LITIX™ Basic+ LED driver Family

Diagnosis and fault management

About this document

Scope and purpose

This document explains the main operating principles of the diagnosis and fault management features integrated in the LITIX™ Basic+ family. Additionally the component dimensioning process and configuration possibilities are described.

Intended audience

HW designers, LED system architects and engineers for LED lighting applications

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1 Diagnosis features in LITIX™ Basic+

The LITIX™ Basic+ LED driver family offers several diagnostic features. The diagnostic features can monitor the LED load or the device temperature. The LED load failures which can be detected are open load, short circuit to ground and single LED short (SLS). Table 1 shows the diagnosis feature overview of the Basic+ family.

Table 1 LITIX™ Basic+ Family diagnosis feature overview

Device	Open Load	Short circuit to GND	Single LED short	Overtemperature detection
TLD1114-1EP	No	No	No	OT shutdown + diagnosis
TLD2132-1EP	Yes	Yes	Yes	Thermal derating, no diagnosis
TLD2131-3EP	Yes	Yes	Yes	Thermal derating, no diagnosis
TLD2331-3EP	Yes	Yes	Yes	Thermal derating, no diagnosis
TLD2142-1EP	Yes	Yes	No	Thermal derating, no diagnosis
TLD2141-3EP	Yes	Yes	No	Thermal derating, no diagnosis

The LED load diagnosis integrated into the LITIX™ Basic+ family is based on the measurement of the output voltage and comparison to certain voltage references. To increase the reliability of the fault detection, a filter for entering and exiting fault conditions is integrated. A fault condition is successfully detected when the fault condition is continuously present for typical 80 µs, the fault detection filter time t_{fault} (datasheet parameter P_7.5.19). Once the fault is properly detected, the communication to external circuitry will be done by pulling the ERRN-pin down (see chapter 1.5) and the configured fault management routine will start, as described in chapter 4.

1.1 Open load diagnosis

During an open load fault condition the circuit between a LITIX™ Basic+ output, its LED load and ground is opened. This can be caused by e.g. a high ohmic fail of an LED or a broken wire. As the current path to ground is not present anymore the high-side current source pulls the output towards the supply voltage V_S. This means the voltage drop on the power stage $V_{PS} = V_S - V_{OUT}$ goes towards zero and therefore below the open load detection threshold $V_{PS(OL)}$ (P_7.5.5).

During an open load fault condition the power stage is automatically disabled and only a small current $I_{OUT(fault)}$ (P_7.5.7) is sourced to the output. With this current, the output tracks the supply voltage keeping the channel in the open load condition ($V_{PS} < V_{PS(OL)}$), also during transients on the supply pin VS. When the open load condition is removed and the LED load is connected again the output voltage will drop to the forward voltage of the LEDs. The full output current will be driven again once the power stage voltage drop exceeds $V_{PS(CC)}$ (P_6.5.36 to P_6.5.39).

1.2 Short circuit to ground diagnosis

A short circuit to ground condition is detected when the output voltage drops below $V_{OUT(SC)}$ (P_7.5.6). When the output voltage is below $V_{OUT(SC)}$ threshold voltage the output stage is automatically disabled as a protective measure. This happens independently of the diagnosis enable state. Once the power stage is deactivated, only a small current $I_{OUT(fault)}$ is sourced to the output for further diagnosis and restart.

1.3 Single LED short diagnosis

Since it is important to detect all kinds of LED failure modes, the single LED short diagnosis has been integrated into three devices out of the LITIX™ Basic+ LED driver family (TLD2132-1EP, TLD2131-3EP and TLD2331-3EP). Standard diagnosis mechanisms, such as an open load or short circuit to ground diagnosis are not able to detect this kind of LED failure. When one LED of an LED chain fails in a short circuit, the output voltage of the channel driving the faulty LED chain drops, roughly by the forward voltage of one LED, as indicated in Figure 1. The output current continues to flow through the LEDs because there is still a closed current path. The single LED short diagnosis works by monitoring the output voltage and checking if it drops below a reference voltage.

