supply the larger RAM version for all purposes. Therefore, the unit used in the 6000 was made obsolete and ASI Controls, wishing to become 'green', selected another microprocessor of the same line, a lead-less unit, but with lower power consumption. It is the desire of all electronic manufacturers to produce products with no lead in the constituents. Several hundred ASIC/1-6000s were manufactured with this lower power microprocessor. ASI Controls has since elected to return to a higher power derivative microprocessor from the same family offered by the same vendor. The aim to stay 'green' will be attained by using this other 'lead free' microprocessor.

Description of ASIC/1-6000 operations

The ASIC/1-6000 is a Variable Air Volume damper controller with integrated motorized actuator. An internal Air Sensor gathers equivalent air volume performance and an intelligent algorithm then determines the appropriate position of the damper to regulate the zone temperature by means of adjusting air flow via the damper position.

In the cases of interest to this operational problem, there is also a means of providing heat to the local zone via a hot water coil, through which hot water is controlled by means of a motor driven fluid valve also controlled from the ASIC/1-6000.

The two motor driven devices are manufactured by the same vendor and have equivalent motor and internal control circuitry, both deriving their entire motive and control power from the output ports of the ASIC/1-6000. This power is provided from the local 24volt A.C. power circuit providing power to the controller itself. The actuation of the motorized devices is caused by using a Triac at the various outputs of the controller and turning this alternating current Triac on and off from the logic circuits of the microprocessor on the controller board.

A Triac is a four-layer semiconductor device with two of the layers connected to the alternating current circuit and two layers connected internally to a single control line called a Gate. When direct current (D.C.) logic voltage is applied to the Gate, the Triac is turned on and acts very much like a perfect mechanical switch, causing the A.C. circuit to operate the motor circuit and rotate the damper or the water valve open or closed. There is a separate Triac for each direction of the motor drives. By the nature of the physical characteristics of 4-layer devices, any On state Triac will turn off if and only if the logic level applied to the Gate is low or at common potential AND the alternating current passes through the zero voltage level of the sinusoidal current waveform. Therefore, Triacs turning OFF are considered very well-behaved devices, making no electrical noise when turning off.
The case of turning a Triac ON, however, is a slightly different story. Upon applying a high logic level to the Gate of the Triac, the layers connected to the A.C. circuit start conducting immediately anywhere in the sinusoidal waveform the circuit happens to be. There is no synchronization between the sinusoidal A.C. circuit and the logic applying the Gate signal.

Both of the motorized devices controlling the damper and the water valve are inductive by the very nature of coil wound motors, whether A.C. or D.C. operation. The voltage generated across any inductance is proportional to the rate of change of the current flowing through the inductance (E=Ldi/dt). Because of this characteristic of the physical laws of nature, it can be seen that when a Triac goes OFF, at the point of zero current flowing through the inductance of the motor, there is essentially ZERO voltage generated across the inductance and therefore the Triac has a zero voltage drop across it and is therefore considered well-behaved.

When the Triac turns ON, just anywhere in the sinusoidal waveform of the applied A.C. circuit, the story is different. If the waveform is at zero-crossing, no voltage is generated across the inductance of the motor. If the waveform is non-zero, there will be a spike of voltage generated determined by the rate of change of the imposed current through the inductance. Low sinusoidal voltage will force relatively low currents to be driven through the inductance and because of the resistance found in all wiring, the rate of rise of small currents will also be relatively small, resulting in low voltage spikes.

In the event of turning ON at peak sinusoidal voltages, a maximum voltage drop will force a large current to change in a short time, therefore, there will be a much larger voltage spike generated for a short time, long enough for the current to maximize and then the spike will disappear, usually in a few micro-seconds. It is the amplitude of the voltage spike across the inductance and therefore imposed across the Triac that we are interested in.

Effected circuit description

The ASIC/1-6000 offers five (5) output ports, all with Triacs, all operated from logic circuitry attached to the output port of the microprocessor utilized in the controller. The circuitry between the microprocessor port and the Triac is identical in all five cases, however the routing of signal leads is somewhat different for two of the circuits, as compared to the other three. The two that differ from the others follows a path that passes over a large area of the circuit board internal ground or common plane. This is the copper layer that is normally connected to the local building ground in all applications. Noting that there is a very thin layer of non-conducting insulator material between the ground plane and the leads leading to the Triac from the interposing circuitry, a considerable amount of distributed capacitance is to be found between the control leads and the ground plane. Distributed capacitance is that incremental capacitance that any variable electric signal encounters as it progresses along the leads. It is not the same thing as a lumped capacitance such as is applied at many positions in all electronic circuits. Lumped capacitors do their job when the signal gets to them, whereas distributed capacitance must be electrically charged as the electrical signal moves down the path. Charging of any capacitance takes energy and that energy is supplied from the electrical signal itself.

Because of the nature of changing logic signals from microprocessors, it is impossible to apply lumped capacitance to any of the input/output signal ports, as that would bring the entire microprocessor to a standstill. The distributed capacitance is in place by the physical nature of printed circuit boards and is normally thought to be a limitation to the speed with which microprocessors can perform. In this case, the distributed capacitance for the two leads of interest is of some benefit, as will be seen.

The two Triac circuits with the larger amount of distributed capacitance are outputs numbered one (1) and two (2). In the default configuration for outputs in the VAV controller configurable memory, these two outputs are applied to the damper circuit, number 1 for opening the damper and number 2 for closing it. In all cases and installations, the controller is attached to this integral damper motor and is always tested in that position.

