TEXAS INSTRUMENTS

Application Report
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TPS929120-Q1 Fault Handling Routing

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ABSTRACT

The TPS929120-Q1 device is capable of multiple diagnostics that can help automotive lighting designers to realize full-functional protection for automotive lighting system. Detailed instructions on how to identify the exact fault type is introduced in this document. Basic software flow is provided according with a real automotive lighting application case to help accelerate programming design. It is demonstrated that full diagnostic and protection both in normal state and fail-safe state can be achieved to significantly improve the reliability of the lighting system.

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1 Introduction

The TPS929120-Q1 device provides abundant fault diagnostics, including undervoltage lockout (UVLO) and power-on-reset (POR), low-supply warning, reference fault diagnostic, pre-thermal warning, overtemperature protection, communication lost fault diagnostic, LED open-circuit diagnostic, short-to-GND circuit diagnostic and single-LED short-circuit diagnostic. Besides that, the integrated on-chip analog-to-digital convertor (ADC) allows controller of the real-time monitor loading conditions. To further increase robustness, the unique fail-safe of the device state machine allows automatic switching to fail-safe states in the case of communication loss.

2 Functional Block Diagram

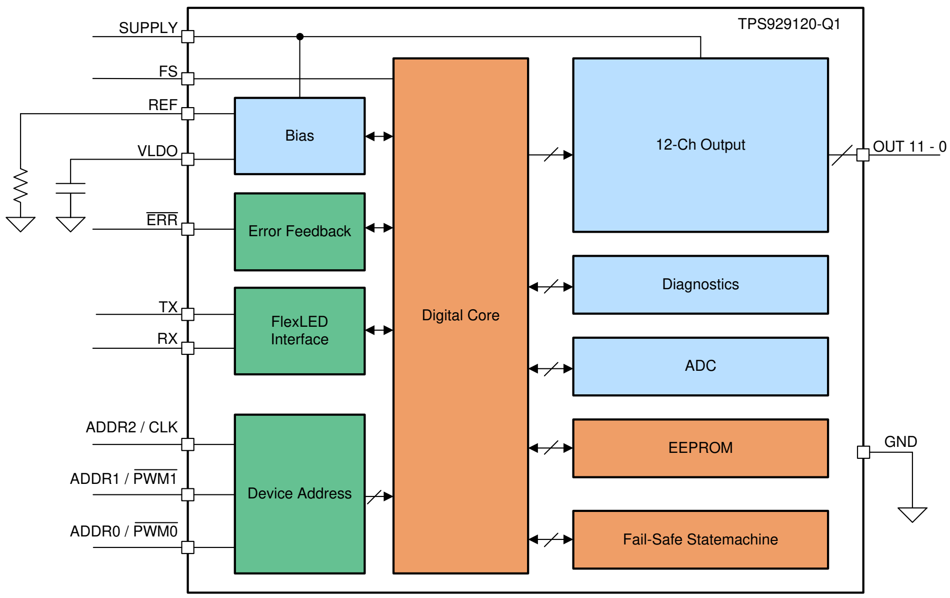

Figure 1. Functional Block Diagram

2.1 Device Bias and Power

The TPS929120-Q1 device is AECQ-100 qualified for automotive applications. The power input to the device through SUPPLY pin can be low to 4.5 V and up to 40 V for both 12-V and 24-V automotive battery systems. The TPS929120-Q1 has an integrated low-drop-out linear regulator, which is powered by supply voltage to provide a stable 5-V output with up to 80-mA constant current capability. The LDO has an internal current limit for protection and soft start.

2.2 12 Channels Output

The TPS929120-Q1 device has 12 channels of high-side current sources. Each channel has its own enable configuration register to enable or disable the channel output. And each output channel supports individual 64-step programmable current settings, which can be used to set binning values for output LEDs or to calibrate the LEDs to achieve high brightness homogeneity.

The TPS929120-Q1 also integrates independent 12-bit PWM generators for each output channel. The frequency for PWM dimming has 16 options covering from 200 Hz to 20.8 kHz. A 1-µs minimum pulse current for all 12 channel outputs is supported by the TPS929120-Q1.

2.3 FlexWire Interface

The FlexWire is a UART-based protocol supported by most microcontroller units (MCU). The FlexWire supports adaptive communication frequency ranging from 10 kHz to 1 MHz and master-slave with star-connected topology. Each FlexWire bus supports a maximum 16 slave devices.

For every normal mode communication, the TPS929120-Q1 will check the CRC byte sent from the MCU. If there is a failure when the TPS929120-Q1 checks CRC, it ignores the message without sending the feedback. The master does not receive any feedback if the communication is unsuccessful.

2.4 Digital Core

The digital core controls the TPS929120-Q1 device to work between specified function modes. After POR, the TPS929120-Q1 will enter initialization state immediately and stay in initialization state for a specified period. Then the device will enter and stay in normal state. While working in normal state, the TPS929120-Q1 can be configured to enter fail-safe state or EEPROM programming state.

2.5 ERR Output

The $\overline{ERR}$ pin is a programmable fault indicator pin. The $\overline{ERR}$ pin is a open-drain output with current limit up to 5 mA.

In normal state, the $\overline{ERR}$ pin is used as fault indicator bus. When a fault is triggered, depending on the fault type, the $\overline{ERR}$ pin is either pulled down constantly or pulled down for a single 50-µs pulse. Basically the TPS929120-Q1 only reports the faults and will not take any actions. The master controller is needed to determine what action to take according to the type of the failure.

In fail-safe states, the $\overline{ERR}$ pin is used as fault bus. When a fault is triggered, the $\overline{ERR}$ is constantly pulled down by internal current sink. The TPS929120-Q1 will also monitor the voltage of the $\overline{ERR}$ pin. If the device is configured as one-fails-all-fail mode, all current enabled channels are turned off when the $\overline{ERR}$ pin voltage is detected as low.

2.6 ADC

The TPS929120-Q1 has integrated a successive-approximation-register (SAR) ADC for diagnostics. The internal ADC can be initiated to detect the voltage on VLDO, SUPPLY, REF and all 12 output pins, the current through the REF pin and internal die temperature.

2.7 EEPROM

The TPS929120-Q1 has a user-programmable EEPROM with high reliability for automotive applications, which can be overwritten and burned up to 1000 times. The value burned into the EEPROM will be kept after powering off and be reloaded into corresponding configuration registers after POR to provide a default value for all the corresponding configuration registers.

2.8 Fail-Safe State

The TPS929120-Q1 supports fail-safe working mode, which is also known as standalone working mode. There are two fail-safe states, fail-safe 0 and fail-safe 1, decided by the FS pin state. For each fail-safe state there are independent channel enable settings. The diagnostics are still working in fail-safe mode, and the device will react through one-fails-all-fail or one-fails-others-on based on the user's advanced configuration.

There are mainly two conditions when the TPS929120-Q1 will enter fail-safe state:

- Watchdog timer flows: The user can set the watchdog period. If there is not a successful communication between the MCU and the TPS929120-Q1 during the specified watchdog period, the TPS929120-Q1 will enter fail-safe state automatically.
- Forcing entering fail-safe state: The user can set related register to force the device to enter the fail-safe state immediately.

After entering fail-safe state, the TPS929120-Q1 can also be recalled back to normal mode through setting related registers if the communication is re-established.

3 Diagnostic and Protection

The TPS929120-Q1 has full-diagnostics coverage for supply voltage, current output, and junction temperature both in normal state and fail-safe state.

In normal state, the device detects all failures and reports the status out through the ERR pin and setting related FLAG registers. The TPS929120-Q1 will not take any actions. So the master controller must handle all fault actions. The master controller can be triggered through the ERR pin pulldown status or reading the FLAG_ERR register value directly to detect if a fault occurred, then read FLAG0 and FLAG1 registers in detail and follow the diagnostic flow as Figure 2 and Figure 3 describe to identify the exact fault type. After identifying the exact fault type, the master controller can take the required action: for example, to disable all used channels to realize one-fails-all-fail function or only report the fault to higher level body controller to realize one-fails-others-on function.

