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Published by
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High-speed switching of IR-LEDs — Background and data sheet definition

Application Note

Valid for:
all IR emitters, e.g. IR OSLON® Black

Abstract

This application note deals with the (optical) transient response of OSRAM Opto Semiconductors infrared (IR) — LEDs. The application note covers briefly the physical background and the relevant OSRAM Opto Semiconductors data sheet testing setup.

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A. Introduction

There are various applications requiring high-speed switching of IR-LEDs. Besides the traditional data communications space (e.g. indoor data communication) it is the emerging area of 3D-cameras operating via ToF-principle (time-of-flight). The emergence of new high-power and high-efficient IR-LEDs such as the SYNIOS® series from OSRAM Opto Semiconductors make them ideally suited for this kind of applications. High-speed modulation is often one key parameter for system performance. Hence judging how the data sheet values are derived becomes the key element to understand and achieve high-speed performance.

B. Theoretical background

This section briefly describes the theoretical background concerning optical rise and fall times of OSRAM Opto Semiconductors IR-LEDs. The general scenario is based on an electrical pulse according to Figure 1 and describes the optical response of the IR-LED.

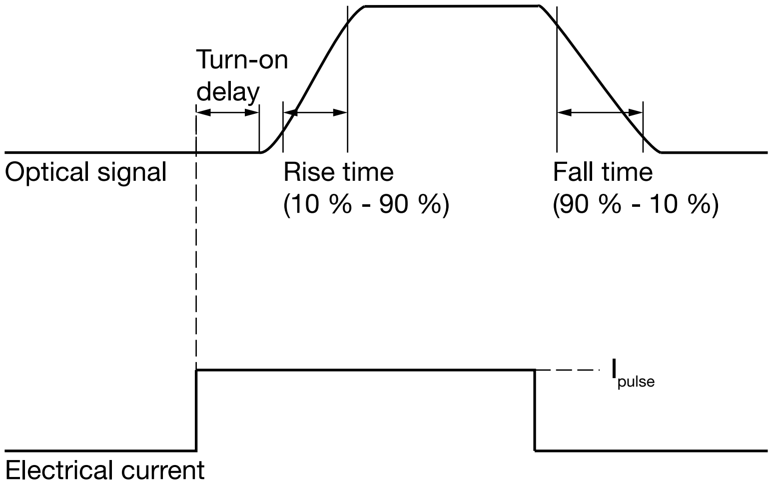
Important definition I . Throughout this paper the term t_r and t_f always refers to the optical rise and fall time — except where explicitly otherwise stated.

Important definition II. OSRAM Opto Semiconductors specifies its optical rise and fall times as 10 % / 90 % values. This is important in comparing different IR-LEDs from different vendors as their definition is sometimes different. A 20 % / 80 % definition compared to a 10 % / 90 % definition can yield e.g. up to a factor of two in difference. Conversions can be done via the following Eqs.:

$$t_{r(20/80)} \approx 0.65 \cdot t_r \qquad \text{Eq. (1)}$$

$$t_{f(80/20)} \approx 0.56 \cdot t_f \qquad \text{Eq. (2)}$$

Figure 1: Typical optical response of an IR-LED on a rectangular current pulse



Optical turn-on delay time

The time between the start of the electrical current pulse and the start of optical emission is called turn-on delay (see Figure 1). This turn-on delay time is caused by the initial filling of the depletion (junction) capacitance C_j of the LED. After the junction is charged radiation starts. The charge-up time is dependent on the RC_{LED}-time constant of the LED and the pulse current I_{pulse}. Note that in most applications the turn-on delay can be neglected.

However, if the turn-on delay is of any concern in the application it is recommended to use either of the following methods to minimize this delay (valid for OSRAM Opto Semiconductors thinfilm IR-LED's):

- In a current driven environment it is common to bias the IR-LED with an off-current of some µA to avoid / minimize the charge-up process (similar to operating Laser diodes).