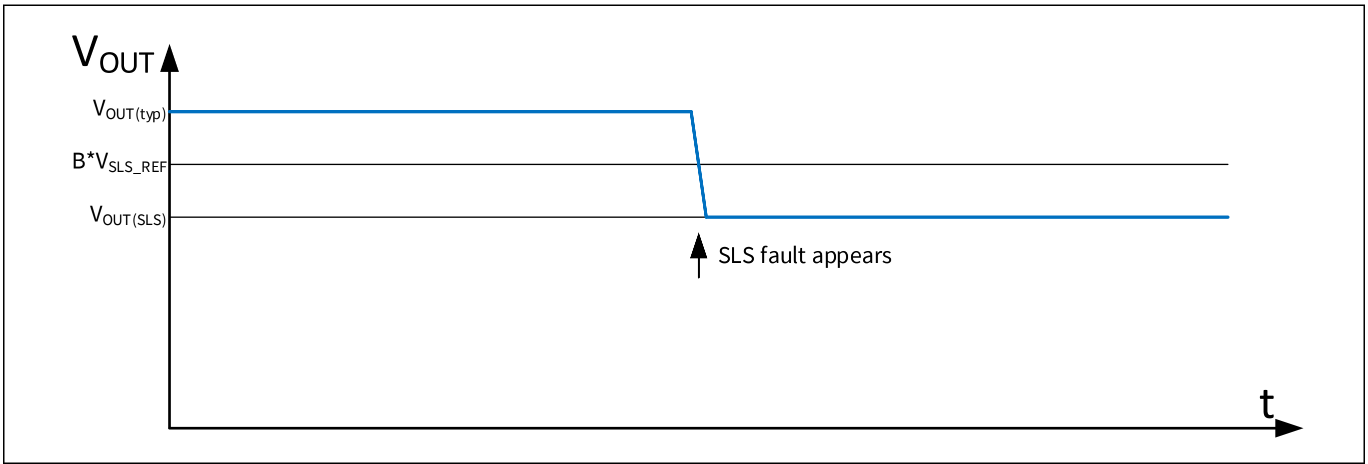

Figure 1 Output voltage change during single LED short failure

Depending on the used LEDs and their operating point, this reference voltage needs to be adapted. In LITIX™ Basic+ this is done via a fixed voltage reference which can be selected by placing a resistor at the SLS_REF-pin to ground. For the dimensioning of this resistor, refer to chapter 3. A single LED short fault is detected when the total output voltage drops below the defined single LED short reference.

1.4 Overtemperature diagnosis

LITIX™ Basic+ devices featuring an overtemperature shutdown circuit additionally report the overtemperature condition on the ERRN-pin. This can be used to deactivate other LITIX™ Basic+ devices connected to the same ERRN network. This leads to a faster system cooldown.

1.5 Fault communication on ERRN

Detected fault conditions are reported using the ERRN-pin. This pin is a double function pin used for fault communication and device deactivation, as shown in Figure 2. When a Basic+ device detects a fault condition it pulls down the ERRN-pin with a current $I_{ERRN(fault)}$ (P_7.5.2). To achieve N-1 functionality (see chapter 4.1.2 for further details) several Basic+ devices can be connected together using the ERRN-pin, as indicated in Figure 3. In this case the total current consumption of the LED module will be reduced down to a few mA (see chapter 5), which can be detected by the master module (e.g. body control module) supplying the LED driver module. In addition a pull-up resistor (typically 20 kΩ) is needed to rise the ERRN line towards VS during normal operation. When no fault condition is present the ERRN pins only monitor the applied voltage. If one of the devices detects a failure it will pull down the ERRN line. In this case all devices, connected to the ERRN line, will start to raise the voltage at the D-pin (if not connected to GND) and will turn off once the D-pin reaches its high threshold $V_{D(th)}$ (P_7.5.8). TLD1114-1EP will turn off immediately as it features no D-pin to delay the turn-off.

