

Product Document

LED diagnosis in automotive applications

Application Note



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Abstract

One requirement especially in automotive applications is the diagnosis of failures in functions and systems. Therefore light functions realized with LEDs like break light, daytime running light, low and high beam may require a diagnostics function. This application note describes some items which have to be taken into account, when a diagnostic function for a LED string or a multi LED module has to be realized.

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A. Introduction

To fulfill a light function, often several LEDs are connected in series, which is called a LED string. The diagnostic requirement is to detect an open string (e.g. by a broken bond wire) and a shortcut LED (e.g. by an ESD or EOS event) within this string at any time. This requires additional effort either in the electrical circuit or in a software routine, or both. This diagnostics function has to work reliable under the following conditions and should not create wrong failure indications:

- Full temperature range
- Defined input voltage range
- Specified life time of the product

Because a LED is a device optimized for light output the electrical parameters have a wider variation than for other diodes with pure electrical function. Some

properties of LEDs have to be considered in detail especially for the diagnostic function.

B. Electrical behavior of a LED

A LED is mainly electrically characterized by its forward current (I_F), reverse current (I_R), the forward voltage (V_F), reverse breakdown voltage (V_R) and the junction temperature (T_j). The characteristic is similar to a silicon diode, but has several differences:

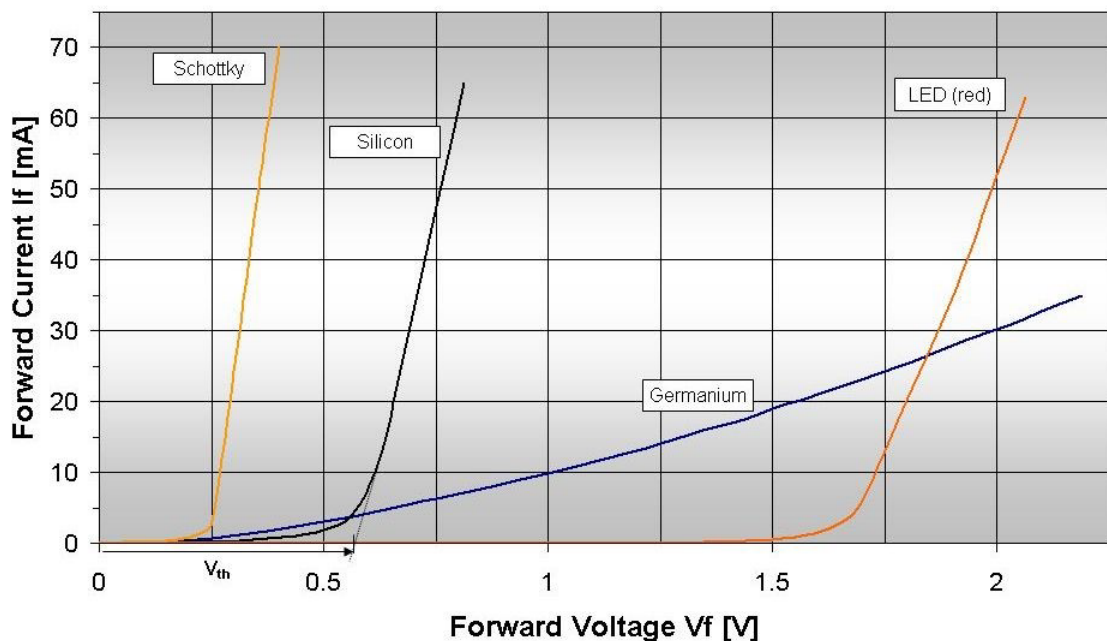
- A higher V_F
- A higher V_F production distribution
- A higher negative V_F coefficient
- A higher leakage current

The characteristic curves of diodes (Figure 1) are described by the Shockley equation which can be found in the literature.

This equation is also the basis for many simulation tools such as PSPICE. In this application note the approach, to describe the characteristic curve by the equivalent circuit of a LED, is chosen.

For diagnosis purpose in general the forward direction of a power LED is used because of the potential presence of a parallel connected ESD protection device. Therefore only this direction is described in more detail.

