Application Report
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Comparing Voltage and Processor Monitoring Solutions: Discrete vs Voltage Supervisors and Watchdog ICs

Michael DeSando

ABSTRACT

This document compares the advantages and disadvantages of voltage and processor monitoring solutions at each level of integration from discrete components to integrated circuits (ICs) to using the integrated solutions found in more complex devices such as microcontrollers (MCUs) and microprocessors (MPUs).

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1 Introduction

Voltage and processor monitoring is common in applications with various power rails, important power conversion or regulation, and systems that incorporate specific power and processing requirements found in systems using MCUs and MPUs. When starting a design, there are a plethora of options and design choices in terms of components and architectures to create the subsystems that make up the system. Each application has specific requirements such as size, cost constraints, power efficiency, accuracy, performance, programmability, redundancy, etc. These application requirements combined with the designer's preference lead to the design solution. Design architectures range from using discrete components that work together in subsystems to fully integrated solutions that use a highly specialized ICs to integrate most of the functionality required in the design. This document serves to provide a comparison between discrete solutions at the basic component level, solutions using integrated circuits such as voltage supervisors and watchdogs, and the solutions that rely on the highly specialized devices such as MCUs and MPUs with integrated features and functionality.

2 Discrete Component Solutions

2.1 Discrete Voltage Monitoring

The discrete component level solution to voltage monitoring is accomplished using comparators with a voltage reference in addition to some resistors. The amount of components required depends on the number of rails being monitored and if each rail is monitoring undervoltage only or undervoltage and overvoltage. Figure 1 shows a discrete solution to monitor a single voltage rail for an undervoltage condition requires a minimum of one comparator, one voltage reference, and four resistors. To learn more about this discrete approach, read *Using TL431LI as a Voltage Comparator*.

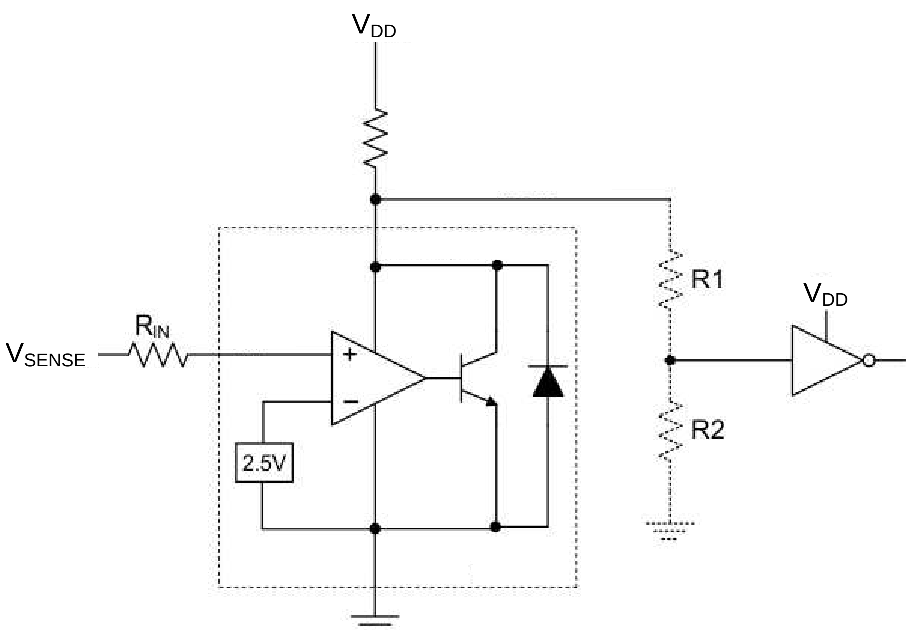

Figure 1. Single Channel Undervoltage Monitoring Solution Using Discrete Components

For two voltage rails for undervoltage only or for monitoring a single voltage rail for undervoltage and overvoltage, the solution requires two comparators, two voltage references, nine resistors, and a diode as shown in Figure 2.

