TUTORIAL

The Why, What, How, and When of Using Microprocessor Supervisors

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Abstract

Microprocessor supervisor circuits provide low-cost and effective insurance; a means to monitor and maintain system operation when software-based errors occur, a critical feature for today's complex electronic systems. Applying techniques developed over the past several years, today's supervisors feature low power consumption, low cost, and a wide range of integrated functions in very small packages. The following tutorial provides an overview of these circuits and helps system developers troubleshoot any design issues that can occur, helping to quickly and efficiently resolve them, so that important system design continues without difficulty.

Why Supervisory Circuits Are Important

The world throws a wide range of problems at microprocessor system designers: power supplies that come up in the wrong sequence, ramp up or stabilize too slowly; supply voltages that glitch up and down due to external-component loads; or peripheral components and boards that fail to power up and communicate in synchronization with the needs of the processor. As system designers, we do everything we can to minimize these events within a fixed budget, but the most successful engineers design their system to operate safely even when a problem occurs. We want to ensure that our microprocessor-based system starts properly every time; that it detects when a system error has occurred or is about to occur; that the system minimizes the effect of these errors; and that it returns safely from an error with little or no user intervention.

The modern microprocessor supervisor circuit is a low-cost and effective method for monitoring and maintaining such system activity. Applying techniques developed over the past several years, today's supervisors provide the insurance needed by microprocessor systems. They feature low power consumption, low cost, and a wide range of integrated functions in very small packages.

Let's look further into some standard supervisory devices to better understand how and why they are used with real-life problems and solutions associated with microprocessor systems.

What Supervisors Can Do for Your Design

Voltage Detection

Why would a system need a voltage monitor or reset IC? If a power-supply rail goes out of tolerance, the circuit may operate erratically, stop operating, or even catch on fire (well-known product recalls prove the impact and cost of these issues). A voltage monitor allows supervision of supply rails to prevent such conditions. Voltage detectors and power-on reset circuits both provide an early indication of supply-voltage deviations to protect the system. Voltage detectors simply indicate that a voltage is above or below a specific value. They do not provide any timing delays and generally have very limited noise immunity.

One example of a voltage detector is the MAX16012, a single-voltage detector that can be configured for overvoltage or undervoltage monitoring. The open-drain output asserts low when the monitored voltage exceeds (above or below) the set threshold. The output de-asserts when the monitored voltage returns to normal operating range.

A power-on reset IC, as discussed later, monitors a supply voltage and resets or turns off another device, like a microprocessor, if the supply voltage is low. These devices usually have a programmable output delay to prevent the system from returning from reset before the supply voltage is stable. Voltage detectors and reset ICs have different features and parameters, making it tough to choose the right one for a given application. The process can be simplified by using a customizable supervisor decision table that presorts based on the most common features, including power consumption, package size, highest threshold accuracy, lowest monitored voltage, high-supply voltage and IC temperature range. The key to choosing a voltage supervisor is to know the features you need and then select one based on your needs.

Multiple-Supply Monitoring

The newest processors and many other systems require multiple-supply voltages. The trend toward multiple-supply devices is especially evident in high-speed small-geometry digital signal processors, which can communicate with a standard system I/O voltage of 3.3V but operate with a core logic of 2.5V or lower. Often, these systems must also communicate with sensors of different I/O voltages. These devices often require that both supplies be within the processor's tolerance before the power-on reset (POR) is released. Similarly, a complex system can maintain four or five supply voltages (12V, 5V, -5V, 3.3V, and 2.5V, for example), which support a variety of analog and digital components.

An undervoltage condition on any of these voltages can cause a system failure. A simple remedy is an RC circuit. Despite being low cost, a simple RC network cannot monitor multiple supplies simultaneously while providing a single valid logic level for the system reset.

A multivoltage monitoring IC provides voltage monitoring for several voltage rails. Some versions use factory-set threshold voltages, while others use external pins to select the threshold voltages. For maximum flexibility, some monitoring devices are available with an SMBus™ or JTAG interface to program the threshold voltages.