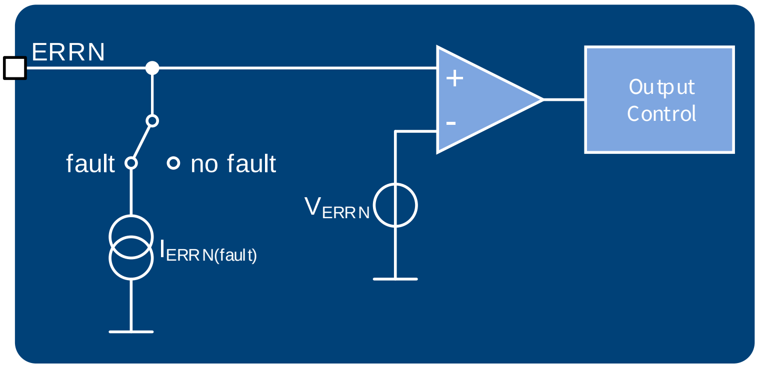

Figure 2 **ERRN-pin block diagram**

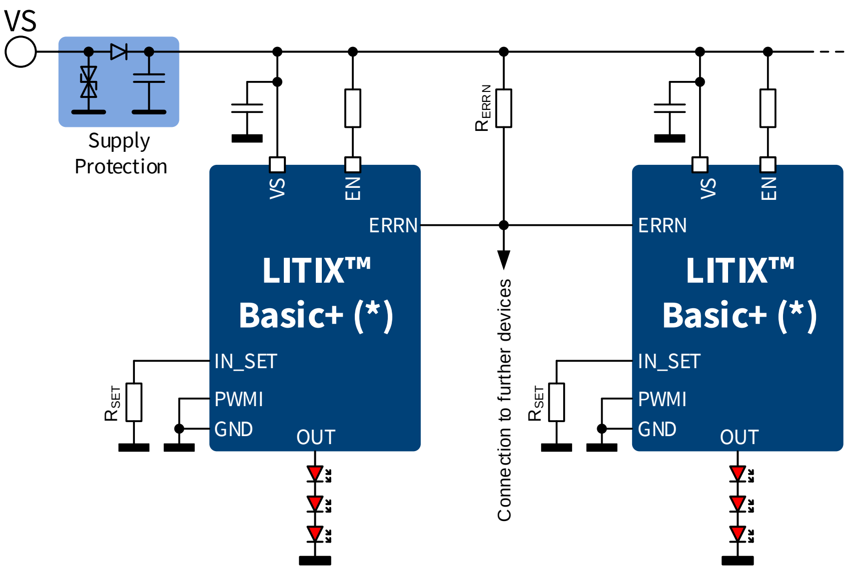

Figure 3 **ERRN connection between multiple devices**

The LITIX™ Basic+ devices recognize an external fault when the voltage level at the ERRN-pin is below $V_{ERRN(th)}$ (P_7.5.3). In LITIX™ Basic+ devices there is no pull-up functionality implemented. This means that an external pull-up resistor has to be added. The maximum pull-down current strength in case of fault $I_{ERRN(fault)}$ is < 2 mA. Therefore, when at its highest possible supply voltage (e.g. 16 V) the resistor current limitation should be below the pull-down current $I_{ERRN(fault)}$ in order to ensure a safe deactivation of all devices in the ERRN network. Typically a 20 kΩ resistor is used. The minimal R_{ERRN} resistor size can be determined with

$$R_{ERRN(min)} = V_{S(max)}/I_{ERRN(fault,min)}$$

2 Enable and diagnosis enable

All LITIX™ Basic+ devices with integrated LED load diagnosis feature a combined enable and diagnosis enable pin EN/DEN. This is a double function pin which sequentially enables the LED driver and its diagnostic functions when the applied voltage is above $V_{EN(th)}$ and $V_{DEN(th)}$ respectively:

- Device enable threshold $V_{EN(th)}$ = 1.4 V – 1.8 V (P_5.2.9)
- Diagnosis enable threshold $V_{DEN(th)}$ = 2.4 V – 2.8 V (P_5.2.11)

The diagnostic enable function is typically used to disable the diagnostic functions if the supply voltage is close to the LED forward voltage. In this case the diagnosis mechanism for open load which monitors the voltage drop on the power stage, can detect a false open load fault as the behavior is similar to a normal open load condition ($V_{OUT} \sim V_S$). The threshold voltage to deactivate the diagnosis in low voltage can be set by placing a proper voltage divider at the EN/DEN pin as shown in Figure 4. It is recommended to use this function as the false diagnosis may cause an unwanted oscillating activation of the outputs when the supply voltage is close to the LED forward voltage. This oscillation may happen as the current change during the turn-off causes a reduction of the voltage drop on the supply line and the optional reverse diode. Depending on the supply network this may cause a short reactivation of the outputs.

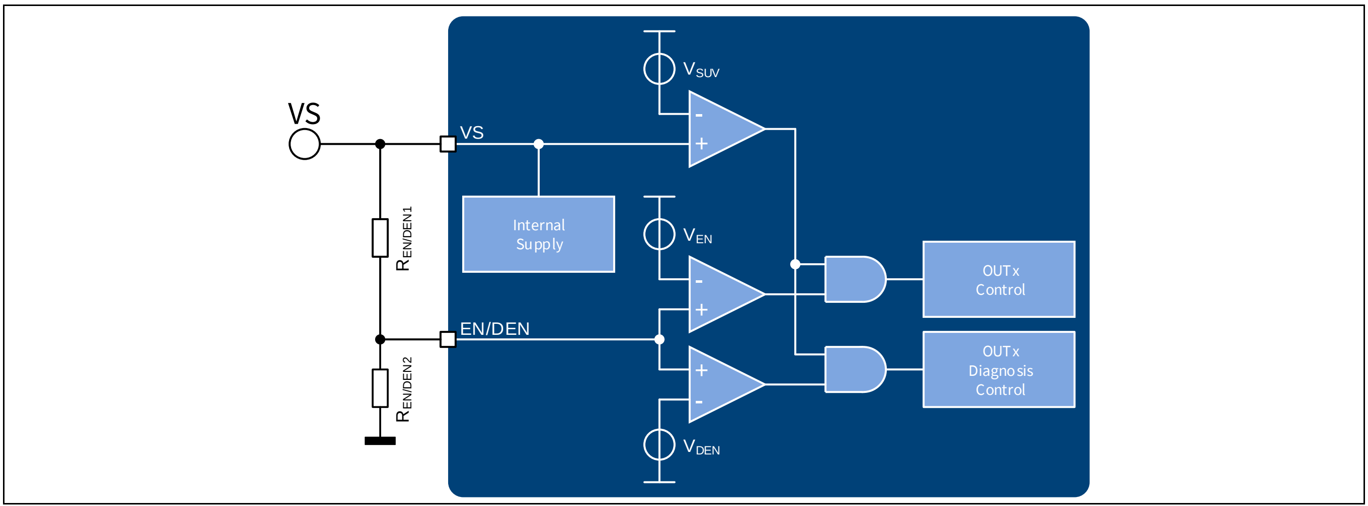

Figure 4 Input structure and external circuitry of enable and diagnosis enable pin EN/DEN

For the dimensioning of the EN/DEN voltage divider the following points are taken into account. Diagnostic features are deactivated when the voltage applied to the EN/DEN pin is below 2.4 V (P_5.2.11, $V_{DEN(th,min)}$). The minimal supply voltage directly at the VS pin where enabled diagnosis ($V_{S(DEN)}$) is acceptable, is given by:

- $V_{S(DEN,min)} = V_{OUT(max)} + V_{PS(OL,max)}$

For LITIX™ Basic+ devices with active single LED short diagnosis it is recommended to increase this voltage to:

- $V_{S(DEN,min)} = V_{OUT(max)} + V_{PS(CC)}$

The reason for this is that the single LED short diagnosis relies on a precise forward voltage of the LEDs which depends on the applied LED current. The drop voltage needs to be high enough ($V_{PS} > V_{PS(CC)}$) to ensure that the output current is at the desired operating point. If the LED current is lower the forward voltage drops, which can cause a false single LED short detection.

