Application Report

Voltage and Processor Monitoring Solutions in Factory Automation and Control Applications

Michael DeSando

ABSTRACT

This document covers recommendations for voltage and processor monitoring in factory automation and control applications. These recommendations can be applied to industrial applications that use the common voltage rails mentioned in this document.

Table of Contents

List of Figures

List of Tables

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1 Introduction

In every factory automation application, and most industrial applications, there are multiple power rails that power various subsystems within the application. Figure 1-1 shows some of the common subsystems in nearly all factor automation applications and in many industrial applications that require voltage and processor monitoring. At the front end, the AC power coming from the grid is converted to a DC voltage of 12V or 24V. This main supply rail is then converted to the various lower voltage rails required by the rest of the system. The number of rails and the rail voltages differ from application to application but the need to monitor these voltage rails to make sure they are in the correct range never changes. Almost every microcontroller (MCU), microprocessor (MPU), field programmable gate array (FPGA), or application specific integrated circuit (ASIC) requires very tight tolerance on the power supply otherwise the device will not function properly thus requiring a voltage monitoring solution to shut the system down if the power supply is out of range. In large industrial machines, a faulty voltage rail can lead to system failure resulting in damage or injury. Even once the voltage rail is within range, there is a change that software or faulty code can cause the MCU, MPU, or FPGA to latch up and stop working as expected. There is no reason to risk operating such applications in faulty conditions so monitoring the voltage rails and processors are always recommended and even required in safety critical applications. At the bare minimum, the main supply voltage rail along with the core rails for the MCUs, MPUs, and FPGAs need to be monitored.