A variety of multivoltage monitors are available, from simple two-voltage supervisors to twelve-voltage devices with multiple thresholds and integrated features such as ADCs, temperature sensors, and current-sense amplifiers. Some monitors have additional options including a built-in watchdog timer, capacitor-adjustable reset timeout, and individual comparator outputs.

Supervisors with multiple reset voltages like the MAX6351–MAX6360 family, are designed for dual- and triple-supply applications, and offer several options for factory-trimmed standard reset thresholds (that is, those associated with supply voltages of 3.3V and 2.5V, for example). An adjustable detector allows users to monitor a third supply voltage (as for a 5V analog peripheral) and hold off the processor start until all voltages are within tolerance. Modern packages and processes allow extra functionality in a multivoltage SOT23 reset supervisor, along with a watchdog timer of an extended start period and a manual-reset input.

Low-power and high-precision voltage monitor supervisors like the MAX16132-MAX16135 family monitor up to four input voltages from 1.0V to 5.0V, with 1% accuracy and a single rail OV/UV monitoring solution. A single or dual reset option asserts when input voltages fall outside of factory-programmed threshold levels. The reset timeout ranges from 20µs to 1200ms with 23 reset timeout periods and a logic state guaranteed for V_{DD} greater than 1.0V.

Power-On Reset

The first and most commonly used safeguard for microprocessor systems is the POR function. Almost every computer and embedded processor includes a means for cold-starting the system in the proper configuration when power is first applied. Most processor data sheets provide a minimum reset period, during which the device should remain out of operation until the local power supply has stabilized for a specified interval (200ms is typical). The processor is not guaranteed to correctly operate if brought out of reset too quickly. During this reset interval, the processor's clock is allowed to stabilize and the internal registers have time to load properly. Most processor data sheets specify a minimum reset time, but they provide few guidelines for achieving this delay. A common approach that is inexpensive but risky is to delay the reset signal using a resistor-capacitor (RC) lowpass filter at the microprocessor's reset-input pin. You can select the component values to provide a wide range of reset delays based on a slow, exponential RC rise time. As the capacitor charges from ground to V_{CC}, the voltage crosses a threshold recognized by the microprocessor as a valid (high) input voltage (V_{IH}). This action releases the processor from reset, and it should (ideally) begin normal operation. Unfortunately, this approach has several drawbacks.

The first power-on problem occurs when the supply voltage rises slowly relative to the processor's reset time period. The capacitor voltage closely follows V_{CC} for low slew rates. As a result, the reset input voltage at the processor can reach a valid V_{IH} level before V_{CC} arrives within the tolerance range specified for the device. For a 3.3V supply with ±10% tolerance, for example, the reset should not deassert until V_{CC} > 2.97V. The system, however, can achieve a minimum V_{IH} level of 2.31V (0.7V_{CC} for most processors) long before the supply is ready for processor operation. That is, the processor can be released from reset when the supply is still 20% or more below its nominal operating level.

A second shortfall of RC circuits is the lengthy reset-delay interval required for most processors (200ms typical), which compels a low rate of voltage slew at the processor's reset input. Reset logic inputs are usually designed to recognize digital signals that make quick transitions from V_{IL} to V_{IH}. The delayed reset voltage, filtered to a slow µV/µs slew rate, can provide insufficient overdrive to the processor's digital input, a condition that results in reset metastability. A Schmitt trigger between the RC filter and processor input can increase the apparent slew rate, but it can contribute power-up concerns of its own (besides additional cost and component area).

How to Implement Supervisor Circuits

Microprocessor Reset

Microprocessors require a reset pulse during power-up to initialize the internal registers and prevent unwanted code execution. Without a reset, the device could attempt to run even when the clock oscillator or V_{CC} has not stabilized, thereby causing unpredictable operation. A microprocessor reset improves reliability by ensuring that your microprocessor is properly initialized regardless of external conditions.

