Reliability of electronic drivers
An industrial approach

Watté, P.; van Hees, G.; Engelen, R.; van Driel, W. D.

DOI
10.1115/IPACK2021-72293

Publication date
2021

Document Version
Final published version

Published in
Proceedings of ASME 2021 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, InterPACK 2021

Citation (APA)
Watté, P., van Hees, G., Engelen, R., & van Driel, W. D. (2021). Reliability of electronic drivers: An industrial approach. In *Proceedings of ASME 2021 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, InterPACK 2021* Article v001t07a005 (Proceedings of ASME 2021 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, InterPACK 2021). American Society of Mechanical Engineers. https://doi.org/10.1115/IPACK2021-72293

Proceedings of the ASME 2021 International Technical Conference and Exhibition on
Packaging and Integration of Electronic and Photonic Microsystems
InterPACK2021
October 26-28, 2021, Virtual, Online

IPACK2021-72293

RELIABILITY OF ELECTRONIC DRIVERS: AN INDUSTRIAL APPROACH

P. Watté[1], G. van Hees[1], R. Engelen[1], W.D van Driel[1,2]

[1]Signify Research, Eindhoven, The Netherlands
[2]Delft University of Technology, EWI, Delft, The Netherlands

ABSTRACT

Reliability of electronic drivers, or systems, is crucial for the business of Signify. We manufacture and sell more than a million drivers per year. Field returns taught us what failure modes are important, but this is not sufficient to provide lifetime claims for our products. Being in this business for almost a century, in order to provide detailed lifetime claims, we have established an internal reliability tool. This tool provides our designers the correct information for flawless driver development. The specially developed Electronics Reliability Tool (ERT) uses on the one hand FIT tables provided by handbooks like e.g., Telcordia and on the other hand also considers wear-out mechanisms due to e.g., lightning strikes. Validation and verification of our predictions is performed by collecting sold quantities, field returns, do extensive failure analysis and compare these values with calculated ones. Each internally designed driver is subjected to an ERT calculation. The forecasted lifetime is used as a yard stick to witness the drivers' targeted lifetime. In our presentation we will demonstrate the tool. In this paper, we describe details of how ERT calculates failure rates. We will also present the comparison between field performance and calculated values of our electronic drivers.

Keywords: Driver reliability, FIT, parts count, derating.

NOMENCLATURE

Elcap	Electrolytic capacitor
ERT	Electronics Reliability Tool
FIT	Failure In Time
PPM	Parts Per Million
R	Reliability
Rand.comp	Random component part
Syst	System part
W.O.	Wear out part

1. INTRODUCTION

The penetration of LED-based products has significantly increased in the past years [1 - 6]. Here, an LED-based product is an apparatus that distributes, filters, or transforms light transmitted from one or more LED light sources. It is a system that includes all the parts necessary to support, fix, and protect light sources and (where necessary) circuit auxiliaries, along with the means to connect them to the supply but not the light sources themselves. The global LED lighting market grew by 3.2% from 2018 to almost 60BEuro in 2019 [1]. It is expected that the market will grow at a compound annual growth rate (CAGR) of 2.8% largely based on the expected growth in healthcare and industrial applications [1]. Several reports in the past years [4-6] predict that, compared to conventional incandescent, halogen, fluorescent, and high-intensity-discharge white-light sources, the rate of LED market penetration will increase steadily, rising to 75-85% percent by 2030.

This level of adaptation 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 lifespan [7]. All 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 semiconductors, magnetic elements, and other passives such as capacitors and resistors to convert the AC power to a low voltage DC signal. All these electronic elements raise an important question for LED applications: While LEDs themselves are extremely reliable and have a long lifetime, one could question whether the LED drivers based on power electronics can provide the required current/voltage input to the LEDs over their whole lifetime.

With the advent of connected lighting, the use of sensors and wireless technology became widespread. As such, LED drivers support more features, like PIR and microwave sensors, used for presence detection. In outdoor applications, light poles stay in touch with servers that store information (electrical signals, temperature, application mission profiles, etc.). The data sets that are constituted accordingly are highly suited for prognostics purposes.

There are many different approaches for executing a reliability study. We can divide them into four categories: Reliability prediction methods based on 'field data', 'test data', 'handbooks' and 'stress and damage models' [8, 9]. In this paper we will present an industrial approach that combines field and test-data with handbook approaches using a significant history of engineering learnings.