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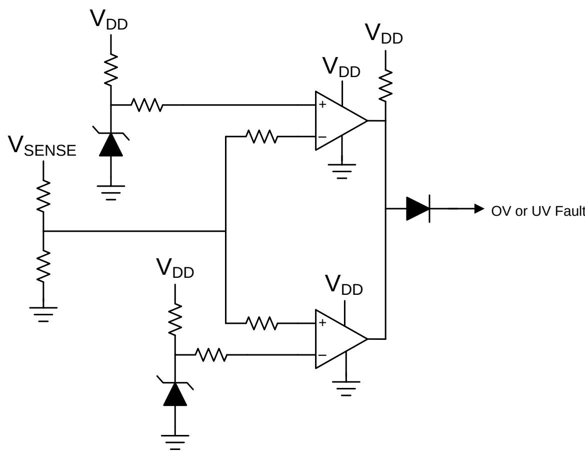

Figure 2. Single Channel Undervoltage and Overvoltage Monitoring Solution Using Discrete Components

The advantage of using a discrete solution is that the individual components are low cost and are usually readily available. The disadvantage is that this requires several components, takes up more board space, and isn't highly adjustable in terms of timing and hysteresis. The lack of flexibility becomes an issue in applications that have specific power sequencing requirements, or require return from fault delays also called reset delays. Also if the voltage rail is noisy or has a significant voltage ripple, the solution could potentially cause false fault triggers. A sample layout is shown in Figure 3. The specifications of the discrete solution are found in Table 1. Notice the number of components required, the total size footprint, and the voltage monitor accuracy as this discrete example is compared to the integrated solution example in the next section.

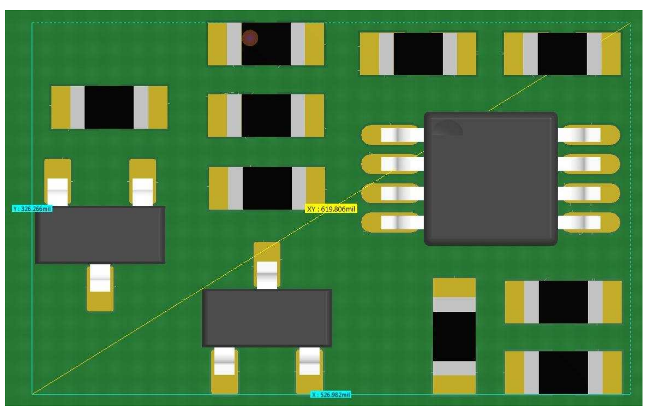

Figure 3. Example Layout of Discrete Dual Rail Undervoltage or Single Rail Under and Overvoltage Monitor Solution

Table 1. Undervoltage and Overvoltage Monitoring with Discrete Components

Design Consideration	2x TL431LI + LM2903 Dual Comparator
Type of Voltage Monitoring	Undervoltage + Overvoltage
Number of Components	12
Approximate Footprint Area	0.62 in^2
Max Input Voltage	36 V
Max Approximate Supply Current	~2 mA (TL431LI typical) + ~2 mA (TL431LI typical) + 2.5 mA (LM2903 max) = 4.5 mA
Typical Voltage Monitoring Accuracy	3% to 6%
Approximate Cost (1k units)	2x $0.07 + $0.08 + 9x $0.02 = $0.40

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2.2 Processor Monitoring Using Discrete Components

Processor monitoring is the monitoring of a microcontroller (MCU) or microprocessor (MPU) using a solution that flags a fault if the MCU or MPU latches up or gets stuck in a program or software routine. Processors ideally execute code in a precise and controlled manner but when the MCU or MPU is not executing the routines correctly, a processor fault occurs. Processor monitoring using discrete components isn't common because the discrete components don't really add any advantage when compared to watchdog ICs and integrated watchdogs. The discrete solution consists of a multiple components such as a timer or clock for setting the timeout period, a current source or reference voltage with a Schmitt trigger to compare against to detect if a signal from the processor has arrived on the input, and multiple logic devices to determine what to do if a signal has arrived as expected. Each discrete component adds a potential failure point in addition to inaccuracy. The processor monitoring discrete solution isn't practical because of the amount of board space required, the numerous discrete components required, and the lack of precision and programmable timing. In every application that requires a processor monitoring solution, the designer must choose between a watchdog IC or using the watchdogs built into some MCUs, MPUs, and other highly integrated devices.