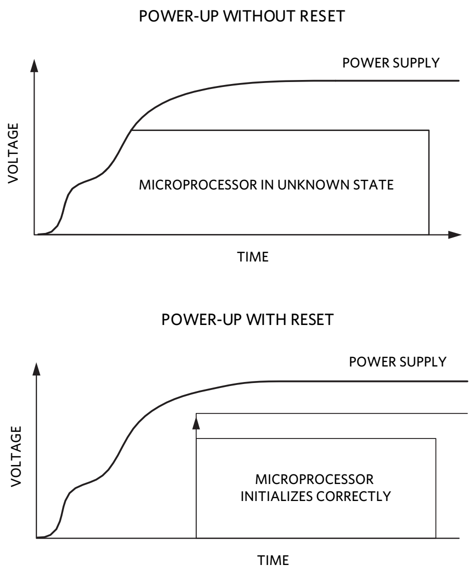

Figure 1. Supervisory circuit power-up with and without reset.

Design Tip: When to use an integrated microprocessor reset.

Integrated reset circuits combine an accurate voltage monitor with precise timing circuitry.

The circuit below shows an inexpensive, discrete method to add a reset function to a microprocessor that needs an active-low reset signal. Although low cost, the circuit has limitations—namely, inaccurate voltage and timing specifications.

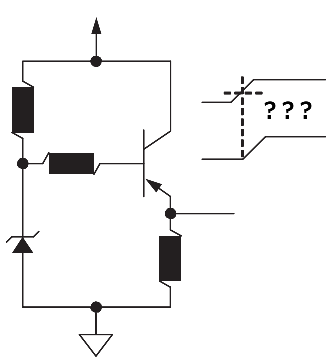

Figure 2. Discrete implementations are plagued by inaccurate voltage and timing specifications.

Integrated reset ICs solve the problems associated with discrete circuits. They should be used when an application requires the system voltage to fall within narrow tolerances before operating normally, or when a delay is needed to allow the clock oscillator to start up. These circuits include multiple reset-output types, precision reset thresholds, threshold hysteresis, and accurate reset timeouts.

Reset ICs like the MAX16072, MAX16073, and MAX16074 integrate functions such as a manual-reset (MR) input, a watchdog timer, and an additional comparator input and output. These reset ICs can squeeze critical features into an ultra-small, 1mm x 1mm, chip-scale package making them perfect for applications with limited board space.

Featured Technology

Reset ICs like the MAX16053 integrate an accurate voltage monitor and precise timing circuitry.

Industry-leading threshold accuracy provides superior protection against stray voltages

nanoPower ultra-low current supervisors with manual reset ICs like the MAX16140 feature 370nA quiescent current to extend battery life and monitor voltages from 1.7V to 4.85V in 50mV increments. A factory-programmable MR input can be set to rising-edge, falling-edge, active-low, or active-high input. The reset output is also factory programmable for active-low or active-high output configurations.

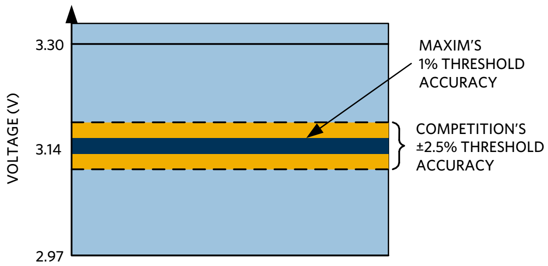

Figure 3. Threshold accuracy determines the best protection for microprocessor-reset circuits.

When looking for the best option for your design, consider microprocessor-reset circuits that have multiple reset-output types, precision reset thresholds, threshold hysteresis, and accurate reset timeouts.