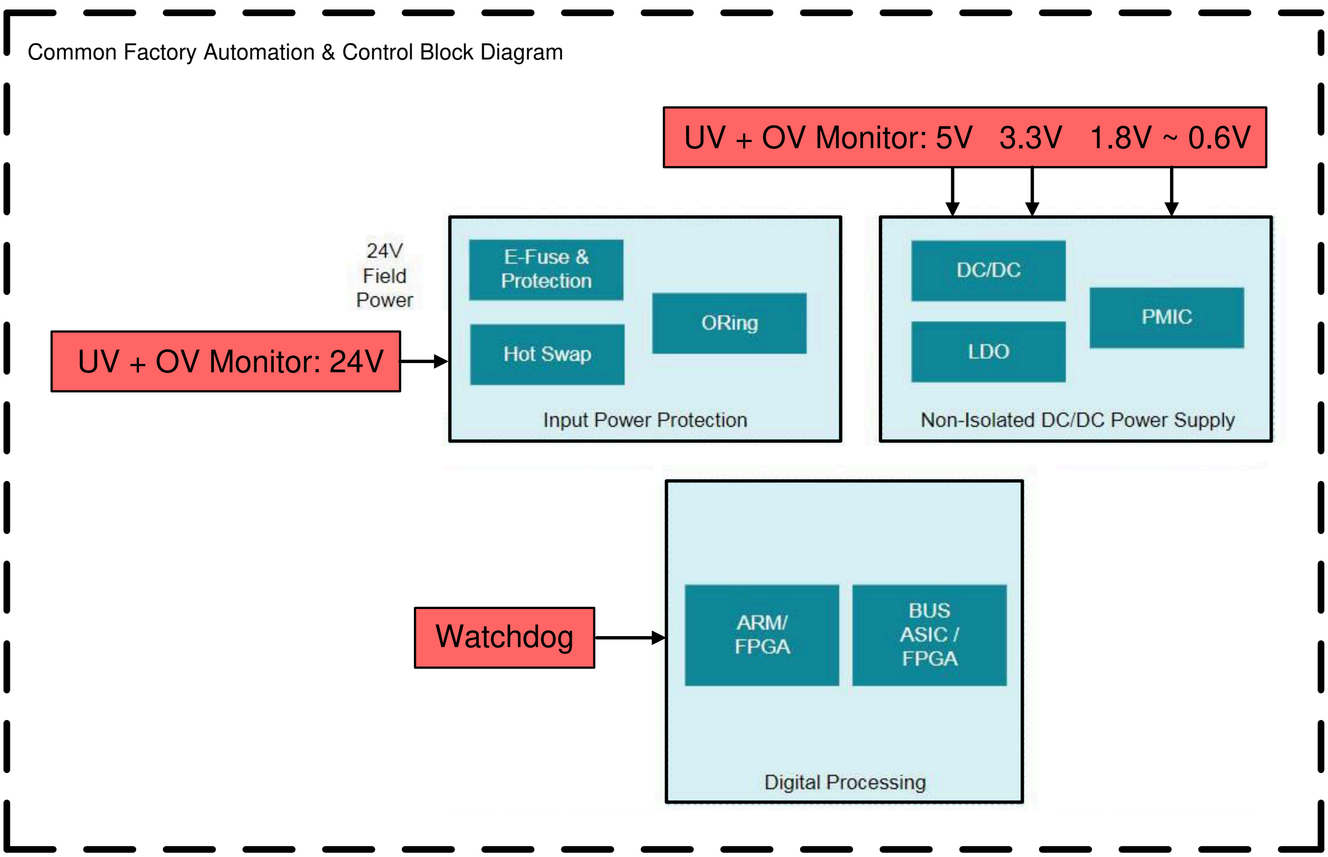

Figure 1-1. Typical Monitoring Required in Factory Automation and Control Applications

If the application must meet safety requirements, every core voltage needs undervoltage and overvoltage monitoring. In addition to voltage monitoring, processor activity must also be monitored using an external watchdog. The highest safety ratings require monitoring every voltage rail for both undervoltage and overvoltage in addition to using independent window watchdogs for every MCU, MPU, and FPGA in the system. With so many different voltage rails often found in industrial applications, the monitoring solutions can become confusing and overwhelming. This document serves to provide the recommended monitoring solutions for various subsystems commonly found in industrial applications.

2 Voltage Monitoring

Voltage monitoring is accomplished with a voltage supervisor also called a reset IC. When the voltage supervisor does not have a reset delay when returning from a fault condition, the device is called a voltage detector. In some cases, specifically when monitoring high voltage rails, a shunt voltage reference can be used as a lower cost solution with less features and flexibility compared to voltage supervisors.

2.1 24-V Rail Monitor

There are two recommended solutions for monitoring the 24-V rail common in many industrial applications. The first recommendation consists of a single wide Vin voltage detector that is highly adjustable and very accurate providing as shown in Figure 2-1. The second solutions uses multiple devices working together to create a monitoring solution that is less adjustable, less accurate, larger footprint, but can be lower cost as shown in Figure 2-3.

- **TPS3701:** wide Vin voltage detector can monitor voltages up to 36 V and provides 0.25% typical monitoring accuracy. The size of the 6-pin SOT package is 2.9 mm x 1.6 mm and only requires three external resistors to set the fault threshold and at least one external pull-up resistor for the open-drain output as shown in Figure 2-2. The TPS3701 provides both undervoltage and overvoltage monitoring in a convenient single device solution.
- **Two TL431LI + Two Comparators:** This solutions uses four lower cost components to create an undervoltage and overvoltage monitoring solution. The solution requires at least four external resistors to set the fault threshold of the two TL431LI devices in addition to two pull-up resistors for each. An additional two external resistors for each comparator is required if level shifting is needed. Although this solution can be lower cost, often times the size of the devices plus the external components make it a large footprint solution as shown in Figure 2-4. The monitoring accuracy depends on the grade of TL431LI in addition to the grade of the resistors used. This solution provides typical monitoring accuracy between 3% to 6% and does not provide accurate hysteresis.