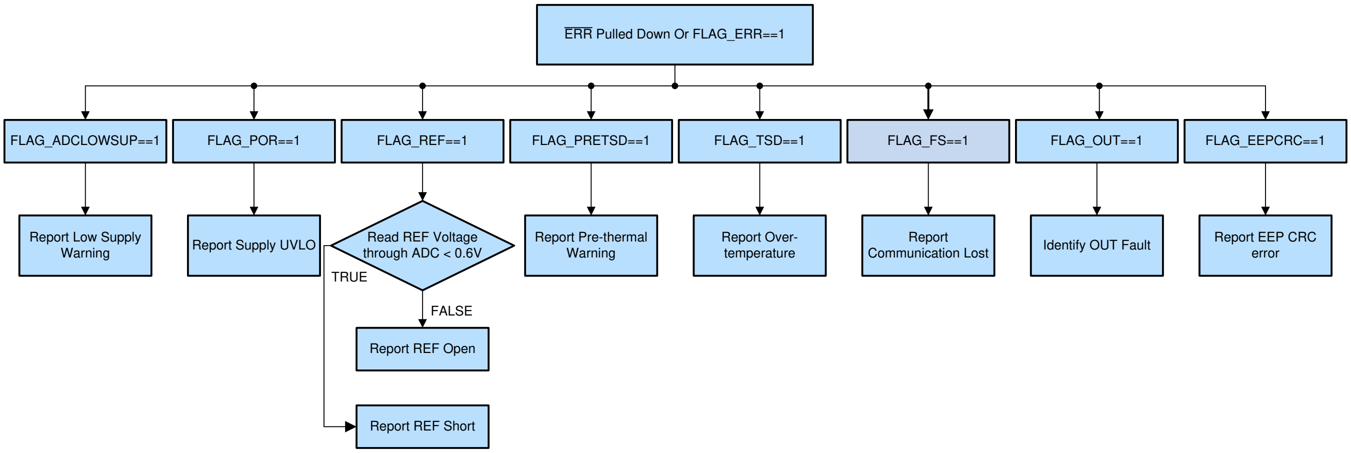

Figure 2. Fault Diagnostic Flow in Normal State

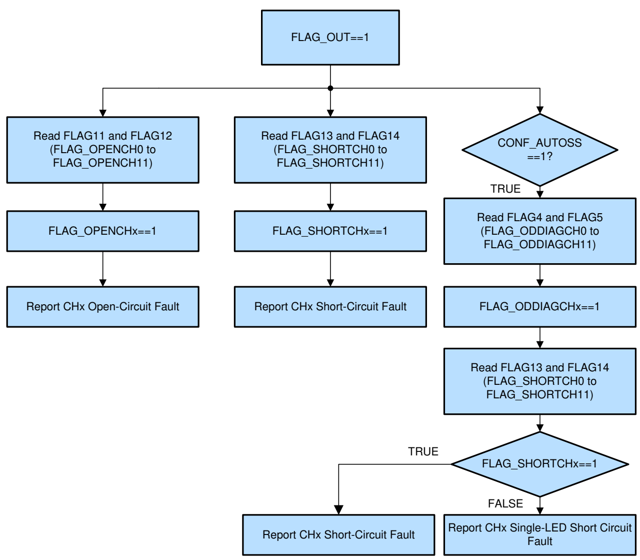

Figure 3. Output Fault Diagnostic Flow in Normal State

The TPS929120-Q1 also provides on-demand diagnostic methods when outputs are disabled. The user can initiate the on-demand diagnostic to check if there is any fault before turning on the LEDs. Figure 4 shows the fault diagnostic flow.

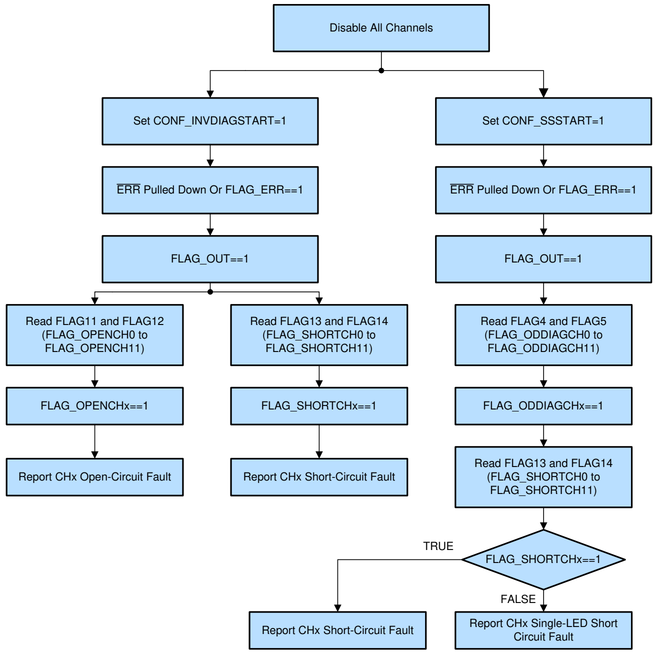

Figure 4. On-demand Diagnostic Flow in Normal State

In fail-safe state, the TPS929120-Q1 also detects all failures and reports the status out by constantly pulling down the $\overline{ERR}$ pin and setting the related FLAG registers. The TPS929120-Q1 actively takes the action to turn off the failed output channels, retry on the failed channels, or restart the device to keep device operating without being controlled by the master.

Table 1 summarizes the available fault detection in normal state and fail-safe state.

Table 1. Available Diagnostics in Normal State and Fail-Safe State

Fault Type	Normal State	Fail-Safe State
Supply UVLO	√	√
Low-supply warning	√	√
Reference fault	√	√
Pre-thermal warning	√	
Overtemperature protection	√	√
Communication lost fault	√	
LED open-circuit fault	√	√
LED short-circuit fault	√	√
On-demand off-state invisible diagnostic	√	
On-demand off-state single-LED short-circuit	√	
Auto single-LED short circuit	√	
EEPROM CRC error	√	√

3.1 *Undervoltage Lockout (UVLO) and Power-On-Reset (POR)*

To ensure a clean start-up, the TPS929120 uses UVLO and POR circuitry to clear its internal registers upon power-up and to reset registers with its default values. The TPS929120-Q1 has internal UVLO circuits so that when either power supply voltage or LDO output voltage is lower than its UVLO threshold, POR is triggered. In POR state, the device resets digital core and all registers to the default value. The FLAG_POR register is set to 1 for each POR cycle to indicate the POR history.

Before both power supply and LDO output voltages are above UVLO thresholds, the TPS929120-Q1 stays in POR state with all outputs off and ERR pulled down. Once both power supplies are above the UVLO threshold and the LDO output voltage is above the LDO UVLO threshold, the device enters initialization mode for initialization and releasing ERR pulldown. A programmable timer starts counting while entering initialization state. When the timer is completed, the device switches to normal state.

Upon powering up, the TPS929120-Q1 automatically loads all settings stored in EEPROM to correlated registers and sets the other registers to default values which do not have correlated EEPROM. All channels are powered up in off-state by default to avoid unexpected flash. After powering up, the FLAG_POR is set 1 to indicate that the power-on-reset occurred. The muster controller must write 1 to CLR_FAULT register to clear the flags.

3.2 Low-Supply Warning

The TPS929120-Q1 continuously monitors the supply voltage and compares the results with internal low supply warning threshold, which has total 16 options covering from 5 V to 18 V.

