MCD multi-channel driver

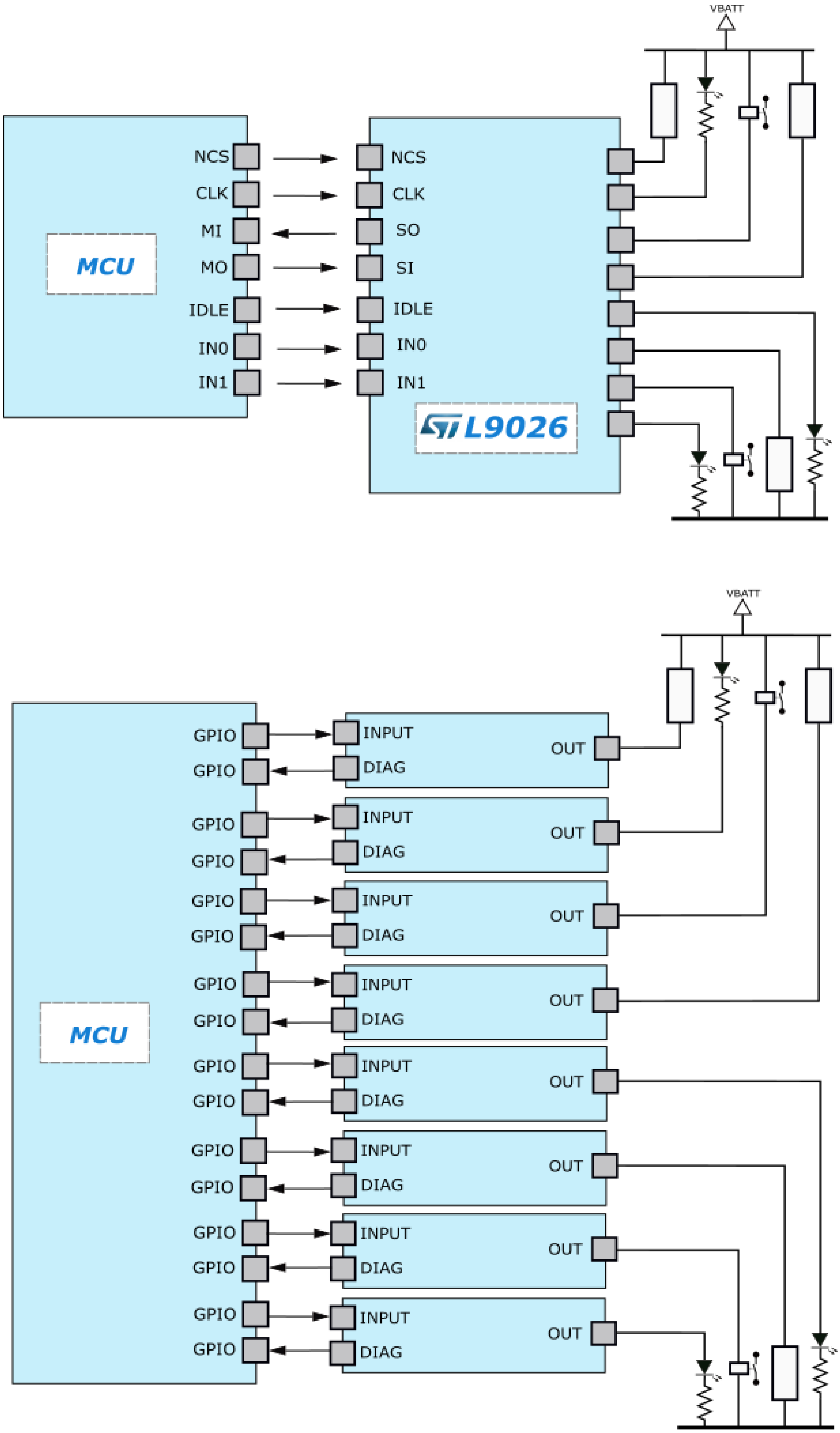
Introduction

This application note has the purpose of integrating the information that are provided in the technical datasheet of the product L9026 (see Section Appendix A Reference documents). It facilitates the correct use of the limp-home mode foreseen to manage extremely critical working conditions. Configuration and diagnostic items involved are highlighted, with a specific focus on open-load ON and OFF diagnosis.

1 MCD features

One of the main advantages using a multichannel driver is the integration and scalability compared with a discrete solution. Figure 1 shows the two options listed above it. The advantage of an integrated solution is evident also in terms of the quantity of connections between the different devices.

Figure 1. Discrete vs integrated solution



Other relevant characteristics of MCD are summarized below:

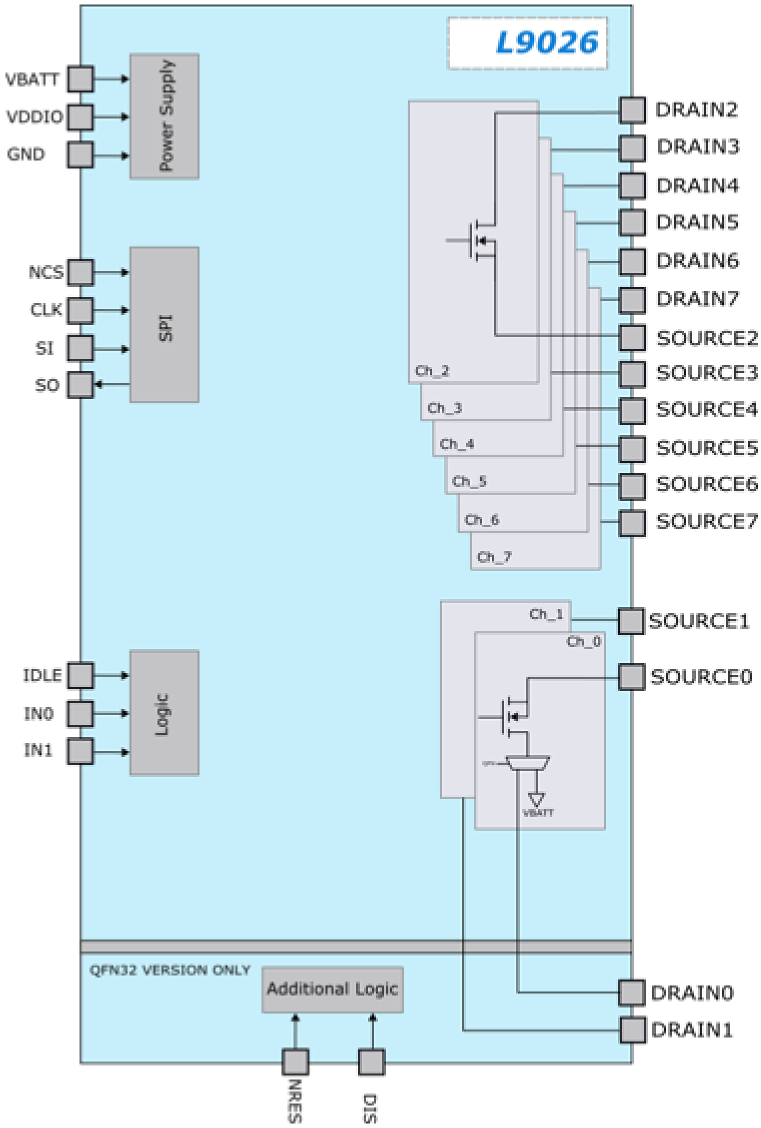
- Eight channels, with 2 fixed HS drivers and 6 configurable HS/LS drivers designed for automotive applications (LEDs and relays).
- Advanced protection function, such as open-load at ON, OFF diagnosis, overcurrent and overtemperature detections.
- A serial peripheral interface (SPI) is used for control and configuration of the loads as well as of the device.

All the other MCD features are listed below:

- Six configurable LS/HS drivers
- Two high-side drivers
- 16-bit serial peripheral interface for control and diagnosis
- Daisy chain capability SPI, also compatible with 8-bit SPI devices
- 2 parallel input pins with input mapping functionality
- Cranking capability down to VBATT = 2.9 V
- Digital supply voltage range compatible with 3.3 V and 5 V µC
- LED mode
- Bulb inrush mode (BIM) to drive 2 W lamps and electronic loads
- 2 internal PWM generator for µC offload
- Very low quiescent current (with usage of IDLE pin)
- Limp-home mode (with usage of IDLE and IN pins)

Figure 2 shows the main internal blocks and the external pins of the device with also underlined the differences between the 2 package options available. MCD device is available in two different package options: HTSSOP24 and QFN32. The QFN32 option offers all the functionalities of HTSSOP24 and in addiction provides two external pins NRES and DIS specifically designed for functional safety issues. The NRES pin is active low. With its assertion, the device is held in an internal reset state. All outputs channels are disabled, and all registers are reset to their default values. The DIS pin is active high, when asserted all channels are disabled. For a detailed description refers to the datasheet of L9026 (see Section Appendix A).

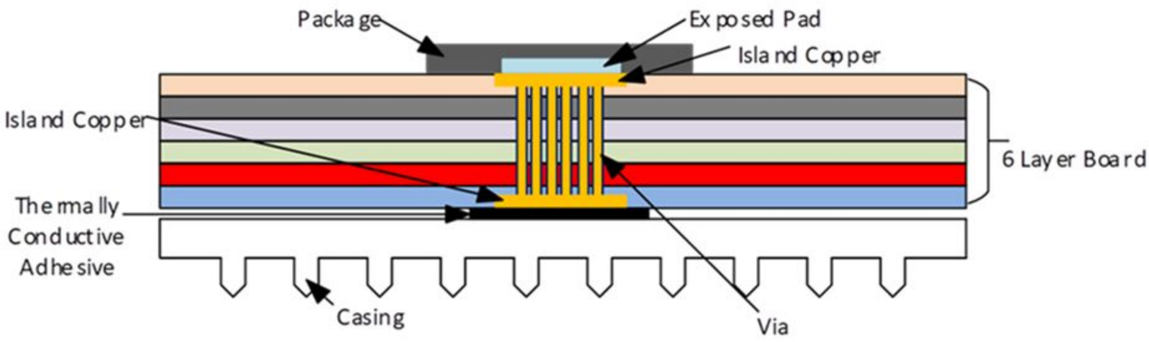
Figure 2. **L9026 block diagram**



If the reverse battery functionality is required, available on VBATT pin and on drain pins of HS configured channels, it is necessary to leave the exposed pad electrically floating.

The following figure shows a possible implementation on a six-layer PCB designed with the target to obtain the electrical insulation with an optimized thermal dissipation. IC substrate reference has been designed, when reverse is applied, to track the negative voltage down to 16 V; in case the EP is connected to GND, the substrate of IC is not free to go down and latch-up can be triggered, which will destroy the part.