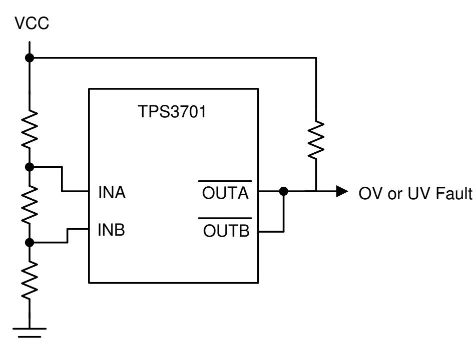

Figure 2-1. TPS3701 Undervoltage and Overvoltage Monitoring Solution

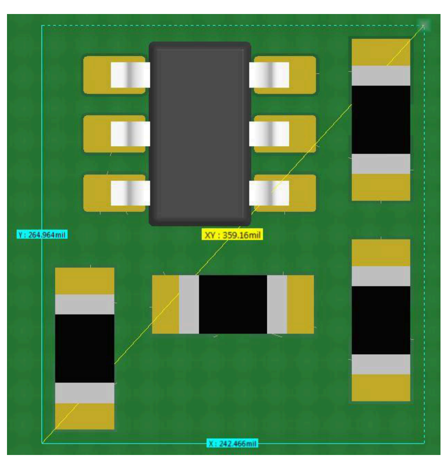

Figure 2-2. TPS3701 Example Layout

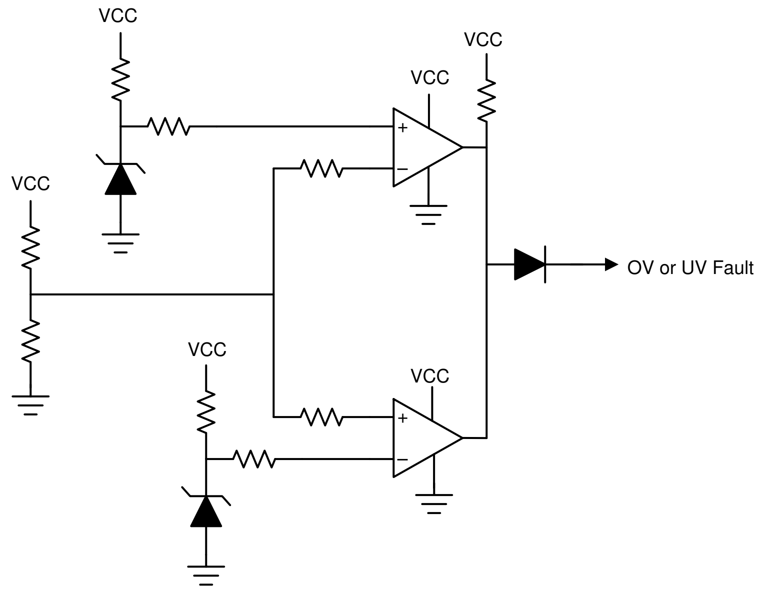

Figure 2-3. Two TL431LI + Dual Comparator Undervoltage and Overvoltage Monitoring Solution

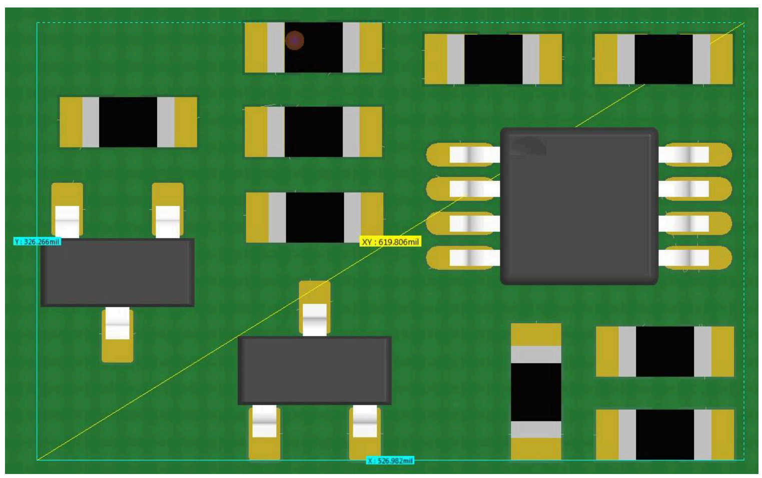

Figure 2-4. Two TL431LI + Dual Comparator Example Layout

Table 2-1 shows a comparison between the undervoltage and overvoltage solution using discrete components vs an voltage supervisor IC.