Figure 1: Examples of different diode characteristics

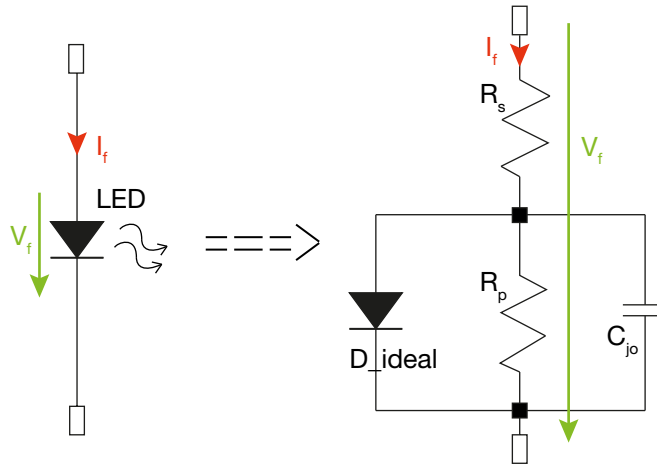


LED equivalent circuit

The electrical behavior of a LED in forward direction can be better explained by an equivalent circuit.

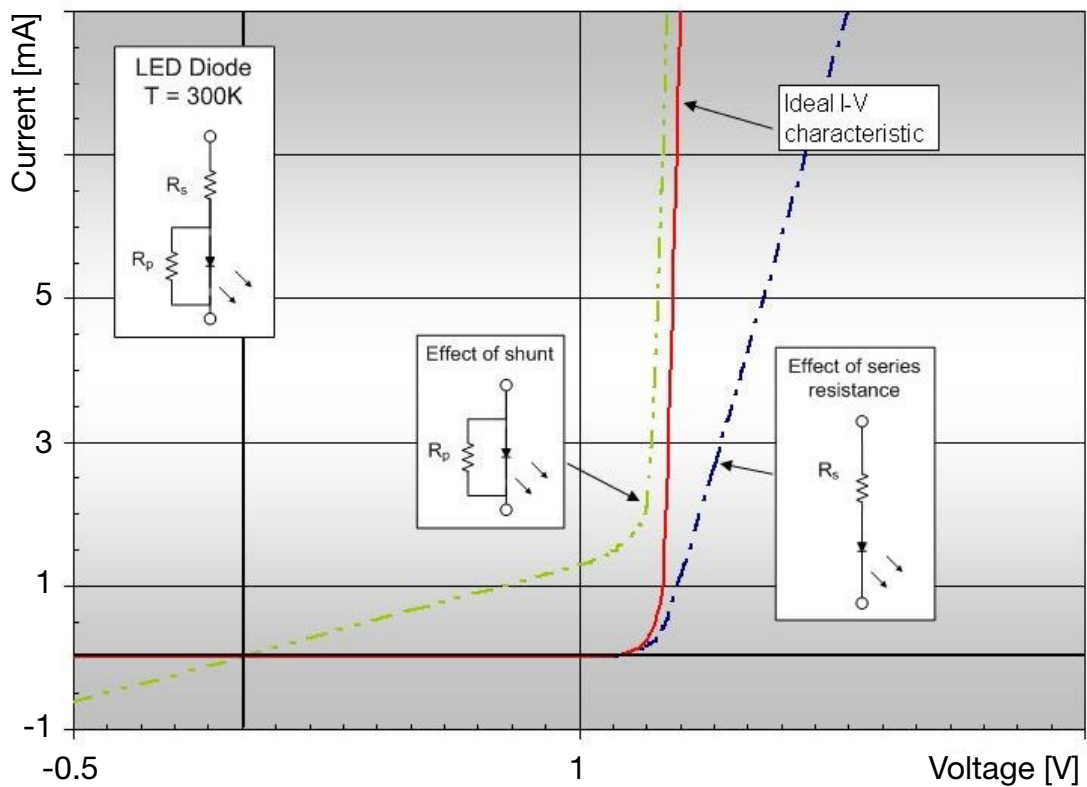
It consists of an ideal diode behavior with higher V_F , a series resistor R_s , a parallel shunt resistor R_p and a capacitor C_{jo} which is of minor importance for diagnosis (Figure 2).

Figure 2: One possible LED equivalent circuit



The series and parallel resistance of the LED together with the threshold voltage determine the characteristic curve (Figure 3).

Figure 3: Effect of series resistance R_s and parallel resistance R_p of a LED in forward direction

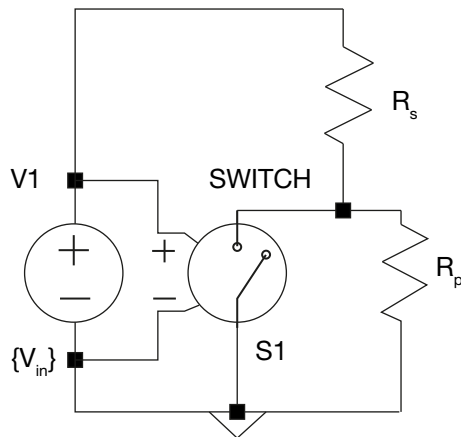


For a LED the threshold voltage happens in a more distributed way rather than sharp. Therefore it is sometimes also called a sub-threshold turn-on.