- In a voltage driven circuit it is recommended to switch the IR-LED not from $V_F = 0$ V, instead keep it biased around $V_F < 1.4$ V for the 850 nm respectively 1.25 V for a 940 nm IR-LED (just below the “knee-voltage”).
- Use of 940 nm emitters as they feature a lower C_{j0} compared to their 850 nm counterparts (roughly by a factor of 2.5). This automatically leads to a reduction of the turn-on delay (valid for current generation OSRAM Opto Semiconductors thinfilm IR-LED’s).
- Drive circuit which provides current peaking during the turn-on phase.

As an example, the circuit in Figure 3 automatically biases the IR-LED with the FETs leakage current (around 1 µA). This automatically leads to some IR-LED off-state bias voltage of around < 0.7 V, which reduces the turn-on delay already significantly.

The typical C_{j0} values for the different IR-LEDs are available via the PSPICE models found on the OSRAM Opto Semiconductors website.

Optical rise time

The optical rise time in the most basic setup (such as in the circuit of Figure 2 or 3, e.g. no current peaking) is governed by the following Eq.:

$$t_r = 1.49 \cdot \frac{1}{\sqrt{k_{LED} \cdot I_{pulse}}} \qquad \text{Eq. (3)}$$

with k_{LED} as an LED-typical characteristic constant (depending on the IR-LED chip, see also Section D).

The essence from Eq. (3) is that the optical rise time depends on the pulse current: **Quadrupling of the LED current reduces the optical rise time by a factor of two**.

Figure 2: Traditional data sheet setup for measuring optical rise and fall times

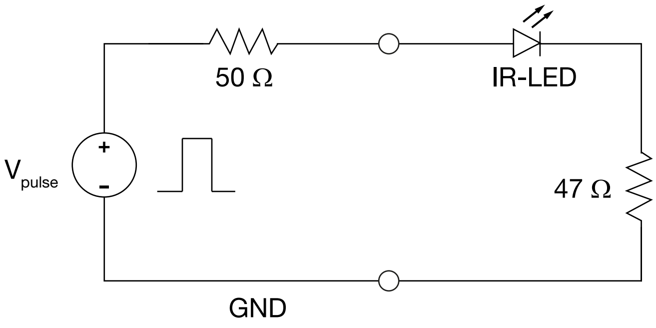
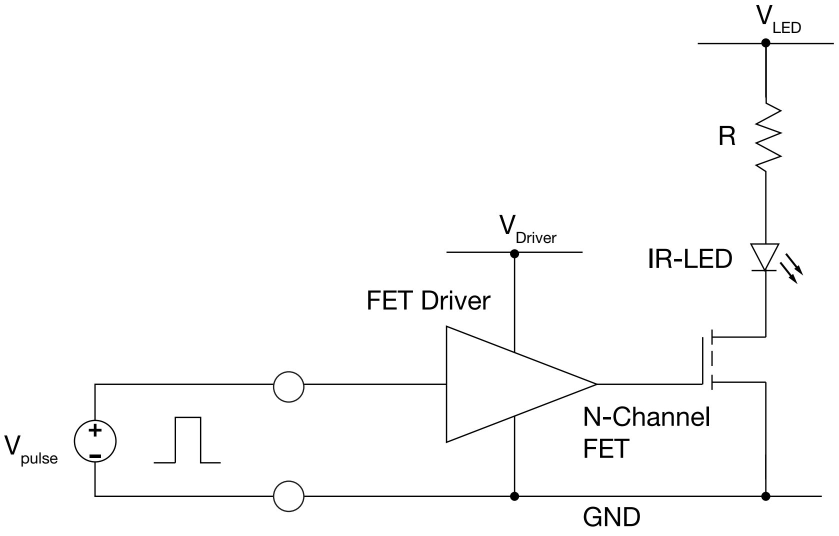


Figure 3: New datasheet setup for measuring optical rise and fall times



Optical fall time

The emphasis here is that the LED is switched into a high-ohmic off-state (i.e. leaving the IR-LED “disconnected” after turning the current off, like in the circuit of Figure 2 or 3) so that the injected charge carriers can decay by themselves governed by the charge carrier lifetime.