Taking this into account, the following formulae can be applied to dimension the voltage divider:

- $R_1 = (V_{S(DEN,min)} - V_{DEN(th,min)}) / I_{R12}$
- $R_2 = V_{DEN(th,min)} / I_{R12}$

The resistor values in this case are calculated using an ideal voltage divider. For the current I_{R12} a small current (e.g. 1 mA) can be selected. In this case the current consumption of the EN/DEN-pin $I_{EN/DEN(PD)}$ (P_5.2.17) is not considered. When the EN/DEN currents are considered in the calculation, the resulting $V_{S(DEN)}$ will increase slightly.

A calculation example with $V_{OUT(max)}$ = 7 V is shown below:

- $V_{S(DEN,min)} = V_{OUT(max)} + V_{PS(OL,max)}$ = 7 V + 400 mV = 7.4 V
- $R_1 = (V_{S(DEN,min)} - V_{DEN(th,min)}) / I_{R12}$ = (7.4 V – 2.4 V) / 0.5 mA = 10 kΩ
- $R_2 = V_{DEN(th,min)} / I_{R12}$ = 2.4 V / 0.5 mA = 4.8 kΩ

The voltage divider was designed for 0.5 mA at the target DEN voltage level $V_{DEN(th,max)}$ = 2.8 V. The worst case current consumption of the EN/DEN pin $I_{ENDEN(PD)}$ at this voltage level is 60 µA (see parameter P_5.2.17). With this current consumption the supply voltage levels for diagnosis enabling would increase slightly:

$V_{SDEN(min)}$ = 7.9 V instead of 7.4 V

$V_{SDEN(max)}$ = 9.2 V instead of 8.6 V

The typical current consumption of the EN/DEN pin is lower (typically below 10 µA) than the values specified in the datasheet and therefore the influence on the voltage divider decreases.

Note: *All protection functions implemented within Basic+ are fully active once the device is enabled. These functions are independent of the diagnosis enable state.*

When several Basic+ devices share a common voltage divider the same calculation steps may be applied. For the tolerance calculation the current consumption of the EN/DEN pins can be multiplied. This also applies to the TLD1114-1EP as its enable threshold is compatible with the remaining Basic+ devices with combined EN/DEN pin.

The calculation steps above take into account that the voltage divider is connected directly to the VS pin, at the cathode side of the reverse battery protection diode. With this approach the reverse diode is excluded from the resistor dimensioning and therefore the $V_{SDEN(th,min)}$ may be placed closer to the ideal value of $V_{OUT(max)} + V_{PS(OL,max)}$. In case the voltage divider is connected to the supply node prior to the reverse battery protection diode (at its anode side) the forward voltage of the reverse diode has to be taken into account.

3 Single LED short diagnosis and dimensioning of R_{SLS_REF}

To detect a single LED short fault condition an adjustable reference voltage is placed in between the expected forward voltage of all LEDs and the remaining forward voltage when one LED is shorted. As the forward voltages change because of several factors, this threshold needs to be selected accordingly. The single LED short reference voltage threshold $V_{OUT(SLS\_ref,typ)}$ should be placed in the middle between the

- lowest output voltage with all LEDs functional $V_{OUT(nom,min)}$ and the
- highest output voltage during a single LED short event $V_{OUT(SLS,max)}$

As shown in Figure 5. For the minimum and maximum voltage the temperature drift in the target temperature area needs to be considered. Therefore the reference voltage can be placed at:

$V_{OUT(SLS\_ref,typ)} = (V_{OUT(nom,min)} + V_{OUT(SLS,max)})/2$

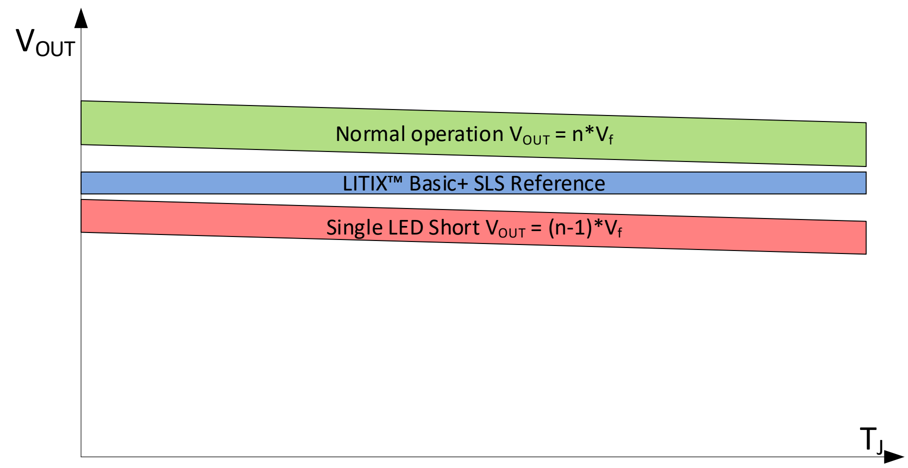

Figure 5 Single LED short reference voltage placement

This predefined reference voltage is fixed using an external resistor R_{SLS_REF} as shown in Figure 6. The reference voltage is created by sourcing a current I_{SLS_REF} through R_{SLS_REF}. The current I_{SLS_REF} is a direct copy of the output reference current I_{IN_SET}:

$I_{SLS\_REF} = k_{SLS\_REF} * I_{IN\_SET}$

In the case TLD2331-3EP is used

$I_{SLS\_REF} = k_{SLS\_REF} * I_{IN\_SET2}$

Where $k_{SLS\_REF} = 1$ (P_7.5.13) and is therefore not stated in the equation below. The additional gain factor B (See parameters P_7.5.21 to P_7.5.24) also has to be considered. This leads to the following equation:

$R_{SLS\_REF} = V_{OUT(SLS\_ref,typ)}/(B*I_{IN\_SET}) = (V_{OUT(SLS\_ref,typ)}*k)/(B*I_{OUT})$

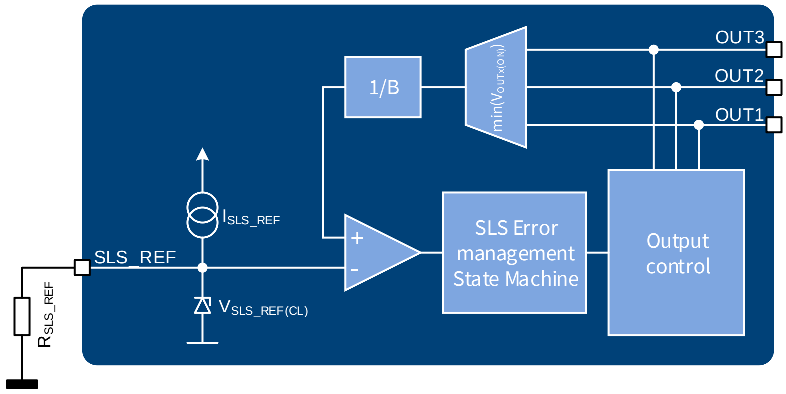

Figure 6 **Reference voltage generation for single LED short diagnosis and comparison to V_{OUTx}**

As shown in Figure 6 the smallest output voltage of the activated channels is used for the comparison with the reference voltage. The selection is automatic using a minimum selector.

There may be cases in which the two voltages overlap and no room to place the reference voltage is present. This can happen when LEDs with an increased forward voltage range are used. Another case would be when the number of LEDs in series is big (e.g. six LEDs). In these cases the selection of forward voltage binned LEDs and/or decreased LED chain length can help to improve the situation.

For the multichannel devices TLD2131-3EP and TLD2331-3EP the output voltages need to be balanced in normal operation. In case of an uneven distribution of LEDs, an additional output voltage balancing is needed. For example when eight LEDs are driven with one three-channel device (3 LEDs at OUT1 & OUT2 and 2 LEDs at OUT3) one of the channels is already in the single LED short fault condition. The voltage balancing can be done by adding an additional series resistor in the string with lower voltage or alternatively silicon diodes.

4 Fault management

LITIX™ Basic+ offers a programmable fault management. With this, the behavior of an LED lighting system can be tuned to the applications specific diagnostic requirements.

The configuration of the fault behavior is done using the D-pin. Devices which are equipped with single LED short diagnosis are additionally equipped with the DS-pin, which is used to provide further configuration possibilities specific for single LED short diagnosis, described in chapter 4.2.

4.1 General configuration

The three configuration possibilities are shown in the chapters 4.1.1, 4.1.2 & 4.1.3. For single LED short diagnosis additional configurations are described in chapter 4.2.

4.1.1 Constant active configuration

In this configuration all channels, except the faulty channel, will stay active. This can be used if only diagnosis but no reaction is needed. This mode can also be used when the diagnosis functionality of the Basic+ device is not needed. To avoid a possible false open load detection during low supply voltage ($V_S \sim V_{OUT}$) the EN/DEN pin should be connected to the battery using a properly designed resistor divider.

To configure the constant active mode the D-pin has to be connected to ground. In case a device with single LED short diagnosis is used, the DS-pin may be connected to ground or left open. For further details refer to Chapter 4.2.1.

4.1.2 N-1 configuration

In this configuration, when a fault on at least one LED string occurs, all the LED drivers in the same functional group are turned off. This behavior is often referred to as "N-1" or "1 off all off". All devices are in low power consumption mode with deactivated channels when a fault condition occurs. The faulty channel is further monitored to observe whether the fault is removed or not. For this a small diagnosis current $I_{OUT(fault)}$ is sourced to the output. Once the fault is removed and the fault detection filter time (t_{fault}) has passed without reoccurrence of the fault all channels will be reactivated automatically.

The device deactivation causes a significant supply current drop which can be recognized by the main control unit and further strategies (e.g. light function deactivation, dashboard notice) may be applied. Typically a fault current consumption below 10 mA per light function is required (for further details refer to chapter 5).

To select the N-1 configuration the D-pin has to be left open. To achieve N-1 functionality with more than one Basic+ device the ERRN-pins have to be connected.

