Application Note
Low-Cost AC Zero-Crossing Detection Design

TEXAS INSTRUMENTS

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ABSTRACT

This application note presents a simplified methodology for detecting zero-crossing points in AC power lines operating at voltages up to several hundred volts. The design lies in the minimal external component requirement—requiring only a single resistor to implement a fully functional detection circuit. Based on this, this delivers significant advantages in cost-driven and space-constrained applications.

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1 Implementation

This design requires only a single external resistor combined with the internal clamping diodes of the MSPM0 microcontroller to achieve reliable zero-crossing detection.
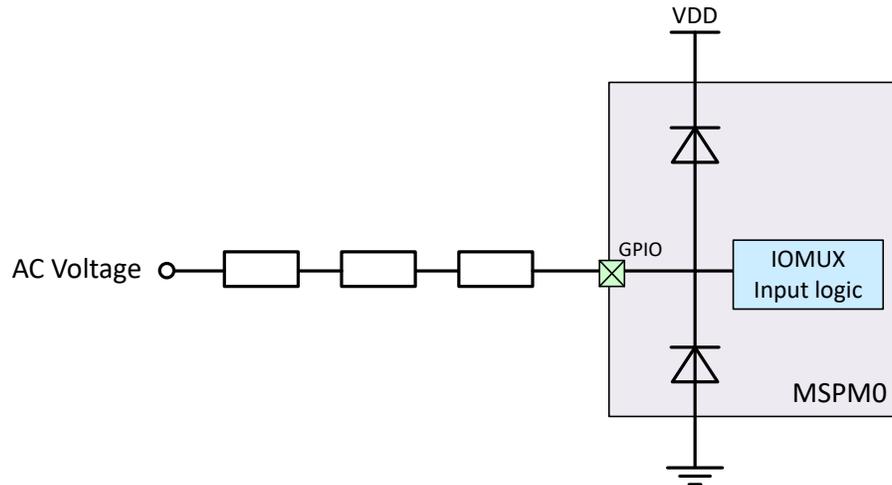
Figure 1-1. ZCD Diagram

The built-in clamping diodes protect the MCU from electrostatic discharge (ESD) by limiting the input voltage to the range of -0.3V to VDD + 0.3V. For detailed information about internal IOMUX, see *MSPM0 C-Series Microcontrollers*. In this design, this clamping mechanism makes sure that any externally applied AC voltage beyond the VDD or below 0V is forcibly restricted within the 0–VDD range. Importantly, the original AC signal segments that naturally fall within this valid voltage window remain unaffected, thereby preserving the zero-crossing characteristics. As a result, the MCU can reliably detect AC zero-crossing moments through GPIO interrupts or similar methods while maintaining strict compliance with the specified operational conditions. This approach enables precise AC signal monitoring without compromising device integrity.
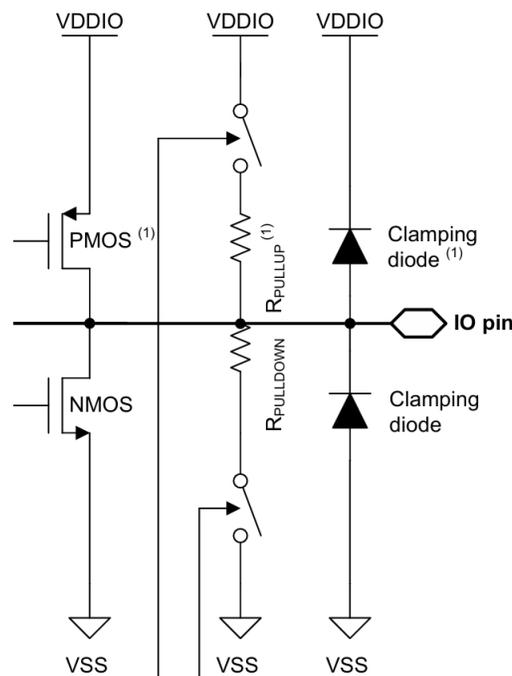
Figure 1-2. MCU IOMUX Diagram

To strictly adhere to the specified GPIO input current limit of 6mA for the MSPM0 microcontroller as defined in the data sheet, a high-impedance current-limiting design using a series-connected resistor network is the least expensive method. Here 1MΩ is selected. This configuration effectively restricts the peak input current to approximately 311µA when exposed to China's standard 220VAC/50Hz mains voltage (calculated as 220Vrms × √2 / 1MΩ), which verifies reliable operation well within the absolute maximum ratings of the device.

The adoption of a distributed resistor topology - employing multiple series resistors rather than a single high-value component - was specifically selected to enhance the performance characteristics of the circuit: this approach not only verifies voltage withstand capability through improved electric field stress distribution but also optimizes long-term reliability by minimizing thermal aging effects and eliminating single-point failure modes.

2 GPIO Selection in MSPM0

All general-purpose I/O (GPIO) pins on the MSPM0 are equipped with clamping diodes except the 5V-tolerant open drain IO pins. If using ODID pins, additional external protection circuitry can be required.

