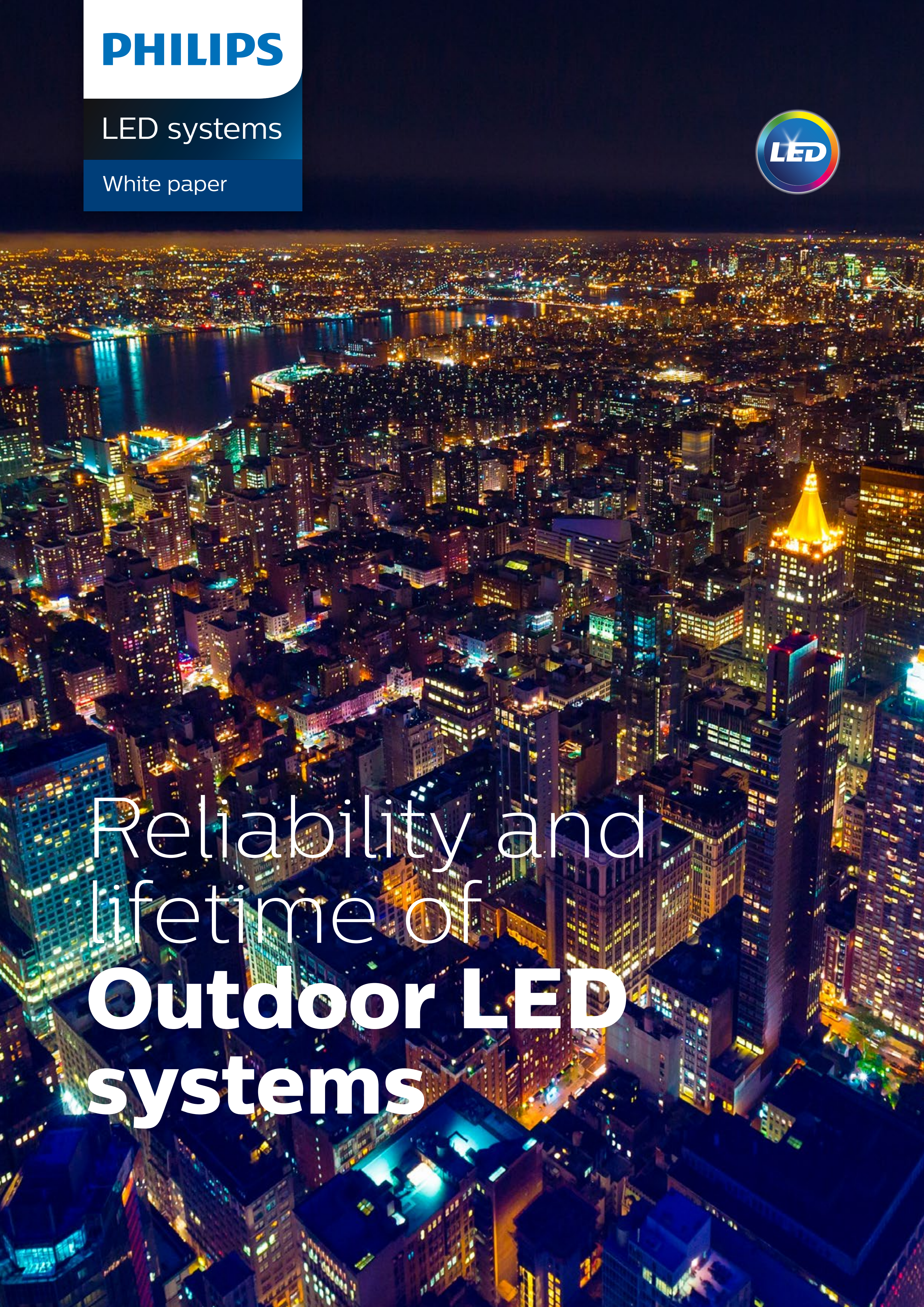
PHILIPS

LED systems

White paper



Reliability and lifetime of **Outdoor LED systems**

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While LED’s 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.

Introductions

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.

LED modules typically consist of an array of LEDs soldered on a copper board and separated from a heat sink by an electrically isolating but thermally conductive material. These LED arrays are powered by a LED driver connected to the AC line. LED drivers consist of many components such as semiconductor, magnetic elements and other passive such as capacitors and resistors. 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?