4.1.3 N-1 configuration with additional turn off delay

An additional turn-off delay can be added to the N-1 configuration described in chapter 4.1.2. This adds an additional fault detection filter to further deglitch the fault detection.

The delay time can be configured by adding an additional capacitor C_D from the D pin to ground. The behavior with this additional capacitor is shown in Figure 7. When the fault condition is detected and reported on ERRN, a current $I_{D(fault)}$ is sourced from the D-pin to charge the capacitor. Once the capacitor voltage reaches a threshold voltage $V_{D(th)}$ the outputs are turned off. The size of the capacitor determines the length of the additional turn off delay. The capacitor size is given by the required turn off delay $t_{D(set)}$:

$$C_D = I_{D(fault)} * t_{D(set)} / V_{D(th)}$$

The capacitor will be further charged up to $V_{D(cl)}$. Once the fault condition is removed and ERRN is above $V_{ERRN(fault)}$, the capacitor is discharged by a current $I_{D(PD)}$. When the D-pin voltage drops below $V_{D(th)}$, the outputs are reactivated. This discharging process adds an additional turn-on delay $t_{D(reset)}$:

$$t_{D(reset)} = C_D * (V_{D(CL)} - V_{D(th)}) / I_{D(PD)}$$

The N-1 configuration described in chapter 4.1.2 shows the same charging and discharging behavior on the D-pin but with faster transitions resulting in a neglectable delay t_D.

To save external components the D-pins of several Basic+ devices may be connected together to one single capacitance. This capacitance is then charged and discharged with higher currents ($n*I_D$). Therefore, to keep the same delay time the capacitance needs to be scaled up accordingly.

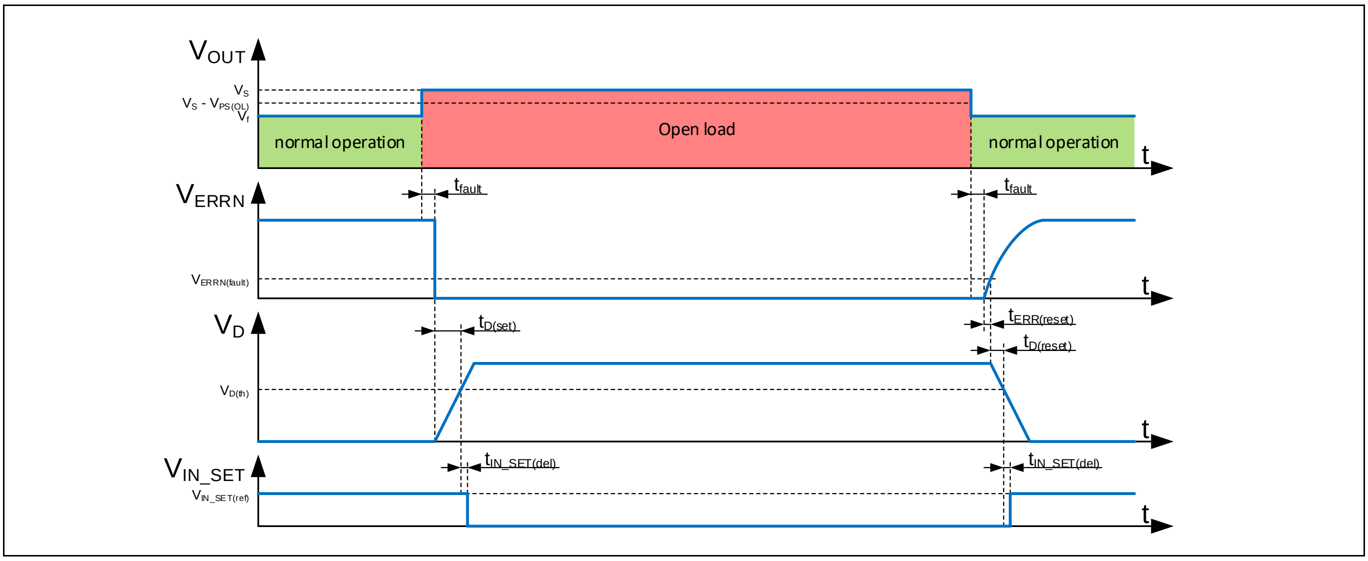

Figure 7 **Open load fault condition in N-1 configuration**

Note: Please note that in all three fault management configurations the diagnosis is fully active and the faults will be communicated over the ERRN line.

4.2 Fault management for single LED short

The single LED short diagnosis works by measuring the LED forward voltage at a defined operating point. This means the channel has to be completely "on" and the target current must be flowing through the LED, to ensure a reliable fault diagnosis. Whereas open load and short circuit to ground can be detected in off-state, by applying a small diagnosis current to the output, the single LED short fault can only be detected in on-state.

Due to this, an additional pin, DS was introduced. With DS-pin and D-pin and the SLS_REF-pin, which is used to set the detection threshold voltages to the used LED type, the following configurations (Chapters 4.2.1, 4.2.2, 4.2.3 & 4.2.4) can be made:

4.2.1 Constant active configuration

The constant active configuration in the single LED short diagnosis case is very similar to the description in chapter 4.1.1. The main difference is that in this case the faulty channel is not deactivated but continues to drive the target output current because an LED load is still connected.

