Case Study : Philips Topic 9

Technical Safety White Paper

LED Drivers in High-Temperature Industrial Environments

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1. Introduction

This white paper analyzes the reliability and fire risks of LED drivers operating in high-temperature industrial environments, based on Philips reference data (Case Temperature 50 °C, 500 PPM/1000h, MTTF ≈ 2 million hours) and extended Arrhenius lifetime modeling.

2. Baseline Case – Philips Data (50 °C)

According to Philips' white paper:

- Case Temperature = 50 °C
- Failure Rate = 500 PPM/1000h (0.05% per 1000h)
- MTTF ≈ 2,000,000 hours

This value serves as an industry reference baseline under controlled conditions.

3. High Temperature Extrapolation

Using the Arrhenius rule of thumb (every +10 °C halves the lifetime / doubles the failure rate):

- At 90 °C (ΔT=+40 °C): failure rate ×16, ≈ 8,000 PPM/1000h, MTTF ≈ 125,000 hours
- At 145 °C (ΔT=+95 °C, corresponding to ambient ≈105 °C): failure rate ×724, ≈ 362,000 PPM/1000h, MTTF ≈ 2,760 hours

Note: 145 °C is beyond rated limits of most electrolytic capacitors and represents catastrophic degradation.

4. Comparison Table

Case Temp (°C)		Failure Rate (PPM/1000h)	MTTF (hours)	Notes
50 °C	25~35 °C	500	≈2,000,000	Philips reference data
90 °C	55~65 °C	≈8,000	≈125,000	16× higher failure rate
145 °C	85~105 °C	≈362,000	≈2,760	Beyond rated limits, catastrophic risk

Ambient Temperature

5. Failure Mechanisms and Fire Risks

Common failure mechanisms in LED drivers under high temperature include:

- Electrolytic capacitor dry-out and rupture

• MOSFET thermal overstress
• PCB and plastic carbonization at >110–130 °C
• Surge vulnerability in industrial power grids

These failures can escalate from loss of light to smoke, arcing, or fire ignition, especially in environments with flammable dust or fibers.

6. Driverless ACCOB Architecture

To mitigate risks, ACCOB (All-Solid-State, Driver-on-Board) technology removes electrolytic capacitors and MOSFET-based switching drivers. Instead, it employs solid-state AC LED engines with inherent surge resistance and fail-safe open behavior. Advantages include:
• No electrolytic capacitors → no dry-out risk
• Fail-safe wire-bond fuse network → open-circuit on fault
• High-temperature resistant materials (quartz, ceramics, UL94 5VA polymers)
• Proven 60,000h survival at 100 °C case without ignition

7. Standards and Insurance Implications

• NFPA and USFA statistics categorize LED driver fires under 'wiring and lighting equipment'.
• CPSC recalls (2024) have confirmed high-bay LED driver fires in warehouses.
• Insurance underwriters classify operation beyond rated 55 °C as 'non-compliant use', potentially excluding claims or increasing premiums.

8. Conclusion

Traditional LED drivers exhibit a baseline failure rate of 500 PPM/1000h at 50 °C case temperature, but this increases exponentially with temperature, reaching catastrophic levels above 90 °C. In industrial environments with ambient temperatures of 65–105 °C, reliance on electrolytic capacitor-based drivers poses unacceptable fire risks. Driverless ACCOB architecture eliminates these risks by design, providing a safe and reliable alternative for high-temperature industrial lighting applications.

Philips White Paper: LED Driver Lifetime and Reliability — Key Summary

1. Background

While LED light sources themselves are extremely long-lived and reliable, the LED driver (power supply) is the critical component that determines whether the luminaire can sustain its expected lifetime. The Philips white paper focuses on the Xitanium series drivers and explains strategies to extend lifetime and enhance reliability.

2. Reliability and Lifetime Definitions

• Reliability: Statistical measure of random failure rates in a population of products, expressed in FIT (Failures in Time) or MTTF (Mean Time to Failure).
• Lifetime: The usable time before wear-out failures, typically defined at 90% survival rate. Example: 100,000 hours lifetime means 90% of units are still functioning.
• Bathtub Curve: Describes the three stages of early failures, stable operation, and wear-out failures.