2. MATERIALS AND METHODS

One of the common approaches toward reliability assessment of LED drivers is using handbook methods such as MIL217 [10] and/or Telcordia [11]. These methods have been criticized for several reasons, such as providing no information about failure modes and ignoring the interactions of the system's components over each other's reliability [8]. Handbook prediction methods can be used for reliability prediction for electronics and electrical components and systems when the failure mode is standard and previously established. The data in these handbook methods are an amalgam of historical data collected from field testing or lab testing, usually from different manufacturers of the components. For system level reliability calculations, most of the handbook methods assume that the components fail independent from each other. All handbook prediction methods contain one or more of the following types of prediction [10]:

- Tables of operating and / or non-operating constant failure rate values arranged by part type
- Multiplicative factors for different environmental parameters to calculate the operating or non-operative constant failure rate
- Multiplicative factors that are applied to a base operating constant failure rate to obtain non-operating constant failure rate.

There are lots of handbooks and some of them are written for specific application fields. The first one is MIL-HDBK-217 [10] which was published in the 1960s. Examples of some popular and more updated ones are: RIAC's 217PLUS, Telcordia RS332, RDF 2000/2003-IEC62380, and FIDES 2009. Within Signify, we developed our internal reliability tool for LED drivers, based on approaches described in these handbooks.

2.1 ELECTRONICS RELIABILITY TOOL

In order to guarantee flawless operation during the projected service life, LED drivers are tested in our well-equipped labs with state-of-the-art test facilities. Development teams follow detailed test validation plans to mitigate product risks along the project execution. The most common executed tests are thermal cycle and shock tests, relative humidity tests, salt mist tests, surge tests, damp heat tests, vibration and mechanical shock tests. The challenge is to embed the knowledge from these tests into a dedicated modelling tool to re-use prior knowledge.

In only 8 bullets we can describe ERT as follows:

- The driver reliability model considers the effects of all components on lifetime, with corrections for deviating voltages, temperatures, ripple currents (only electrolytic capacitors), powers (only resistors), and dimming. Dimming lowers the operating temperature and thus increases lifetime.
- Apart from the Elco's and critical solder joints, the components are assumed to fail randomly in time. Consequently, constant failure rate (or exponential) models are used. These models are based on the FIT numbers. FIT means Failures In Time indicating the PPM level per 1000 hours.
- The base FIT numbers are based on supplier data, and or Philips CE & Lighting Electronics experiences.
- The FIT corrections for deviating voltages, temperatures, etc., are based on experiments within Philips, supplier knowledge, MIL and Telcordia standards.
- For each individual Elco the drying out of the electrolytic capacitor (= wear-out) is modelled. Its wear-out depends on the load life and on the difference between 0-hr and minimum design value.
- For the most critical solder joint (typical for the largest component) the wear-out is modelled taking into account the number of hours per cycle, ΔT-solder in use, and the solder joint & PCB materials.
- By means of correction factors the effects of humidity, lightning, LF surges & dips, and mechanical stresses are considered.
- Transient overstress during lamp starting or ignition are not modelled since component stresses are designed to remain within the derating rules.

Following the bath-tub curve shown in Figure 1, the well-known parts count method in reliability is employed to construct the flat part, using the base FITs (failures in a billion hour of operation) of the components of the board assembly. For calculation purposes, the latter are corrected for local temperatures, using Arrhenius approaches. For electrolytic capacitors (ELCAPs) ripple currents and local temperatures are envisaged since the latter determine the failure rate. The third part of the bathtub curve pertains to the wear out. We know from history that solder joint cracking and degradation of electrolytic capacitors [12] are the most important wear out failures for LED drivers. Dedicated physical and empirical models are (being) built and maintained to be integrated in our prototyping tools.

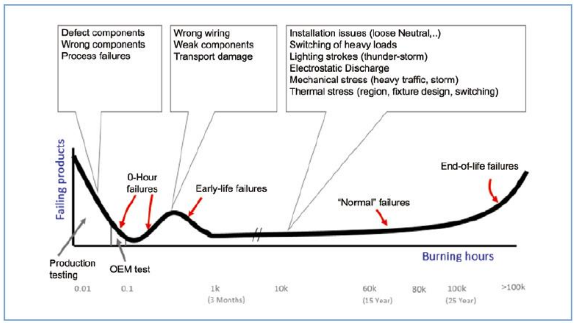


FIGURE 1: BATH_TUB CURVE IN REALITY [7].