The series resistance is mainly determined by contributions of the semiconductor chip and the package. It stays — in general — stable over lifetime. The parallel resistance is determined by any channel that bypasses the PN junction of the LED. It can slightly change in the beginning of the lifetime especially for the InGaN material system (blue, green and white LEDs).

The simplest electrical equivalent simulation model will contain an ideal switch for the diode with a serial and a parallel resistor (Figure 4).

Figure 4: LED equivalent circuit with R_s , R_p and a switch



The threshold for the switch is defined by the band gap energy E_g of the material system which is mainly responsible for the threshold voltage of the LED. The parallel resistor R_p determines the behavior at voltages below the threshold voltage of the LED (switch is OFF).

The current flow below the threshold voltage in forward direction is also called bypass current and is always present. The series resistance R_s determines the behavior after the threshold voltage is reached (switch is ON). The combination of the series resistance and the parallel resistance is unique within a certain range for each LED device and influences the $I_F(V_F)$ curve. It is besides the band gap distribution — responsible for the V_F distribution of high power LEDs at its grouping (also called binning, or nominal) current.

Between those ranges the curve is fitted by the Shockley equation. A LED has more a distributed turn-on voltage range and no dedicated threshold voltage U_{th} such as a Silicon diode. This range derives from the band gap energy E_g and the internal structure.

Figure 5: Comparison of theoretical curves with different R_s , R_p combinations and real measured values (black dots)

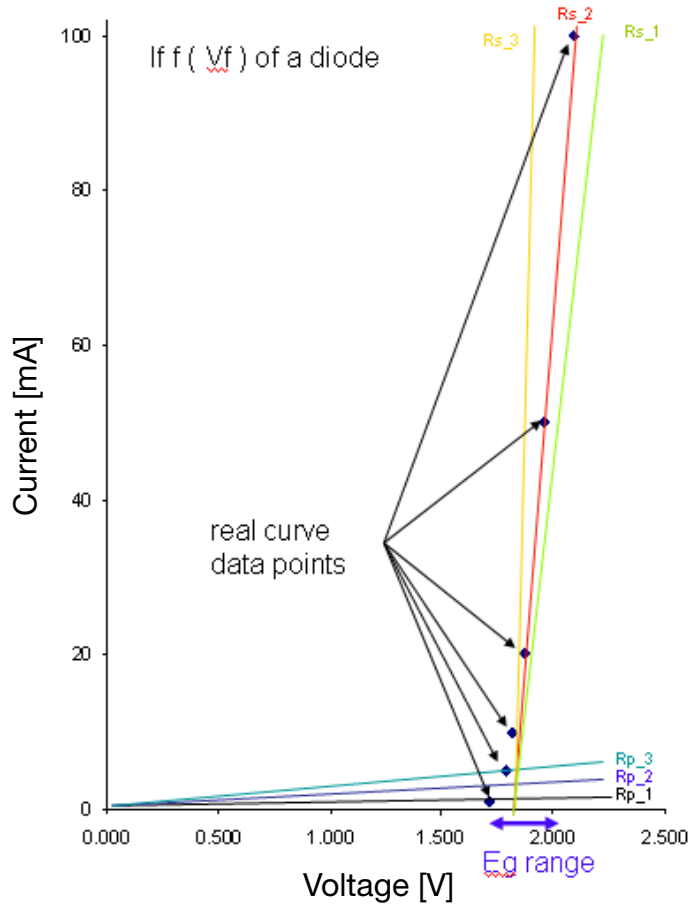
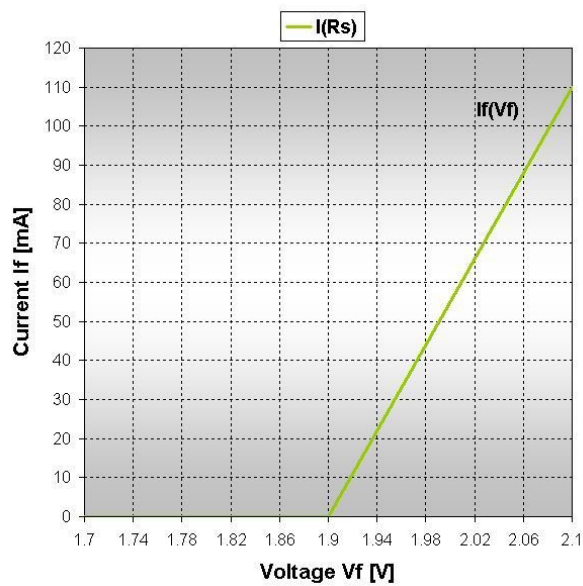


Figure 6: LED equivalent circuit simulation result for one R_p , R_s combination



The band gap energy depends on the LED technology, the material composition and other parameters.