3. MTTF Prediction

• Uses MIL-HDBK-217F model for calculation.
• Example: 150W Xitanium driver at 50°C case temperature → estimated failure rate ≈ 500 PPM/1,000h, corresponding to MTTF ≈ 2 million hours.
• Real-world field data often shows even better reliability than theoretical predictions.

4. Design Strategies for Reliability Improvement

• Topology: Flyback for low power, two-stage or LLC for higher power to reduce stress and losses.
• Efficiency: Higher efficiency means less heat dissipation and longer lifetime.
• Thermal protection: Drivers include derating mechanisms to prevent overheating.
• Component derating: Electrolytic capacitors derated by 20%, semiconductors by 10–20%, to ensure stable performance.

5. Key Role of Electrolytic Capacitors

• Capacitors are the most failure-prone component.
• Lifetime rule of thumb: Every 10°C reduction doubles the lifetime.
• Driver lifetime can be directly derived from capacitor lifetime.

6. System-Level Factors

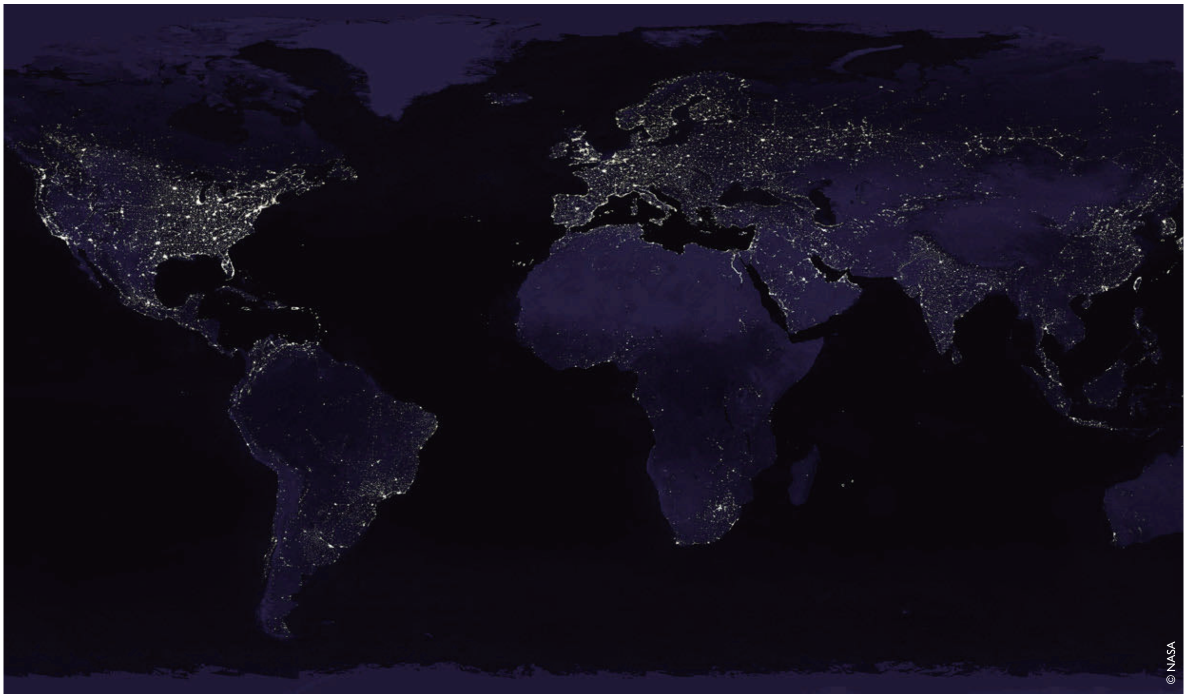
• Driver and LED module mutual heating can increase case temperature by 20–25°C.
• Frequent on/off cycles accelerate thermal cycling degradation → dimming is preferred over frequent switching.
• Voltage fluctuations and surge events shorten lifetime → surge protection is essential.

7. Testing and Validation

• Design stage: HALT and MEOST accelerated lifetime testing.
• Production: Burn-in, thermal cycling, and humidity tests before release.
• Field return data comparison: Ensures new drivers maintain or exceed prior reliability levels.