Such a circuit leads to an optical fall time of around

$$t_f = 2.11 \cdot \frac{1}{\sqrt{k_{LED} \cdot I_{pulse}}} \qquad \text{Eq. (4)}$$

The essence from Eq. (4) is — equivalent to the optical rise time behavior — that the optical fall time depends on the pulse current immediately prior to turning the IR-LED current off: **Quadrupling of this LED current reduces the optical fall time by a factor of two.**

Furthermore comparing Eq. (3) with Eq. (4) unveils that the fall time is usually by a factor of ~ 2 slower compared to the optical rise time (always considering a high impedance setup according to Figure 2 or 3).

Practical implementations

In general the above relations hold for ideal shaped current pulses which follow the pulse depicted in Figure 1 (with electrical rise / fall times << optical rise / fall times). However, circuit or component parasitics can influence the electrical pulse shape and subsequently have an impact on the optical rise / fall times.

C. OSRAM Opto Semiconductors (data sheet) setup

For datasheet characterization OSRAM Opto Semiconductors uses the following setups which deliver — if employed properly — identical optical rise and fall times. The background for choosing this measurement philosophy is that it allows comparable and reproducible optical rise and fall time characterization (component resp. setup independent). Both circuits can be described as high-impedance setups, as during the LED-off phase the circuit is switched into a high impedance state. In this context, even some Ohms already qualify as high-impedance.

Traditional (50 Ω-based) setup

This is the “traditional” setup. It is based on a 50 Ω impedance matching setup (see Figure 2). The pulse current is monitored across an e.g. 47 Ω resistor (to account for IR-LED impedance in forward biased operation).

New (FET-based) setup

An alternative, FET-based, setup is depicted in Figure 3. This setup mirrors much closer the real application. This is especially true if one considers that modern high power IR-LEDs can be biased above 1 A. This would require fast high voltage pulse sources if a circuit according to Figure 2 is used. The advantage of the FET-based circuit in Figure 3 lies in the fact that a low voltage setup, depending on the choice of R, is possible. The pulse current is monitored as a voltage drop across R (OSRAM Opto Semiconductors typically uses R = 2.7 Ω here per default).

Detector

As an optical detector a high-speed avalanche photodiode (APD) is employed. As an alternative, the pin-photodiode SFH 2701 can be used. The complete system setup features the required bandwidth without distorting the electrical / optical pulses.

D. Optical rise and fall times

The following data were obtained by using the data sheet circuits (Figure 2 and Figure 3) which provide electrical / optical pulse shapes without transient peaking currents during the turn-on and / or turn-off sequence. It is worth to note that by unintended current peaking during the turn-on / turn-off sequence the optical rise and fall times can differ (e.g. become significantly faster).

Pulse current dependence

Figure 4 to 9 present optical rise and fall times versus different pulse currents for various OSRAM Opto Semiconductors thinfilm IR-LEDs.

The graphs group all IR-LEDs into three different classes, depending on the chip size respective maximum allowed peak pulse current (please refer to the data sheet). This binning is more or less independent of the emitting wavelength of the IR-LED. The classification — valid for OSRAM Opto Semiconductors thinfilm IR-LED’s — is:

- low-power LEDs (max. 700 mA peak pulse current)
- mid-power LEDs (max. 1000 mA peak pulse current)
- high-power LEDs (max. 2 A or 5 A peak pulse current)

This notation is applied throughout this application note.

The measurements are performed by applying a single 100 ns pulse (duty cycle < 1 %).

Figure 4: Optical rise and fall time vs. pulse current for a low-power IR-LED ($I_{max(pulse)}$ = 700 mA, T_A = 25 °C)