For this configuration the D-pin has to be connected to ground and the DS-pin can be left open or connected to ground.

4.2.2 N-1 configuration with active retry

As described in chapter 4.2, the single LED short diagnosis only works when the LED load is at its defined operating point (turned "on"). To achieve this functionality and still achieve low module current consumption in N-1 configuration, an active retry mode was introduced.

To configure the active retry mode a capacitor C_{DS} (e.g. 220 nF) has to be connected between the DS-pin and ground, a properly sized resistor has to be placed at the SLS_REF-pin and the D-pin can be left open or connected with a capacitor C_D (e.g. 10 nF) to ground to add an additional turn-off delay.

Figure 8 shows the resulting behavior during a single LED short fault. Under fault condition the ERRN pin starts sinking a current $I_{ERRN(fault)}$ to ground and the voltage level on this pin drops below $V_{ERRN(fault)}$. After $t_{D(set)}$ the voltage $V_{D(th)}$ is reached at the D-pin and the IN_SET-pin goes into a weak pull-down state with a current consumption $I_{IN\_SET(fault)}$, after an additional latency time $t_{IN\_SET(del)}$. Thereafter, contrary to the management of open load and short circuit to ground detection, the voltage at DS-pin starts rising with the pull-up current $I_{DS(PU)}$ (P_7.5.17), until it reaches the threshold $V_{DS(H)}$ (P_7.5.15), when it starts discharging with the current $I_{DS(PD)}$ (P_7.5.18). When the DS voltage crosses the lower voltage threshold $V_{DS(L)}$ (P_7.5.16 a full wait time cycle $t_{SL(WAIT)}$ is completed and the device performs a load reactivation retry, turning the outputs back on. If the single LED short fault condition persists, a new $t_{SL(WAIT)}$ cycle is started. If at the end of one wait cycle the fault is not detected anymore, the device goes back to normal operation. The dimensioning of typical $t_{SL(WAIT)}$ is prescribed by the following equations:

$$t_{DS(rise)} = C_{DS} * V_{DS(H)} / I_{DS(PU)}$$

$$t_{DS(fall)} = C_{DS} * (V_{DS(H)} - V_{DS(L)})/I_{DS(PD)}$$

$$t_{SL(wait)} = t_{DS(rise)} + t_{DS(fall)} + t_{IN\_SET(del)}$$

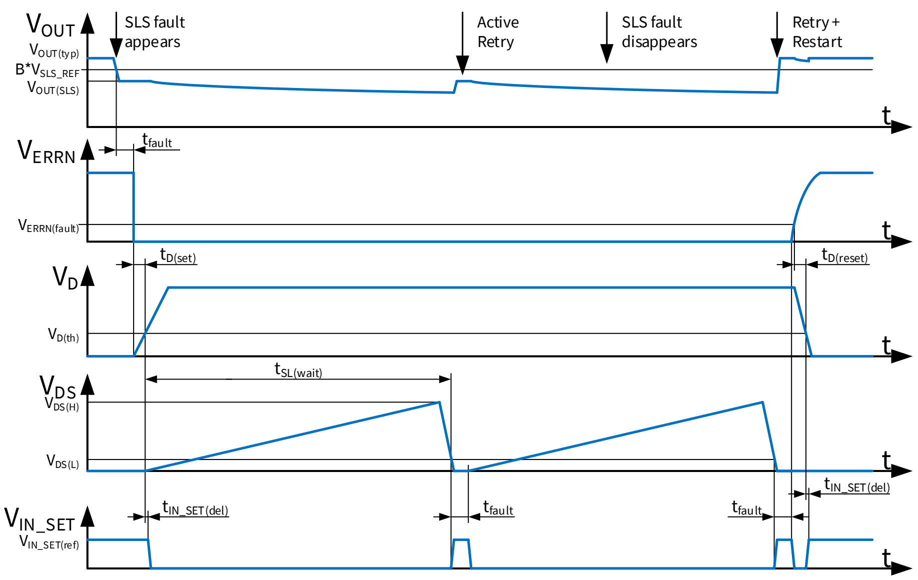

Figure 8 Single LED short fault N-1 configuration with active retry mode

The retry frequency ($f_{SLS} = 1/t_{SL(wait)}$) has to be placed high enough to avoid flickering effects.

4.2.3 N-1 configuration with latched turn off

The active retry configuration described in Chapter 4.2.2 works by cyclically reactivating the channels of the device and retesting the fault condition for a short period of time (~t_{fault}). This means the LEDs are driven in a low duty cycle PWM resulting in a small visible light output. As in some applications a completely turned-off lamp is required, Basic+ devices can be configured to stay disabled once a single LED short fault has been detected.

To configure a latching behavior of the single LED short diagnosis, the DS-pin needs to be connected to ground and the D-pin can be left open or connected with a capacitor C_D (e.g. 10 nF) to ground to add an additional turn-off delay. Connecting the DS-pin to ground avoids the charge/discharge cycle described in chapter 4.2.2, locking the device in a low current consumption state with deactivated outputs. To reset the fault condition a toggle of either the VS or EN/DEN voltage is necessary. Alternatively also disconnecting the DS-pin from ground resets the latch condition (assuming that a capacitive load is connected to the DS-pin).