8. Conclusion

• Theoretical MTTF values are only design-stage estimation tools, not equivalent to actual lifetime.
• Electrolytic capacitors and solder joints are the most likely failure points.
• Real-world lifetime must be validated with field return data.
• Philips employs rigorous design–test–feedback loops to ensure Xitanium drivers deliver reliability beyond theoretical values.



LED Driver Lifetime and Reliability

While LEDs themselves are extremely reliable and have a long lifetime, are electronic LED drivers capable of providing the required current/voltage input to the LEDs over their whole lifetime? This paper aims to address the above question in general and for the Xitanium family of LED drivers developed by Philips Lighting specifically. It will describe some of the strategies which Philips applies to maximize the LED drivers' lifetime and reliability and support the application of LED-based outdoor lighting.

PHILIPS

In recent years, LED-based lighting technology as well as the number of applications that have embraced it have advanced rapidly. This is primarily because LEDs bring several advantages to the lighting industry, including high efficiency, durability, environmental friendliness and reduced maintenance requirements due to their superior life. All of these factors translate to energy and maintenance savings, and overall reduction in the cost of ownership over the product's lifetime.

High-power LED modules typically consist of an array of LEDs soldered to a copper board, separated from a heat sink by an electrically isolating but thermally conductive material. These LED arrays are powered by a LED driver, which could be either configured as a constant current source or as a constant voltage source, depending on application requirements. In most applications, these drivers are connected to the AC line on their input side. Like other power converters, the LED drivers consist of several semiconductor switches, magnetic elements, passive capacitors, resistors and other active components. All these electronic elements raise an important question for LED applications: *While LEDs themselves are extremely reliable and have a long lifetime, are the LED drivers based on power electronics capable of providing the required current/voltage input to the LEDs over their whole lifetime?*

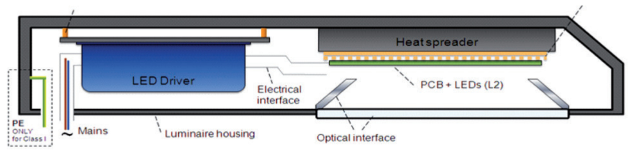


Figure 1. LED system

This paper aims to address the above question in general and for the *Xitanium* family of LED drivers developed by Philips Lighting specifically. It will describe some of the strategies which Philips applies to maximize the LED drivers' lifetime and reliability, to avoid a bottleneck in the application of LED-based outdoor lighting.

Definitions related to Reliability and Lifetime

It is important to first understand the definitions related to the lifetime of LED drivers and electronic products in general. Reliability experts often describe the reliability of a population of electronic products using a graphical representation known as the *Bathtub Curve*, as illustrated in Figure 2. The Bathtub Curve can be divided into three periods. The first is an initial period of infant mortality, where the defective/weak products fail. This is followed by the normal life of the product with a low and relatively constant failure rate. Following this is the final period of the product lifetime where wear-out mechanisms of the product kick in and the failure rates increase.