Figure 3. **Exposed-pad connection example**

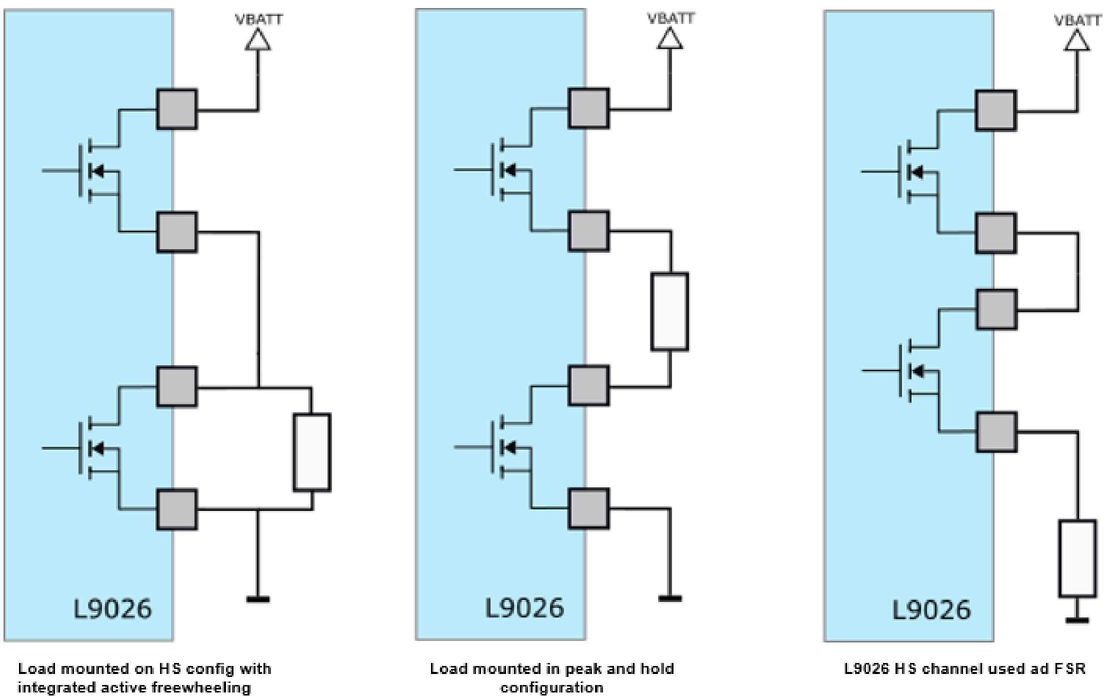


1.1 Different configuration topologies

The two main topologies to drive a load are high-side and low-side. The less expensive configuration is the low-side one mainly because does not require the charge pump structure. When the main requirement is the flexibility the most suitable structure is the configurable driver. In this case it is possible to choose and eventually change the configuration as requested in the specific application. In the configurable driver solution, both source and drain pins are available. The basic options for the configurable driver are low-side or high-side but a variety of different configurations can be considered the main ones are pointed out in Figure 4.

In addiction, it is also possible to configure 4 of the 8 channels available into an H-bridge structure. In this case the micro needs to correctly drive the gate signals.

Figure 4. **Different configuration topologies**



1.2 Power dissipation estimation

The power stage shows a typical on-state resistance $R_{DS(ON)}$ of 0.75 Ω with a T_J = 25 °C and a maximum of 1.5 Ω within operative ranges. The power stage is protected in case of overcurrent, overload, overtemperature and overvoltage. In addiction there are also presented the OFF diagnoses and the open-load at ON diagnosis.

Being L9026 featured by high integration scale factor, the power dissipation is crucial in order to guarantee the device working inside its safe operating area, far away from over temperature condition, which would lead the affected channel to be switched OFF.

The power estimation needs to consider the conduction losses related to the value $R_{DS\,(ON)}$ value, with the usage of the following equation:

$$P_{cond} = \sum_{Ch1}^{Chn} I^2 R_{DS\,(ON)} \tag{1}$$

The worst-case scenario is at 150°C with a value of 1.5 Ω. Moreover, in case of switching channels is necessary to consider the switching losses estimated with:

$$P_{\text{switching}} = \sum_{Ch1}^{Chn} I_{Chn}^2 \quad V_S\, F \left(T_{rise} + T_{fall}\right) \tag{2}$$

The V_S is the supply voltage, nominal value 14 V. The T_{rise} and T_{fall} are directly related to slow rate limits influenced by the supply voltage.

The last contribution needed to have the complete overview is the operative power dissipated by the device logic estimated with the following equation:

$$P_{operative} = V_S\, I_{Active} \tag{3}$$

The total power dissipation is obtained with the sum of the three components as shown in the following equation:

$$P_{TOT} = P_{operative} + P_{\text{switching}} + P_{cond} \tag{4}$$

1.3 Cranking

The device is able to guarantee operations under the cranking scenario down to VBATT=3V. In this condition it is possible to switch on and off the channels as in normal operation, also the diagnosis functions are available. SPI communication is possible if VDDIO supply is also above the undervoltage threshold.

During cranking, operation VBATT supply can assume a value lower than VDDIO. In this condition also the logic is supplied from VDDIO as result the current sunk increase.