3 Integrated Circuit (IC) Solutions

3.1 Voltage Monitor Solutions with Voltage Supervisors / Reset ICs

This section discusses devices that integrate the voltage reference and comparator into an IC called a voltage supervisor (sometimes called reset IC). Voltage supervisors are devices that monitor a voltage rail through the VDD or SENSE input pins, and trigger a fault signal at the $\overline{\text{RESET}}$ or SENSE_OUT output pins when the monitored voltage falls outside of the configured range. Voltage supervisors have features and options that aren't available in the basic discrete solutions mentioned above such as programmable reset delay, built- in hysteresis, manual reset (MR) / enable (EN), multichannel monitoring, window voltage monitoring, and various output topologies in a small package size. A typical voltage supervisor block diagram is shown in Figure 4.

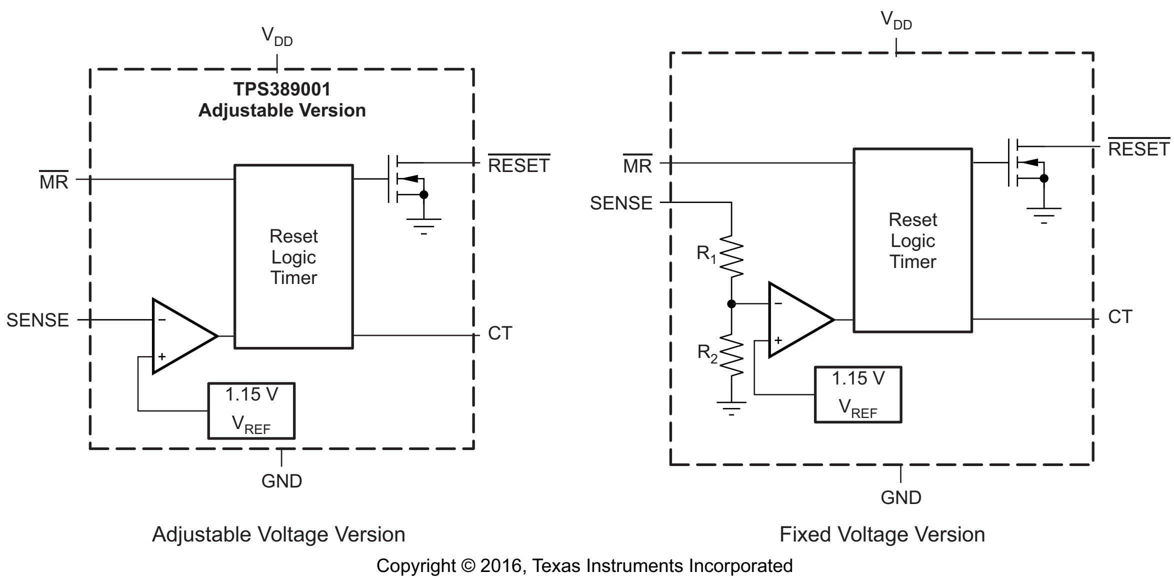

Figure 4. TPS3890 Voltage Supervisor Block Diagram (Left: Adjustable, Right: Fixed)

The voltage threshold for a voltage supervisor can be set with external resistors as shown on the left of Figure 4 or can be integrated into the device to monitor a common fixed voltage as shown on the right. Multiple comparators can be integrated into the device for mutichannel voltage monitoring saving space and component count. Voltage supervisors come in a variety of sizes based on the features included and the package type.