It is temperature dependent and therefore has an influence on the V_F of a diode.

The curve dominated by R_s shifts parallel with the temperature. The respective parameter is called temperature coefficient of V_F and is indicated in the data sheet either as parameter (Figure 7) or graph (Figure 8).

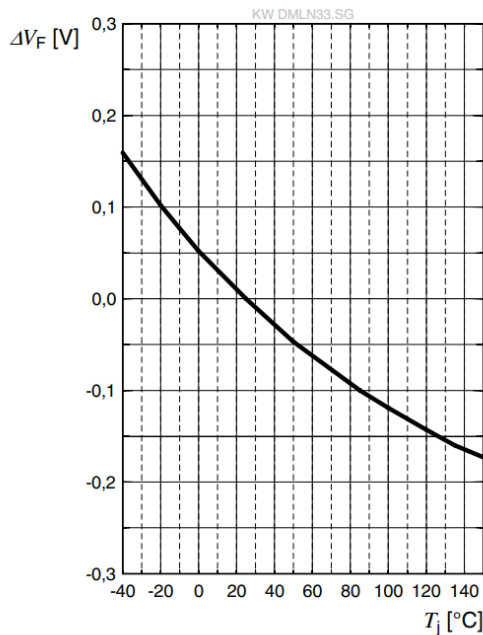
Figure 7: Typical temperature coefficient value for one LED type in a data sheet

Temperature Coefficient of Forward Voltage -10°C ≤ T ≤ 100°C	TC_{V_F}	typ.	-1.4 mV / K
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Figure 8: Typical temperature coefficient as a graph

Forward Voltage ⁶⁾

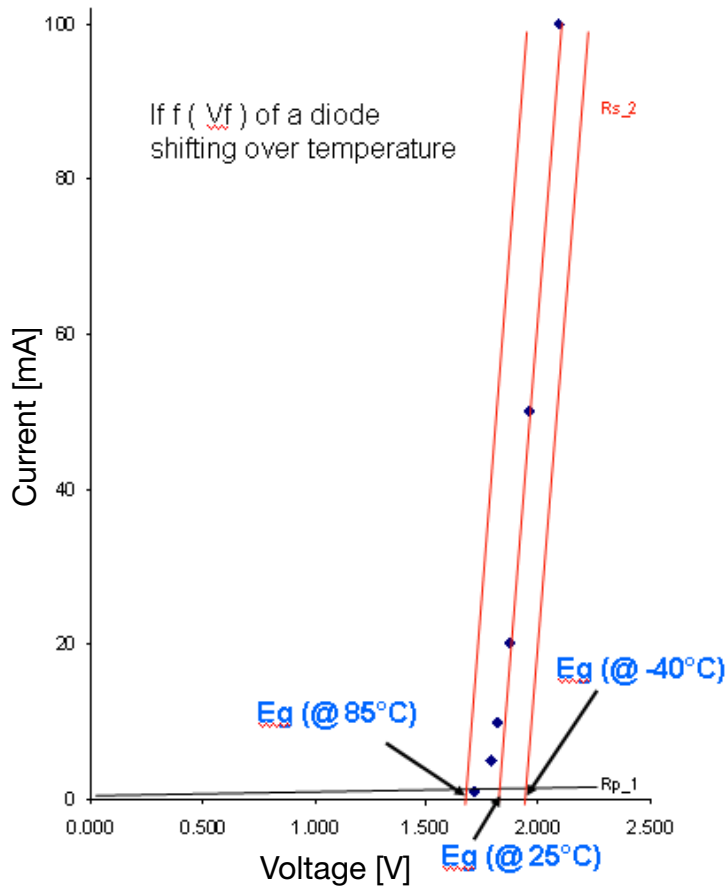
$$\Delta V_F = V_F - V_F(25 \text{ °C}) = f(T_j); I_F = 200 \text{ mA}$$



This parameter is nearly constant for a wide temperature range but has also a certain production distribution. The effect on the curve is as following (Figure 9).

For a LED the low current through the shunt resistor is normally not significant compared to the high current flow at the operating point. However for diagnostic strategies at voltages below the threshold voltage - it is mandatory to know this behavior. The value is mainly dependent on the material system and the manufacturing process each single LED has seen and has to be asked from the manufacturer of the LED.