Table 2-1. Comparison Between Discrete vs Integrated for Undervoltage and Overvoltage Monitoring Solution

	2x TL431LI + LM2903 Dual Comparator	TPS3701
Number of Components	12	5
Approximate Footprint Area	0.620 in^2	0.36 in^2
Max Input Voltage	36 V	36 V
Max Approximate Supply Current	~2 mA (TL431LI typical) + ~2 mA (TL431LI typical) + 2.5 mA (LM2903 max) = 4.5 mA	11 µA (TPS3701 max)
Typical Voltage Monitoring Accuracy	3% to 6%	0.25%
Approximate Cost (1k units)	2x $0.07 + $0.08 + 9x $0.02 = $0.40	$0.89 + 4x $0.02 = $0.97

2.2 12-V Rail Monitor

In some factory automation and control applications, the 24-V rail is regulated down to 12 V for powering lower voltage regulators or drive circuitry such as LED drivers found in CNC machines. Sometimes a window voltage monitoring device is required whereas sometimes just a undervoltage monitoring device can be used. The requirements of the application will determine the recommendation to choose.

- **TPS3700:** window voltage detector monitors up to 18 V and provides 0.25% typical monitoring accuracy. This device is offered in the 6-pin SOT and 6-pin WSON packages previously described and requires three external resistors to set the fault threshold and at least one pull-up resistor for the open-drain output. Use this device when monitoring higher than 5 V but less than 18 V and undervoltage and overvoltage monitoring are required.
- **TPS3710:** voltage detector monitors voltages up to 18 V and provides 0.25% typical monitoring accuracy. This device is offered in the 6-pin SOT and 6-pin WSON packages previously described and requires two external resistors to set the fault threshold and at least one pull-up resistor for the open-drain output. Use this device when monitoring higher than 5 V but less than 18 V and only undervoltage monitoring is required.

2.3 5-V and 3.3-V Undervoltage and Overvoltage Rail Monitor

The 24-V rail is typically regulated down to lower common rail voltages of 5 V or 3.3 V for various subsystems in the application. In CPU subsystems, the 5-V and 3.3-V rails are used for the MCU, MPU, or FPGA making these rails critical for the success of the application. In this case, the 5-V rail and 3.3-V rails must be monitored for undervoltage and overvoltage because of how critical these rails are for the rest of the system as any voltage fault on these rails could be catastrophic for the system. There are two recommended monitoring solutions for these critical rails.

- **TPS3850:** window voltage supervisor monitors up to 5 V for both undervoltage and overvoltage and provides 0.8% typical monitoring accuracy. The size of the 10-pin VSON package is 3 mm x 3 mm and only requires at least one external pull-up resistor for the open-drain output. The key value add for this device is the built-in window watchdog that monitors processor activity for both early and late timing faults. Window watchdogs are a system requirement to meet the higher safety ratings when the application uses MCUs, MPUs, and FPGAs to improve reliability by preventing a faulty software issue from causing system failure.
- **TPS3703-Q1:** window voltage supervisor monitors voltages up to 5.5 V and provides 0.25% typical monitoring accuracy. The size of the 6-pin WSON package is 1.5 mm x 1.5 mm and only requires at least one external pull-up resistor for the open-drain output. The TPS3703-Q1 provides both undervoltage and overvoltage monitoring in a convenient single device solution in addition to programmable delay for sequencing purposes or return from fault deglitching and manual reset for disabling the device via an external signal. When the TPS3703-Q1 is being used to monitor a MCU, MPU, or FPGA in a safety-critical application, an additional standalone window watchdog must also be used to monitor the processor activity to meet the safety standards that require the highest reliability.

2.4 Monitoring Multiple Voltage Rails Between 5 V and 0.4 V

The 5-V and 3.3-V rails may also be used for other devices other than the processors and are further regulated down to various low voltage rails used throughout the subsystems for MCU, MPU, FPGA, or PMIC core rails, DDR, SD cards, USB power, etc. The voltage monitoring requirement for these various rails will differ from system to system so the recommended monitoring solutions must be evaluated on a case by case basis. There can be duplicate rails or any number of voltage rails that need monitoring depending on the system requirements and complexity of the system. The voltage monitoring solution for these rails can use any combination of the below recommendations to cover nearly all power tree situations.

2.4.1 Single Channel Voltage Monitoring

These devices monitoring one voltage rail with a sense input that can be fixed for a common voltage rail or can be adjustable with an external resistor divider for voltage monitor flexibility.