This paper aims to address the above question in general and for the Xitanium Xtreme family of LED drivers developed by Philips Lighting specifically. It will describe application parameters and strategies which Philips applies to maximize these LED drivers’ lifetime and reliability to secure our customers a long-life of LED-based outdoor lighting.

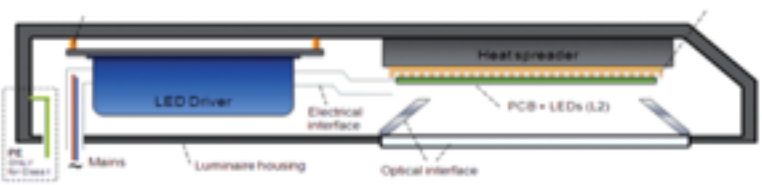


Figure 1: LED system

Extreme climate conditions

Outdoor fixtures must withstand extreme conditions such wide variety in temperatures of the frigid cold in the North and the intense heat in tropical areas), moisture (fog, hail, rain) and even lightning and aggressive exhaust gasses. At the same time, these fixtures must perform within these difficult surroundings having the right light level at the right time over a long lifetime in hard-to-access locations.

Application aspects in outdoor

Looking to the installation many aspects will determine the eventual lifetime, it's not hard to imagine that a luminaire operating in the tropics with night temperatures above 30°C will suffer more than when this luminaire operates in a mild climate with an average night temperature of 15°C. Next to temperature the number of switching will also influences the lifetime because of thermal shock of specifically soldering, in case a presence sensor or a controller is used this needs to be taken into account. In some cases, it's therefore recommended not to completely switch light off but keep light burning in dimming mode. Probably the next biggest reason for early failures is electrostatic discharge or surge currents caused by high voltages caused by lightning. The voltage on top of a high pole or the voltage caused by a hit nearby could generate a devastating current in the installation. Next to these so-called common mode voltages the system also should be protected against surges present on the AC input line, these differential mode voltages are typically generated by high power switching in the installation. Finally, the lifetime of the fixture will be determined by mechanical stress caused by for example heavy traffic or stormy weather.

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 below figure

At production and in initial period of use (infant mortality), in this short period (hours, weeks) typically drivers will fail because of weak components. 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.

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. Electronic devices 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 conditions1, in a typical installation (population), 90% of the products installed would be expected to last 100,000 hours before failure.