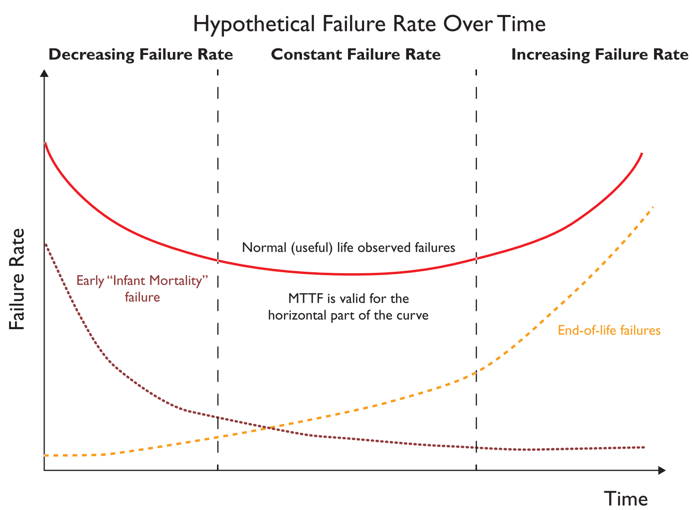


Figure 2. *The Bathtub Curve*

It is important to understand that the Bathtub Curve does not depict the failure rate of a single item, but describes the relative failure rate of an entire population of products over time. Some of the units will fail during the infant mortality period; others will last till the wear-out period while a few of the units will fail during the normal life. Reliability deals with random failures in a population of products and is expressed in terms of rates, such as *Failures in Time* (FIT) or *Mean Time to Failure* (MTTF). MTTF is the theoretical accumulation of random statistical failures of all components in the product, expressing the "constant failure rate" over lifetime. On the other hand, lifetime refers to the length of time that a single product may be expected to function properly before a known wear-out mechanism renders the product unfit for use. Lifetime is typically expressed in hours and normally indicates the duration of time with a minimum survival rate of 90% (obtained from the MTTF calculations). For instance, a lifetime of 100,000 hours implies that under normal conditions[1], in a typical installation (population), 90% of the products installed would be expected to last 100,000 hours before failure.

[1] Please refer to individual product datasheets for specified operating conditions.

MTTF Predictions: While the lifetime of the LED driver depends on the component that is most likely to fail, the failure rate of the driver depends on all the components within the driver. The MIL-HDBK-217F reliability model is used to predict the theoretical failure rate of the *Xitanium* LED drivers.

As an illustration, for a typical 150W Xitanium LED driver operating at a case temperature of about 50º C, a theoretical failure rate of 500 PPM/1000 hours and a MTTF value of approximately 2 million hours is obtained. Please note that for the MTTF calculation, worst case electrical stresses are assumed to obtain a conservative estimate of the LED driver's MTTF. If more realistic values are assumed, higher MTTF values are expected. These calculations also assume a typical operating temperature. If the operating temperatures were higher, the stress levels on the driver components would increase, leading to increased failure rates. Please note that the MTTF data are based on theoretical calculations only and by no means can substitute for actual field data. Past experience has shown that this theoretical prediction is much more conservative than the actual field data. Therefore, whenever possible, actual field return data should be used for predicting reliability.

Designing for Long Lifetime and High Reliability

Developing the most reliable product, which delivers the longest lifetime while also meeting the constraints of cost, size and time to market, is a challenge for every product designer. The *Xitanium* LED drivers are developed through a tightly controlled design and development process, where the quality of product is evaluated at each milestone and activities to realize deliverables (and guidelines on how to perform such activities) are clearly defined. A snapshot describing the overall development process is illustrated in Figure 3.

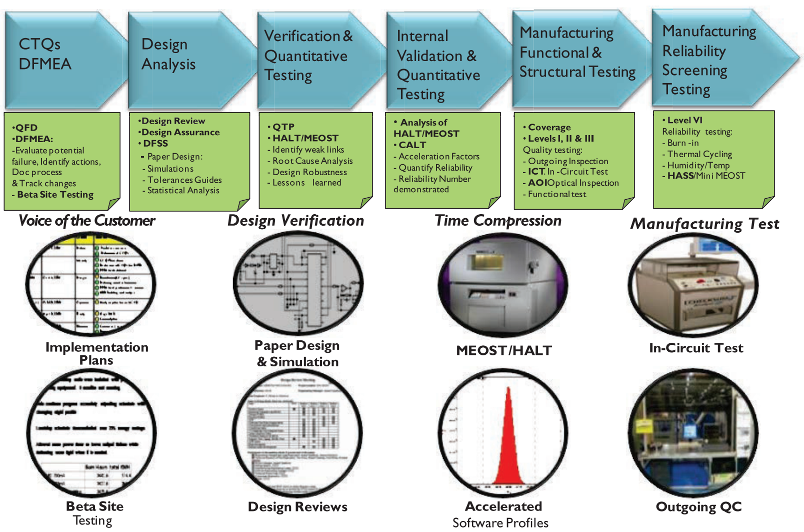


Figure 3. Product development process

Key factors that have to be taken into account to develop the most reliable product are described in the following paragraphs.

Topology Selection: For LED drivers, the first issue is the selection of the most robust power conversion topology given the constraints of power, size, cost, etc. For instance, while a flyback-based topology may be suitable for low power/low voltage applications because of low parts count, with increase in the operating power, a two stage topology might be more suitable from the operating stress and power loss standpoint. High-efficiency topology with soft starting LLC might also be used to further reduce the switching losses of the semiconductor switches thereby further improving efficiency and reducing power loss.