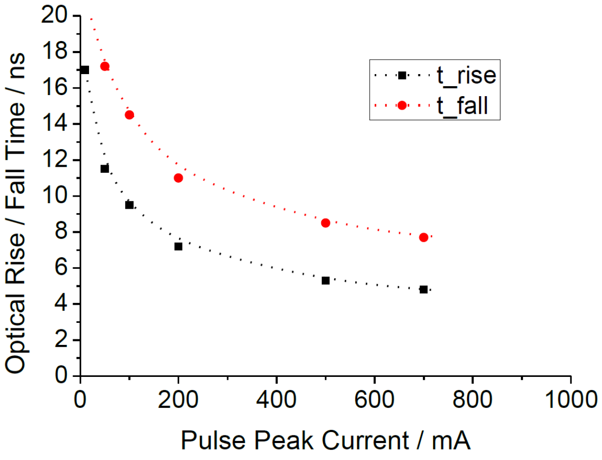


Figure 5: Optical rise and fall time vs. pulse current $\sqrt{\frac{1}{I_{max\ pulse}}}$ for a low-power IR-LED ($I_{max(pulse)}$ = 700 mA, T_A = 25 °C)

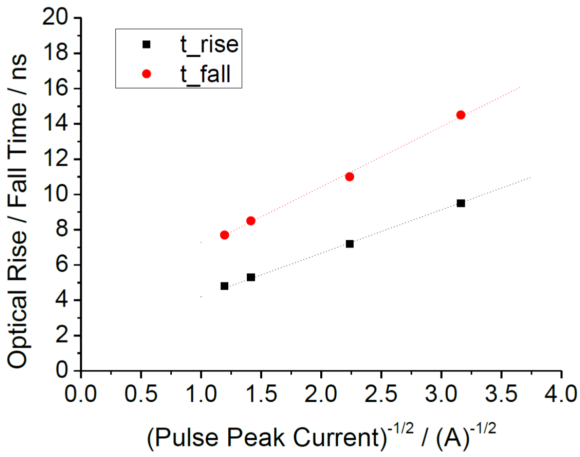


Figure 6: Optical rise and fall time vs. pulse current for a mid-power IR-LED ($I_{max(pulse)}$ = 1000 mA)

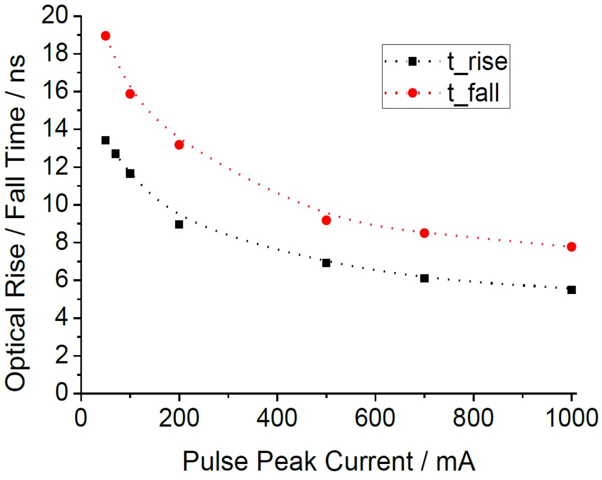


Figure 7: Optical rise and fall time vs. pulse current $\sqrt{\frac{1}{I_{max\ pulse}}}$ for a mid-power IR-LED ($I_{max(pulse)}$ = 1000 mA)

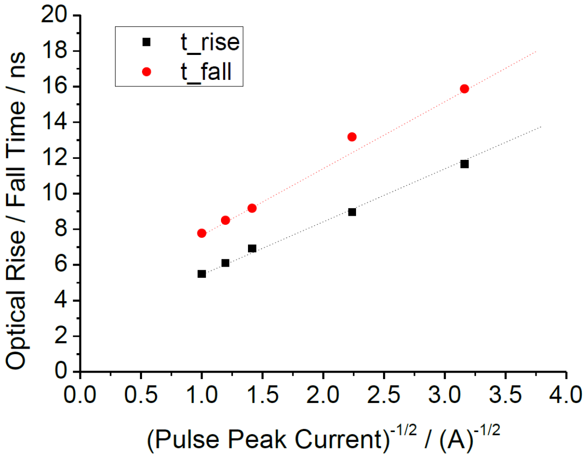


Figure 8: Optical rise and fall time vs. pulse current for a high-power IR-LED ($I_{max(pulse)}$ = 2000 mA or 5000 mA)