1.4 Limp-home mode

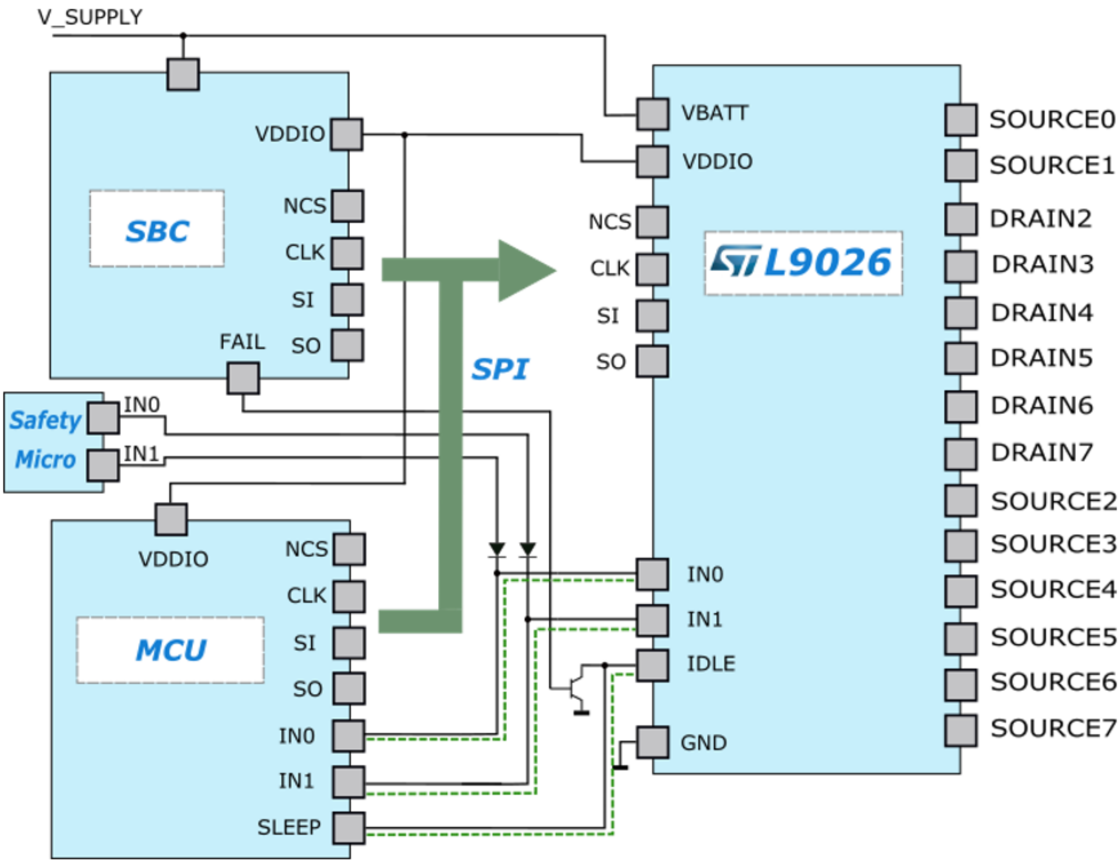
The limp-home is intended to handle limited functionality of the device in critical faulty situations.

A typical application scenario is reported in Figure 5 with a system, which is reconfigured during limp-home as per Figure 6.

In case of failure of the micro that controls the device, an external safety micro takes over which controls the parallel inputs IN0 and IN1. The SBC forces the IDLE signal low, which brings the device in limp-home. Once the switching activity on IN0, IN1 is finished, since the IDLE pin is still deasserted, the device will go into sleep mode.

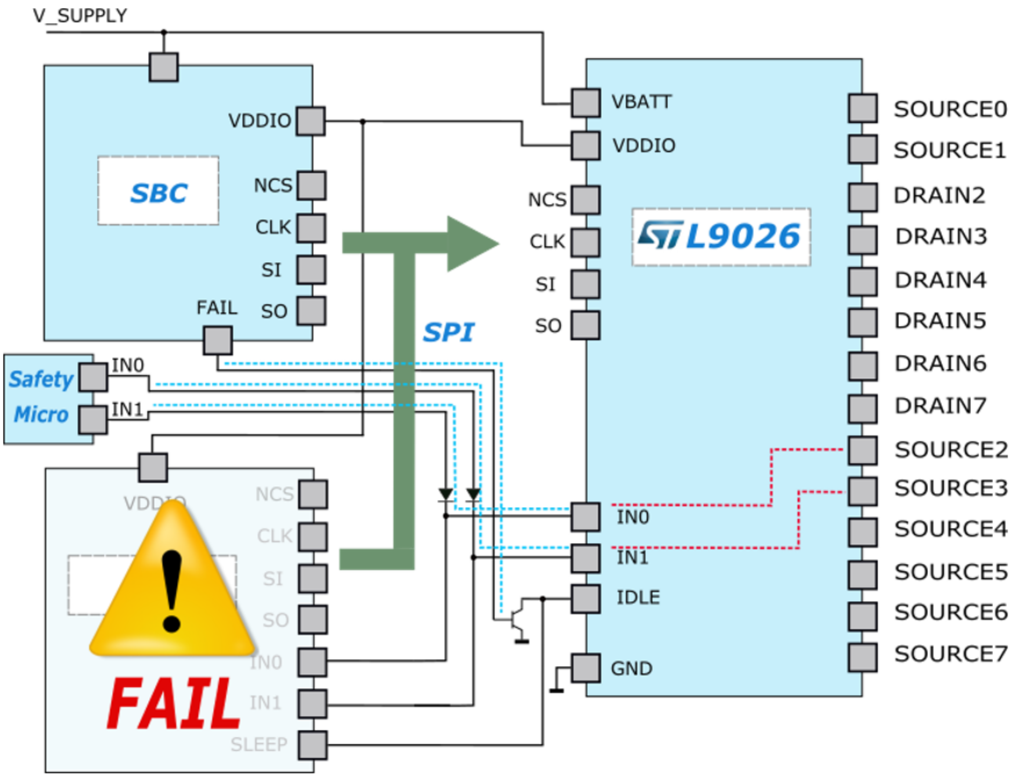
During this mode active, L9026 is only capable of driving two outputs that is, OUT2 through IN0 and OUT3 through IN1; such a mapping is fixed and overcomes an eventual different mapping programmed via SPI once the limp-home is reached.

Figure 5. **Possible system configuration during normal operating conditions**



In Figure 5 the dotted green lines mark the signals path when the device is operating in normal node, IDLE, IN0, IN1 are provided by the main MCU. Figure 6 shows a possible Limp Home configuration where the dotted blue lines mark the signals path.