- **TPS3703-Q1:** window voltage supervisor is described above and is the top recommendation for monitoring undervoltage and overvoltage for 5-V rails and lower.
- **TPS3808:** voltage supervisor monitors many of the common voltage rails using the fixed voltage variants and voltages down to 0.405 V using the adjustable variant. TPS3808 provides programmable reset delay along with manual reset and requires a pull-up resistor for the open-drain output.
- **TPS3620:** back-up battery voltage supervisor monitors a voltage and switches over to an external battery when the main power fails.

2.4.2 Dual Channel Voltage Monitoring

- **TPS3779:** dual voltage detector monitors two independent channels down to 1.074 V for undervoltage faults and provides 1% typical monitoring accuracy. The independent sense inputs correspond to two independent active-low $\overline{\text{Reset}}$ push-pull outputs so no pull-up resistors are required.
- **TPS3110:** voltage supervisor monitors undervoltage faults down to 0.86 V and includes a built-in standard watchdog. This device provides 0.75% typical monitoring accuracy and includes a manual reset.

2.4.3 Triple Channel Voltage Monitoring

- **TPS3307:** triple channel voltage supervisor monitors three independent channels down to 1.25 V at 2.4% monitor accuracy and provides a single common push-pull output so no pull-up resistor is required.
- **TPS3306:** triple channel voltage supervisor monitors three independent channels down to 1.25 V at 2.4% monitor accuracy and provides two open-drain outputs that each require a pull-up resistor. This device also includes a built-in standard watchdog.

2.4.4 Quad Channel Voltage Monitoring

- **TPS386956:** quad channel device monitors four independent channels, one for 3.3-V rail monitoring, and the other three channels are adjustable down to 0.4 V at 0.25% monitoring accuracy. This provides a single open-drain output so a pull-up resistor is required and also includes a manual reset.
- **TPS386000:** quad channel device monitors four independent channels down to 0.4 V at 0.25% accuracy and provides four corresponding independent open-drain outputs each requiring a pull-up resistor unless tied to together. This device also includes a built-in standard watchdog, a manual reset, and an additional monitoring pin that is used for overvoltage monitoring for the fourth sense pin.

3 Processor Monitoring

Monitoring MCUs, MPUs, and FPGAs are accomplished with watchdogs. Watchdogs are devices that monitor a processor and create a fault signal if the processor stops working correctly. The watchdog is configured to expect a signal from the processor every so often and if the signal doesn't arrive at the correct time, the watchdog triggers a fault. Some watchdogs include a voltage supervisor that monitors voltage in addition to the watchdog that monitors the processor in a single device. If the device is just a watchdog, this is called a standalone watchdog. Watchdogs are categorized into two categories: standard and window. As Figure 3-1 shows, 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 *too early*, too late, or not at all.

