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Driving a High-Side MOSFET Input Switch Using Active Low Output for System Power Cycling

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Abstract

Applications such as wireless transceivers where systems are placed in remote areas and usually powered with a battery require continuous operation since they are rarely visited and intervened. A system reset is required after persistent inactivity or a system hang-up to restore operation. This can be achieved by cutting off the supply voltage, disconnecting it from the system, and connecting it again to initiate a restart.

This article discusses methods and techniques for using the active low output of a supervisory circuit to drive a high-side input switch to execute a system power cycle.

Introduction

One way to improve the reliability and robustness of electronic systems is to implement protection mechanisms that can detect faults and respond promptly. These mechanisms function as safeguards, mitigating potential damage and ensuring the proper function of a system. Power cycling is a method to ensure proper operation and protect systems and is generally conducted on unresponsive and inactive systems to allow them to work continuously. Power cycling uses a power switch that opens the path between the power supply input and the downstream electronic system, and then closes the path to initiate a system restart. Once the microcontroller unit (MCU) of the system becomes unresponsive, the system will enter reset mode and begin power cycling if inactivity persists.

The most common way of implementing a high-side power path or input switch is by using a MOSFET. Either an N-channel or P-channel MOSFET can be used as an input switch, each with a different driving requirement. Driving an N-channel MOSFET as a high-side switch is a little complicated—thus, a P-channel MOSFET is commonly preferred.

Supervisory circuits can easily sense system inactivity by monitoring the voltage supply and/or using a watchdog timer to detect the absence of pulses. The watchdog timer function enhances the capabilities of supervisory circuits as comprehensive protection solutions. Once inactivity is detected, the watchdog timer asserts a reset output, which is typically an active low signal. This signal can be used to put the microcontroller into reset mode or trigger a nonmaskable interrupt to take corrective action. While an active low output is primarily used to reset the microcontroller, in some cases, such as when the system is unresponsive for too long, it is desirable to power cycle. This can be achieved using various techniques to drive a high-side P-channel MOSFET input switch from a supervisory circuit active low output for optimal system reliability.

Using a MOSFET as a High-Side Input Switch

Figure 1 shows an application circuit using a high-side input switch to protect the downstream electronic system from errors during brownout conditions. A MOSFET is a considerable choice to be used as a system high-side switch. The appropriate voltage and current rating can easily be selected for the application.

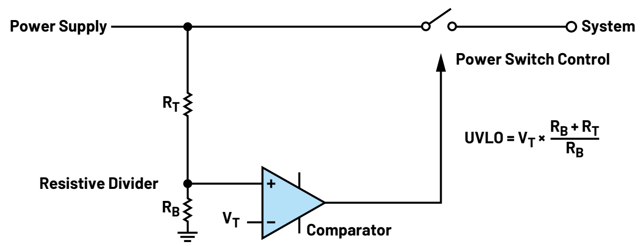

Figure 1. An example of a high-side input switch implementation to protect the system from malfunction during a brownout condition.

A high-side input switch can be an N-channel or a P-channel MOSFET. The N-channel MOSFET switch opens and disconnects the supply voltage when its gate voltage is low. To completely close an N-channel MOSFET and connect the supply to the downstream electronic system, the gate voltage must be higher than the supply by at least the MOSFET threshold voltage. This requires additional circuitry such as a charge pump when using an N-channel MOSFET as a high-side input switch. Some protection circuits integrate a comparator and a charge pump to drive a high-side N-channel MOSFET while keeping the solution simple. Using a P-channel MOSFET as a high-side input switch does not require a charge pump, but the polarity is reversed. This is a common approach for many applications due to its simplicity.

Supervisory Circuit Output to Drive the Input Switch

When utilizing a P-channel MOSFET in a circuit, it is important to first establish the appropriate biasing conditions for the gate, source, and drain terminals. The gate-source voltage (V_{GS}) plays a key role in controlling the conduction of the MOSFET. In the case of a P-channel MOSFET, the gate voltage must be lower than the source voltage by at least the threshold voltage. This negative bias ensures that the P-channel MOSFET is biased into its active region, allowing the current to flow from the source to drain. Additionally, the gate-source threshold voltage ($V_{GS(th)}$) determines the minimum voltage between the gate and source terminals required to create a conducting channel. For a P-channel MOSFET, $V_{GS(th)}$ is typically specified as a negative value, indicating that the gate voltage needs to be sufficiently negative with respect to the source to allow conduction. Another important consideration is the drain-source voltage (V_{DS}), which is the voltage applied across the drain and source terminals. It is essential to operate the MOSFET within the specified V_{DS} limits to prevent damage to the device.