Further Reading

1. Power-On Reset and Related Supervisory Functions
2. Choosing Supervisor Outputs
3. Keep the Product Working—Microprocessor Supervisors Offer Big Insurance in Small Packages
4. CPU Supervisors: Frequently Asked Questions (FAQs)
5. Supervisory Circuits Keep Your Microprocessor Under Control

Manual Reset with Pushbutton Controllers and Switch Debouncers

An input for manual (pushbutton) reset is a useful addition to the simple reset generator. Manual reset allows the user, or an external system component, to trigger a microprocessor reset while the supply voltage remains within tolerance. If the processor locks up for some unknown reason, the manual reset lets you start again without turning off the system power. This function is especially important for products that never power down the controlling processor, even in the "off" mode. It is also useful for debugging and for final system testing. In all cases, a manual reset can guarantee that the processor receives the necessary timeout period during reset.

Manual resets are often initiated with a low-cost pushbutton switch. Reset devices like the MAX6335–MAX6337 series usually include input-debouncing circuitry to mask the effect of ringing initiated by contact closure in the grounded switch. Because the switch can be remote to the processor (often on a back panel or hidden in a battery or power-supply compartment), the best manual-reset circuits accommodate long board runs by rejecting short (100ns typical) noise-induced pulses. To guarantee valid reset inputs (1µs typical), they also require a minimum input pulse width. The manual reset can be implemented as an independent input to the supervisor or as a dual-function pin that serves both as reset output and manual-reset input.

Some microprocessors now integrate the power-on-reset circuitry with their power-management functions. Although these embedded reset circuits are usually better than the RC-delay approach, the µP IC process is optimized for high-speed or low-power digital performance rather than accurate and reliable analog measurement and timing. Thus, internal resets can provide reasonable power-on timing under normal operating conditions, but they are poorly qualified to handle the supply transients and brownouts that can cause processor errors. For robust operation, most processors provide an additional reset input that can be driven by an external, dedicated reset supervisor.

Pushbutton controllers and switch debouncers like those in the MAX16122–MAX16125 are the simplest and most cost-effective solutions for microprocessor supervision and manual reset. Features such as ESD protection, low power operation, and small packages make them ideal for harsh environments and portable applications. The MAX16122/MAX16123 feature a unique dual pushbutton controller, allowing a hard reset function to be utilized by two software-controlled switches. The MAX16124/MAX16125 feature a single pushbutton control. In addition, these devices offer pin-programmable and resistor-adjustable pushbutton delay and the full -40°C to +125°C automotive temperature range, all in an ultra-tiny 0.86mm x 1.27mm WLP.

Long-Delay Pushbutton Controllers

Portable and consumer electronics devices with a soft power-off function usually use the main microprocessor to control power to the device. This works well until a software error causes the microprocessor to hang, in which case, a hard reset is required. Often the battery is not accessible by the user, so a pinhole in the case provides access to an internal hard-reset pushbutton.

Design Tip: When to use a long-delay pushbutton IC.

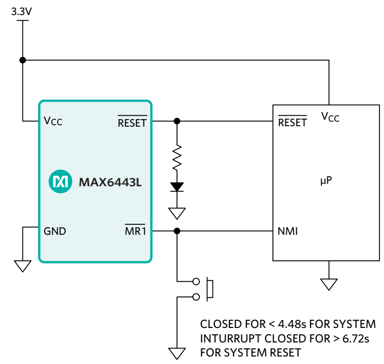

Figure 4. Pushbutton reset devices allow reuse of existing pushbuttons for a hard-reset function.

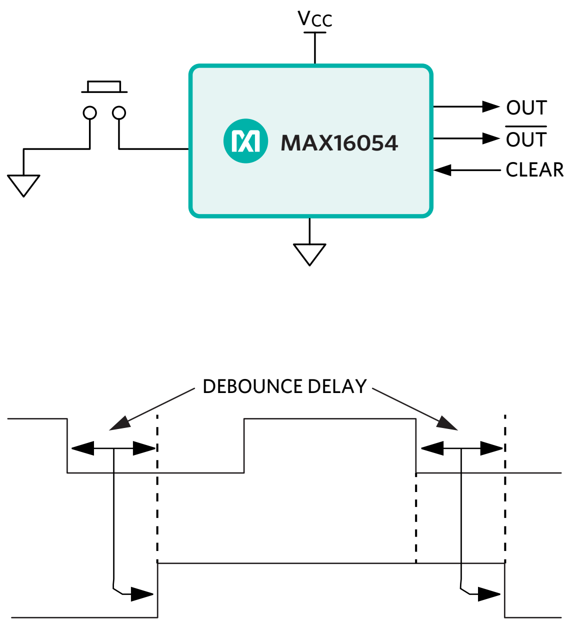

Figure 5. Pushbutton on/off controllers save power and improve power function reliability.

