A Voltage Monitor With Diagnostics

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Monitoring voltage rails is important to discover faults of the power source. For example, in functional safety applications, an undervoltage or overvoltage fault can lead to an undefined behavior of a microcontroller, which can lead to a dangerous undetected fault causing harm for people, the environment, and properties.

Comparators check the monitored voltage, VMON, against a threshold voltage, V_{THR}, and provide a two-level output dependent on which voltage is larger. A window comparator consists of two comparators and a common precision, low drift voltage reference, V_{REF}. This allows you to monitor a voltage within a window, bounded by a lower and upper threshold.

Per design, V_{MON} is expected within the specified voltage window at all times. The monitor triggers if any threshold is crossed. This puts applications where the correct operation of the monitoring function is essential. How can the system designer be sure that the monitor works as expected if it never trips during normal operation? For example, what if a stuck-at high fault at a comparator output has occurred, preventing the expected level to change the output signal during an out-of-range event? Without additional actions, this fault can lead to undesirable consequences.

An approach to address this issue is to periodically trigger the monitor to test its function. Such a feature must be as simple as possible to avoid additional fault sources.

This tech note describes a simple way to test a voltage monitor by using a single GPIO from a microcontroller without affecting the monitored power rail. Figure 1 shows an example of a connection diagram.

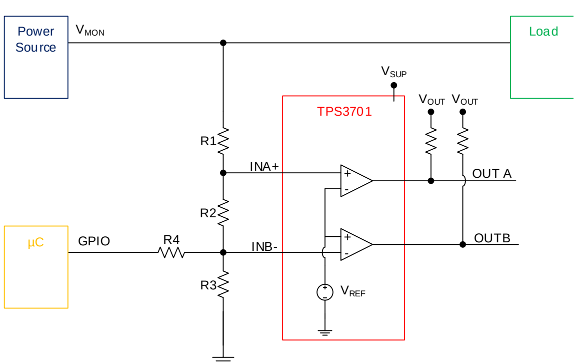

Figure 1. Simplified Schematics

The window monitor in this tech note is the TPS3701. It features a threshold accuracy of 0.75% over full temperature range and a maximum supply voltage, V_{SUPP}, of +36 V. The maximum voltage of the outputs, V_{OUT}, is limited to +25 V. V_{MON} can be higher than V_{SUPP} as the external resistor ladder divides V_{MON} to about 400 mV, which is the internal V_{REF} plus the trip voltage for both comparators. Dependent on the application, V_{MON}, V_{SUPP}, and V_{OUT} can be combined or separated in any combination (within the data sheet voltage limits).

The aim is to develop a voltage monitor for a load, which requires a nominal +3.3 V supply rail with a maximum tolerance of ±10%. This translates to a valid voltage window range of:

- $V_{MON(UV)}$ = 3.3 V × 0.9 = +2.97 V and
- $V_{MON(OV)}$ = 3.3 V × 1.1 = +3.63 V

The following calculation uses the procedure in the application section of the *TPS3701 36-V Window Supervisor With Internal Ref for Over/Undervoltage Detection Data Sheet*. Figure 2 shows a graphical representation of the voltage ranges.

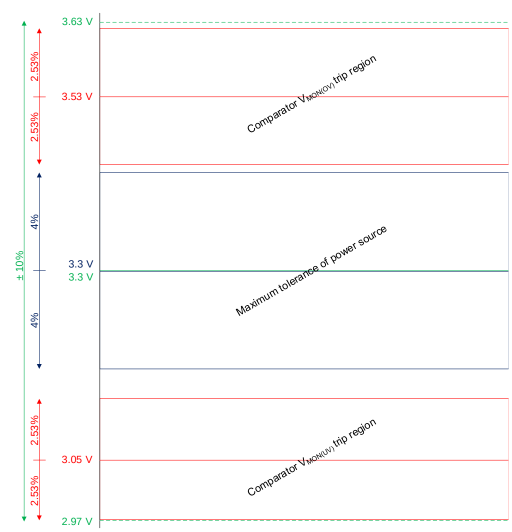

Figure 2. Voltage Regions for Power Source, Load, and Monitor

First, the overall tolerance is calculated using Equation 1.

$$\%ACC = \%TOL(V_{IT+(INB)}) + 2 \times \left(1 - \frac{V_{IT+(INB)}}{V_{MON(OV)}}\right) \times \%TOL_R = 0.75\% + 2 \times \left(1 - \frac{0.4V}{3.63V}\right) \times 1\% = 2.53\% \quad (1)$$

With an assumed resistors tolerance of 1%, the worst-case error is 2.53%. This error narrows the voltage range:

1. $V_{MON(UV)+ERR}$ = 2.97 V+2.53%=3.045 V and
2. $V_{MON(OV)+ERR}$ = 3.63 V-2.53%=3.538 V

The current through the resistor network, R_{TOTAL}, is set to 13 µA. Equation 2 to Equation 5 calculate the resistor ladder values R_1, R_2, and R_3.