- In normal state, if the supply voltage is less than the threshold, the $\overline{\text{ERR}}$ pin is pulled down for 50 µs and related flags are set to 1. The muster controller must write 1 to CLR_FAULT register to clear the flags.
- In fail-safe state, if the supply voltage is less than the threshold, only the related flags are set to 1. The flags return to 0 automatically after fault removal.

In addition, the LED open circuit fault and single LED short circuit fault diagnostic is disabled if the supply voltage is below the low supply warning threshold, which can be used to prevent LED open circuit fault and single LED short circuit fault from being mis-triggered while the output stage is working in low dropout mode during powering up progress.

3.3 Diagnostic Enable and Fault Mask

The TPS929120-Q1 provides fault masking capability using masking registers. The device is capable of masking faults by channels or by fault types as Figure 5 shows. The fault masking does not disable diagnostics features but only prevents a fault being reported to the FLAG_OUT register, FLAG_ERR register, and $\overline{\text{ERR}}$ output.

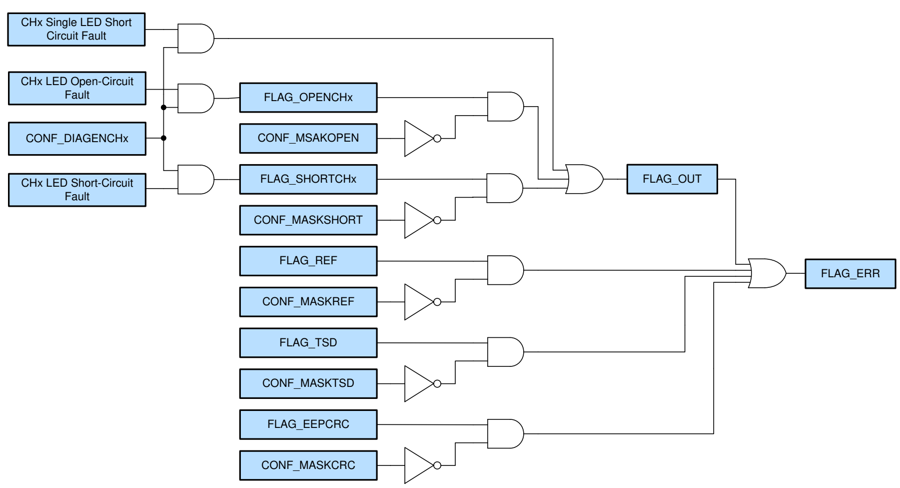

Figure 5. Diagnostic Enable and Fault Mask

3.4 Reference Fault

The TPS929120-Q1 continuously monitors the voltage on the REF pin and output current through the REF pin. If the REF voltage is less than the reference short threshold, then the reference short fault transpired. Otherwise, if the REF current is less than the reference open threshold, the reference open fault occurred. No matter what reference fault is detected, the related flags will be set to 1 and the $\overline{\text{ERR}}$ pin is constantly pulled down.

- In normal state, the device itself does not take any further actions automatically. TI recommends forcing the master controller to shut down the device outputs and report errors to the upper level control system such as body control module (BCM). The muster controller must write 1 to the CLR_FAULT register to clear the flags and release the $\overline{ERR}$ pin pulldown status after fault removal.
- In fail-safe state, the device turns off all used channels. The flags return to 0 and the $\overline{ERR}$ pin automatically returns to high after fault removal.

3.5 Pre-Thermal Warning

The TPS929120-Q1 has pre-thermal warning at typical 135°C and overtemperature shutdown at typical 175°C. When the junction temperature $T_{(J)}$ of TPS929120-Q1 rises above pre-thermal warning threshold, the device reports pre-thermal warning.

- In normal state, the device pulls the $\overline{ERR}$ pin down for 50 µs and sets the related flags to 1. The muster controller must write 1 to CLR_FAULT register to clear the flags.
- In the fail-safe state, the device only sets the related flags without taking any further actions. The flags return to 0 automatically after fault removal.

3.6 Overtemperature Protection

When the device junction temperature $T_{(J)}$ further rises above the overtemperature protection threshold, the device shuts down all output drivers, pulls the $\overline{ERR}$ pin down constantly, and sets the related flags to 1.

- In normal state, when the junction temperature falls below $T_{(TSD)} – T_{(TSD\_HYS)}$, the device resumes all used channels automatically. The muster controller must write 1 to the CLR_FAULT register to clear the flags and release $\overline{ERR}$ pin pulldown status after fault removal.
- In fail-safe state, when junction temperature falls below $T_{(TSD)} – T_{(TSD\_HYS)}$, the device resumes all used channels, clears all used channels, and releases the $\overline{ERR}$ pin pulldown status automatically.

3.7 Communication Lost Fault

The TPS929120-Q1 provides the watchdog function to monitor the communication bus status or master controller status. The watchdog function is enabled through setting the specified watchdog period. If there is not a successful communication between the master controller and TPS929120-Q1 device in the specified watchdog period, the TPS929120-Q1 will consider there is problem with the master controller or the communication bus and enter the fail-safe state immediately.

3.8 LED Open-Circuit Fault

The TPS929120-Q1 integrates LED open-circuit diagnostics to allow users to monitor the LED status in real time. The device monitors voltage differences between SUPPLY and OUTx to judge if there is any open-circuit failure. The SUPPLY voltage is also monitored by the on-chip ADC with programmable threshold to determine if supply voltage is high enough for open-circuit diagnostics.

The open-circuit monitor is only enabled during PWM-ON state with programmable minimal pulse width greater than $T_{(ODPW)} + T_{(OPEN\_deg)}$. The $T_{(ODPW)}$ is programmed by register CONF_ODPW. If PWM on-time is less than $T_{(ODPW)} + T_{(OPEN\_deg)}$, the device does not report any open-circuit fault.

When the voltage difference $V_{(SUPPLY)} – V_{(OUTx)}$ is below threshold $V_{(OPEN\_th\_rising)}$, with a duration longer than $T_{(ODPW)} + T_{(OPEN\_deg)}$, and the device supply voltage $V_{(SUPPLY)}$ is above the threshold $V_{(ADCLOWSUPTH)}$ set by register CONF_ADCLOWSUPTH, the TPS929120-Q1 reports the open-circuit fault. If any channel is disabled by CONF_ENCHx to 0, the LED open-circuit diagnostics skip the channel.

- In normal state, the TPS929120-Q1 pulls the $\overline{ERR}$ pin down for 50 µs and sets the related flags to 1. The master controller must write 1 to CLR_FAULT to clear the flags after fault removal.
- In fail-safe state, the TPS929120-Q1 pulls the $\overline{ERR}$ pin down constantly, sets related flags, turns off the fault channel and decides whether to turn off all the remaining used channels depending on the current one-fails-all-fail or one-fails-others-on settings. The TPS929120-Q1 will retry the failed channel with low-current retry pulses every 10 ms. If the retry is successful, the device automatically releases the $\overline{ERR}$ pin pulldown status, recovers the turned off channels, and clears the flags.

3.9 LED Short-Circuit Fault

The TPS929120-Q1 has internal analog comparators to monitor all channel outputs with respect to a fixed threshold to judge if there is any short-to-GND fault failure.

The short-circuit detection is only enabled during PWM-ON state with a programmable minimal pulse width of $T_{(ODPW)} + T_{(SHORT\_deg)}$. The $T_{(ODPW)}$ is programmable by register CONF_ODPW. If PWM on-time is less than $T_{(ODPW)} + T_{(SHORT\_deg)}$, the device cannot report any short-circuit fault.

When the voltage $V_{(OUTx)}$ is below threshold $V_{(SG\_th\_rising)}$ with duration longer than deglitch timer length of $T_{(ODPW)} + T_{(SHORT\_deg)}$, the TPS929120-Q1 reports the short-circuit fault. If any channel is disabled by CONF_ENCHx to 0, the LED short-circuit diagnostics skip the channel.