A long-delay pushbutton IC allows the end user to perform a hard reset by holding down a pushbutton. Pushbutton reset devices allow the reuse of an existing pushbutton for the hard-reset function. Long-delay pushbutton controllers provide a long setpup delary so that the user has to push one or two buttons for more than 6s to trigger a hard reset.

Design Tip: When to use a pushbutton on/off controller.

A pushbutton on/off controller IC lets a low-cost momentary pushbutton to replace a power switch instead of using an existing microprocessor or microcontroller to create a soft power-off function.

For example, a pushbutton on/off controller with debounce like the MAX16054 can be used to save power and improve the reliability of the power function. This device allows you to push a button to toggle the state of OUT and active-low OUT while eliminating contact bounce during the switch opening and closing. The appropriate output can connect to a series-pass MOSFET or LDO—enable input to control power to the rest of the circuit. The microprocessor can then shut itself off (soft power-down) by pulsing CLEAR.

Further Reading

1. Tiny IC Debounces Pushbutton Switch
2. Switch-Debouncer IC Creates a Long-Period Timer
3. Switch Bounce and Other Dirty Little Secrets
4. Single-Pushbutton ON/OFF Power Control

Watchdog Timers

Even the best-designed systems are subject to errors other than power-supply fluctuation. Bugs in the program code, incorrect clocking signals, or poorly responding peripherals can all force the processor out of its normal operating code or into a dead-end loop. When a processor leaves the expected instruction path, it may have no way of knowing that it is incorrectly operating and needs to restart.

To solve this problem, many supervisor ICs (like the industry-standard MAX823 family and newer MAX6316–MAX6318 devices) include a watchdog timer as a low-cost means for ensuring that the processor is executing within the proper code boundaries. This scheme requires that the processor update a watchdog logic input continually, within a specified minimum time period. Otherwise, the supervisor issues a system alert.

A common industry-standard timeout period for watchdogs is 1.6s, but suppliers offer options from 1ms to 1 minute. Because the watchdog update consumes processor-cycle overhead, you should select the watchdog period by asking, "How long can the system be allowed to operate incorrectly before a reset is initiated?" Some devices allow a longer startup timeout (1 minute, for example) before dropping back to the normal 1.6s short-timeout operating mode. This dual-timeout capability allows the system to execute a lengthy boot process during startup and then become responsible for the faster routine watchdog updates.

The watchdog output can, at times, be tied to a non-maskable processor input, which lets the supervisor attempt to bring the processor back to normal operation without losing volatile memory data. To fully reinitialize the system on detection of any error, the watchdog can be tied in common with the POR/brownout-detect output.

Design Tip: When to use an external watchdog timer.

Many microprocessors integrate a watchdog timer as a low-cost means for ensuring that the processor executes within proper code boundaries. However, because the watchdog operates from the same supply voltage and clock inputs as the processor, it is often subject to the same transient errors. These designs are also vulnerable to software errors such as runaway code, which can disable the built-in timer.

An external watchdog timer increases system reliability by automatically resetting your microprocessor when the software hangs. Designers should use an external watchdog timer to guarantee proper inputs to the processor each and every time. Thus, the most robust systems include an independent watchdog, which guarantees proper inputs to the processor each and every time.

Design Tip: When to use a watchdog as a programmable oscillator.

Supervisory circuits with watchdog timeouts such as the MAX16056–MAX16059 can also be used as programmable oscillators to conserve energy, as they consume much less power than integrated oscillators. By connecting WDI to ground, the watchdog will always trigger, creating pulses on the output with timing set by the two external capacitors.