$$R_{TOTAL} = \frac{V_{MON(OV)+ERR}}{I} = \frac{(3.538V)}{13\mu A} = 272.167k\Omega \quad (2)$$

$$R_3 = \frac{R_{TOTAL}}{V_{MON(OV)+ERR}} \times V_{IT+(INB)} = \frac{(272.167k\Omega)}{3.538V} \times 0.4V = 30.77k\Omega \quad (3)$$

Resistor R_3 is set 30.9 kΩ, the closest value in the E96 series.

$$R_2 = \frac{R_{TOTAL}}{V_{MON(UV)+ERR}} \times V_{IT-(INA+)} - R_3 = \frac{272.167k\Omega}{3.045V} \times 0.4V - 30.9k\Omega = 4.85k\Omega \quad (4)$$

Resistor R_2 is set 4.87 kΩ, the closest value in the E96 series.

$$R_1 = R_{TOTAL} - R_2 - R_3 = 272.167k\Omega - 30.9k\Omega - 4.87k\Omega = 236.4k\Omega \quad (5)$$

Resistor R_1 is set to 237 kΩ, the closest value in the E96 series.

Solving Equation 2 for V_{MON_OV+ERR} with the sum of the real values of R_1, R_2, and R_3 leads to V_{MON_OV+ERR} = 3.53 V with the error band of ±2.53% (upper pink band).

Solving Equation 4 for V_{MON_UV+ERR} with the sum of the real values of R_1, R_2, and R_3 leads to V_{MON_UV+ERR} = 3.05 V with the error band of ±2.53% (lower pink band).

This results in an allowed power source tolerance of about ±4.0% (blue colored band). Modern DC/DC converters and LDOs operate well within this error band.

Functional Safety applications with a higher safety integrity level (SIL) may ask for a periodic diagnosis of the circuit to ensure proper operation of the voltage monitor.

The monitor is tested by injecting a positive or negative current to pin INB of the TPS3701 to force a trip of the comparators. A general-purpose input/output (GPIO) of a microcontroller can be used for this purpose. When the GPIO outputs “low”, the voltage at INA gets below $V_{IT-(INA)}$ and output OUTA trips. When the GPIO outputs “high”, the voltage at INB is above $V_{IT+(INB)}$ and the output OUTB trips. The diagnostics feature is disabled when the GPIO is set as input (high-impedance).

A series resistor R4 is added to the GPIO signal to allow for small voltage changes at INA/INB inputs. As the value is not critical, it has the same value as R3 (30.9 kΩ) here. However, the resistor value must be low enough to allow a threshold overdrive of >10% (40 mV) for $V_{IT-(INA)}$ and $V_{IT+(INB)}$ to minimize the GPIO low and high test pulse width as the pulse width is a function of the overdrive voltage (see the minimum pulse duration versus threshold overdrive voltage figure in the *TPS3701 36-V Window Supervisor With Internal Ref for Over/Undervoltage Detection Data Sheet*).

The resulting output switch at OUTA/B of the TPS3701 must be distinguished from a real UV/OV event. For example, if the OV signals only trigger an interrupt of a microcontroller, it can be simply ignored by the software for the test. However, additional hardware, that is a switch in the power path, might be included in the test and has to be transparent to the load.

The *8ch Digital Input Module Focusing on Safety Applications Reference Design* shows that influencing the resistor ladder can also be used to create a sticky fault event, as in, the fault flag remains active,ven if the fault has disappeared. This is useful if the fault event may have caused permanent damage to the device and a automatic restart of the system is not desired.

The monitoring function can also be implemented with a standard dual comparator (TL1702) and a shunt regulator used as voltage reference (TL431LI). The accuracy of such a monitor may be not as good, though. Another limiting factor is the higher V_{REF} (TL431LI: V_{REF} =2.5 V), which limits the minimum voltage of V_{MON}. A V_{MON} of 1.8 V, for instance, can only be monitored if V_{REF} is divided down, adding more error. Generally, the condition V_{MON} >> V_{REF} is desired as R_1 increases and decouples V_{MON} from the diagnostics circuit. In terms of reaction time the TLV1702 switches, its output is less than 1 µs while the TPS3701 takes 9 µs (OUTx asserted) and 28 µs (OUTx back to de-asserted). The importance of this parameter is dependent on the application.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
TLV6710	Same	None
TPS3700	(cost)	Lower Vcc
TLV1702	Speed	No internal reference

Table 2. Related Documentation

Type	Title
Reference Design	*TUV-assessed Digital Input Reference Design for IEC 61508 (SIL-2)*
Product Page	TPS3701: High-voltage window voltage detector with internal reference
Product Page	TLV6710: Micropower, 36V Window Comparator with 400mV Reference
Product Page	TPS3700: Window voltage detector with internal reference
Product Page	TLV1702: Dual, 2.2-V to 36-V, microPower Comparator
End Equipment	Analog Input Module
End Equipment	Digital Input Module

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