- In normal state, the device pulls the $\overline{\text{ERR}}$ pin down for 50 µs and sets the related flags. The device does not take any further actions in response to the LED short-circuit fault. The master controller must write 1 to register CLR_FAULT to clear the flags after fault removal.
- In fail-safe state, the TPS929120-Q1 pulls the $\overline{\text{ERR}}$ pin down constantly, sets the related flags, turns off the fault channel, and decides whether to turn off all the remaining used channels depending on the current one-fails-all-fail or one-fails-others-on settings. The TPS929120-Q1 will retry the failed channel with low-current retry pulses every 10 ms. If the retry is successful, the device automatically releases the $\overline{\text{ERR}}$ pin pulldown status, recovers the turned off channels, and clears the flags.

3.10 On-Demand Off-State Invisible Diagnostics in Normal State

The TPS929120-Q1 includes a feature to detect LED open circuit faults and LED short-to-GND fault when all output channels are disabled, in normal mode. Once the register CONF_INVDIAGSTART is set to 1, the TPS929120-Q1 will output a small pulse current to each output channel simultaneously and detects if there are any LED open circuit or LED short-to-GND fault failures.

At the end of the current output pulse, if there is any LED open circuit fault or LED short-to-GND fault detected, the TPS929120-Q1 pulls the $\overline{\text{ERR}}$ pin down for 50 µs and sets related flags. The master controller must write 1 to the CLR_FAULT register to clear the fault flags. TI recommends turning off all output channels before invisible diagnostics.

3.11 On-Demand Off-State Single-LED Short-Circuit Diagnostics in Normal State

In normal mode, the TPS929120-Q1 includes a feature to detect single-LED-short faults when all output channels are disabled. Once the register CONF_SSSTART is set to 1. The TPS929120-Q1 will sequentially turn on all outputs with a small pulse current starting from OUT0 to OUT11. At the end of each current pulse, the device initiates an AD conversion to detect the voltage of the current output channel and compares it with respect to a pre-set single-LED-short threshold, and then moves to the next channel.

After all channels have been checked, the TPS929120-Q1 will check if the supply voltage is higher than the low supply warning threshold. If the supply voltage is higher than the low supply warning threshold and any one channel output voltage is lower than single-LED-short threshold, the TPS92910-Q1 pulls the $\overline{\text{ERR}}$ pin down for 50 µs and sets the related flags. The master controller must write 1 to the CLR_FAULT register to clear the fault flags after fault removal that is verified by another on-demand off-state single-LED short-circuit diagnostic.

3.12 Automatic Single-LED Short-circuit Detection in Normal State

In normal state, the TPS929120-Q1 also provides the feature to detect single-LED-short fault when channels are enabled. Setting the CONF_AUTOSS register to 1 enables the scanning of each current output channel at the beginning of every PWM cycle. Every automatically single-LED short-circuit (AutoSS) detection takes two PWM cycles to complete scanning. The channel OUT0 to OUT5 are scanned in first cycle and the OUT6 to OUT11 are scanned in second cycle.

On the PWM rising edge, the device waits for a programmable delay $T_{(ODPW)}$ programmable by CONF_ODPW. The minimal pulse width of PWM must be longer than programmable delay $T_{(ODPW)}$ plus 6 times AD conversion time $T_{(CONV)}$ to make sure 6 output channels can be scanned in one PWM cycle. At the end of the sixth AD conversion in each PWM cycle, the TPS929120-Q1 will check if the supply voltage is higher than the low supply warning threshold. If the supply voltage is higher than the low supply warning threshold and any one channel output voltage is lower than pre-set single-LED-short threshold, the TPS92910-Q1 pulls the $\overline{ERR}$ pin down for 50 µs and sets the related flags. The master controller must write 1 to the CLR_FAULT register to clear the fault flags after fault removal.

3.13 EEPROM CRC Error

The TPS929120-Q1 will calculate a CRC value based on all current EEPROM register values except for EEP_CRC and stores it in the CALC_EEPCRC register. The TPS929120-Q1 compares the value stored in EEP_CRC, which needs the customer to write while doing the EEPROM programming, with the calculated CRC value in CALC_EEPCRC while loading the EEPROM register values to configuration registers. If the value in two registers are not the same, the EEPROM CRC fault transpired.

- In normal state, the TPS929120-Q1 pulls the $\overline{ERR}$ pin down for 50 µs and sets the related flags to 1.
- In fail-safe state, the TPS929120-Q1 turns off all used channels, pulls the $\overline{ERR}$ pin down constantly, and sets the related flags.

Table 2. Diagnostics Table in Normal State

Fault Type	Detection Criteria	Conditions	Fault Actions	Fault Output	$\overline{ERR}$ Pin	Recovery
Supply UVLO	$V_{(SUPPLY)} < V_{(POR\_falling)}$ or $V_{(LDO)} < V_{(LDO\_POR\_falling)}$		Device switch to POR state	FLAG_POR FLAG_ERR	No action	Device switch to INIT state when all voltage rails are good. Clear fault flag with CLR_POR
Low-supply warning	$V_{(SUPPLY)} < V_{(ADCLOWSUPTH)}$		No action	FLAG_ADCLOWSUP FLAG_ERR	One pulse pulled down for 50µs	Clear fault flag with CLR_FAULT
Reference fault	$V_{(REF)} < V_{(REF\_SHORT\_th)}$ or $I_{(REF)} < I_{(REF\_OPEN\_th)}$		No action	FLAG_REF FLAG_ERR (Maskable)	Constant pulled down (maskable)	Clear fault flag with CLR_FAULT
Pre-thermal warning	$T_{(J)} > T_{(PRETSD)}$		No action	FLAG_PRETSD	One pulse pulled down for 50µs	Clear fault flag with CLR_FAULT
Overtemperature protection	$T_{(J)} > T_{(TSD)}$		Turn off all channels	FLAG_TSD FLAG_ERR (Maskable)	Constant pulled down (maskable)	Automatically recover upon junction temperature falling below threshold with hysteresis. Clear fault flag with CLR_FAULT
Communication loss fault	$T_{(WDTIMER)}$ overflows		Enter fail-safe states	FLAG_FS	No action	Set CLR_FS to 1 to set the device to normal state
LED open-circuit fault	$V_{(SUPPLY)} - V_{(OUTx)} < V_{(OPEN\_th\_rising)}$ and $V_{(SUPPLY)} > V_{(ADCLOWSUPTH)}$	PWM pulse width greater than $T_{(OPDW)} + T_{(OPEN\_deg)}$ CONF_ENCHx = 1 CONF_DIAGENCHx = 1	No action	FLAG_OPENCHx FLAG_OUT (Maskable) FLAG_ERR (Maskable)	One pulse pulled down for 50 µs (maskable)	Clear fault flag with CLR_FAULT
LED short-circuit fault	$V_{(OUTx)} < V_{(SG\_th\_rising)}$	PWM pulse width greater than $T_{(OPDW)} + T_{(SHORT\_deg)}$ CONF_ENCHx = 1 CONF_DIAGENCHx = 1	No action	FLAG_SHORTCHx FLAG_OUT (Maskable) FLAG_ERR (Maskable)	One pulse pulled down for 50 µs (maskable)	Clear fault flag with CLR_FAULT
On-demand off-state invisible diagnostic	LED Open-circuit or LED Short-circuit fault	Pulse Width: $T_{(OPDW)}$ Current: $I_{(ODIOUT)}$ CONF_ENCHx = 0 CONF_DIAGENCHx = 1 CONF_INVDIAGSTART = 1	No action	FLAG_ODREADY FLAG_ODDIAGCHx FLAG_OUT FLAG_ERR	One pulse pulled down for 50 µs	Clear fault flag with CLR_FAULT
On-demand off-state single-LED Short-circuit	$V_{(OUTx)} < V_{(ADCSHORTTH)}$ and $V_{(SUPPLY)} > V_{(ADCLOWSUPTH)}$	Pulse Width: $T_{(OPDW)}$ Current: $I_{(ODIOUT)}$ CONF_ENCHx = 0 CONF_DIAGENCHx = 1 CONF_SSSTART = 1	No action	FLAG_ODREADY FLAG_ODDIAGCHx FLAG_OUT FLAG_ERR	One pulse pulled down for 50 µs	Clear fault flag with CLR_FAULT after fault removal is verified by another on-demand off-state single-LED short circuit diagnostic
Auto single-LED short circuit	$V_{(OUTx)} < V_{(ADCSHORTTH)}$ and $V_{(SUPPLY)} > V_{(ADCLOWSUPTH)}$	PWM pulse width greater than $T_{(OPDW)} + 6 \times T_{(CONV)}$ CONF_ENCHx = 1 CONF_DIAGENCHx = 1 CONF_AUTOSS = 1	No action	FLAG_ODDIAGCHx FLAG_OUT FLAG_ERR	One pulse pulled down for 50 µs	Clear fault flag with CLR_FAULT
EEPROM CRC error	CALC_EEPCRC is different EEP_CRC		No action	FLAG_EEPCRC FLAG_ERR (Maskable)	One pulse pulled down for 50 µs (maskable)	Clear fault flag with CLR_FAULT