Voltage monitors or supervisory circuits can provide two options for their logic level output: an active low and an active high output signal. On one hand, active low means the output asserts low when the input condition is true and satisfied, and deasserts high when the input condition is false. On the other hand, active high asserts high when the input condition is true and deasserts low when the input condition is false and not satisfied. Since the most common use of supervisory circuits is for microcontroller reset, active low output is used to pull the reset pin of the microcontroller low during faults. Driving a P-channel MOSFET using an active high output is straightforward, especially for open-drain topology.

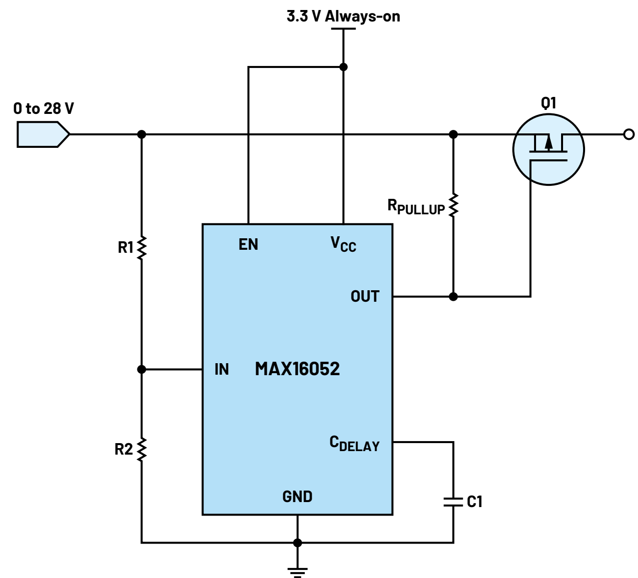

Figure 2. A P-channel MOSFET used as a high-side input switch for overvoltage protection.

The active high output of the supervisory circuit is connected to the gate of the P-channel MOSFET. When the monitored voltage is above the specified threshold, the OUT pin pulls the gate low, turning on the P-channel MOSFET. This connects the load to the supply voltage. When the monitored voltage falls below the threshold, the OUT pin goes high, turning off the P-channel MOSFET and disconnecting the load from the supply voltage.

In Figure 2, the MAX16052, a high voltage adjustable sequencing and supervisory circuit is used as an overvoltage protection circuit. The OUT pin of the device is directly connected to the gate of the P-channel MOSFET. The source of the P-channel MOSFET is connected to the input voltage, and the drain is connected to the load. An external pull-up resistor is connected between the monitored voltage and the gate of the P-channel MOSFET to keep the gate high when the open-drain OUT pin is in high impedance state.

When the monitored voltage is below the MAX16052's specified fixed threshold, the OUT pin pulls the gate pin low, causing the P-channel MOSFET switch to be in a short-circuited state or on state. When the monitored voltage exceeds the threshold, the OUT pin goes high, turning off the P-channel MOSFET and disconnecting the load from the supply voltage.

In some applications, the desired supervisory specification may only be available with an active low output. This means that the output signal is low when the monitored condition is met. In these cases, it is necessary to use techniques to control the input switch with an active low output. For example, in a system where the microcontroller needs to be reset after 32 s of inactivity and the system needs to be power cycled after 128 s of inactivity persistence, a watchdog timer can be used to detect the inactivity through its watchdog input (WDI) pin. The watchdog output (WDO) goes low when there is no pulse or transition detected for a certain period of time (watchdog timeout, t_{WD}). The MAX16155 nanopower supervisor