When configuring a GPIO with analog ADC functionality, adjacent pin current effects must be carefully considered. During ADC conversion on one channel, if injection current occurs on an adjacent pin exceeding VDD (positive injection), this activates the PMOS switch while pulling the mid-node to ground. This creates an alternate current path to ground rather than through the ADC channel, thus preventing leakage interference and maintaining conversion accuracy.

Conversely, negative injection (<0V) activates the NMOS switch when the adjacent pin drops to -0.7V, causing unintended leakage flow through the ON channel, as shown in Figure 2-2. This introduces an voltage drop across the conducting path, ultimately distorting ADC readings and potentially causing code errors.
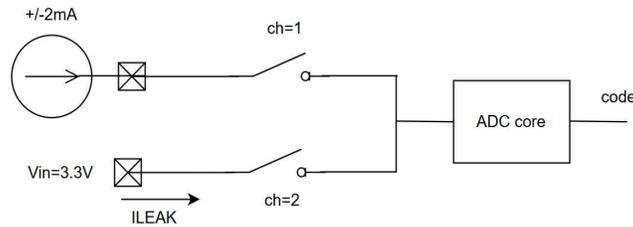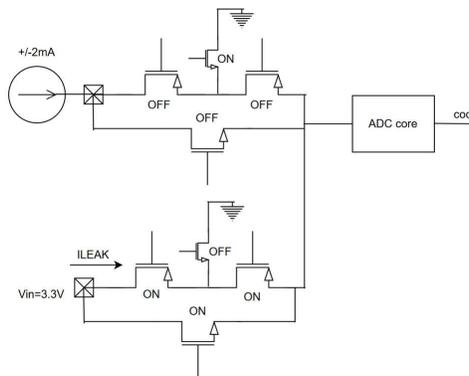

Figure 2-1. ADC Channel Diagram

Figure 2-2. ADC Internal Circuit

Fortunately, this issue is resolved in our newer hardware revisions. For current production devices, the ADC functionality performs as intended without adjacent-pin leakage risks. However, when working with earlier devices (for example, MSPM0L1x0x or MSPM0Gx50x), TI strongly recommends avoiding GPIO channels assigned to ADC analog functions to prevent potential signal integrity issues.

3 Typical Application

3.1 AC Drop

In industrial equipment front-end AC signal monitoring systems, zero-crossing detection (ZCD) methodology proves particularly valuable for real-time power failure detection. The implementation involves passing the AC signal through a full-bridge rectifier configuration, where the rectified output flows through a high-value current-limiting resistor. Clamping diodes are strategically employed to restrict the voltage amplitude within safe operational boundaries while verifying signal integrity. The voltage after being clamped by the internal diode of the MCU is shown in Figure 3-1.

For standard 220V and 50Hz mains monitoring, the voltage typically rises from 0V to VDD within approximately 50µs after zero-crossing. By implementing a software algorithm that starts a 100µs watchdog timer upon zero-cross detection, any failure to recover high voltage within this window reliably indicates power failure. Additionally, precise AC frequency measurement can be derived from the time intervals between consecutive zero-crossings. This approach effectively detects both complete outages and frequency variations while requiring minimal computational resources.
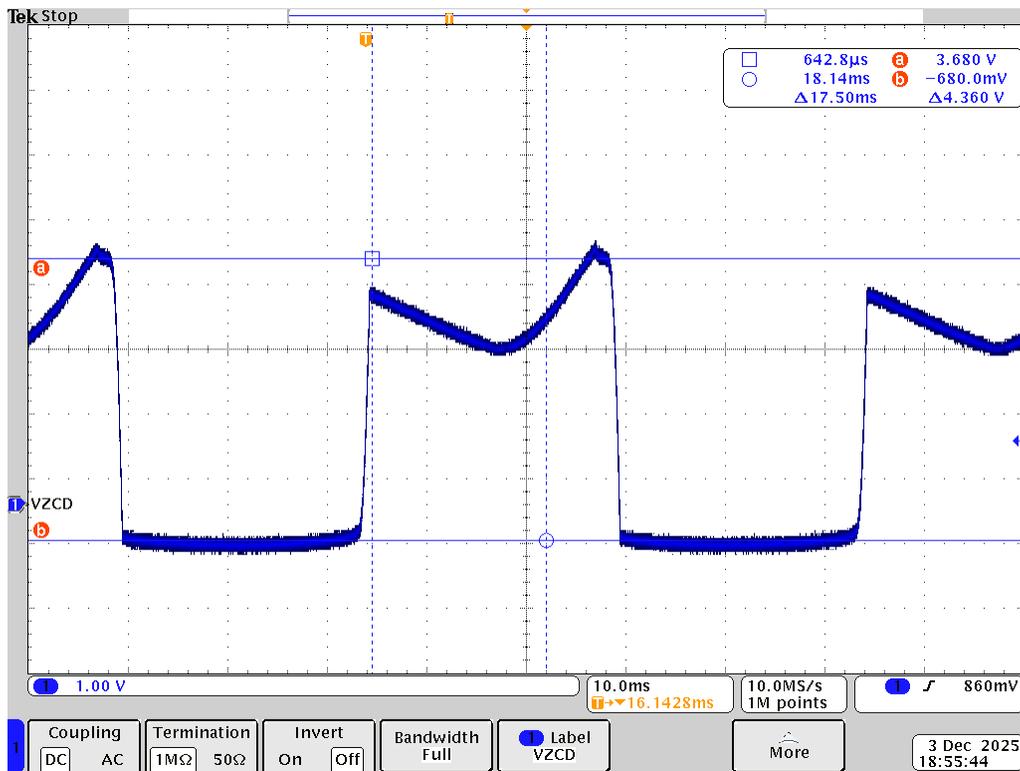