From experience, it is known that two types of solder joints are the most vulnerable to fatigue cracking [13].

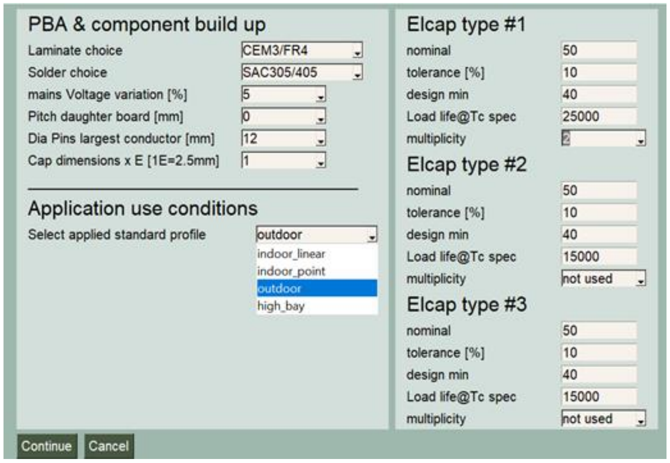
- Through-hole components like large transformers, can be quite susceptible to solder fatigue cracking, especially when they have large dimensions, combined with relatively large CTE mismatches with the printed boards.
- Board-to-board connections are also critical, in cases when there is a strong mismatch in thermal expansion coefficient (CTE). Not only during the thermal cycling in application, but already during the processing (wave soldering), the solder joints might receive severe thermal excursions, that imposes high stresses. The latter are frozen in as residual stresses after the cooling down to room temperature.

Degradation of electrolytic capacitors is modeled here by means of a stochastic method [12]. Because Signify partners with ELCAP suppliers, we have access to their validation tests and hence know the typical shapes of the degradation curves. These shapes are approximated and by means of Monte Carlo simulations, one can find the ELCAP failure distribution, whereby the end-of-life is set at a threshold capacitance value.

When all former elements are available it is possible to constitute the overall reliability curve as the following multiplication of reliability functions [8]:

$$Rsyst(t) = \prod_{i=1}^{L} R_i^{rand,comp}(t) \times \prod_{j=1}^{M} R_j^{elcap,W.O.}(t) \times \prod_{k=1}^{N} R_j^{solder,W.O.}(t) \tag{1}$$

In equation 1, W.O. denotes the wear out and 'rand' points to random failures. Rather than working with the bath-tub curve, the tool depicts the cumulative probability curve for failure as a function of time, F(t)=1-R(t). Failure points are determined on this function F(t) via Newton Raphson root finding. Screenshots of the ERT are depicted in Figure 2.



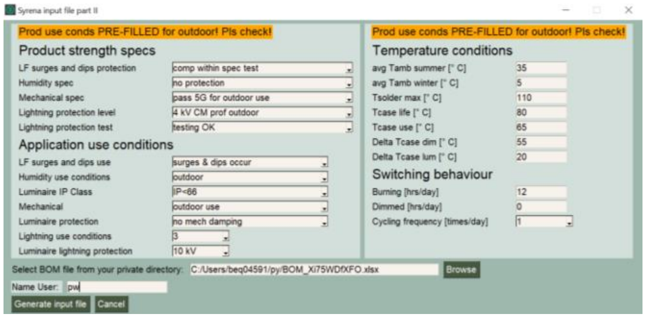
PBA & component build up
Laminate choice: CEM3/FR4
Solder choice: SAC305/405
mains Voltage variation [%]: 5
Pitch daughter board [mm]: 0
Dia Pins largest conductor [mm]: 12
Cap dimensions x E [1E=2.5mm]: 1

Application use conditions
Select applied standard profile: outdoor
indoor_linear
indoor_point
outdoor
high_bay

Elcap type #1
nominal: 50
tolerance [%]: 10
design min: 40
Load life@Tc spec: 25000
multiplicity: 2

Elcap type #2
nominal: 50
tolerance [%]: 10
design min: 40
Load life@Tc spec: 15000
multiplicity: not used

Elcap type #3
nominal: 50
tolerance [%]: 10
design min: 40
Load life@Tc spec: 15000
multiplicity: not used



Syrena input file part II

Prod use conds PRE-FILLED for outdoor! Pls check!