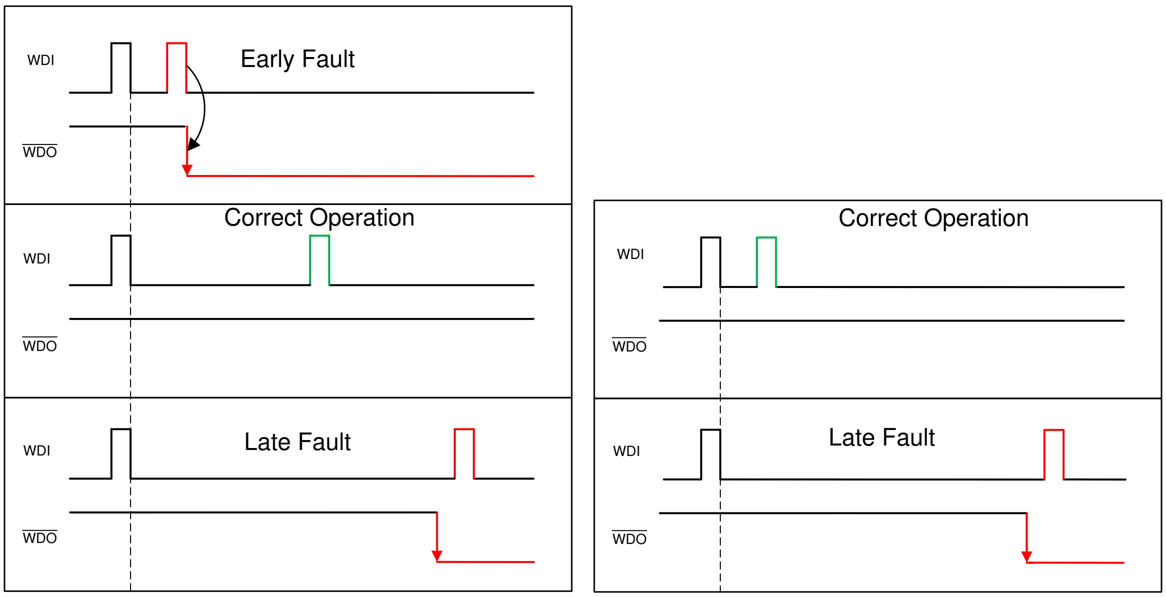

Figure 3-1. Window Watchdog (left) vs Standard Watchdog (right)

3.1 Watchdog Solutions

A standard watchdog is the minimum recommended monitoring solution for any processor in the application. If the application intends to meet higher safety ratings, a window watchdog is required for every processor in the application. The higher safety ratings require a window watchdog in addition to monitoring the processor core rails for undervoltage and overvoltage. In this case, an voltage supervisor + watchdog device may be used and/or multiple monitoring devices working together. Monitoring devices in any application serve to add protection, reliability, redundancy, and robustness. Below are some of the top watchdog recommendations.

3.1.1 Standalone Window Watchdog

Standalone watchdogs only monitor processor activity and do not include any voltage monitoring capability.

- **TPS3430:** standalone window watchdog with fully programmable watchdog timeout, watchdog reset delay, and disable.

3.1.2 Window Watchdog + Single Channel Voltage Monitor

- **TPS3850:** a fully programmable window watchdog in addition to a single channel undervoltage and overvoltage voltage supervisor.
- **TPS3813:** a fully programmable window watchdog in addition to a single channel undervoltage only voltage supervisor.

3.1.3 Standard Watchdog + Single Channel Voltage Monitor

- **TPS3823:** a fixed voltage supervisor for common rails and includes a built-in fixed standard watchdog.

- **TPS3123:** a fixed voltage supervisor for common *low voltage* rails and includes a built-in fixed standard watchdog.

3.1.4 Standard Watchdog + Multi-channel Voltage Monitor

- **TPS3110:** a dual voltage supervisor with adjustable rails and includes a built-in fixed standard watchdog.
- **TPS3306:** a triple voltage supervisor (two sense inputs and one power-fail input) and includes a built-in fixed standard watchdog.
- **TPS386000:** a quad voltage supervisor and includes a built-in fixed standard watchdog.

4 Safety Related System Monitoring

Some factory automation and control applications must meet certain safety ratings with the main three safety levels being safety integrity level (SIL), category level (CAT), performance level (PL). The risk level of the particular application failing determines the safety rating required. This section does not provide specific safety rating requirements as the safety ratings require a case by case analysis but will provide general recommendations to increase the safety rating of the system.

4.1 Minimum Safety Recommendation

At a bare minimum, these following recommendations must be met:

- All main voltage rails should be monitored: 24 V, 5 V, 3.3 V.
- All MCU, MPU, and FPGA core rails should be monitored.
- Every MCU, MPU, and FPGA should be monitored with a watchdog unless the device has a built in watchdog being used or if the device has no impact on the system functionality.

4.2 Medium Safety Recommendation

To meet the next level of safety ratings often required in applications designed to meet basic safety compliance, the following recommendations should be met:

- All main voltage rails should be monitored for undervoltage **and** overvoltage: 24 V, 5 V, 3.3 V.
- All MCU, MPU, and FPGA core rails should be monitored for undervoltage **and** overvoltage.
- Every MCU, MPU, and FPGA should be monitored with a **window** watchdog regardless if the device has a built in watchdog being used.