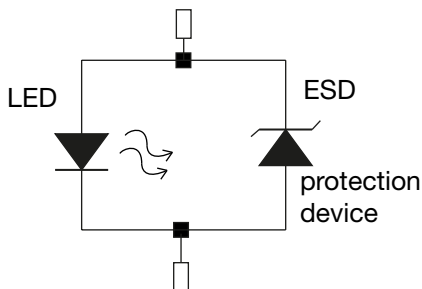
Figure 9: Temperature behavior of a LED



LED with ESD protection device

Because LEDs are often sensitive against ESD impulses especially in reverse direction, most of them have an ESD protection component on board. This could be for example an anti parallel 5 V or 50 V Zener diode (Figure 10).

Figure 10: LED with an ESD protection device



The behavior of such an ESD protection device might also have an influence on the diagnostic function.

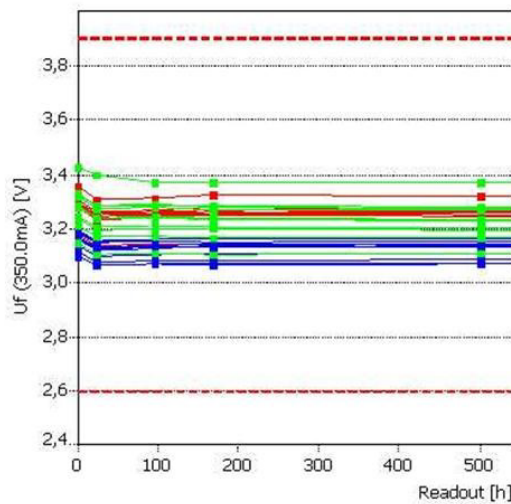
LED behavior in reverse direction

Driving a LED in reverse direction is mostly forbidden, first of all as the LED is not designed for latched operation and because of the inherent ESD protection device. For diagnostic purpose this makes no sense because the properties of the ESD protection device dominates in reverse direction over the properties of the LED. Even if the LED does not have an ESD device the reverse behavior does not give more information about a shorted LED and the reverse driving will cause additional effort in the driver.

V_F behavior over time

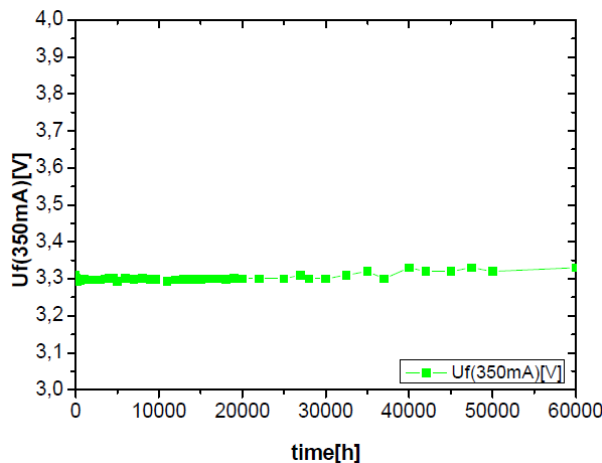
The V_F of a LED can slightly vary at power up in the first one hundred hours (Figure 11). This effect is best seen at an accelerated SSLT test.

Figure 11: Example of V_F variation within the first hundred hours of an InGaN LED in SSLT test at 85 °C. ($I_F = 350 \text{ mA}$)



This value can decrease or also increase. After that time the settled V_F stays in general stable (Figure 12) and the V_F stays unchanged when the LED is not powered up.

Figure 12: Example of developing of V_F over 60 kh



V_F binning in production

For parallel string applications realized with a simple current limiting resistor like e.g. a STOP and TAIL combined function in automotive, a V_F binning is mandatory. In this case the produced V_F range of the LED is divided into several sub bin ranges and taped accordingly (Figure 13). Each produced reel contains then LEDs only in this specific voltage bin range.

Figure 13: Possible forward voltage groups of a red / amber LED

Forward Voltage Groups

Group	Forward Voltage ⁴⁾	Forward Voltage ⁴⁾
	$I_F = 700$ mA min. V_F	$I_F = 700$ mA max. V_F
M3	2.15 V	2.30 V
Q3	2.30 V	2.45 V
T3	2.45 V	2.60 V
W3	2.60 V	2.75 V

Such V_F sub range might also be used to realize the diagnostic function of a LED string.