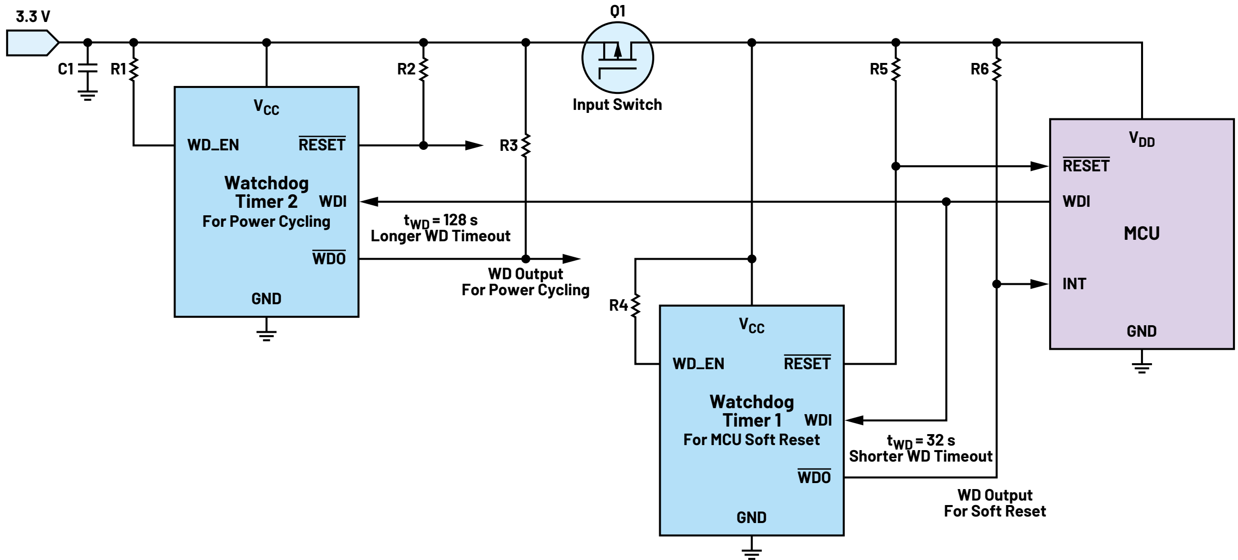

Figure 3. Two MAX16155 watchdog timers with different watchdog timeout are utilized—one to do a soft reset and another one to do power cycling.

with watchdog timer has variants with the desired watchdog timeout of 32 s and 128 s, respectively. Two watchdog timers are required to achieve the desired functionality—one to reset the microcontroller and one to initiate the power cycling routine shown in Figure 3. The primary challenge is determining how to use the low output of the watchdog timer variants to open the input switch during inactivity or system unresponsive state for power cycling.

NPN Bipolar Junction Transistor as a Driving Circuit

One approach to drive the P-channel high-side switch is to use an NPN bipolar junction transistor (BJT) as shown in Figure 4. This circuit forms an inverter that converts the active low signal coming from the watchdog output into a high logic signal required by the P-channel MOSFET switch.

When the system is active, the watchdog output of the MAX16155 WDO pin is in its idle state, which is normally high. It is then connected with a current limiting resistor network to the base pin of the driving transistor. The normally high output of the WDO pin supplies the necessary base-emitter voltage as the control input for the NPN bipolar junction transistor. It establishes enough voltage across the base-emitter junction, causing the transistor to enter its conducting state.

A resistor divider is connected to the gate pin and source pin of the high-side MOSFET switch to control its gate-source voltage (V_{GS}). This gate-source voltage determines whether the MOSFET remains in its on or off state. When the NPN bipolar junction transistor is activated by the WDO pin, current flows through the transistor. This pulls the resistor divider low to GND, which changes the voltage at the junction point in the resistor divider. This voltage is then applied to the gate pin of the high-side MOSFET. This produces a potential difference where the gate pin is at a lower potential than the source pin, which effectively turns on the MOSFET. With the MOSFET in its on state, the power supply is provided to the system microprocessor or the load. Figure 5 shows the current flow when the system is active and the power supply is provided through the switch, Q2.

However, when the microprocessor becomes unresponsive or fails to provide input pulses within the predefined timeout period of the MAX16155 watchdog timer, a watchdog timeout event occurs and WDO asserts low. This consequently pulls the base of the NPN BJT Q1 to the ground, turning it off. When Q1 opens, the voltage on the gate and the source of the P-channel MOSFET Q2 will be approximately equal, which is enough to turn it off.

