

Using a Comparator in a Zero-Crossing Detector

AND90422/D

Introduction

A zero-crossing detector (ZCD) is an electronic circuit used to identify the precise instant at which an input signal crosses a defined reference level, most commonly 0 V. At this transition point, the polarity of the input waveform changes. Zero-crossing information is fundamental in numerous applications, including AC phase control, motor control, grid synchronization, and timing or frequency extraction.

A comparator (such as NCS2250) represents an optimal functional element for implementing a ZCD. By comparing an input signal against a reference voltage, the comparator produces a digital-like output that switches states whenever the polarity relationship between its inputs changes. Owing to their fast propagation delay and well-defined switching behavior, comparators are widely adopted for reliable zero-cross detection.

Principle of Operation

A comparator output saturates to one of its supply rails depending on the sign of the input voltage difference. When configured as a zero-crossing detector, the reference input is set to 0 V (or close to 0 V), and the detected signal is applied to the other input.

- If the detected signal (connected to non-inverted input) is positive, the comparator drives its output to a positive saturation level.
- If the detected signal (connected to non-inverted input) is negative, the output swings to a negative saturation level.

Comparators are naturally suited for this task because they are designed to operate with saturated output rails and sharp transitions between states.

Circuit Description

Basic Zero-Cross Detector Structure

A conventional comparator-based ZCD consists of the following functional blocks:

- A comparator IC (dedicated comparator preferred due to faster switching and absence of internal compensation).
- Input signal conditioning, which may include attenuation, filtering, overvoltage protection, or galvanic isolation (e.g., transformer or optocoupler).
- A reference input, fixed at 0 V or close to 0 V.
- An output stage interface, compatible with downstream logic, microcontrollers, or control circuitry.

Upon crossing the reference voltage, the comparator output switches between its saturation rails, generating a clean digital representation of the input signal polarity.

Hysteresis (Optional but Recommended)

In the absence of hysteresis, noise present around the zero-crossing point can cause multiple unwanted output transitions. To mitigate this effect, positive feedback may be introduced to generate hysteresis, thereby establishing two distinct switching thresholds:

- A slightly positive threshold
- A slightly negative threshold

Hysteresis significantly enhances noise immunity and ensures stable operation in electrically harsh environments. Circuits employing this technique are often described as threshold detectors with hysteresis. Please see the datasheet for details on hysteresis design.

Principal Schematic

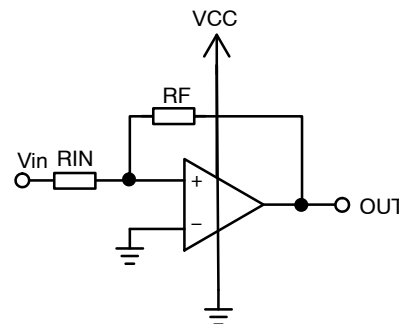


Figure 1. Comparator Configured for Zero-crossing Detection with Optional Hysteresis Feedback

Design Considerations

Comparator Selection

Key parameters for comparator selection include:

- Output level – compatible with subsequent circuitry
- Propagation delay – appropriate for the signal frequency and required system response time
- Output configuration – Push-pull or open-collector based on interface and level-shifting requirements
- Input common-mode range – encompassing the expected signal range

Input Signal Conditioning

Direct connection of high-voltage or mains-referenced AC signals to a comparator is not permissible. Therefore:

- Use a safe attenuation network and appropriate clamping circuits.
- Consider galvanic isolation where safety or regulatory requirements dictate.
- Input common-mode and absolute maximum ratings specified in the datasheet must not be exceeded.

Output Interface

Depending on system requirements, the comparator output may be configured as:

- Push-pull output for minimum propagation delay, provided the logic system tolerates the comparator supply voltage.

- Open-collector or open-drain output with pull-up resistance, enabling level shifting and multi-voltage domain compatibility.

Example Operation Waveforms

When the AC signal is applied to the input:

- As the waveform rises from negative to positive and crosses 0 V, the comparator output switches from negative rail to positive rail almost instantaneously (assuming minimal hysteresis and short propagation delay).
- As the waveform falls back below 0 V, the output switches again to the opposite rail.

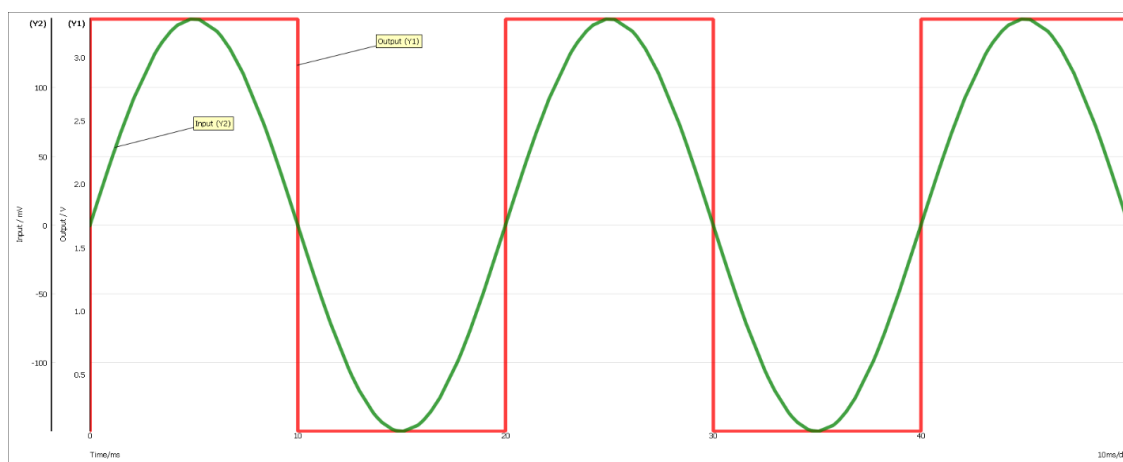


Figure 2. Depicts the Qualitative Relationship between the Input Sinusoidal Waveform and the Resulting Comparator Output

Applications

Zero-cross detectors built with comparators are used in:

- AC signal phase control
- Motor control and soft-start circuits
- Grid synchronization for inverters
- Frequency measurement and timing extraction
- Control loops in switch-mode power supplies (buck, boost, PFC stages, synchronous rectification)
- Safety monitoring and protective shutdown mechanisms

Limitations

Despite their simplicity and effectiveness, comparator-based zero-crossing detectors exhibit several practical limitations:

- Input offset voltage and bias currents introduce a finite zero-crossing error.
- Noise and high dv/dt signals may cause jitter without adequate filtering or hysteresis.
- Propagation delay imposes a phase error that increases with signal frequency.

- Input common-mode range limitations restrict usable signal amplitude, especially in single-supply designs.
- Saturation recovery time may affect high-frequency or narrow-pulse applications in some comparator architectures.

These constraints must be considered during system design to ensure reliable operation.

Summary

A comparator provides a robust and efficient solution for implementing a zero-crossing detector, offering fast switching, rail-to-rail saturation, and a digital-compatible output. Proper component selection, careful input conditioning, and the judicious use of hysteresis significantly improve accuracy and noise immunity. When system-level limitations are accounted for, comparator-based ZCDs remain a well-established and reliable building block for AC signal processing applications.

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REVISION HISTORY

Revision	Description of Changes	Date
0	Initial document release.	6/2/2026

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