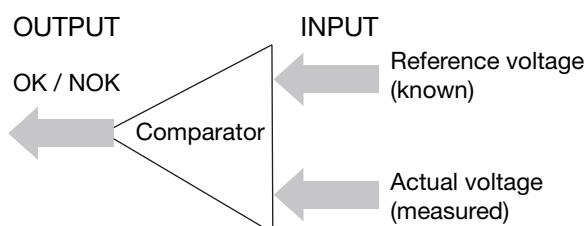
C. Possible diagnostic strategies

The diagnosis of a LED string may require the detection of an open contact and/ or a shorted LED. While an open contact interrupts the whole string, in case the ESD protection device has no influence, and so no current can flow. The short of one LED in a string is more difficult to be detected. Therefore under cost benefit aspects many applications only diagnose the open LED failure.

The fact that every LED type has a V_F distribution caused by its production and the behavior of a temperature dependence of V_F makes it difficult to find a simple electrical diagnostic strategy for a shorted LED especially for a longer string. Therefore the strategy is dependent of the string length and the overall system approach (e.g. strings in parallel). For each approach an appropriate diagnostic strategy has to be found.

Basically the principle is the comparison of the initial (OK) forward voltage (which has to be known) with the actual forward voltage in the application (which has to be measured).

Figure 14: Principle of diagnosis



LED open contact

If a LED in a string gets an open contact — which is the more probable case — it depends on the ESD protection device, if the string is interrupted. In some applications like street lamps this is not desired so that the internal ESD device or an external electrical device bypasses the LED and maintains the current flow.

In automotive applications this is not the case. The ESD protection device could be for example a 50 V Zener diode which needs a massive voltage increase before carrying the current. Either the power source is not capable of this voltage increase or it can easily detect this increase and switch off the driver.

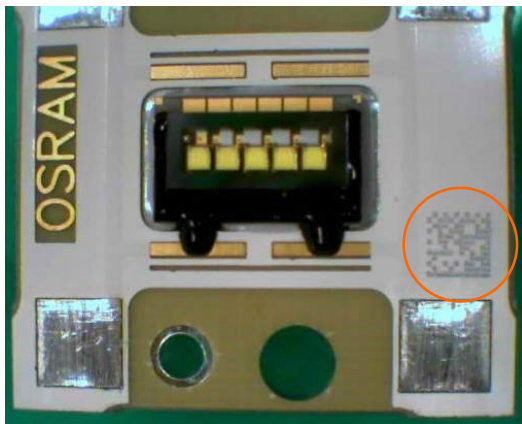
LED short

The short can only be detected by the voltage change which happens when the LED string is driven by constant current or by the current change when the string is driven with constant voltage. The first case is recommended and discussed therefore in more detail.

Reference V_F information on PCB

On a LED light source (several chips in one housing or on a board) a barcode or data matrix code can be placed and can contain the measured V_F information from line end test (Figure 15). This can be read by an automated scanner in production.

Figure 15: Example of a LED carrier with V_F information in data matrix code

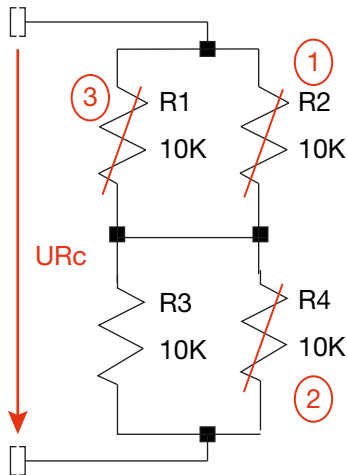


This line end test is normally performed at 25 °C (cold state) and at nominal current. With the known temperature gradient of V_F and a temperature measurement in the application for temperature protection purpose, a diagnosis can be set up. Care has to be taken for the different variation of the gradient and when the string is not driven at the nominal current. The V_F variation will then differ.

Equivalent to the data matrix code, the information can be coded with resistors inside the application.

In case single LEDs are mounted on an application specific PCB the string voltage has to be measured after mounting and a coding resistor can be matched for example by a laser the following way.

Figure 16: Matching of a coding resistor for V_F information



No change will lead to a 10K resistance. Removing R2 will follow to a 15K resistance. Removing R2 and R4 will follow to a 20K resistance and removing R1, R2 and R4 will follow to a high impedance.

LED information in an on-board nonvolatile (FLASH) memory

A LED can be equipped with an on-board nonvolatile memory which can be accessible via a 1-wire interface. All relevant data, measured at line end test in production can be stored for each individual LED. The information will be available at any time for diagnosis purpose.

Intelligent mixing of V_F bins

A V_F binning might be available for a single LED by the reel barcode information and by the data matrix code on multi LEDs. By a sorting strategy (sorting placement) of the V_F groups on the PCB or Multi-LED carrier the overall string voltage can be kept in a certain predefined range. This can avoid any coding system.

Electronic circuit based diagnosis (by hardware)

An electronic circuit can avoid a diagnosis by software. The circuit can be placed near the LED string so that it is one unit with the light source.