4.2.4 Deactivation of single LED short diagnosis

The single LED short diagnosis mechanism can be deactivated by connecting the SLS_REF-pin to ground. This can be done in case the LED chains, connected to the outputs, do not match (e.g. unbalanced chains, high number of LEDs) or when this particular diagnostic feature is not needed.

5 Fault current consumption

The current consumptions of the LITIX™ Basic+ devices in fault state are defined in the datasheets as:

- $I_{S(fault,ERRN)}$ < 850 µA, if disabled externally over the ERRN-pin (P_5.2.4)
- $I_{S(fault,OUT)}$ < 1.25 mA, if a fault on one channel occurs (P_5.2.16)

For the total fault current consumption $I_{VS(fault)}$ of a typical LED driver module (with n LITIX™ Basic+ devices) at a given supply voltage V_S, the following currents have to be summed up:

- $I_{S(fault,OUT)}$
- $I_{S(fault,ERRN)}$ * (n – 1)
- $I_{ERRN} = V_S/R_{ERRN}$
- $I_{RENDEN} = V_S/(R_{ENDEN1} + R_{ENDEN2})$

Figure 9 shows the fault current contributors in a typical LED driving circuit. Additional circuitry needs to be considered as well in the calculation above.

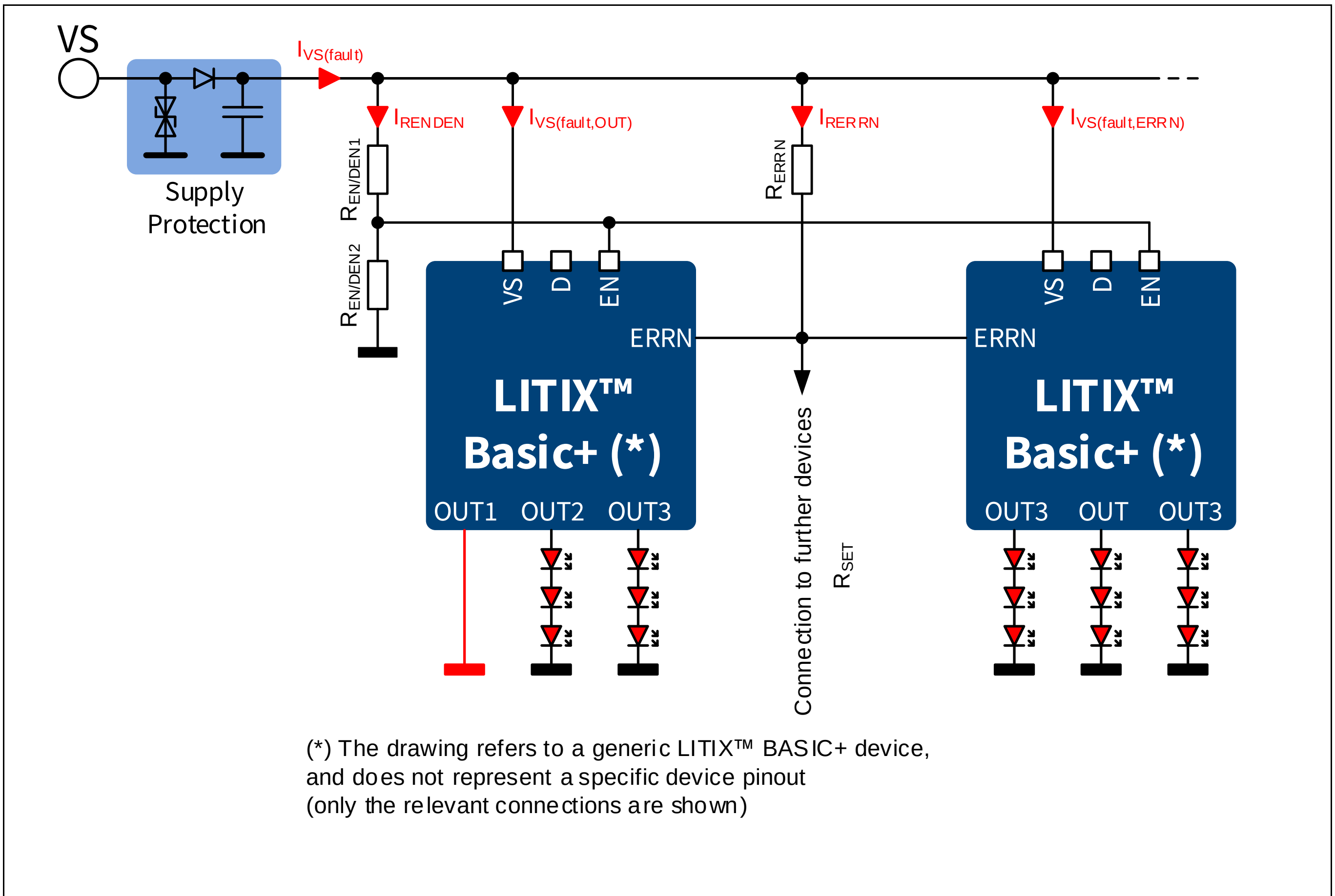

Figure 9 Fault current consumption of a Basic+ based LED driving system with ERRN link in between devices

Revision history

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V1.0	14.02.2019	Initial version created

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