Table 3. Diagnostics Table in Fail-safe State

Fault Type	Detection Criteria	Conditions	Fault Actions	Fault Output	$\overline{ERR}$ Pin	Recovery
Supply UVLO	$V_{(SUPPLY)} < V_{(POR\_falling)}$ or $V_{(LDO)} < V_{(LDO\_POR\_falling)}$		Device switch to POR state	FLAG_POR FLAG_ERR Automatically clears flag register and recover upon fault removal.	No action	Device switch to INIT state when all voltage rails are good. Clear fault flag with CLR_POR
Low-supply warning	$V_{(SUPPLY)} < V_{(ADCLOWSUPTH)}$		No action	FLAG_ADCLOWSUP FLAG_ERR	No action	Automatically clear fault flags when supply voltage is above threshold.
Reference fault	$V_{(REF)} < V_{(REF\_SHORT\_th)}$ or $I_{(REF)} < I_{(REF\_OPEN\_th)}$		Turn off all channels	FLAG_REF FLAG_ERR (maskable)	Constant pulled down (maskable)	Automatically recover, release $\overline{ERR}$ and clear fault flags upon fault removal.
Overtemperature protection	$T_{(J)} > T_{(TSD)}$		Turn off all channels	FLAG_TSD FLAG_ERR (maskable)	Constant pulled down (maskable)	Automatically recover, release $\overline{ERR}$ and clear fault flags upon fault removal.
LED open-circuit fault	$V_{(SUPPLY)} - V_{(OUTx)} < V_{(OPEN\_th\_rising)}$ and $V_{(SUPPLY)} > V_{(ADCLOWSUPTH)}$	PWM pulse width greater than $T_{(OPDW)} + T_{(OPEN\_deg)}$ CONF_ENCHx = 1 CONF_DIAGENCHx = 1	Turn off the failed channels and retries every 10 ms	FLAG_OPENCHx FLAG_OUT (maskable) FLAG_ERR (maskable)	Constant pulled down (maskable)	Automatically recover, release $\overline{ERR}$ and clear fault flags upon fault removal.
LED short-circuit fault	$V_{(OUTx)} < V_{(SG\_th\_rising)}$	PWM pulse width greater than $T_{(OPDW)} + T_{(SHORT\_deg)}$ CONF_ENCHx = 1 CONF_DIAGENCHx = 1	Turn off the failed channels and retries every 10 ms	FLAG_SHORTCHx FLAG_ERR (maskable) FLAG_OUT (maskable)	Constant pulled down (maskable)	Automatically recover, release $\overline{ERR}$ and clear fault flags upon fault removal.
EEPROM CRC error	CALC_EEPCRC is different EEP_CRC		Turn off all channels	FLAG_EEPCRC FLAG_ERR (maskable)	Constant pulled down (maskable)	Automatically recover, release $\overline{ERR}$ and clear fault flags upon fault removal.

4 Application and Implementation

4.1 *Identify the Exact Fault Type in Normal State*

In normal mode, the master controller can detect the $\overline{\text{ERR}}$ pin status or read the FLAG_ERR to judge if a fault happened. To identify the exact fault type, the master controller needs to continue to read additional corresponding registers to get the detailed information.

4.1.1 Design Requirement

A total of 48 LEDs with 2 LEDs in each string are required in one turn indicator module. The 24 strings must be controlled independently to achieve the water flow animation effect. All 24 LED strings are required to sequentially turn on in 180 ms and keep all on for 220 ms, then turn off all LED strings and keep off for 400 ms. Then start another of the same cycle.

LED open circuit fault and LED short-to-GND circuit fault diagnostics are required after turning on each LED string. Once a fault occurs, the master controller needs to identify the exact fault type and take related actions according to the requirement.

4.1.2 Detailed Design Procedure

4.1.2.1 Hardware Setup

Two TPS929120-Q1s are selected to realize the dynamic turn indicator (TI). Every output port of the TPS929120-Q1 will connect two LEDs in series. The TX and RX terminals of two devices are connected together to the related UART interface of the MCU separately. The MCU will read the FLAG_ERR directly to judge if any fault occurred without monitoring the $\overline{\text{ERR}}$ pin pulldown status, so each $\overline{\text{ERR}}$ pin of the device is simply pulled up without connecting to the MCU port. The MCU can receive the command from the body control module (BCM) and can send data back to the BCM through the CAN bus.

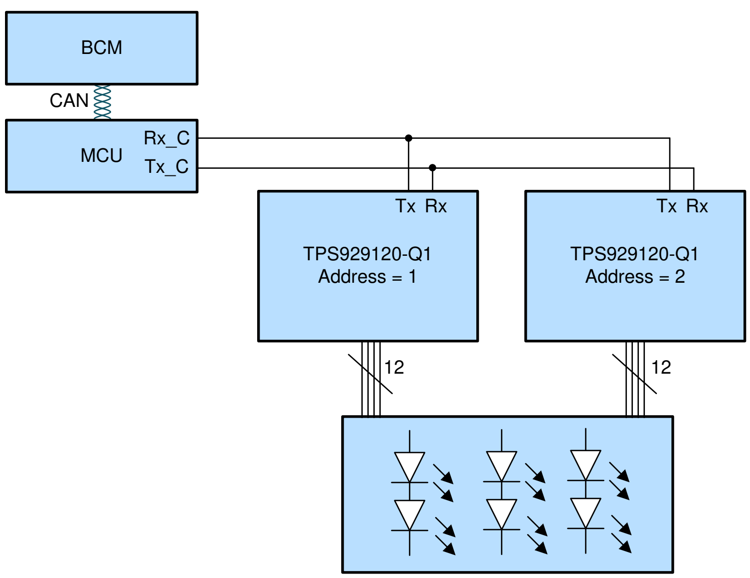

Figure 6. Turn Indicator System Block Diagram in Normal State

4.1.2.2 Software Flow

When the MCU receives the turn indicator start command from the BCM, the MCU program will run into the turn indicator function to turn on the 24 LED strings in order. After turning on each LED string, the program will send the command to read the FLAG0 register to retrieve the FLAG_ERR bit to judge if any fault occurred. If there was a fault, the program can check the fault type following the diagnostic flow shown in Figure 3. Figure 7 shows the entire software flow.