Figure 17: Principle diagnosis of an eight LED string by a voltage comparator with temperature compensated reference voltage

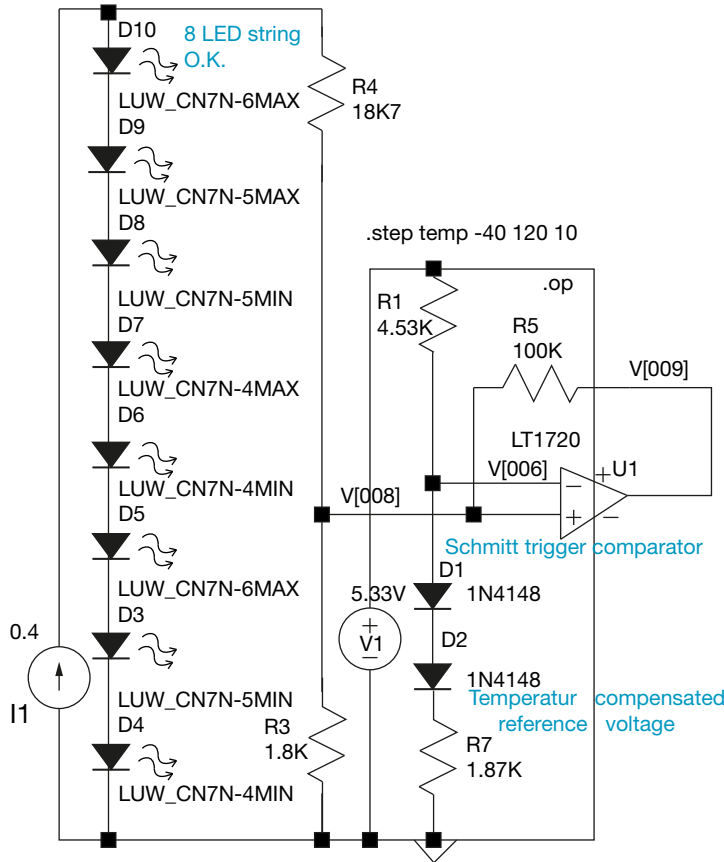
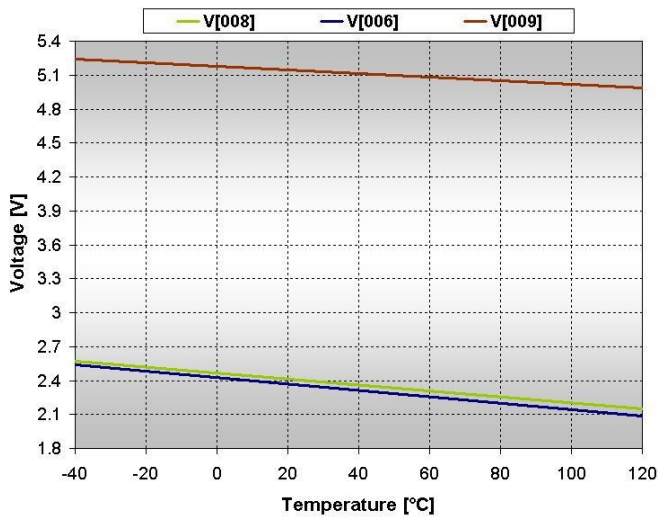


Figure 18: Output of comparator is high



The principle circuit is a comparator which compares the LED string voltage with a reference voltage. The reference voltage has the same temperature drift like the voltage of the LED string. Is one LED shortened the voltage of the string drops below the reference voltage and indicates the failure.