Figure 6. **Possible system configuration during limp-home**



2 Diagnostics features

2.1 OFF diagnosis

The device is able to detect two kinds of faults in OFF, open-load and short (to battery in HS configuration or to ground in LS configuration).

This diagnosis is available upon request SPI. Once the diagnosis has been started on one or more channels, any new diagnosis request is ignored until the end of the current cycle.

The diagnosis strategy is implemented over two different phases:

- First the IC distinguishes between faulty and no faulty condition.
- In the event of a fault found in the previous step, a specific procedure is put in place to detect the nature of the fault.

The diagnosis is slightly different depending on an LS or HS configured output.

The strategy in LS configuration is reported below and referred to Figure 7; the HS case is quite similar, except for the order in which pull up and pull-down current generators are activated and for the pin involved (SOURCEn for an HS configured channel, DRAINn for an LS).

- This first phase lasts for t_{OFF1LS}. The current generator marked with ‘pldw’ (driven by dw_on) is active while the current generator marked as ‘plup’ is off. In this condition, if the drain voltage remains above the threshold VDS(OL), the comparator output is low, which means that a load is present. If the drain voltage decreases below the threshold, instead, the comparator flags the presence of a fault.
- This second phase lasts for t_{OFF2LS}.

  Once the first stage of diagnosis is complete, the comparator output is set to "1" if a fault condition has been detected. The current generator marked with ‘plup’ (driven by the signal up_on) is activated while ‘pldw’ is off.

In case, after the pull-up activation, the drain voltage rises and overcomes the comparator threshold again, an open-load fault is reported.

If the voltage remains constant and equal to zero for the whole diagnosis time, instead, a short to ground fault is recognized and flag is recorded.

Figure 8 shows the diagnosis in case of LS configured channel (that is, channel 2). The time measure is taken in open-load condition between the SPI message to request the diagnosis on the channel and the voltage increase on DRAIN2 pin. OFF diagnosis for HS configured channel case is reported in Figure 8. Open-load condition was detected and time interval between SPI request and voltage drop in SOURCE2 pin was measured.