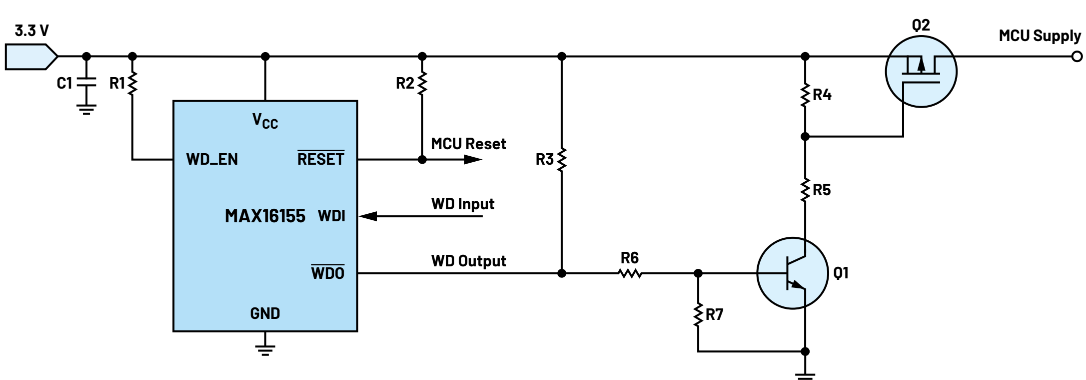

Figure 4. Using an NPN bipolar junction transistor (Q1) in driving a P-channel MOSFET (Q2) from an active low output.

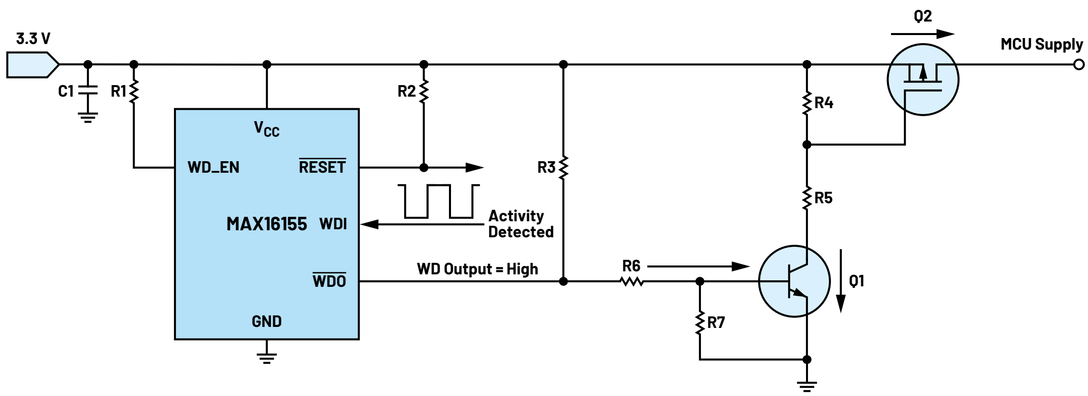

Figure 5. Current flow at normal operation—the system is active.

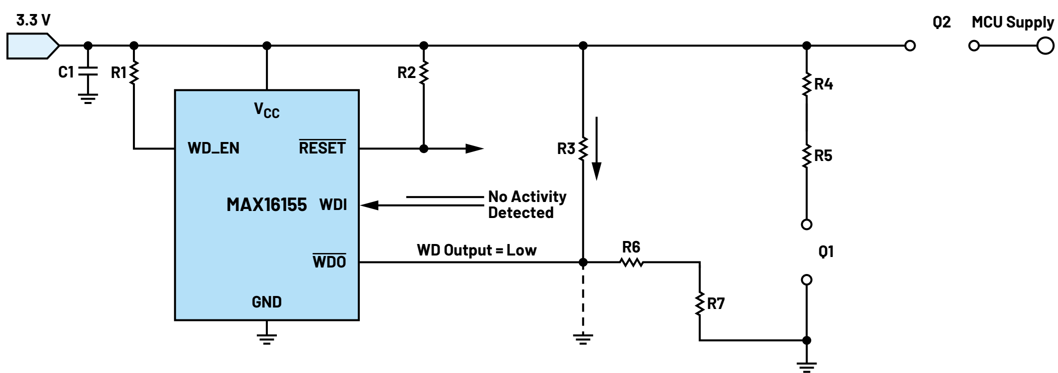

Figure 6. Current flow during system inactivity—power cycle occurs.