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3.1.1 Saving Space With Integration

By integrating the discrete components into a single IC, the same functionality is created with much less area. TPS3831 for example, is a nano-Iq voltage supervisor that includes a built-in voltage reference and comparator and fits into 1mm x 1mm with the X2SON package which can't be done with discrete components. TPS3307 is a triple channel voltage supervisor that monitors three inputs with three separate internal comparators and fits into 3 mm by 3.9 mm SOIC package. TPS3701 is an undervoltage and overvoltage wide Vin voltage detector IC and has a much smaller 2.9 mm x 1.6 mm (SON-6 package) footprint compared to the discrete solution. For direct comparison, Figure 5 shows the TPS3701 typical circuit schematic compared to the discrete schematic in Figure 2. The Figure 6 shows an example layout of TPS3701 for direct comparison to the discrete solution layout in Figure 3.

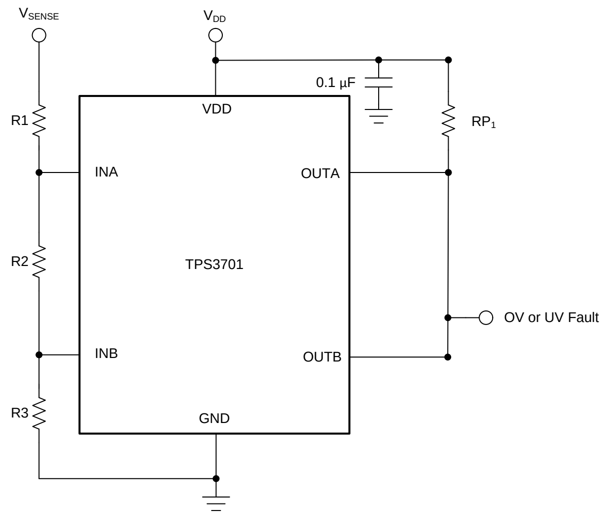

Figure 5. TPS3701 Typical Circuit Schematic: Undervoltage and Overvoltage Monitoring Solution

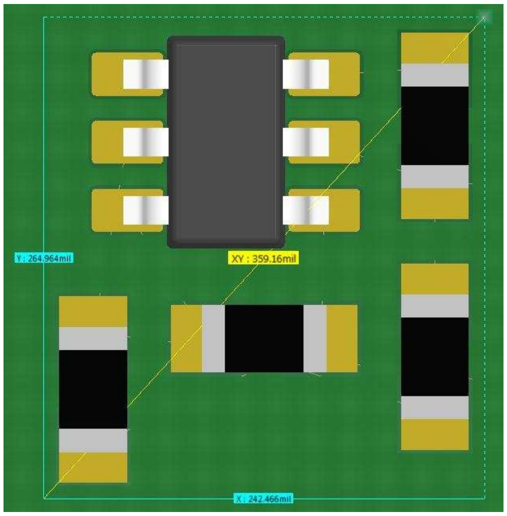

Figure 6. Example Layout of TPS3701: Undervoltage and Overvoltage Monitoring Solution

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Apart from saving board space, the performance measured in supply current (Iq) and voltage monitor accuracy of voltage supervisors give the integrated solution a big advantage compared to discrete component solutions is another advantage. The discrete component solution can monitor at approximately the accuracy of the voltage reference + comparator + external resistors. As you increase the accuracy of the individual components, the cost increases. Voltage supervisors have the voltage reference and comparators integrated and accounted for in the device accuracy specification. When comparing the TPS3701 vs two TL431LI (A grade) with LM2803 Dual Comparator, TPS3701 offers 0.25% typical voltage monitoring accuracy compared to 1% + 1% + ~18mV offset. The total solution supply current is 11 µA typical vs the discrete solution of several milliamps. Table 2 shows the voltage supervisor solution specifications for undervoltage and overvoltage monitoring which can be compared directly to Table 1.