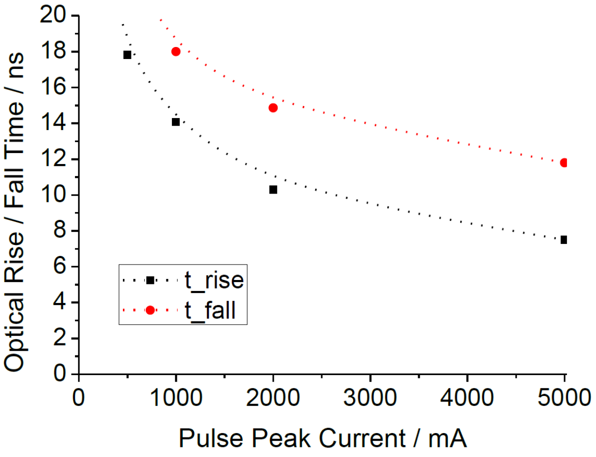
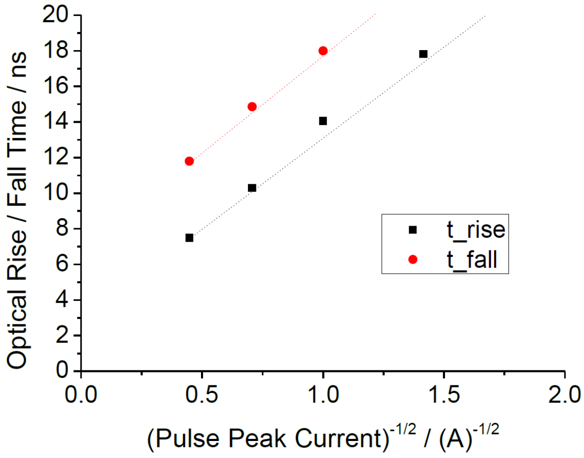


Figure 9: Optical rise and fall time vs. pulse current $\sqrt{\frac{1}{I_{max\ pulse}}}$ for a high-power IR-LED ($I_{max(pulse)}$ = 2000 mA or 5000 mA)

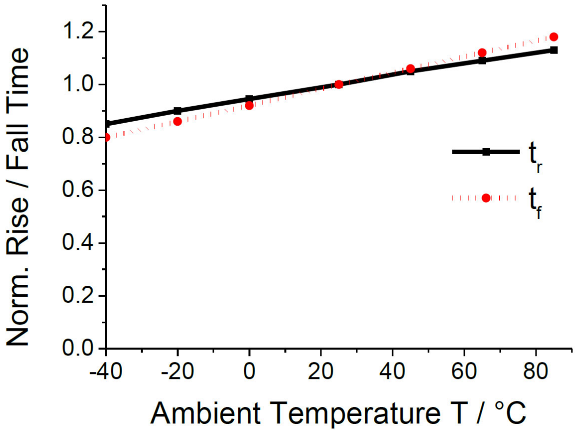


Temperature dependence

Figure 10 presents the typical dependence of the optical rise / fall time on ambient temperature (applying a single 100 ns pulse to minimize internal heating). As seen, the behavior vs. ambient temperature is quite stable.

The typical temperature dependence of the optical rise time is around 0.2 %/K, i.e. operating the IR-LED at 85 °C slows down the rise time by only around 12 % (compared to 25 °C). The optical fall time dependence is similar with around 0.3 %/K.

Figure 10: Typical normalized optical rise and fall time vs. ambient temperature (typ. temp coefficient: $TC_r \approx 0.2$ %/K and $TC_f \approx 0.3$ %/K. Operation: single 100 ns pulse