As shown in Figure 5, the collector pin of the NPN bipolar junction transistor is connected to the resistor divider across the high-side MOSFET. Due to the off state of the NPN bipolar junction transistor, the voltage on the junction point of the resistor divider and the gate will be approximately equal to the voltage in the source pin. This will result in a zero potential difference between the gate and the source of the MOSFET, which fails to meet the V_{GS} threshold value required to keep the MOSFET Q2 in its conducting state. Consequently, with the MOSFET now turned off, the 3.3 V supply to the microprocessor is disconnected, effectively cutting off power to the microprocessor or the load. The equivalent circuit and current flow during system inactivity and power cycling are shown in Figure 6.

After the WDO output pulse width is completed and returns to a high voltage level, the system reverts to its normal operation. During this phase, the microprocessor resumes sending regular input pulses to the WDI pin, preventing further watchdog timeout events. The NPN bipolar junction transistor returns to its active state, allowing the high-side MOSFET to remain ON, ensuring an uninterrupted power supply to the microprocessor or load. Figure 7 shows the waveforms during the power cycling event using the NPN bipolar transistor. As shown in CH1, there are no transitions detected in the WDI signal which implies system inactivity. After the timeout period, the WDO signal in CH2 asserts low, and during this time, the high-side input switch Q1 opens. Thus, there is no voltage measured in CH3 and the MCU supply voltage and system restart is initiated. CH4 is the output current that is drawn by the load that turned to zero amperes showing that the load was disconnected to the supply voltage.

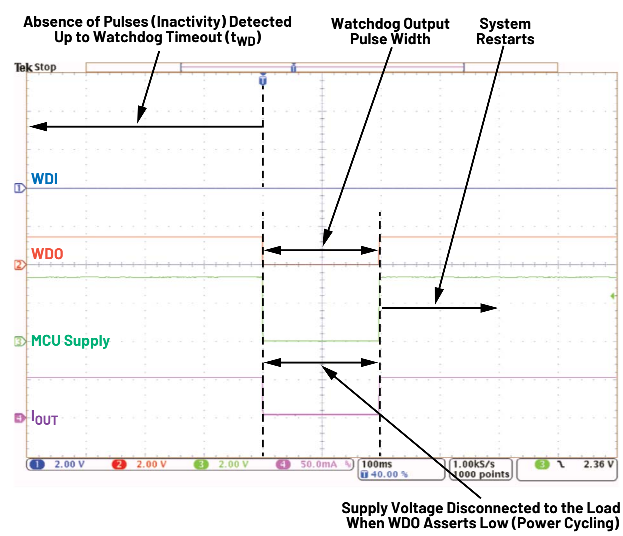

Figure 7. Signals using an NPN bipolar junction transistor in the driving circuit (CH1—WDI signal; CH2—WDO signal; CH3—MCU supply; CH4—I_{OUT}).

One of the major advantages of using an NPN bipolar junction transistor as the driver of the high-side switch is the lower cost of bipolar junction transistors. However, biasing the NPN bipolar junction transistor requires proper tuning with the help of additional external components such as resistors.

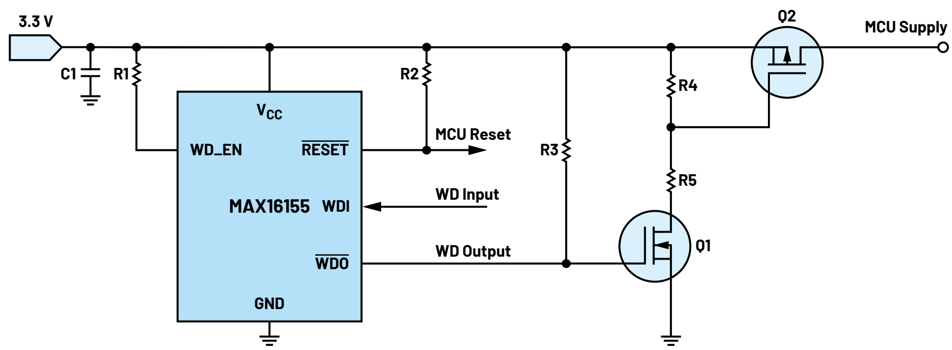

Figure 8. Using an N-channel MOSFET (Q1) in driving a P-channel MOSFET (Q2) from an active low output.