Table 2. Undervoltage and Overvoltage Monitoring with a Voltage Supervisor

Design Consideration	TPS3701
Type of Voltage Monitoring	Undervoltage + Overvoltage
Number of Components	5
Approximate Footprint Area	0.36 in^2
Max Input Voltage	36 V
Max Approximate Supply Current	11 µA (TPS3701 max)
Typical Voltage Monitoring Accuracy	0.25%
Approximate Cost (1k units)	\$0.89 + 4x \$0.02 = \$0.97

3.1.2 Additional Features Integrated into Voltage Supervisors

Voltage Supervisors also provide additional advantages by include integrated features not offered with the basic discrete solution.

3.1.2.1 Manual Reset

In some applications, there may be a need to force a reset of the system by push-button or some other logic signal. Some applications also want to disable the voltage monitoring during power up. Many voltage supervisors come with a manual reset ($\overline{MR}$) feature that allows an external signal to force a reset or keep the voltage monitoring device disabled until the $\overline{MR}$ is logic high. To create this feature block in a discrete solution requires a pull-up resistor to allow the manual reset input to default to a logic high value in addition to a Schmitt trigger for determining the logic status. Integrating this feature into the voltage supervisor saves space and component cost compared to the discrete component solution.

3.1.2.2 Reset Delay

Voltage supervisors can also include programmable reset delay, that is the delay of the reset output when returning from a fault condition. The discrete voltage monitor solution relies on the propagation of the comparators which is usually fixed in the range of tens of nanoseconds to a few microseconds. This is often too quick of a delay when needing delay upon start-up for power sequencing for example or if the application requires a specific amount of time after recovering from a fault before enabling or turning on devices in the system. Some voltage supervisors come with a fixed reset delay whereas programmable voltage supervisors require a single capacitor to program the reset delay. There are also voltage detectors that do not have additional reset delay and rely on the propagation delay of a few microseconds for those applications where reset delay is not needed. Note: any voltage detector with an open-drain reset output can add reset delay by adding capacitance to the reset output. Adding reset delay to voltage detectors can be useful because some voltage detectors have much wider Vin compared to some programmable voltage supervisors. Please see *Adding Reset Delay to Voltage Detectors* for more information.

3.1.2.3 Built-In Watchdog

Voltage supervisors can also include built-in watchdogs for integrated voltage and processor monitoring. TPS382x family of basic voltage supervisors with a built-in standard watchdog are available in 2.9 mm x 1.6 mm with SOT-23 package which is not possible to create a discrete solution in the same board space. For programmable watchdogs with more funtionality, please see Section 5.

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3.2 Watchdog ICs

This section discusses the processor monitoring solutions offered by watchdog ICs. Watchdog ICs integrate all of the necessary components to create a processor monitor into a single device. Watchdogs are devices that monitor an input signal coming from the processor, and trigger a fault at the watchdog output if the signal does not arrive as expected. Watchdogs are categorized into two types: standard and window. Standard watchdogs require a pulse before a certain time period otherwise a fault occurs. Standard watchdogs trigger a fault when the processor sends a pulse too late or not at all. Window watchdogs require a pulse within a certain time window otherwise a fault occurs. Window watchdogs trigger a fault when the processor sends a pulse to early, too late, or not at all.

3.2.1 Additional Features Integrated Into Watchdog ICs

The advantage of watchdog ICs are that they can include voltage supervisors in the same device and can be programmable. Having the ability to program the watchdog timeout and watchdog reset delay provides flexibility not offered with watchdogs integrated into MCUs, MPUs, and other highly integrated devices. In addition, nearly all watchdogs integrated into MCUs and MPUs are standard type watchdogs meaning they can only detect late or missing pulses but do not include window capability that detects early faults. Using external window watchdogs adds an extra processor monitoring feature that increases system reliability. Lastly, having external watchdogs independent of the MCU increases system robustness because if the MCU fails, the MCU's integrated watchdog also fails unlike in the case when using independent external watchdog IC. Even if the application uses the MCU's integrated watchdog, an external watchdog still must be used for redundancy.

Table 3 shows some watchdog ICs offered by Texas Instruments. These watchdog ICs can be compared to the watchdogs integrated into MCUs and MPUs shown in Table 4.