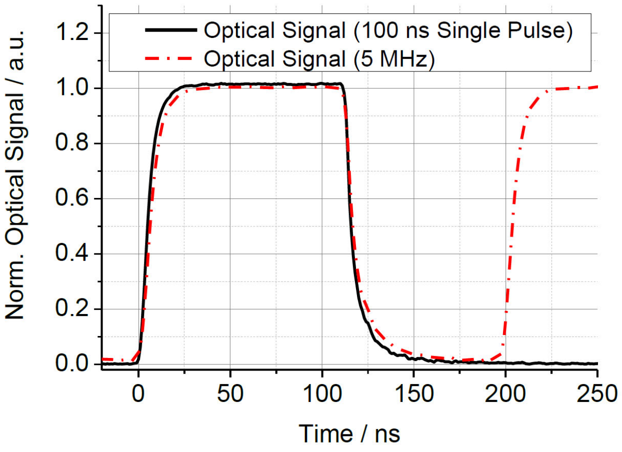
Burst length dependence

As Figure 10 indicates, the optical rise and fall time depends on the ambient temperature, i.e. on the IR-LED's junction temperature. Pulse width and repetition rate have direct influence on the junction temperature and subsequently on the optical rise and fall time (as well as optical output power). Figure 11 shows the difference between a single 100 ns pulse and a 5 MHz

(50 % duty cycle) signal, both operated at 2 A. The optical rise and fall time is increased roughly 15 % to 20 % for continuous 5 MHz operation compared to a single pulse operation. This depends strongly on the IR-LED junction temperature T_j (determined by e.g. operating conditions as well as thermal management, such as the PCB type).

Note: During a burst sequence the junction temperature rises. Subsequently the optical rise and especially the fall time can vary during the duration of the burst, i.e. being slower towards the end of the burst sequence and settle to a fixed value when thermal equilibrium is reached.

Figure 11: Difference between a single 100 ns pulse and continuous 5 MHz operation. In continuous operation the optical fall and rise time increase slightly due to internal heating of the IR-LED



E. Alternative drive circuits and general remarks

There exist many different circuits to drive a LED. Some of them feature (current) peaking to speed-up the optical rise time. Others employ passive or even active carrier sweep-out to reduce the optical fall time.

The aforementioned methods can improve the switching speed of LEDs considerably compared to their data sheet values. Thus a careful selection of the drive circuit is recommended to meet the application requirements if high-speed operation is of particular interest.

Like with any circuit design, OSRAM Opto Semiconductors strongly recommends to verify the actual design. In general, the influence of unintended parasitic components and their impact on current / voltage spikes and ringing can speed-up or slow-down the optical rise and / or fall time.

In this context OSRAM Opto Semiconductors strongly suggests not exceeding the IR-LEDs maximum rating, especially the maximum pulse current.

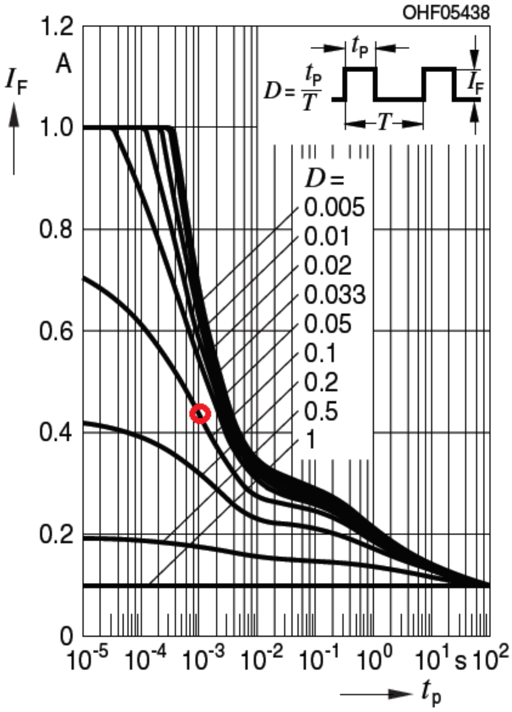
F. Permissible pulse handling capability

For applications with pulsed current driving it is very important to not exceed the maximum allowed pulse current.

For that reason, OSRAM Opto Semiconductors usually provide diagrams for the maximum allowed pulse current for most of the IR-LEDs.

Figure 12 shows an example diagram of the maximum permissible pulse current for the SFH 4550 with reference to the ambient temperature T_A = 25 °C.