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

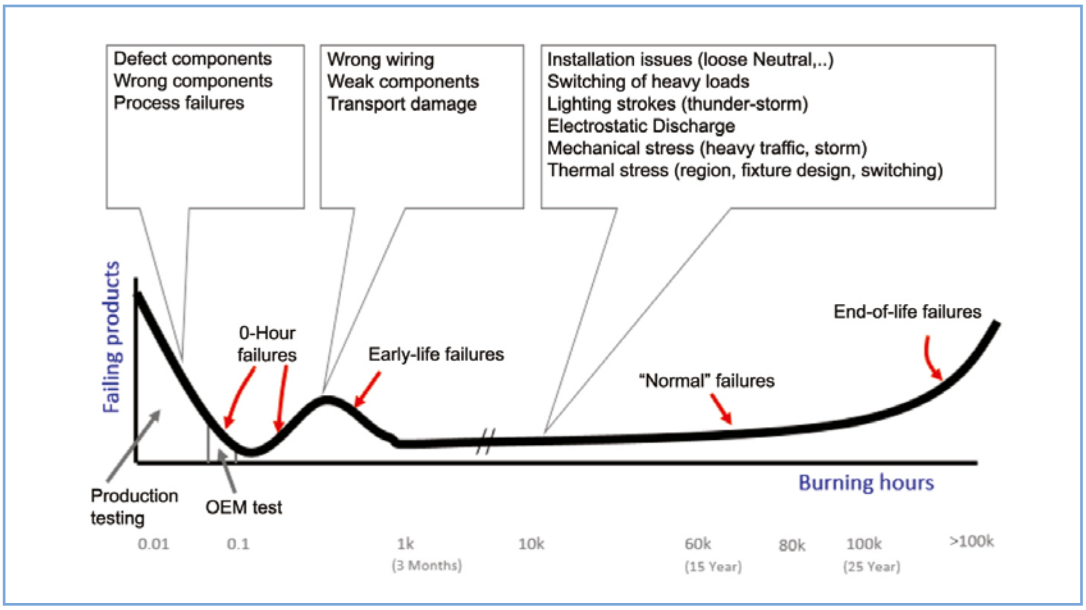


Figure 2: Bathtub Curve

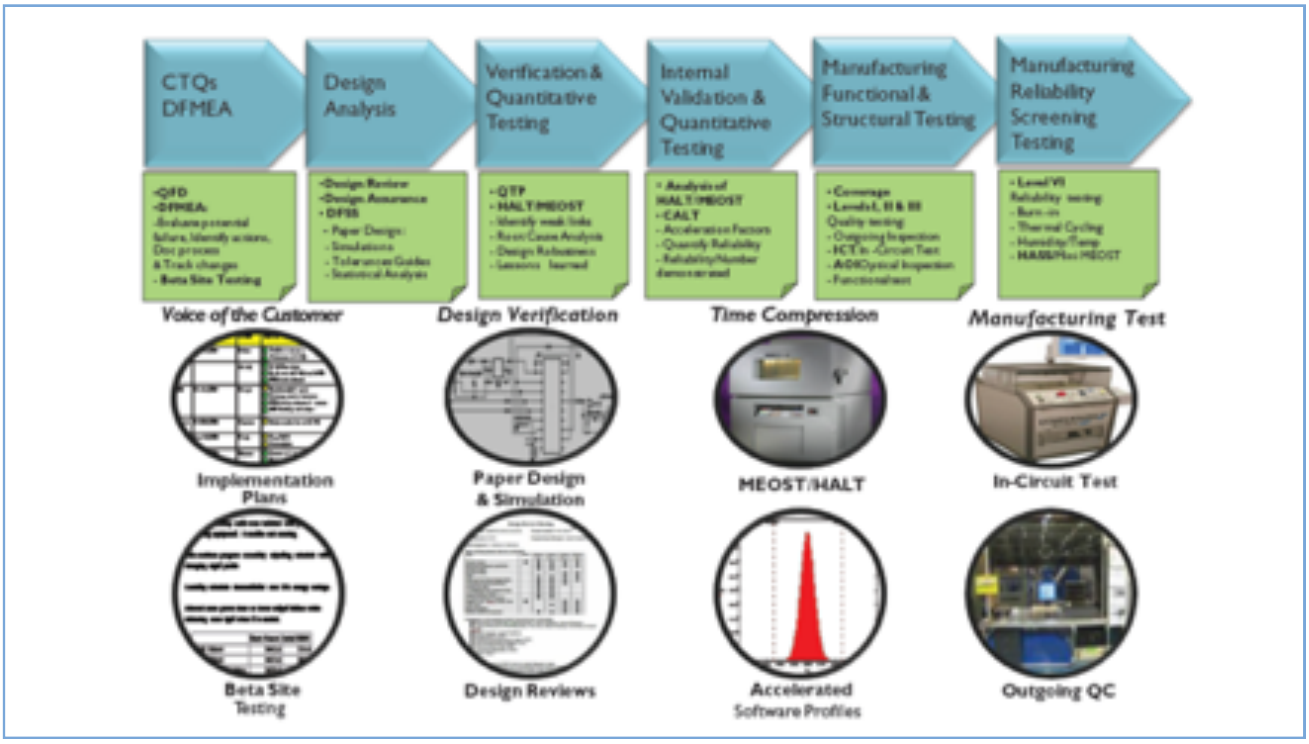


Figure 3: Product development process

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.

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. Philips drivers are designed based on the long time experience in outdoor application and uses latest topologies and components to guarantee our customers the efficiency and needed reliability in these demanding applications worldwide.

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.

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. Careful attention is paid during the design phase to ensure that all components operate well within their maximum temperature ratings.

Lifetime Calculations

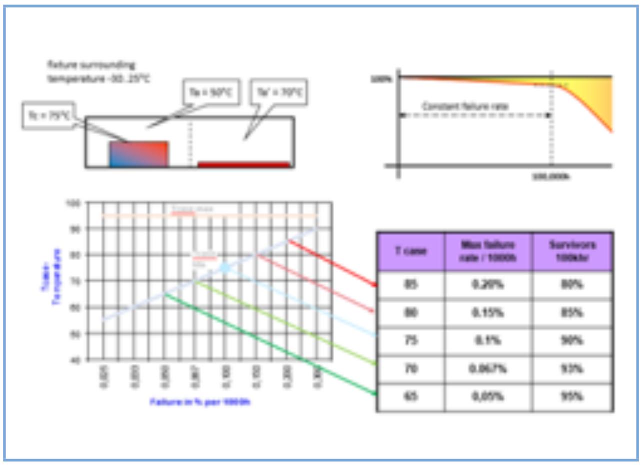
Having selected the components, it is important to determine which components are most likely to fail. Based on the knowledge of HID and LED drivers the components most likely to fail are taken into account, especially when the driver is operating at relatively high temperatures. As example of a critical component let's consider the lifetime of a capacitor. The typical equation to calculate the lifetime at a certain ambient temperature, is defined by:

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

where is a factor that depends on the ripple current flowing through the capacitor; is the temperature of the operating temperature; is the lifetime of the capacitor at the rated case temperature. This equation above shows that every 10º C drop in the operating temperature of the capacitor doubles its lifetime. Also known as Arrhenius law.

System Performance

For simplicity this rule can also be applied around the Tcase temperature of the driver because capacitors are often the lifetime determine components at higher operating temperatures, in the table left you can find a simplified overview of the survival rate with an example of of a driver with a Tcase of 75 degrees.



Please note that in the datasheets of Xitanium drivers, the lifetime is typically expressed in terms of the case temperature. Both Tcase life and Tcase max is specified. Above the value of Tcase max a build-in protection will limit the output to protect the driver and therefore the luminaire.

This further reiterates the need for high-efficiency LED drivers, to minimize power dissipation and therefore lower component temperatures. Next to this the construction of the fixture and the ability to lower the temperature of both driver and LED module have a significant effect on the lifetime. One critical aspect in this 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 20-25º 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.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Minsk	-2,7	-1,4	3,3	11,5	18,3	21,5	22,4	22,2	15,9	9,6	2,6	-1,0	10,1
Stockholm	-0,7	-0,6	3,0	8,6	15,7	20,7	21,9	20,4	15,1	9,9	4,5	1,0	10,0
Budapest	1,2	4,5	10,2	16,3	21,4	24,4	26,5	26,0	22,1	16,1	8,1	3,1	15,0
London	7,9	8,2	10,9	13,3	17,2	20,2	22,8	22,6	19,3	15,2	10,9	8,8	14,8
Paris	6,9	8,2	11,8	14,7	19,0	21,8	24,4	24,6	20,8	15,8	10,4	7,8	15,5
Barcelona	13,4	14,5	15,9	17,6	20,5	24,2	27,5	28,0	25,5	21,5	17,0	14,3	20,0
Lisbon	14,8	16,2	18,8	19,8	22,1	25,7	27,9	28,3	26,5	22,5	18,2	15,3	21,5
Valencia	16,1	17,2	18,7	20,2	22,8	26,2	29,1	29,6	27,6	23,6	19,5	16,8	22,3
Athens	12,9	13,6	16,0	20,3	25,3	29,8	32,6	32,3	28,9	23,1	18,6	14,7	22,3

Another challenge is related to the number of system starts, which can Temperatures in outdoor will vary during night and day, per region and over the seasons. Although Philips systems are protected against over-temperature it remains important to not exceed the maximum temperatures. For lifetime calculations the ambient temperatures in the table can be used and in general it may be stated a luminaire installed in Stockholm would have half of the failure rate of same luminaire installed in Barcelona.

To protect over-temperature of the module Philips driver provide an input to connect a temperature sensor (NTC) and a feature called MTP (Module Temperature Protection) can be programmed in such a way that the connected module will be dimmed down at over-temperature and protects the module without switching the light off.

Lifetime and switching:

Next to the operating temperature also switching will have a big impact on system lifetime. The temperature difference (shock) between a system at rest in a cold ambient environment and a running system could be in the range of -10º to 35º C. This drastic temperature change will lead to thermal shock. Frequent switching, for example frequent switching by means f a presence detection, will shorten the lifetime of the system. It is preferable to dim the light in order to maximize system lifetime.

Mains voltage:

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. Because there is no way to foresee these occurrences, Philips Full Prog drivers therefore have a build-in feature called MainsGuard to protect the luminaire and installation. This MainsGuard features takes care the light will remain on even at low input voltage, the fixture is protected against under voltage and the Input current will be limited to max 130% to prevent tripping of MCB or fuse.

Surge protection: 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 and/or high load switching).