Table 3. Watchdog Devices Available at Texas Instruments

Design Consideration	TPS3430	TPS3431	TPS3823	TPS3850	TPS3851	TPS3813
Type of Watchdog	window	standard	standard	window	standard	window
Type of Voltage Monitoring	none	none	undervoltage	undervoltage + overvoltage	undervoltage	undervoltage
Number of Voltage Monitor Inputs[(1)]	0	0	1	1	1	1
Number of Additional Components	1	1	0	2	2	1
Typical / Max Supply Current	10 µA / 19 µA	10 µA / 19 µA	15 µA / 25 µA	10 µA / 19 µA	10 µA / 19 µA	9 µA / 25 µA
Watchdog Timeout	programmable: 11 ms to 77 s	programmable: 62 ms to 77 s	200 ms, 1.6 s	programmable: 11 ms to 77 s	programmable: 62 ms to 77 s	programmable: 68 ms to 25 s
Package Type (# of pins)	VSON (10)	VSON (8)	SOT-23 (5)	VSON (10)	VSON (8)	SOT-23 (6)
Package Size	3 mm x 3 mm	3 mm x 3 mm	2.9 mm x 1.6 mm	3 mm x 3 mm	3 mm x 3 mm	2.9 mm x 1.6 mm

(1) For more watchdog devices that monitoring more than one voltage rail, please visit the watchdog device parametric search: Multichannel Voltage Monitors with Watchdog

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4 MCUs and MPUs with Integrated Voltage Monitoring and Watchdog Features

Many MCUs and MPUs integrate the voltage supervisor and watchdog functionality into the device. For some applications, the built-in functionality included inside the MCU or MPU will suffice but in some cases they are not enough. For example, applications that meet safety standards often require a window watchdog, that is a watchdog that detects early timing faults in addition to late timing faults. This can't be accomplished by the standard watchdogs integrated into MCUs and MPUs as they do not have window processor monitor capability. Also, many applications require specific timing requirements which sometimes can't be accomplished with the fixed timing options of the watchdogs integrated into MCUs and MPUs but can be met with programmable watchdog ICs. In every case, the voltage supervisor and watchdog functionality is designed for monitoring the device itself and is not used for monitoring other external devices.

Table 4. MCUs and MPUs with Integrated Voltage Supervisors and Watchdogs

Device	MSP430FR2xx (Ultra-low-power MCU)	MSP432E401 (SimpleLink MCU)	TMS320F2802x (Piccolo MCU)	TMS320F2833x (Delfino MCU)	AM3351 (Sitara MPU)
Voltage Supervisor Type	Undervoltage	Analog Comparator	Undervoltage	none	none
Number of Monitor Inputs	1 (V_{DD})	3 (requires external reference)	2 (V_{DD}, V_{DDIO})	n/a	n/a
Voltage Monitor Threshold	1.81 V (SVS-), 0.1 V (BOR-)	adjustable	2.65 V	n/a	n/a
Reset Delay Time	10 µs (SVS Reset), 10 ms (BOR Reset)	1 µA	400 µs to 800 µs	n/a	n/a
Voltage Monitoring Accuracy	5.5%	50%	8.7%	n/a	n/a
Voltage Monitor Iq	1.5 µA	2 µA	50 µA +	n/a	n/a
Watchdog Type	Standard	Standard	Standard	Standard	Standard
Watchdog Timeout	1.95 ms, 15.625 ms, 250 ms, 1 s, 16 s, 4 m 16 s, 1 h 8 m 16 s, 18 h 12 m 16 s	programmable	programmable	programmable	programmable
Watchdog Reset Delay	32ms	2.44µs	programmable	programmable	programmable
Watchdog Iq	148 µA to 402 µA	2.9 mA+	25 µA +	10 µA+	5 mA

As Table 4 shows, the voltage monitor accuracy is much worse compared to voltage supervisors. And the only watchdog type offered by the watchdogs integrated into MCUs and MPUs is standard type meaning they can't detect early timing faults. The voltage monitoring and watchdog functioanlity integrated into MCU's and MPU's often don't meet the strict requirements found in safety applications. The excessive supply current for the MCUs and MPUs also don't work well for the low power applications. The next section summarizes when external voltage monitoring or processor monitoring solutions are recommended and sometimes required.