The Problem encountered

A problem arose in an installation that included a hot water valve control for zonal reheat, attached to controller outputs three (3) and four (4). When the valve motor was actuated, at some point in the normal on and off operation of the valve, the ASIC/1-6000 simply ceased functioning. This is termed 'lockup' and is a completely unacceptable behavior. When reset, and power again applied, the controller continued to operate normally until; again, it would lock up. The time from start of operation to lockup varied from immediately to several minutes. Units returned from this installation were examined and the lockup condition could be replicated in the laboratory with no difficulty. The first test conducted was simply to detach the damper motor from outputs 1 and 2 and apply them to outputs 3 and 4. The change in configuration so that the program would be aware of the change of the damper motor to those outputs resulted in a similar lockup condition. Applying the water valve motor circuit to outputs 1 and 2 and again alerting the program of the change resulted in normal operation of the water valve with no lockup.

It should be born in mind that all tests described herein have been performed on the 'low power' version of the controller board as well as on a control board with the 'high power' original microprocessor in place. Following the principles of the Scientific Method, all tests were performed using the ABA test protocol, i.e., a test is performed with a single change, followed by a test without that change and then re-performed with the change again. This technique provides assurance that the results of tests are reproducible and can be shown to be adequate.

Examination of the printed circuit board verified that the lead variations described above were there and the distributed capacitance on leads 1 and 2 was determined to be the possible explanation for the difference in output behaviors.

Circuit details and characteristics

The interposing circuitry between the Triac and the microprocessor port was examined. The original design had interposed a transistor circuit between the microprocessor port and the Triac Gate, leading to both isolation and signal inversion. When the microprocessor port lead is ON, clamped to common, internal to the integrated circuit, the NPN transistor is kept in the OFF condition, allowing the collector of the transistor to cease conducting current and a resistor connected to +12 volts applies that voltage to the Gate of the Triac, thus turning it ON. Conversely, when the micro port lead is turned OFF, the transistor base is driven positive through the base resistor that is connected to +5 volts. This results in strong conduction through the collector of the transistor to common, such that the resistor that drives the Gate of the Triac is clamped to near common and the Gate turns off and the Triac then turn OFF at the next zero-crossing of the current waveform.

Examining the circuit when turning the Triac ON shows that when that voltage spike due to the inductance of the motor circuit occurs, the interposed transistor is OFF and the microprocessor port lead is ON. The physics of transistors is somewhat complicated to describe in this paper, but the salient point is that in an OFF transistor, the REVERSE voltage required to break down the Collector-Base junction is only about 50 millivolts. Should a voltage spike travel down the circuit from the Gate of the Triac, encounter the transistor collector, it would take very little to break down that junction barrier and travel on down the line to the microprocessor itself.

It must be kept in mind that the voltage spikes encountered when dealing with inductances can and often do induce relatively large currents in associated circuitry. Oscilloscope images cannot display the results of transient currents because such instruments only react to voltages. The currents induced by voltage spikes travel rapidly down circuitry and unless dissipated by charging distributed capacitances, continue un-impeded.

What to do?

The first analysis is to determine whether the low power version of the microprocessor is particularly susceptible to these suspected transient currents? How does a vendor make a 'low power' device out of a 'higher power' unit? It is first necessary to understand how transistors are related to power consumption. In external circuitry, power is dissipated in resistive elements and transistors simply act as switches to change the direction and determine which resistor will dissipate energy and which will not. In the micro-technology of modern microprocessors there are essentially NO resistors, but all transistors are simply tied together through internal micron sized connections. In such cases, the power dissipated by transistors is directly related to their physical size. To make a 'low power' device, the vendors reduce the size of every transistor in the integrated circuit. This reduces the 'bulk' of the semi-conductor material used in the formation of a transistor, but it also reduces the amount of current able to be handled by the transistor. Lower current means lower power, P=IxE.

The same current spike that the low power microprocessor can't handle is adequately handled by the higher power devices, simply because they are more robust. When an output transistor is in the ON state, it is conducting to the ground substrate within the integrated circuit. When a large transient current is sent down that lead, the current travels through the ON transistor and directly into the ground substrate. This bounces the substrate at that locality in the integrated circuit, causing chaotic conditions such that adjacent circuitry malfunctions. Luckily it is not permanently damaging, but just momentarily interrupts normal operation. In larger transistors, the bulk of the semiconductor material more adequately absorbs the energy and avoids catastrophic results.

A Solution

In some fashion, the effect of the distributed capacitance in leads 1 and 2 must be provided for leads 3 and 4, in those controllers that have the low power version of the microprocessor installed. Adding a bulk capacitance to the circuit doesn't offer the same damping effect for reasons described above. However, there is another method that can offer protection from this debilitating current getting back to the microprocessor. That is to insert an energy consuming buffer between the Triac Gate and the microprocessor port lead. Examining the circuit, it is found that a resistor cannot be inserted in series with the microprocessor port lead to the base of the interposing transistor, because it would result in a voltage divider circuit which would prevent the transistor from being turned OFF when the output port of the processor goes ON. Another location that holds promise is between the collector of the transistor and the Gate of the Triac. When a voltage spike occurs due to the Triac turning ON, a resistor stands in the way of any current delivered to the logic circuitry and must be transited prior to reaching that circuitry. Any current traveling through a resistive element results in a voltage drop across that resistive element. That locally generated voltage is then subtracted from the spike of voltage such that the resultant current is diminished.
A value of resistance is then selected that will impede the transit of current sufficiently to deter any ill effects at the microprocessor. The only remaining task is to determine the most efficient method of retrofitting low power boards with the fix. This approach has been applied and has been tested and will be further tested at temperature extremes and power supply variations to assure absolutely accurate performance of the ASIC/1-6000 under all operating environments.