System Efficiency: System efficiency (or power loss) has a direct and significant impact on the reliability and lifetime of a LED driver. This is because all of the lost power is dissipated as heat within the driver, leading to an increase in the temperature of the components within the driver. If the power dissipated in the driver is high, the components within the driver operate at a higher temperature. The reliability of components declines as their operating temperature increases. Therefore, a driver operating with higher efficiency can have a significantly improved lifetime and reliability compared to a lower-efficiency driver.

Additional Protection Mechanisms: In addition to designing for lower power losses, the *Xitanium* LED drivers have a high-temperature roll-off capability. If the case temperature of the driver exceeds a certain value due to abnormal operating conditions, the output current is reduced. This in turn reduces power dissipation and ensures the temperature of the driver's internal components does not rise above a certain threshold. Since the operating temperatures of components have a direct impact on their failure rates, this feature enhances the reliability and lifetime of *Xitanium* drivers. Additional protection schemes are also built into the driver hardware to ensure its reliability. For example, to protect the driver against line surges, e.g. a lightning stroke, additional surge suppressors are added.

Component Selection: Having decided on the right topology that yields the highest efficiency (for a given application), the next challenge is the selection of the components. For the *Xitanium* drivers, each and every component is carefully chosen and passes through extensive design qualification, testing and internal long-term reliability checks. A careful supplier selection process and long-term relationships with the suppliers ensure that only the best components are used in the *Xitanium* drivers. From a design point-of-view, careful analyses of component stresses and adequate derating of the components ensures a highly reliable LED driver that is capable of achieving industry-leading lifetimes. For instance, electrolytic capacitors are operated with a 20% operating voltage margin, while normally semiconductor devices are operated with a 10-20% operating voltage margin. Careful attention is paid during the design phase to ensure that all components operate well within their maximum temperature ratings.

Lifetime Calculations: Having selected the components, it is important to determine which components are most likely to fail. Similar to other power converters, for LED drivers the component most likely to fail, especially when the driver is operating at relatively high temperatures, is the electrolytic capacitor. The electrolyte in the capacitor will vent over time as a function of the operating temperature of the capacitor. Therefore, the lifetime of the driver can be directly derived from the lifetime of the electrolytic capacitor. The operating temperature of the capacitor is a function of the case temperature (which again depends on the power dissipated by the driver and therefore, the driver's efficiency) of the capacitor and the internal heating within the capacitor caused by the ripple current flowing through it. The typical equation for the lifetime of the capacitor operating at a certain ambient temperature, L_T is defined by

$$L_T = kL_0 2^{\frac{T-T_0}{10}}$$

where k is a factor that depends on the ripple current flowing through the capacitor;
T is the temperature at which the capacitor operates;
L_0 is the lifetime of the capacitor at the rated case temperature.

The equation above shows that every 10° C drop in the operating temperature of the capacitor doubles its lifetime. This further reiterates the need to design high-efficiency LED drivers, to minimize power dissipation and therefore lower component temperatures. It is important to size the capacitor properly, to reduce the current ripple flowing into it. Please note that in the datasheets of Xitanium drivers, the lifetime is typically expressed in terms of the case temperature. For obtaining the estimate of the product lifetime, the relationship between the case temperature and the temperature of the electrolytic capacitors is obtained through careful thermal measurements, and it is assumed that the temperature difference between the capacitor and the case is always constant.

System Performance

The preceding discussion focused on lifetime and reliability of individual products. There are other factors which need to be taken into account when addressing lighting system reliability. One critical aspect to consider is the additional thermal stress arising from the mutual heating of different components in a system. Typically the self-generated heat of a driver is 20-25° C. However when the driver is mounted very close to the LED board, the heat from the LEDs will lead to additional temperature increase of the driver. Another challenge is related to the number of system starts, which can have a big impact on system lifetime. The temperature difference between a system at rest in a cold ambient environment and a running system could be in the range of 30° to 60° C. This drastic temperature change can lead to thermal shock. Frequent switching, for example turning the installation off in the middle of the night, will shorten the lifetime of the system. It is preferable to dim the light in order to maximize system lifetime.