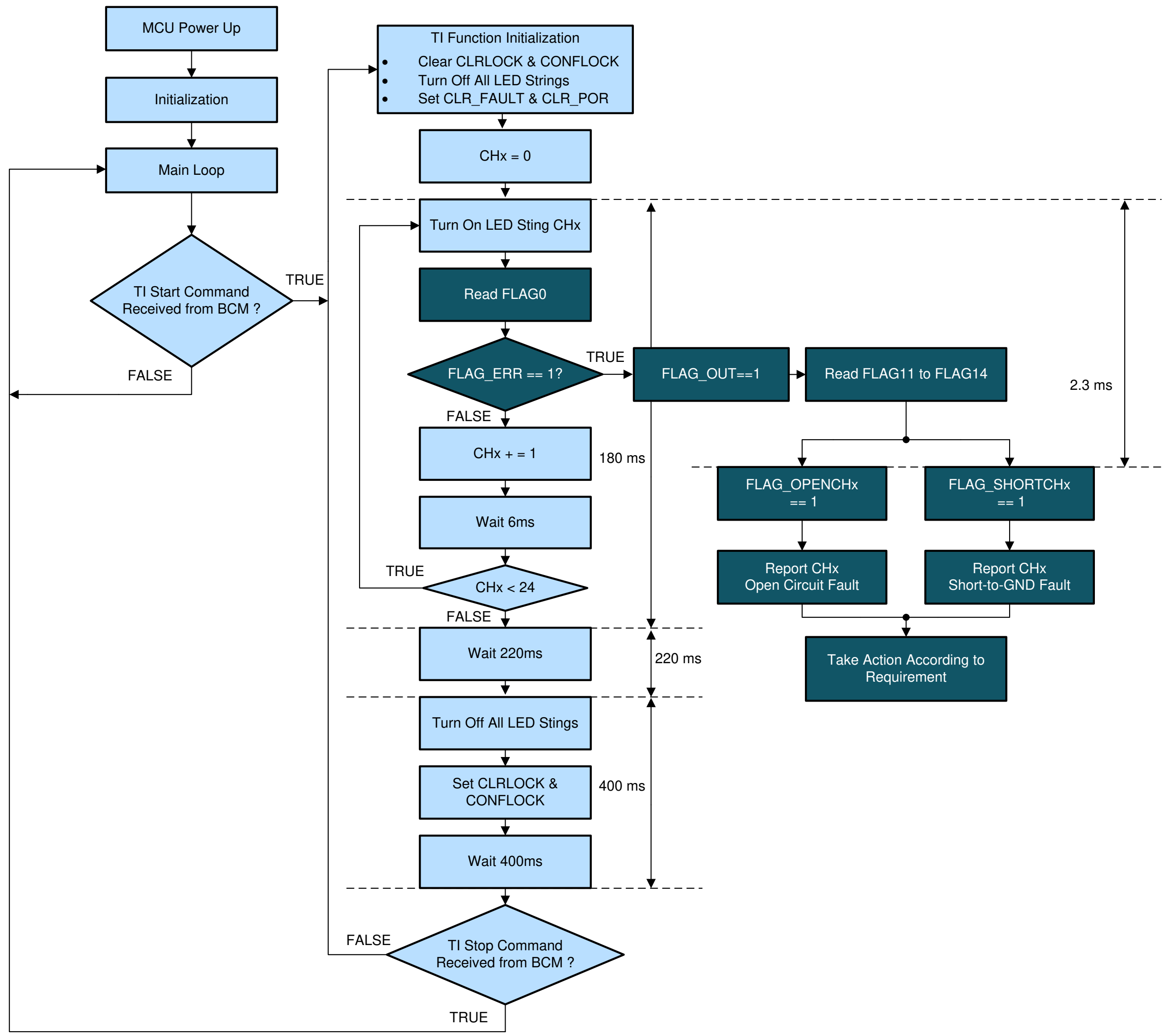

Figure 7. Identify Exact Fault Type in Normal State

Suppose the baud rate setting for the MCU is 200Kbps. The required data transmission time of each communication step in the turn indicator function is calculated out and shown in Table 4. There are two TPS929120-Q1 devices, so every command frame will be sent twice to communicate with each TPS929120-Q1. As the TPS929120-Q1 will ignore the data bit on its RX terminal while sending response bytes through its TX terminal, so the total data transmission time for each communication command frame should contain the byte receiving time and byte sending time.

Table 4. Data Transmission Time for Dynamic Turn Indicator

TI Communication Step	Destination Registers and Operation	Data Transmission Time (ms)
Clear CLRLOCK and CONFLOCK	CONF_LOCK (61h), Write	2 × (5 + 2) × 10 / 200 k = 0.7
Turn Off All LED Strings	CONF_EN0 (50h) and CONF_EN1 (51h), Write	2 × (6 + 2) × 10 / 200 k = 0.8
Set CLR_FAULT and CLR_POR	CLR (60h), Write	2 × (5 + 2) × 10 / 200 k = 0.7
Turn On LED String CHx	CONF_EN0 (50h) and CONF_EN1 (51h), Write	2 × (6 + 2) × 10 / 200 k = 0.8
Read FLAG0	FLAG0 (70h), Read	2 × (4 + 2) × 10 / 200 k = 0.6
Read FLAG11 to FLAG14	FLAG11 (7Bh), FLAG12 (7Ch), FLAG13 (7Dh), FLAG14 (7Eh)	2 × (4 + 5) × 10 / 200 k = 0.9
Set CLRLOCK and CONFLOCK	CONF_LOCK (61h), Write	2 × (5 + 2) × 10 / 200 k = 0.7

As the software flow in Figure 7 shows, the required data transmission time from turning on the LED string to identify the exact fault type for two TPS929120-Q1 devices only takes about 2.3 ms. After identifying the exact fault type, the MCU can take any actions according to the requirement, for example, reports the fault to BCM and turns on all the remaining LED strings to implement one-fails-others-on function, or turns off all the remaining LED strings to implement one-fails-all-fail function.

4.2 Implement One-Fails-Others-On in Normal State

As described in Section 4.1, after identifying the exact fault type, the master controller can turn on all the remaining LED strings to realize one-fails-others-on function.

4.2.1 Software Flow

Whiling doing the dynamic turn indicator function, if the master controller has identified the exact fault type, it can report the fault to BCM and turn on all the LED strings immediately to implement the one-fails-others-on function. And according to the turn indicator design requirement, all the LED strings will continue to keep turning on for 400 ms and turning off for 400 ms, which to make sure the basic turn indicator module still works.