Figure 3-1. Voltage of MCU Input Pin

3.2 Triac Control

In cost-sensitive applications such as basic blenders and vacuum cleaners where minimizing BOM cost is critical, triacs are typically employed as the switching design for driving AC motors. The heart of the system lies in zero-cross detection (ZCD), which:

1. Determine the conduction state of the AC waveform
2. Calculate the firing angle for subsequent triac triggering
3. Synchronize power delivery with the AC cycle

This zero-cross referenced timing mechanism enables effective motor speed control while maintaining the ultra-low-cost implementation of the system – using just a single triac with basic microcontroller supervision, rather than more expensive IGBT-based designs or dedicated motor driver ICs.

In Figure 3-2, channel 1 shows zero voltage detection signal applied to the MCU. The signal is obtained by clamping a large AC voltage and is toggled whenever the mains voltage crosses zero. Channel 2 is the TRIAC gate control signal. MCU detects the voltage zero cross and calculate the firing angle to synchronize the TRIAC gate signal with the mains voltage.
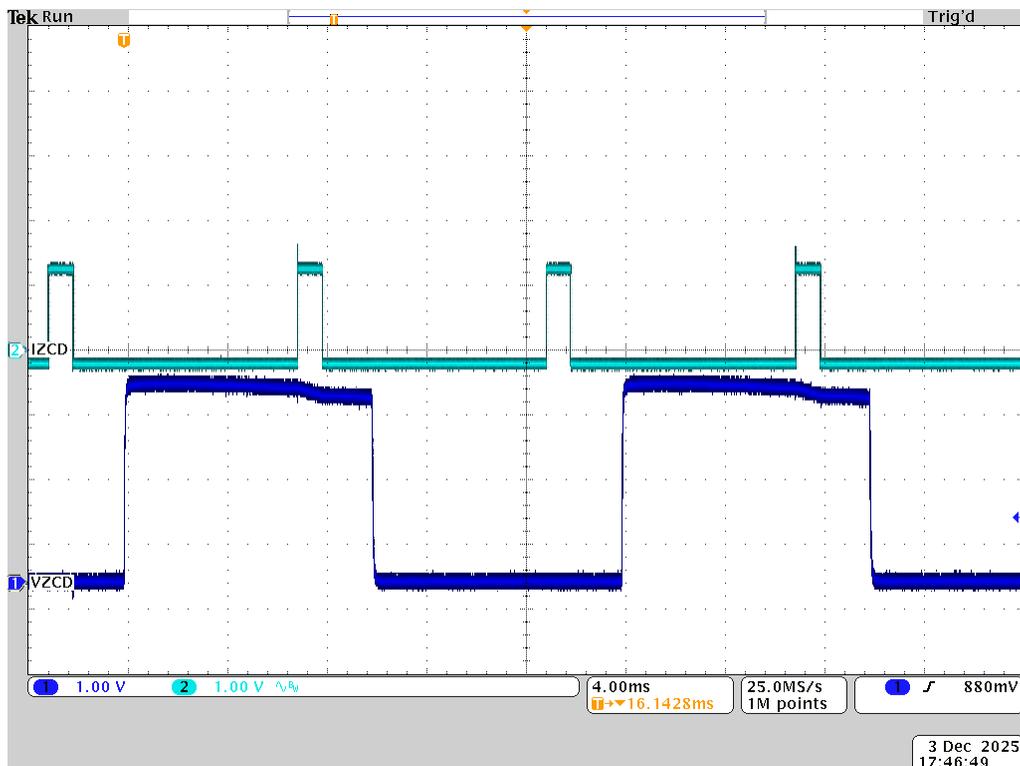

Figure 3-2. Zero Voltage Detection in Triac Motor Driver System

4 Summary

This paper focuses on implementing cost-optimized zero-cross detection (ZCD) designs for AC signal processing. By employing ingeniously simplified circuit designs requiring only fundamental components, the proposed ZCD module can be used in different applications.

5 References

1. Texas Instruments, *MSPM0C110x, MSPS003 Mixed-Signal Microcontrollers*, data sheet.
2. Texas Instruments, *MSPM0L130x Mixed-Signal Microcontrollers*, data sheet.
3. Texas Instruments, *MSPM0C1105, MSPM0C1106 Mixed-Signal Microcontrollers*, data sheet.
4. Texas Instruments, *MSPM0 C-Series Microcontrollers*, technical reference manual.
5. Texas Instruments, *LP-MSPM0C1104 Evaluation Module*, EVM user's guide.
6. Texas Instruments, *LP-MSPM0C1106 Evaluation Module*, EVM user's guide.

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