Figure 12: Example diagram of the maximum permissible pulse current for the SFH 4550 with reference to ambient temperature T_A = 25 °C



With the given pulse conditions such as pulse width t_p, duty cycle D and reference temperature the maximum allowable pulse current can be evaluated.

If we take an example pulse condition of t_p = 1 ms with duty cycle of D = 0.1 (10 %) and a reference temperature in the application of T_A = 25 °C, the maximum allowed pulse current results to $I_{f,pulse,max}$ = 430 mA (Figure 12).

Sometimes, pulse derating diagrams are given in the data sheets for two reference temperatures, such as T_A = 25 °C and T_A = 85 °C.

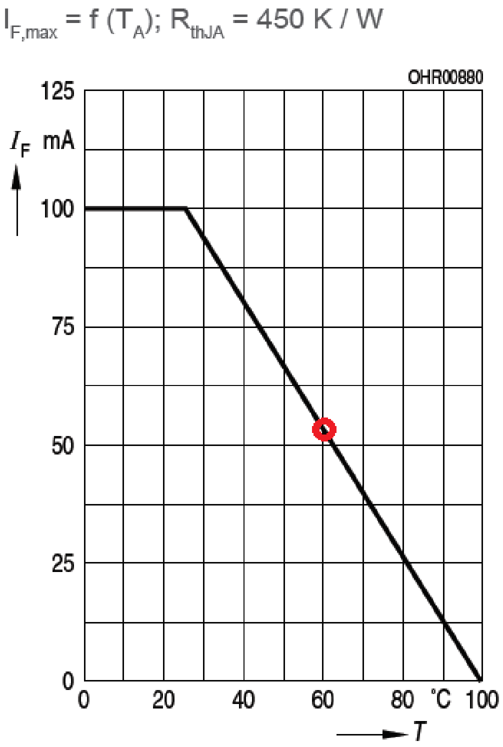
An interpolation for higher temperatures than 25 °C can be done using the diagram for maximum permissible forward current at a given temperature.

Figure 13 shows an example diagram of the maximum permissible forward current (DC mode) for the SFH 4550 depending on the ambient temperature T_A.

If we take our former example pulse condition, but now with higher temperature T_A = 60 °C, we get a ratio of 54 % (54 mA / 100 mA, Figure 13) of the maximum DC current at T_A = 60 °C compared to the current allowed at T_A = 25 °C.

The ratio of 54 % can be applied on the evaluated current of 430 mA (at T_A = 25 °C) to come to the maximum permissible pulse current $I_{f,pulse,max}$ = 232 mA at T_A = 60 °C.

Figure 13: Example diagram of the maximum permissible forward current for the SFH 4550 depending on the ambient temperature T_A



For high power devices such as the IR OSLON® Black family, the reference in this diagrams is most likely not the ambient temperature T_A but the solder point temperature T_S.

In order to measure correctly the solder point temperature, please refer to the application notes “The thermal measurement point of LEDs” and “Temperature measurement with thermocouples”.

For high frequency pulses in burst mode, where the single pulse widths are very short and below 10 µs, please contact your regional sales contact for verifying the maximum allowable current for your conditions.

G. Summary

This application note focuses on the basics of optical rise and fall time definition such as stated in the data sheet. It demonstrates the dependence of the rise and fall time on the LED pulse current by employing the data sheet drive circuit (i.e. quadrupling of pulse current reduces the optical fall / rise time by a factor of two). In parallel we introduce a new datasheet circuit to characterize the switching time of LED’s by using a more practical approach — which delivers the same optical rise and fall times as the traditional setup.

However, by using other electronic drive methodologies, e.g. employing current peaking during the turn-on phase in combination with clamping (passive sweepout) or even active carrier sweep-out during the turn-off phase, the optical rise and fall times can be reduced considerably.

H. References

For a deep theoretical discussion on the physical/mathematical background please refer to:

R. Windisch et al, “Large-Signal-Modulation of High-Efficiency Light-Emitting Diodes for Optical Communication”, IEEE Journal of Quantum Electronics, Vol. 36, No. 2, Dec. 2000, pp. 1445 – 1453.

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