Figure 7. OFF diagnosis circuit

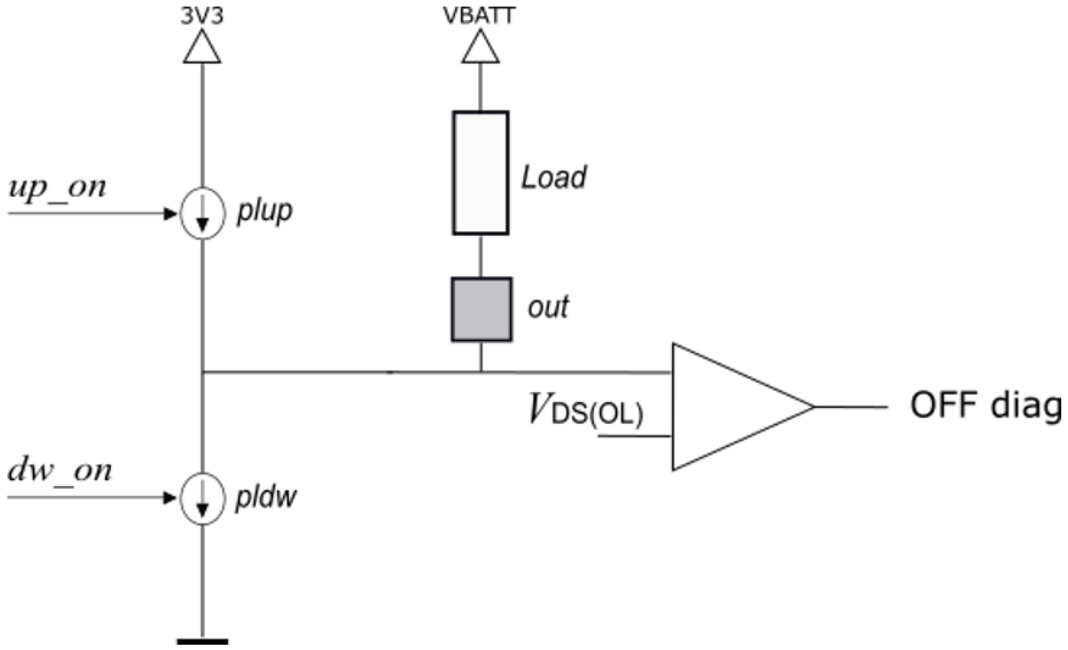


Figure 8. **OFF diagnosis LS open-load condition**

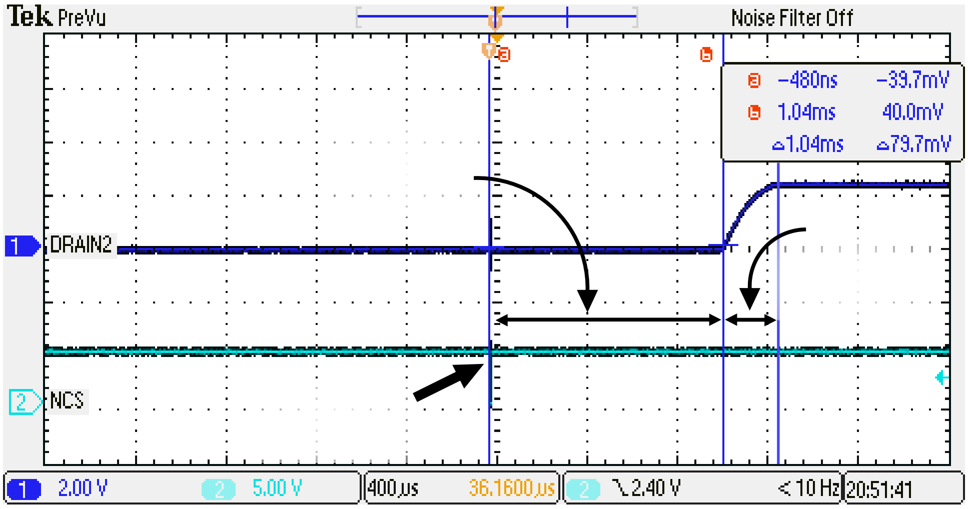
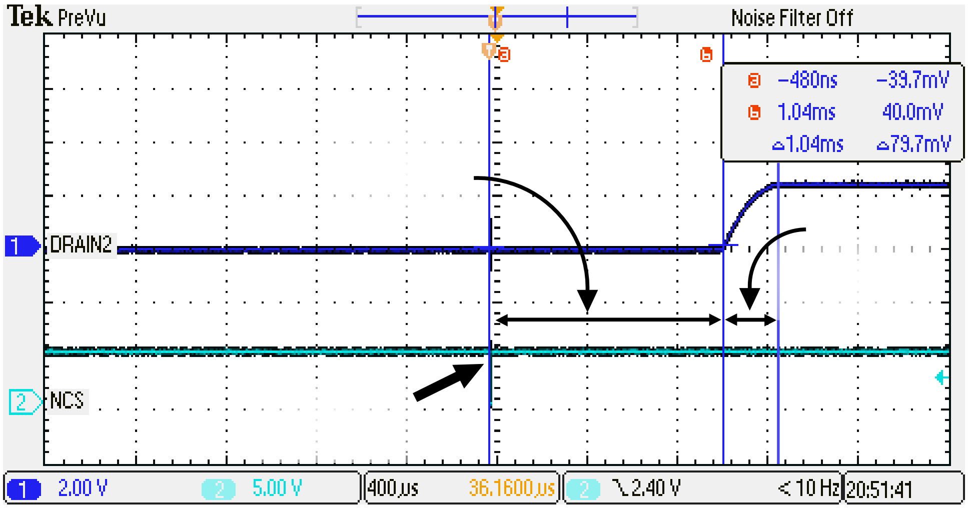


Figure 9. **OFF HS open-load condition**



2.2 Open-load at ON

On each channel it is possible to request the open-load at ON diagnosis.

This diagnosis is designed having in mind a specific case of high-side channels driving LEDs kept fully ON.

Moreover, the device ignores the request of an open-load at ON diagnosis in case the channel is configured as low-side. This means that the diagnosis request register is not updated if a diagnosis is requested on a configured low-side channel.

Such a diagnosis is not recommended in case of loads driven in PWM mode (to avoid eventual interferences with the PWM driving signal) and inductive loads (to avoid unwanted power dissipations during switch OFF transients).

2.2.1 Open-load at ON diagnosis mechanism

The diagnosis cannot be run on more channels simultaneously, but it can work only on one channel at a time. In case open-load diagnosis is requested on more channels simultaneously the SPI request are ignored.

This can be activated by setting the bit corresponding to the desired channel in the DIAG_OPL_ON_EN register.

During the diagnostic loop, the channel is switched off every t_{OPLCYC} for a maximum time of t_{OPLEN}.

Such a time is designed to be short enough to result in a negligible variation of the luminescence of LED during the test.

During the short switch-off time required to perform the diagnosis a pull-up current generator $I_{L(OL)}$ is applied to the source of the channel, as can be seen from Figure 10.

If the load is present the source voltage drops suddenly, the output of the comparator is set and the channel immediately restarts.

If an open-load condition exists, instead, the pull-up current $I_{L(OL)}$ is capable of keeping the source voltage to battery and the Vds value remains stable for the whole diagnosis time interval.

In this case once t_{OPLEN}, is elapsed, the comparator output is still low and the flag related to the fault is set; the channel is anyway restarted.

The OPL ON diagnosis lasts just a t_{OPLEN} time in the worst-case scenario, that is, when the open-load is detected.

Once an SPI frame commanding the diagnostic is received, the diagnosis will start a *T*oplcyc time after the corresponding request has been accepted.

As long as the diagnosis request bit remains high the open-load test will be performed every *T*oplcyc and the results of the diagnosis are reported in the register DIAG_OPL_ON: if an open-load on channel ‘n’ is detected, the corresponding bit DIAG_OPL_ONn is set.