Lifetime Outside Specified Operating Conditions: Product specifications include operating parameters for input voltage. Over-voltage, which can occur during switching or load changes, can negatively impact the lifetime of the driver. While there is no way to foresee these occurrences, it is possible to minimize the damage by choosing components with the widest possible specified voltage range. The new Xitanium Programmable LED drivers can operate in a voltage range of 108V - 320V.

In addition to the normal voltage fluctuations in the power line, LED lighting systems are subject to damage from high-voltage surges (e.g. lightning strokes). For a detailed discussion on how to protect your LED installation, please visit www.philips.com/surgeprotection

Lifetime and Reliability in Electronic Gear for Conventional Lighting: While the focus of the discussion has been on performance and reliability of LED drivers, the conclusions are identical for electronic gears for HID lamps. In fact the design of LED drivers is derived from the proven topology of eHID gear, perfected by Philips over the past two decades.

Testing and Qualification: The issues identified above bring us to the next important step in the design process. Extensive qualification testing is performed at the design stage of *Xitanium* drivers to ensure that any design issue is caught during the product development stage. The tests include operating the drivers at all possible operating conditions and also under conditions of extreme humidity and temperature. Furthermore, careful tests are conducted to ensure that all of the components operate within their maximum stress ratings (determined from the derating rules). Additional compliance testing is conducted by various agencies to ensure that the drivers meet all relevant industry standards.

Accelerated life testing, including HALT/ MEOST, is also performed to ensure high driver reliability. For every new product, the data from these tests are compared with those obtained from similar tests done for other released products (which have been operating in the field for a longer duration of time and for which enough field data are available). This ensures that every new product achieves at least the same level of reliability as a previously released product. To limit failures in the infant mortality period, initial burn-in or stress tests are done on statistically relevant sample sizes.

Key Conclusions

This document also describes how the lifetime and reliability of the Xitanium LED drivers are maximized during design and manufacturing. Software modeling is used to estimate the theoretical failure rate of the drivers. Field return data obtained from previously released products show that the estimates obtained using this model are more conservative that actual performance. Therefore, theoretical MTTF data is meant to be an initial estimate and can give an idea regarding weak links in the design. For instance, for Xitanium LED drivers, theoretical calculations reveal that the electrolytic capacitors and the solder joints are the components most likely to fail. It is however recommended that whenever possible, actual field return data should be used.

This document also describes the strict design procedure followed for the development of Xitanium LED drivers to ensure high lifetime and reliability. The design and development of all Xitanium LED drivers pass through a tightly controlled process. The quality of product is critically evaluated at each milestone and activities to realize deliverables (and guidelines on how to perform such activities) are clearly defined. All field return issues are carefully documented and all failure issues are reviewed at the start of each new project so that the learnings can be carried forward to new designs. This feedback and improvement cycle has been part of the Philips product development process for over a decade, resulting in products which perform far better than the theoretical estimates.

Technical abbreviations

CTQs:	Critical to Quality
DFMEA:	Design Failure Mode and Effect Analysis
DFSS:	Design for Six Sigma
FIT:	Failures in Time
HALT:	Highly Accelerated Life Testing
HID:	High Intensity Discharge
ICT:	In -Circuit Test
LLC:	a half-bridge topology with two coils (LL) and one capacitor (C)
MEOST:	Multiple Environmental Overstress Test
MIL-HDBK-217F:	Military Handbook for "Reliability Prediction of Electronic Equipment". MIL-HDBK-217 is published by the Department of Defense, based on work done by the Reliability Analysis Center and Rome Laboratory at Griffiss AFB, NY. The MIL-HDBK-217 handbook contains failure rate models for the various part types used in electronic systems, such as ICs, transistors, diodes, resistors, capacitors, relays, switches, connectors, etc. These failure rate models are based on the best field data that could be obtained for a wide variety of parts and systems; this data is then analyzed create usable models.
MTTF:	Mean Time to Failure
PPM:	Parts Per Million
QC:	Quailty Control
QTP:	Quality Test Plan

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Reference _ https://www.philips.com/global