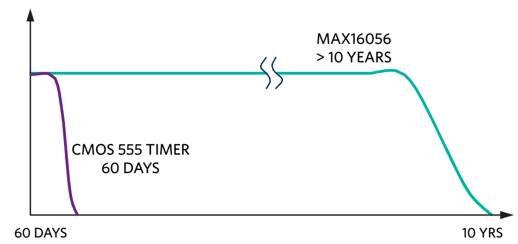

Figure 6. Using a watchdog as a programmable oscillator extends battery life.

A similar circuit constructed with the industry-standard CMOS 555 timer has a supply current of 50µA. A typical CR2016 coin cell has a capacity of 80mAh. The 555 timer circuit will last about 60 days. In comparison, the MAX16056 circuit, with a current consumption of 0.125µA, lasts well beyond the 10-year shelf life of the battery.

Further Reading

1. Different Ways to Use a MAX6369 Series Watchdog Timer
2. Watchdogs Improve System Reliability—How to Choose the Right Part
3. Windowed Watchdog Enhances µP Supervisors
4. Watchdog Timer Allows Entry to Test Mode

Overvoltage Protectors and High-Voltage Regulators with Integrated Reset

Figure 7. Overvoltage protection ICs guard against harsh external environments.

All of the best engineering will not limit what the external environment imposes. Harsh environments, such as factories, processing facilities, and automobiles impose physical challenges to hardware, including transient voltages, high temperatures and contaminants. Overvoltage protection ICs guard against transient voltages, overvoltages, and reverse-battery voltages ideal for automotive and industrial applications. High-voltage regulators provide a clean, well-regulated output voltage regardless of the transient nature of the input.

A simple circuit can protect against transients, sustained overvoltage conditions, and reverse voltages by using a series fuse with a transient-voltage suppressor (TVS) diode.

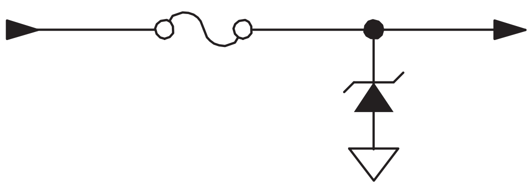

Figure 8. Inexpensive circuits offer poor protection against voltage transients.

Although it is inexpensive, a simple circuit suffers from a number of limitations: the protection threshold is not well controlled and varies dramatically over temperature; the fuse needs to be replaced after an overvoltage, reverse-voltage, or a large-transient condition occurs; larger transients cause the TVS to dissipate more energy; and, in many cases, the TVS diode requires a lot of board space.

Overvoltage protection ICs guard against transient voltages, overvoltages, and reverse-battery voltages.These ICs can protect the circuit from transient voltages up to 72V, overvoltages, or reverse- voltage conditions. These devices use series-pass MOSFETs to instantly disconnect the circuit during a fault condition. After the fault condition is resolved, the MOSFETs turn back on so that the circuit can continue to operate.

Further Reading

1. One Button Turns Microprocessor On and Off
2. Low-Cost AC Supply
3. Battery-Switchover Circuit Accommodates 3V Systems
4. Micropower Circuit Offers Automatic Shutdown and Low-Battery Lockout
5. Latching Regulator Prevents Deep Discharge of Battery

Conclusion

In this tutorial, we reviewed why supervisory circuits play an important role in system design. We highlighted the many events that can cause problems in a microprocessor system, from power supplies in the wrong sequence or peripheral components and boards that fail, to bugs that can sneak into system code. With each issue, we provided the tools to minimize the failure events and showed how modern microprocessor supervisor circuits can be a low-cost and effective method for monitoring and maintaining proper system activity. Finally, we hope you have a better understanding of how a good µP supervisor circuit can greatly enhance the quality and reliability of your designs, saving time and money over the product lifetime.

For more information, visit:
www.maximintegrated.com/en/products/supervisors