Figure 10. **Open-load at ON schematic**

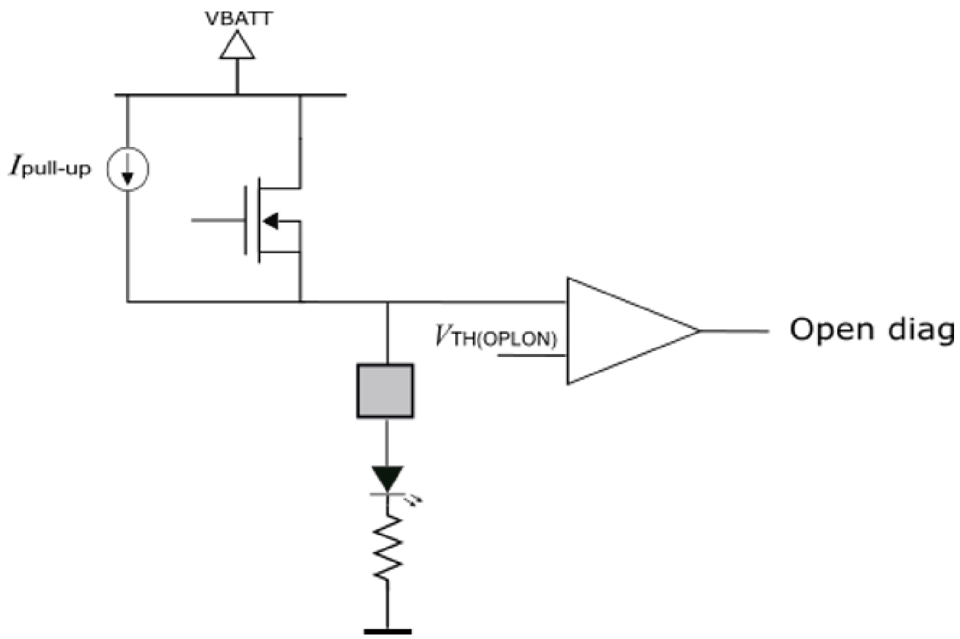
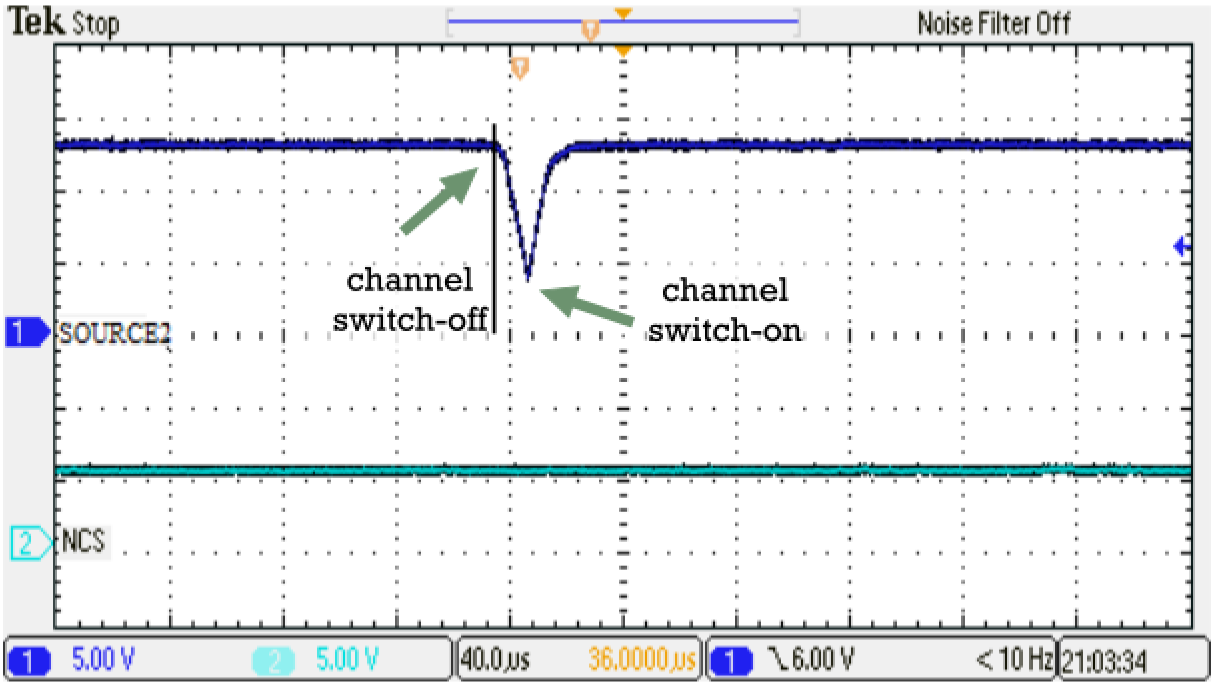


Figure 11. **Open-load at ON with load connected**



The figure above shows the DRAIN pin variation in case of open-load at ON diagnosis, the channel is configured as high-side and with a load connected. It is evident that the OFF time is extremely limited due to the load presence.

3 Application usage

3.1 Energy and clamp

The L9026 implements a circuit to prevent the output voltage at the driver terminals to increase above the maximum allowed voltage and permanently damage the device. For this reason, is important to evaluate if the relay that will be used is in line with the maximum energy that can be dissipated in the device without external components.

The following equation is used to estimate the energy stored in an inductive load.

$$E_L = \frac{1}{2} L I_L^2 \tag{5}$$

With L is the load inductance and I_L is the load current.

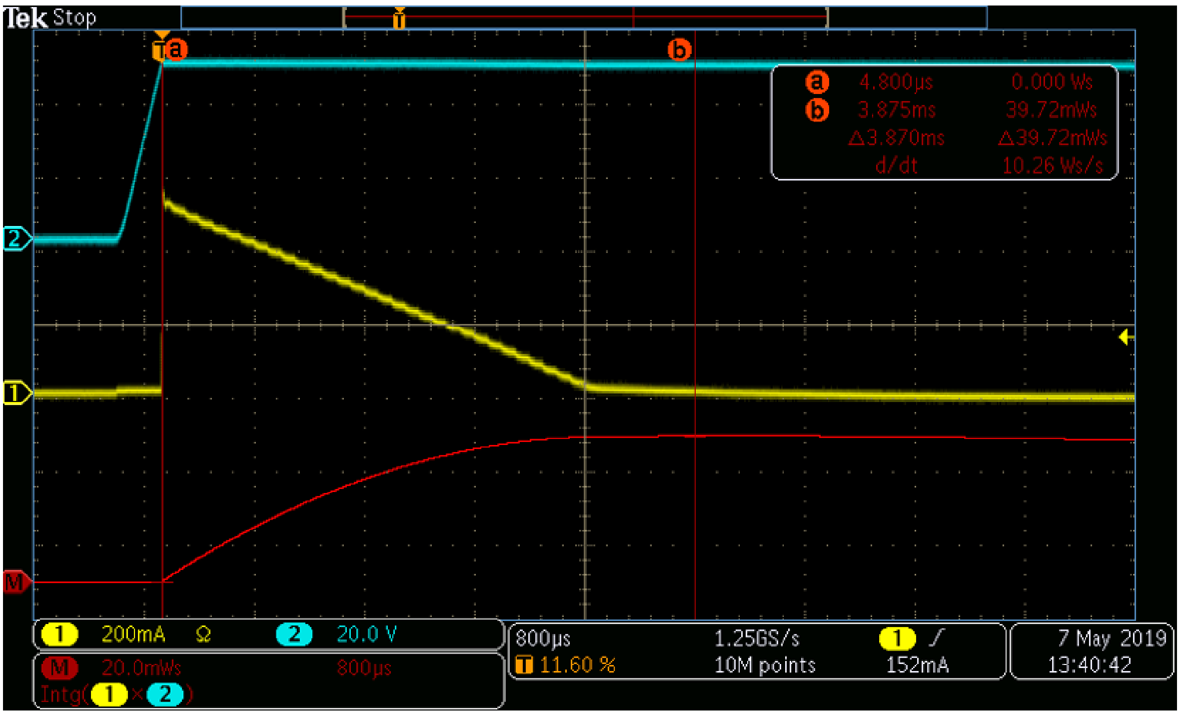
The energy to be dissipated on the power stage during the clamping event is differentiate for the HS and LS case as reported in the following equations:

$$E_{HS} = \left(V_S - V_{OUT(CL)}\right)\left[\frac{V_{OUT(CL)}}{R_L}\ln\left(1 - \frac{R_L I_L}{V_S - V_{DS(CL)}}\right) + I_L\right]\frac{L}{R_L} \tag{6}$$

$$E_{LS} = V_{DS(CL)}\left[\frac{V_S - V_{DS(CL)}}{R_L}\ln\left(1 - \frac{R_L I_L}{V_S - V_{DS(CL)}}\right) + I_L\right]\frac{L}{R_L} \tag{7}$$

With V_S supply voltage, $V_{OUT(CL)}$ source to ground clamping voltage, R_L load resistance, I_L load current, $V_{DS(CL)}$ drain to source clamping voltage and L load inductance.

Figure 12. **Energy at clamp LS config channel**



The figure below shows current and voltage during the clamp action. Channel 1(yellow) represents the current evolution during clamp, channel 2 (blue) shows the voltage on the output V_{SD}.

The energy dissipated on the output stage is evaluated directly on the oscilloscope with the math function that implement the Eq. (8), reported in Figure 12 with the red line.

$$E_L = \frac{1}{2}\int_{t_0}^{t_{clamp}} I_L(t)\, V_{SD}(t)\, dt \tag{8}$$

3.2 Parallel channels

The L9026 gives the option to drive more channels in parallel to increase the current capability above the overcurrent limit.

In the case of a specific application it is necessary to drive a relay or a generic high current load, the solution is to connect the load to several channels in parallel.

To correctly drive the two or more drivers in parallel it is necessary to use the same input signal (SPI, PWM or parallel inputs). This makes it easy to overcome the current limitation. The user is responsible of synchronization between channels eventually mounted in parallel.

3.3 Bulb inrush mode (BIM)

Usually capacitive load or bulbs show an inrush current much higher than the nominal one. This would lead to a switch-off driven by overcurrent diagnostic at startup, with the impossibility to bring the load in steady state.

The L9026 implements BIM function in order to overcome this possible limitation: if overcurrent occurs in normal operation, device needs microcontroller to send an SPI command to clear the latches in order to re-engage the channel. When BIM is enabled, instead, the IC restarts automatically after a time t_{INRUSH}, allowing to transfer the energy to the load required to reach steady state operating mode.

The channel configured with BIM option can be either driven by an SPI command, PWM command (internal generator) or INn parallel inputs.

The automatic re-engagement of the faulty channels lasts for a BIM time (t_{BIM}). Once the *t*BIM counter is started, it is reset only once the t_{BIM} is expired, unless a reset condition occurs (VDDIO_UV, hardware, or software reset).

3.4 PWM generators and LED

The L9026 provides specific function designed to drive LEDs. Open-load at ON has this purpose, is designed considering the case of an LED fully on for which is required to know the status during the ON phase.

The L9026 offers also two indipendent PWM generators. This function can be used on all kinds of loads however is extremely useful to drive LED.

The device has two independent PWM generators, which are defined as “PWM GEN” and “PWM LED” here below. These can be assigned to one or more channels and can be programmed with a different duty cycle and frequencies. Both refer to the same base frequency f_{INT} (8 MHz typ) even if two separate prescalers can be defined.

4 Conclusion

The purpose of this application note is to exploit the main advantages obtainable with the use of MCD in an automotive context. The main system level advantages are:

- Robustness; the different functions to detect faults, like OFF diagnosis, open-load at ON diagnosis, overcurrent and overtemperature, gives high level of robustness against critical conditions.
- Safety features; the limp-home mode is specifically designed to handle harmful events. In addiction cranking capability and all the diagnosis functions increase the safety level of the device.
- PCB size reduction; thanks to the high level of integration achievable with the device is possible to reduce the necessity of external components as a result the PCB are needed is less than a discrete solution.
- Flexibility; the option to configure six outputs as high-side or low-side, the possibility to connect a variety of loads (LED, relay, lamp), makes the device suitable for the usage in a wide range of applications.

Appendix A Reference documents

Table 1. Reference documents

Doc name	Title
DS13397	Automotive configurable multi-channel relay driver 2HS + 6HS/LS

Revision history

Table 2. **Revision history**

Date	Version	Changes
13-Oct-2022	1	Initial release.

Contents

List of figures