Figure 19: Shorted LED, simulated by a low resistance

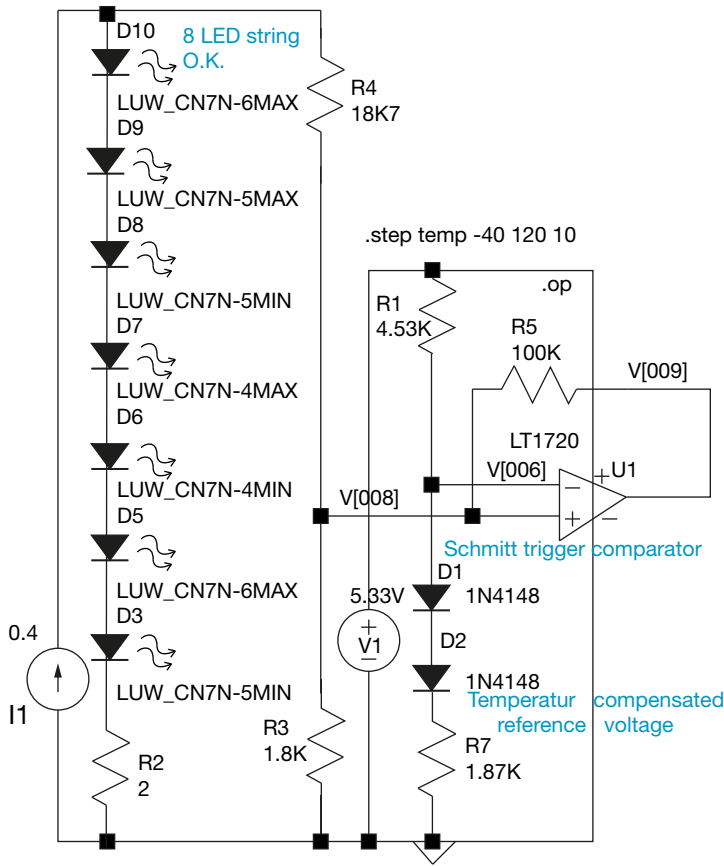
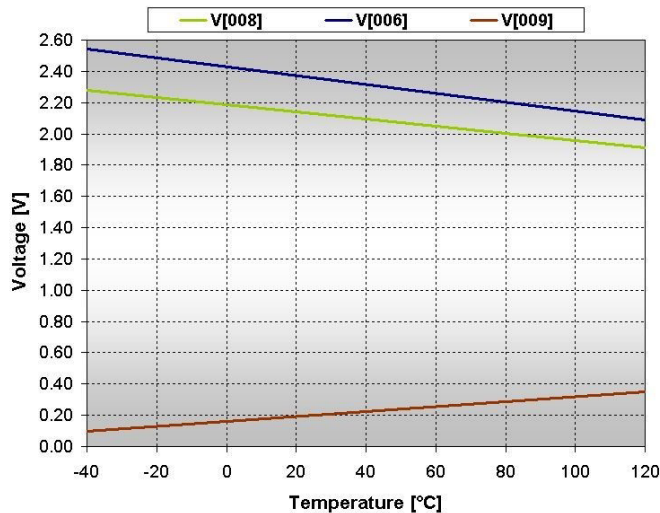
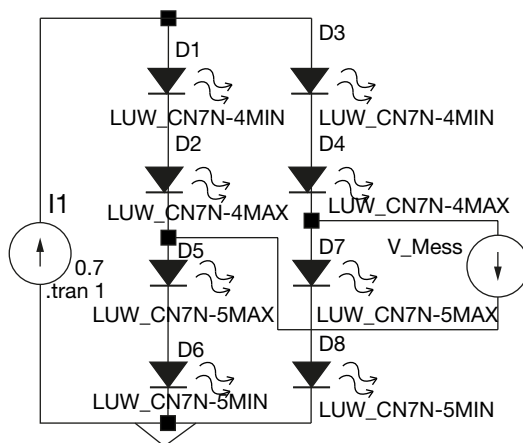


Figure 20: Output of comparator goes low if a LED is shorted



If a PWM signal is used a gated comparator has to be used only changing the signal at powered string. The reference voltage of the LED string has to be divided by a voltage divider and has to be calibrated to the right level by a variable resistor. The advantage of the calibration is that the full V_F range of the LED type can be used without a binning. Another possibility if two strings are used, is to compare the voltage between both strings.

Figure 21: Principle of differential comparison of two strings



The advantage is that both strings follow the same temperature behavior. The disadvantage is that a selection of the LEDs for the positions has to be done and the number of LEDs has to be equal.

Manufacturer of LED driver are more and more supporting diagnostic functions on their integrated circuits (IC) which is sometimes called SOC (system on a chip).

Electronic control unit based diagnosis (by Software)

If the lighting system contains an electronic control unit (ECU) with a micro-controller, the diagnosis can be done by a software routine.

The ECU will use a learning routine (also called adaptation) at car production line end when the strings are well mounted and working properly. By a measurement or a read out of the voltage information from coding, the initial good state at a certain temperature is memorized. Then the light function can be permanently monitored when the string temperature is also available.

D. Summary

There are many different strategies to fulfill the diagnostic specification of a LED string. All strategies must carefully consider the properties and production variation of today's LED technology in order to work reliable over the environmental conditions, time and full specification.

Finally the strategy is also a question of product volume, production flexibility and cost and has to be evaluated right at the design phase of the product. Another aspect which should be taken into account is the exchange of the product in the field and the flexibility in portability of the strategy to similar LED types (also a topic of long term availability).

For further information on the specific LEDs or application support, please contact OSRAM Opto Semiconductors or your sales representative.



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