4.3 Maximum Safety Recommendation

To meet the highest level of safety ratings required by the most safety critical applications, the following recommendations must be met:

- All main voltage rails must be monitored for undervoltage **and** overvoltage: 24 V, 5 V, 3.3 V. These applications require additional fail-safe analysis and circuitry which may include redundant voltage monitoring using two independent devices per voltage rail.
- All MCU, MPU, and FPGA core rails must be monitored for undervoltage **and** overvoltage. Similar to the main voltage rails, these rails may require redundant voltage monitoring using independent devices such that if any one device fails, the entire system doesn't fail as a result.
- Every MCU, MPU, and FPGA must be monitored with a **window** watchdog in addition to the device's built in watchdog or an additional redundant watchdog device.

To reach the highest safety ratings, there must be redundancy in monitoring on every main voltage rail and processor and care must be taken to assure one failure doesn't result in the entire system failing. If a failure does occur, the failure must result in a safe fault mode that does not cause further damage or injury and remains in the fail-safe mode until user intervention.

5 Summary of Devices

Table 5-1 shows a comparison of every device mentioned in this document.

Table 5-1. Comparison of Device Recommendations

	Number of Voltage Monitor Inputs	Voltage Monitor Minimum	Voltage Monitor Maximum	Voltage Monitor Type	Watchdog Type	Features
TPS3808 (1)	1	0.405 V	6.5 V	undervoltage	none	manual reset, programmable reset delay
TPS3620	2	1.15 V	5 V	undervoltage	none	battery backup switch over
TPS3710	1	0.4 V	18 V	undervoltage	none	wide Vin
TPS3700	2	0.4 V	18 V	undervoltage + overvoltage	none	wide Vin, window monitor
TPS3701	2	0.4 V	36 V	undervoltage + overvoltage	none	wide Vin, window monitor
TPS3703-Q1	1	0.9 V	5.5 V	undervoltage + overvoltage	none	window monitor, manual reset, programmable reset delay, latch capability
TPS3779	2	1.2 V	6.5 V	undervoltage	none	dual voltage monitor
TPS3110	2	0.9 V	3.6 V	undervoltage	standard	dual low voltage monitor with standard watchdog
TPS3306	3	1.25 V	6 V	undervoltage	standard	triple voltage monitor with standard watchdog
TPS3307	3	1.25 V	6 V	undervoltage	none	triple voltage monitor
TPS386956	4	0.4 V	6 V	undervoltage	none	quad voltage monitor, manual reset
TPS386000	4	0.4 V	6 V	undervoltage + single overvoltage	standard	quad voltage monitor with standard watchdog, manual reset, programmable reset delay
TPS3430	0	none	none	none	window standalone	programmable window watchdog
TPS3123	1	1.2 V	3 V	undervoltage	standard	low voltage monitor with standard watchdog
TPS3823	1	2.5 V	5 V	undervoltage	standard	voltage monitor with standard watchdog
TPS3813	1	2.5 V	5 V	undervoltage	window	voltage monitor with window watchdog
TPS3850	1	0.4 V	6.5 V	undervoltage + overvoltage	window	window voltage monitor with window watchdog

(1) If monitoring above 1.15 V, use TPS3890 for lower Iq, better voltage monitoring accuracy, and smaller package size.

6 References

There are other references that relate to voltage and processor monitoring that may be useful. Please see the references below for more content and information.

- Importance of monitoring the core voltage rails of MCUs, MPUs, and FPGAs: Oh yes! My FPGA application is safe

Note

This document references TPS3702 but please consider the newer device TPS3703-Q1 as this device has more features and better performance!

- Importance of processor monitoring using a watchdog: What is a watchdog timer and why is it important?
- Voltage Supervisors (Reset ICs): Frequently Asked Questions (FAQs)

Table 6-1. Alternative Device Recommendations

Device	Description
TPS3840	Nano-Iq, 1% Voltage Monitoring Accuracy, Programmable time delay, SOT package type, Active-low / high, Open-drain / Push-pull
TPS3831	150uA Nano-Iq, X2SON (1mm x 1mm) small footprint size
TPS389x	1% Voltage Monitoring Accuracy, Programmable time delay, Active-low / high, Open-drain / Push-pull, USON (1.45mm x 1mm) small footprint size

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (May 2019) to Revision A (August 2021) **Page**

- Updated the numbering format for tables, figures and cross-references throughout the document..................2