5 When External Voltage Supervisors and Watchdogs are Needed

The requirement of adding external voltage supervisors and watchdogs depends on the application and the devices chosen in the subsystems. This section describes cases when the designer must consider adding voltage or processor monitoring devices.

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5.1 Adding Monitoring to a System

The best scenario when a voltage supervisor or watchdog is required is when the system doesn't incorporate voltage monitoring or processor monitoring at all but needs to do so. When the application consists of multiple voltage rails and a single MCU or MPU, there is a good chance an external voltage supervisor is required to monitor the different voltage rails as MCUs and MPUs can only monitor their own input. Most MCUs and MPUs have internal watchdogs that can monitor itself which may be good enough for some applications. If using a device without a internal watchdog, an external watchdog is required to ensure the device is functionality correctly and is not stuck in a processing loop.

5.2 Improving Monitoring in a System

If the application already has voltage monitoring through internal voltage supervisors or from the ADC of the MCU for example, external voltage supervisors still may be required to improve the accuracy of the voltage monitoring or to add window voltage monitoring for undervoltage and overvoltage faults or adjusting the threshold outside of the ADC range. If the MCUs or MPUs already have an internal watchdog, an external watchdog still may be required for redundancy or for adding window processor monitoring or specific timing not available by the internal watchdogs. There are several performance benefits that external voltage supervisors and watchdogs add compared to those internal to the MCUs and MPUs such as accuracy, window monitoring, adjustable thresholds, and programmable timing.

5.3 Functional Safety Requirements

If the application must meet certain safety standards, there may be requirements for adding external voltage supervisors or watchdogs. The lowest safety standards require every voltage rail in the system to be monitored and for the core rails to be monitored for both undervoltage and overvoltage faults. In this case, a multichannel voltage supervisor, such as TPS386000 for 4-channel or TPS3307 for 3-channel, must be used to monitor the various voltage rails. Also a high accuracy window voltage supervisor, such as TPS3703-Q1, must be used to monitor the core rails. The lowest safety standards require a watchdog to monitor the MCUs and MPUs unless they have built in watchdogs. For the highest safety standards, every main voltage rail must be monitored for undervoltage and overvoltage and the core rails must have redundant voltage monitoring so that if any one device fails, the entire system won't fail as a result. The highest safety standards also require every MCU and MPU device to be monitored with a window watchdog, such as TPS3850, and to have redundant processor monitoring so that if any watchdog fails, the system won't fail as a result.

6 Additional Voltage Supervisor and Watchdog Options

Although this document mentions several voltage supervisors and watchdogs, there are a lot more to choose from depending on the requirements of the application. Table 5 below shows some of the top recommendations with a brief description of the device. Please visit *Voltage Supervisors, Reset ICs, and Watchdogs* for the quick reference list of TI voltage supervisors and watchdogs.

Table 5. Alternative Device Recommendations

Device	Description
TLV803E	250 nA nano-Iq, low cost 3-pin voltage supervisor
TPS3831	150 nA nano-Iq, X2SON (1mm x 1mm) small footprint size
TPS3840	300 nA nano-Iq, programmable reset delay voltage supervisor with manual reset
TPS389x	1% accuracy, programmable time delay, multiple voltage variants and topologies, USON (1.45mm x 1mm) small footprint size
TPS3808	Low Iq, high accuracy, programmable time delay, SOT package type
TPS3703-Q1	0.25% accuracy overvoltage and undervoltage reset IC with programable reset delay and manual reset
TPS3850	0.8% accuracy voltage supervisor with window watchdog, programmable reset delay and watchdog timeout
TPS3307	3-channel voltage supervisor
TPS386000	4-channel voltage supervisor with watchdog, programmable reset delay, and manual reset

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