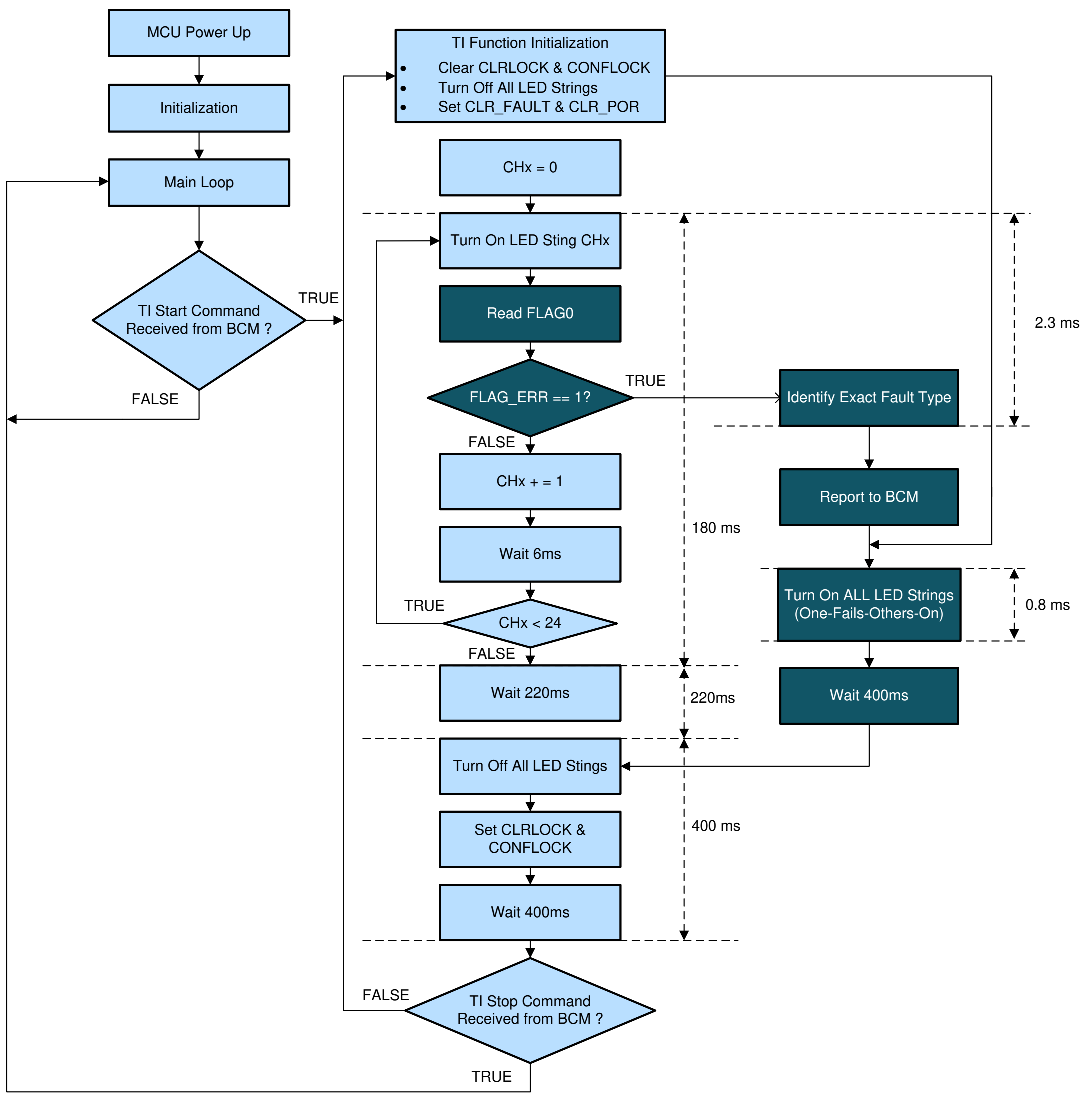

Figure 8. Implement One-Fails-Others-On in Normal State

4.3 Implement One-Fails-All-Fail in Normal State

As described in Section 4.1, after identifying the exact fault type, the master controller can only report the fault to BCM and turn off all the LED strings to realize one-fails-all-fail function. After that it all depends on the BCM to decide what further actions the MCU needs to take.

4.3.1 Software Flow

Whiling doing the dynamic turn indicator function, if the master controller has identified the exact fault type, it can report the fault to BCM and turn off all the LED strings immediately to implement the one-fails-all-fail function. The master controller will wait for the command sent from the BCM to decide what further actions to take.

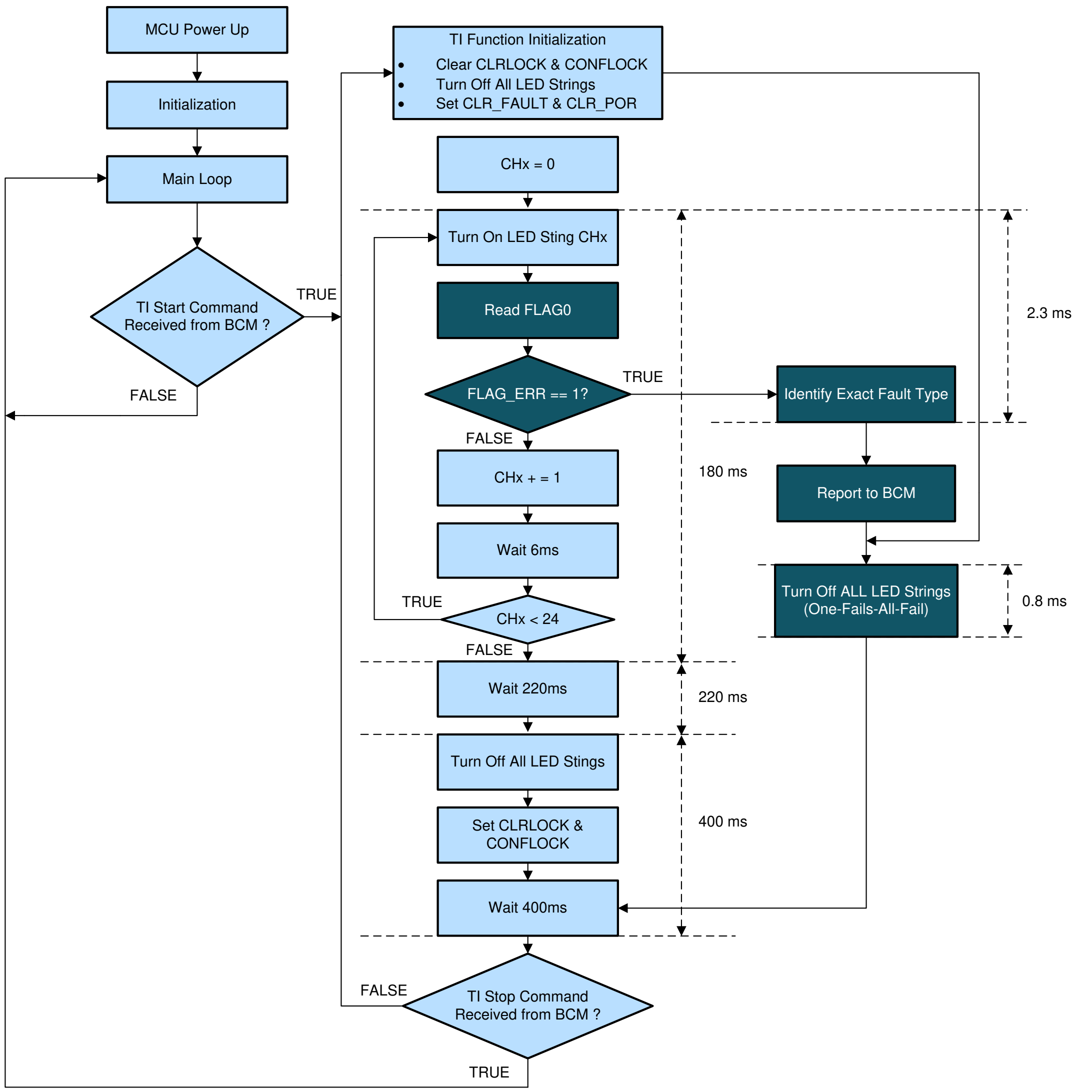

Figure 9. Implement One-Fails-All-Fail in Normal State

4.4 Implement One-Fails-Others-On in Fail-Safe State

The fail-safe mode is also known as stand-alone mode, which means the device is working standalone without the master controller. The TPS929120-Q1 device will enter fail-safe mode automatically if the integrated watchdog function is enabled and the communication is lost. Besides that the TPS929120-Q1 provides two independent 12-bit registers to control the output enable or disable status of the 12 channels. According to the high or low status of the FS pin, the TPS929120-Q1 will select the value of the related 12-bit register to control the output. Based on that, when the device is in fail-safe mode, a simple switch controlling the FS pin voltage high or low can realize basic LED on or off effect.

4.4.1 Design Requirement

As Figure 6 shows, if the communication between the MCU and the TPS929120-Q1 device is lost, the TPS929120-Q1 is required to enter fail-safe mode. A total of 48 LEDs with 2 LEDs in each string are still required to realize the basic function of the turn indicator. All 24 LED strings are required to turn on simultaneously for 400 ms and turn off for 400 ms, then start another of the same cycle. If any fault occurred, all the remaining LED strings are required to keep working. The BCM should be notified once a fault occurred.