Surges can occur in two modes

1. Differential mode is voltage between Line and Neutral and is internally in the Philips Xtreme drivers protected with a so-called Varistor or MOV at 6kV (older drivers were 4kV).
2. Common mode is defined as the voltage between the mains input and metal parts and is internally in the driver determined by a special component for EMI and the isolation, for older drivers this was specified as 4kV and for the new Xtreme drivers this is has been increased to 8kV.

Next to the high surge specification Philips also offers external SPD's which includes a so-called active surge-arrestor (spark-gap) which in case of a high common or differential mode surge voltage will clamp these voltages on the input of the luminaire and divert this the high energy to Earth. This device gives thereby a higher protecting of both the driver and other devices in te luminaire. Because of regulations the clamping component (spark-gap) is not allowed in Class-II luminaires. Philips will introduce a special Class-II SPD which will enhance the protection of common-mode surges.

Do customers need this surge protection?

Experience has learned in normal environments (cities, residential area, street lighting) a surge capability of 4kV will be sufficient. In the latest Philips Xi FP/LP sXt drivers the differential mode surge specification has been increased to 6kV and common-mode voltage to 8kV.
In higher risk areas such as mountains were lightning has a density above >4 Flashes/km2/year or when poles are installed I open field Philips advises to use an active SPD type-3 device to clamp the high-voltage surge at the input from the luminaire to actually protect the driver and module.

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.

The diagnostic capabilities of state-of-the-art LED drivers

The latest generation of LED drivers offer capabilities far beyond providing the LED's with the right operating current, they offer diagnostic capabilities for the complete LED solution. Via NFC enabled SimpleSet setting such as operating current can be set and because NFC technology allows two-way communication this also enables possibility to readout information from the LED driver. Diagnostics includes system information like number of system burning hours and number of system starts.

The FULL prog drivers furthermore enables read-out the temperatures and mains voltage. These parameters can be useful for OEM who wants to give extended warranties in applications for which for example the operating temperatures will be limited. Diagnostics can be an important tool concerning whether a failure is yes or no covered by the warranty. The Xitanium FULL drivers are able to give recordings over a long period in the shape of histograms which can be made visible using the same software used to program the drivers.
Another parameter monitored by the diagnostics function of the Xitanium FULL drivers is whether the LED module is defect. This is a fast way to determine whether a driver - or LED board failure is the cause of a non-functioning LED solution.

A few more parameters offered by the diagnostics are :

- LED module voltage
- LED module temperature
- Whether a short – or open circuit has taken place
- Whether the NTC of the LED module is missing

- Whether the module light reduction is active
- Whether the module temperature has been too high

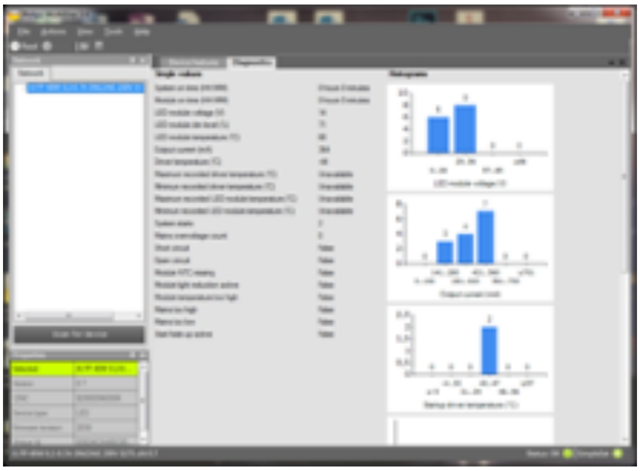
Summary

This document describes how the lifetime and reliability of the Xitanium LED drivers are maximized during design and manufacturing. Testing and qualification assure the quality and with software the actual behavior in the field can be compared with the modeling used to estimate the theoretical failure rate of the drivers.

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 several decades, resulting in products which perform far better than the theoretical estimates.

Technical abbreviations

CTQs:	Critical to Quality
DFMEA:	Design Failure Mode and
DFSS:	Design for Six Sigma
FIT:	Failures in Time
HALT:	Highly Accelerated Life Testing
HID:	High Intensity Discharge
ICT:	In -Circuit Test
MEOST:	Multiple Environmental Overstress Test
MTTF:	Mean Time to Failure
PPM:	Parts Per Million
QC:	Quality Control
QTP:	Quality Test Plan.



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