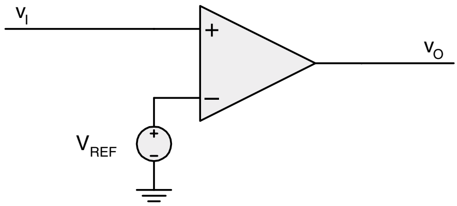

FIGURE 14.28 Open-loop voltage comparator.

when reading through a comparator's data sheet. Specifications such as V_{IO}, I_{BIAS}, I_{IO}, and gain are observed. However, op-amps and comparators are optimized for different characteristics. Op-amps are designed specifically for linear operation in closed-loop configurations. When operated open-loop, some op-amps may exhibit unstable output behavior. A comparator IC is specifically designed for open-loop operation with approximately rail-to-rail output behavior and fast switching times. Op-amp manufacturers discourage using op-amps as comparators for these reasons. Having said this, though, many engineers do adapt op-amps for use as comparators with success. If a quad op-amp such as the LM324 is already in a design that uses only three of its sections, it is tempting and economical to use the fourth section as a comparator if the need arises. In many cases, especially when working with mature bipolar devices, spare op-amps may be safely used as comparators.

The open-loop comparator in Fig. 14.28 is simple, but it has the drawback of being extremely sensitive to minute changes in the input voltage in the vicinity of V_{REF}. When v_I is either less than or greater than V_{REF} by some margin, the op-amp's output is clearly defined. However, when v_I is approximately equal to V_{REF}, the result is less clear. Because of the large open-loop gain, very small changes in v_I cause large changes in v_O. If v_I does not rise or fall monotonically around V_{REF} (consistently increasing or decreasing voltage without any temporary changes in the voltage curve's slope), the minute back-and-forth progression of the voltage curve will be greatly amplified and result in oscillation at the output. This is illustrated conceptually in Fig. 14.29. Note how very small voltage changes around V_{REF} cause v_O to swing from one extreme to the other.

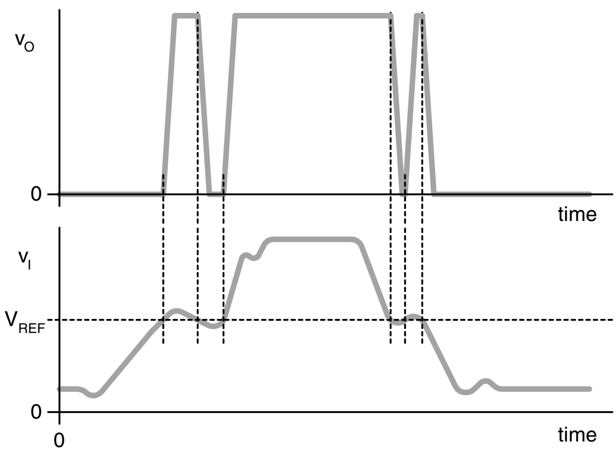

FIGURE 14.29 Unstable voltage comparison without monotonic input.

It can be difficult to achieve a perfectly monotonic signal because of ambient noise in a system. If the signal can be guaranteed to rise and fall quickly, the window of opportunity for noise to trigger an undesired response at V_{REF} is limited. This is how the majority of signals in a digital system operate. The rise and fall times are relatively fast, and the signals remain stable at logic-high and logic-low voltages. Problems do arise, however, when excessive noise or other signal integrity issues manifest themselves by causing nonmonotonic signal transitions. In a purely digital context, such problems can be solved with proper engineering solutions to reduce and shield noise and signal integrity problems. Most real-world analog signals do not behave in a clean binary fashion, which is why they often require analog circuits including op-amps and comparators to properly interface with digital systems.

Threshold comparison can be improved by adding *hysteresis* to an otherwise open-loop voltage comparator. Hysteresis is the application of two thresholds to stabilize a comparator so that it does not change its state with minute changes in the input voltage. Stabilization is desirable in situations wherein the applied voltage hovers near the threshold voltage for more than a brief span of time as seen in Fig. 14.29. Rather than a single threshold, separate low-to-high, V_{TLH}, and high-to-low, V_{THL}, thresholds are designed. V_{TLH} is higher than V_{THL}, as demonstrated in Fig. 14.30, where a much cleaner output is obtained as compared to the previous case. Note that the hysteresis created by the two thresholds prevents the comparator's output from returning to logic 0 when the input declines slightly after triggering a logic-1 output. Similarly, the input's nonmonotonic falling-edge does not cause the output to bounce, because the hysteresis is chosen to be greater than the local perturbation.

A *hysteresis loop* is a common means of representing the two distinct thresholds governing the input/output transfer function. Figure 14.31 shows that, when the input is starting from the low side, the high threshold is used to trigger an output state transition. As soon as the input crosses the high threshold, the output goes high, and the low threshold is now applied to the input comparison. Notice the advantage here. Once the input rises above the high threshold, a lower threshold is instantly substituted. This means that, if the input signal wanders and declines slightly, it is still above the lower threshold, and the output is unaffected. For the output to return low, the input must now fall below the low threshold. And as soon as this occurs, the high threshold is again activated so that the input must rise significantly before an output stage change will occur.

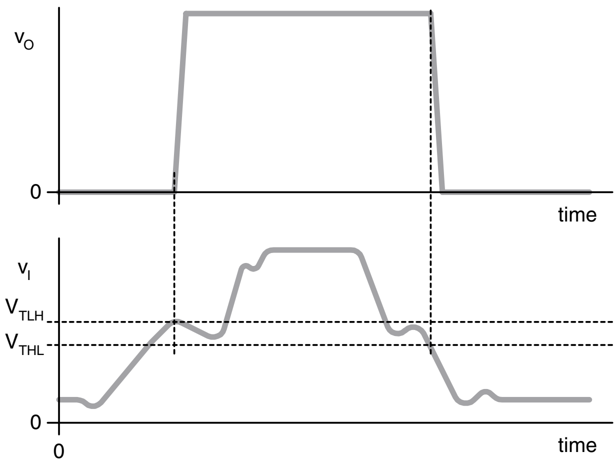

FIGURE 14.30 Effect of hysteresis on nonmonotonic input signal.