Using an N-Channel MOSFET as a Driving Circuit

An alternative driving circuit using an N-channel MOSFET can be implemented for controlling the high-side P-channel MOSFET. This approach has several advantages over using a bipolar transistor.

The N-channel MOSFET's low on-resistance ensures minimal voltage drop across the device, leading to reduced power dissipation and increased energy efficiency. The MOSFET's fast switching capabilities enable quicker response times, enhancing the supervisory system's real-time performance. Another advantage that the MOSFET can offer is that it exhibits reduced switching losses and higher operating frequencies. This allows smooth and efficient operation, resulting in preserving energy such as in battery-powered applications.

Moreover, the gate-drive requirements are less demanding than those of a bipolar junction transistor, simplifying the driving circuitry and reducing the number of components needed. The watchdog output can directly drive the gate of the N-channel MOSFET shown in Figure 8. The pull-up voltage of the WDO should meet the gate threshold voltage $V_{GS(th)}$ of the N-channel MOSFET to work properly. A logic high output voltage of the WDO when the system is active will turn on Q1, which will consequently turn on Q2, delivering power to the system. Like in the case of the bipolar transistor, a logic low output level from the WDO pin during system inactivity will turn off Q1 and open Q2, cutting off the supply voltage to the system. The behavior of the signals during power cycling using the N-channel MOSFET as a driving circuit is shown in the captured waveform in Figure 9.

The discussed approach in driving high-side switches is beneficial not only on wireless transceivers, but also on other applications that require a power cycling routine in system protection during faults, such as overvoltage and overcurrent in functional and intrinsic safety systems. The sensing stage depends on what condition is required for the power cycle to take place. It can be a voltage supervisor in detecting voltage faults, or current sensor in preventing overcurrent, and other techniques. This article discusses how sensory and supervisory devices with active low output can be used in protecting downstream systems with power cycling.

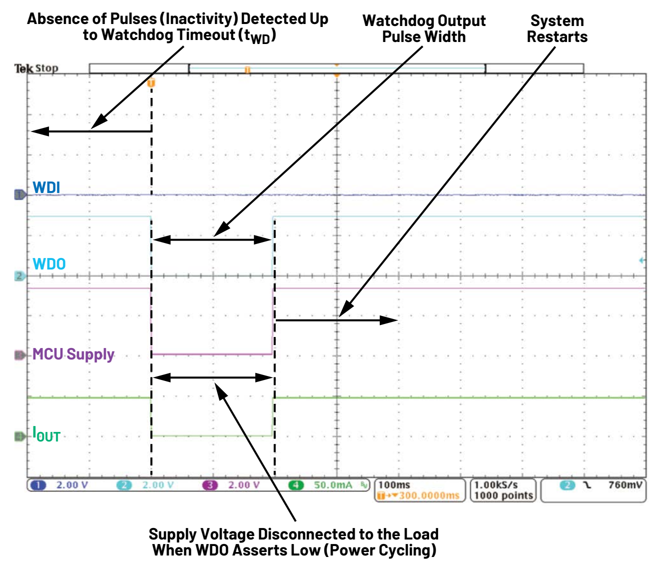

Figure 9. Signals using an N-channel MOSFET in the driving circuit (CH1—WDI signal; CH2—WDO signal; CH3—MCU supply; CH4—I_{OUT}).

Conclusion

There are several techniques for using the active-low signal from a supervisory circuit to drive a high-side switch for power cycling. Using an NPN bipolar transistor with additional components is a lower cost option that meets the requirements for driving the P-channel MOSFET input switch. On the other hand, using an N-channel MOSFET requires fewer components and is easier to implement, but it is more expensive overall. N-channel MOSFETs also have advantages when used as switches at high frequencies. Both approaches are well-proven and provide design advantages for system power cycling.

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Niño Angelo Pesigan joined Analog Devices in June 2022 as a product applications engineer of MMP-East. He holds a bachelor's degree in electronics engineering from University of Santo Tomas in Manila, Philippines. Niño previously worked with the Customer Power Solutions Team and is now focusing on the support of high performance supervisory products and its functional safety compliance.

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