4.4.2 Detailed Design Procedure

4.4.2.1 Hardware Setup

To control all LED strings together, the FS pins of the two devices are connected together to receive the control signal from BCM. The FS control pulse signal is provided by the BCM directly. In fail-safe state, the TPS929120-Q1 will monitor the voltage of the $\overline{\text{ERR}}$ pin. When the $\overline{\text{ERR}}$ pin voltage presents low due to a fault occurring, all enabled output channels will be turned off automatically if the EEPROM register EEP_OFAF equals 1, otherwise, only the failed channel will be turned off. As the fault signal should be passed to the BCM, so the $\overline{\text{ERR}}$ pin of two devices are connected together and pulled up to VLDO though a resistor, then connected to the BCM.

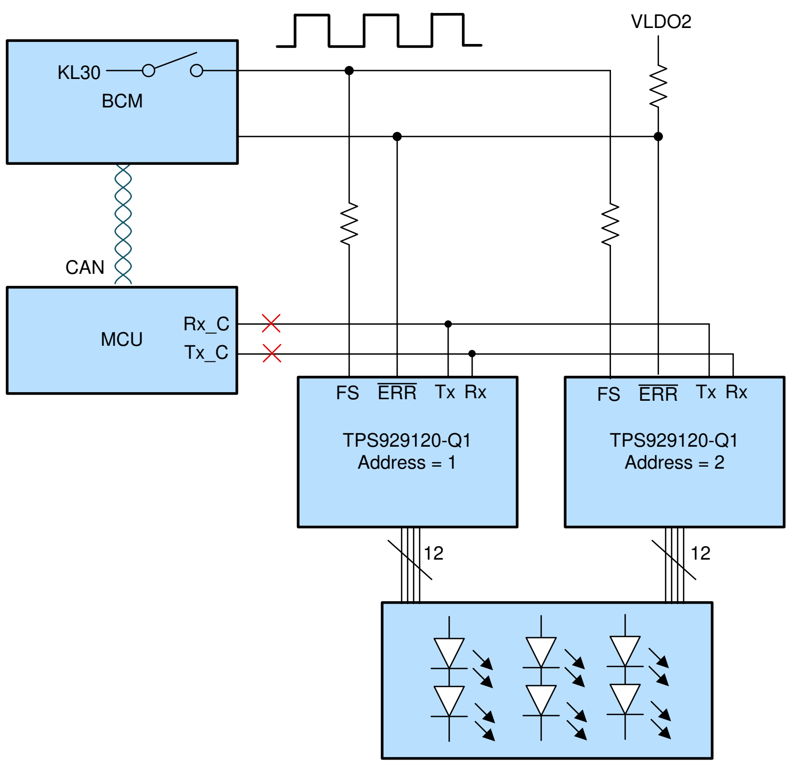

Figure 10. Turn Indicator System Block Diagram in Fail-Safe State

4.4.2.2 Software Flow

To make the device enter fail-safe mode automatically once the communication between MCU and TPS929120-Q1 is lost, the watchdog function of the TPS929120-Q1 should be enabled through burning the related EEPROM with a default value. The turning on and off effect is realized by the FS pulse control signal provided by the BCM. When the FS pulse control signal presents high, the register value of the 12-bit EEPROM, EEP_FS1CH0 to EEPFS1CH11, will load to corresponding 12-bit configuration registers, CONF_ENCH0 to CONF_ENCH11, to control the 12 channels output status. When the FS pulse control signal presents low, the register value of the 12-bit EEPROM, EEP_FS0CH0 to EEPFS0CH11, will load to the corresponding 12-bit configuration registers, CONF_ENCH0 to CONF_ENCH11, to control the 12 channels output status. The default value of the 12-bit EEP_FS1CH0 to EEP_FS1CH11 equals 1 and 12-bit EEP_FS0CH0 to EEP_FS0CH11 equals 0, so there is no need to change their register value. As the default value of the EEPROM register EEP_OFAF is 1, so there is a need to implement the EEPROM programming to burn the EEP_OFAF to 0. The burning operation only needs to do this one time.

In a real application, if a fault occurred, for example, LED open circuit fault or LED short-to-GND circuit fault, the $\overline{\text{ERR}}$ pin will be constantly pulled down with 5-mA sink current. The pulldown status will be passed to the BCM to notify that a fault occurred. As the EEP_OFAF equals 0, only the failed channels will turn off and the remaining enabled channels will keep working, which realize the one-fails-others-on function. At the same time, the TPS929120-Q1 will keep retrying the fault channels, once the external fault is removed, the TPS929120-Q1 will turn on the fault channel and release the $\overline{\text{ERR}}$ pin pulldown status. Then the BCM can be notified that the fault is removed.

4.5 Implement One-Fails-All-Fail in Fail-Safe State

The fail-safe mode is also known as stand-alone mode, which means the device is working standalone without the master controller. The TPS929120-Q1 will enter fail-safe mode automatically if the integrated watchdog function is enabled and the communication is lost. Besides that the TPS929120-Q1 provides two independent 12-bit registers to control the output enable or disable status of the 12 channels. According to the high or low status of the FS pin, the TPS929120-Q1 device will select the related value of the 12-bit register to control the output. Based on that, when device is in fail-safe mode, a simple switch circuit controlling the FS high or low can realize some basic LED on or off effect.

4.5.1 Design Requirement

As Figure 6 shows, if the communication between the MCU and the TPS929120-Q1 device is lost, the TPS929120-Q1 is required to enter fail-safe mode. A total of 48 LEDs with 2 LEDs in each string are required to realize the basic function of the turn indicator. All 24 LED strings are required to turn on simultaneously for 400 ms and turn off for 400 ms, then start another of the same cycle. If any fault occurred, all the remaining LED strings are required to turn off. And the BCM should be notified that a fault occurred.

4.5.2 Detailed Design Procedure

4.5.2.1 Hardware Setup

To control all LED strings together, the FS pins of the two devices are connected together. The FS pulse control signal is provided by the BCM directly. In fail-safe state, the TPS929120-Q1 will monitor the voltage of the $\overline{\text{ERR}}$ pin. When the $\overline{\text{ERR}}$ pin voltage presents low due to a fault occurring, all enabled output channels will be turned off automatically if the EEPROM register EEP_OFAF equals 1, otherwise, only the failed channel will be turned off. As the fault signal should be passed to the BCM, so the $\overline{\text{ERR}}$ pin of two devices are connected together and pulled up to VLDO though a resistor. Figure 10 shows the hardware system block diagram.

4.5.2.2 Software Flow

To make the device enter fail-safe mode automatically once the communication between MCU and TPS929120-Q1 is lost, the watchdog function of the TPS929120-Q1 should be enabled through burning the related EEPROM with a default value. The turning on and off effect is realized by the FS pulse control signal provided by the BCM. As the default value of the EEPROM register EEP_OFAF is 1, so there is no need to change the register value.

In real applications, if a fault occurs, for example, there is one LED string connected to the output of the device1 shorts to GND, the $\overline{ERR}$ pin of the device 1 will be constantly pulled down with 5-mA sink current which will force the $\overline{ERR}$ pin voltage of device 2 to present low. Then all the enabled channels of device 2 will be turned off to realize the function of one-fails-all-fail. At the same time, the TPS929120-Q1 will keep retrying the fault channels, once the external fault is removed, the TPS929120-Q1 will turn on the fault channel and release the $\overline{ERR}$ pin pulldown status. Then the BCM can be notified that the fault is removed.

5 References

1. Texas Instruments, *TPS929120-Q1 12-Channel Automotive 40-V High-Side LED Driver With FlexWire Interface Data Sheet*.