Product strength specs
LF surges and dips protection: comp within spec test
Humidity spec: no protection
Mechanical spec: pass 5G for outdoor use
Lightning protection level: 4 kV CM prof outdoor
Lightning protection test: testing OK

Application use conditions
LF surges and dips use: surges & dips occur
Humidity use conditions: outdoor
Luminaire IP Class: IP<66
Mechanical: outdoor use
Luminaire protection: no mech damping
Lightning use conditions: 3
Luminaire lightning protection: 10 kV

Prod use conds PRE-FILLED for outdoor! Pls check!

Temperature conditions
avg Tamb summer [° C]: 35
avg Tamb winter [° C]: 5
Tsolder max [° C]: 110
Tcase life [° C]: 80
Tcase use [° C]: 65
Delta Tcase dim [° C]: 55
Delta Tcase lum [° C]: 20

Switching behaviour
Burning [hrs/day]: 12
Dimmed [hrs/day]: 0
Cycling frequency [times/day]: 1

Select BOM file from your private directory: C:/Users/beq04591/py/BOM_Xi75WDfXFO.xlsx
Name User: pw

FIGURE 2: USER INTERFACE OF THE ERT.

3. OUTPUT, VALIDATION, AND VERIFICATION

A bill of material file is uploaded that contains so called TVI (**T**emperature, **V**oltage de-rating and **I**ripple de-rating) information. For each component information is gathered about the local temperature, the power and voltage derating and for the ELCAPs ripple current deratings. An example of the output of such a calculation is given in figure 3.

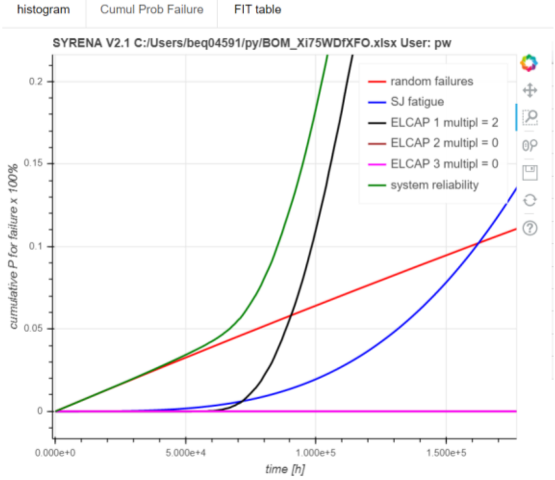


FIGURE 3: CUMULATIVE PROBALITYF FOR FAILURE AS FUNCTON OF LIFETIME FOR AN UPLOADED BILL OF MATERIAL.

The output in Figure 3 allows already from a prototyping phase to make estimations of the projected lifetime of a LED driver. A table with the corrected FIT numbers for each component can also be retrieved. In case of outliers in those numbers it is easy to pinpoint the suspected components for doing design iterations. In case the design is frozen, the tool can be used to set product warranties.

Verification of the ERT was done by comparison with other handbook methods. The analysis was carried out on designs of 4 typical LED drivers for which a list of components with failure rates was made. For this selection of components, the FIT-values were looked up in the relevant databases. The most important problem in finding the FIT-number for the components listed in these databases is the uncertainty about the description of the components. In such databases, the component classes have different descriptions than in engineering databases with a broader application area. Table 1 lists the results of this verification. Given the uncertainty in these calculations, the comparison between both databases is quite acceptable. Each model has advantages when used in the area where the data on which the model is based, not the least being that the component and environment coverage of each model is slightly different and is specific to the originating field. In general, however, the user is best served by obtaining its own field data and using those data as a prediction tool [14].

TABLE 1: COMPARISON OF ERT WITH TELCORDIA BASED CALCULATIONS FOR 4 TYPICAL LED DRIVERS.

Driver	Tcase [degC]	ERT [%] 50khrs	100khrs	Telcordia [%] 50khrs	100khrs
A	70	5.1	9.9	3.9	7.6
B	70	4.6	9.0	3.4	6.6
C	50	3.3	6.5	2.7	5.4
D	70	5.4	10.6	4.2	8.3

Validation of ERT was done by comparison of field data with predicted data. Over a period of 5 years, return data of the above 4 mentioned drivers was obtained. Here the uncertainty comes from the exact application conditions, such as ambient temperatures and stability of the electrical grid and also from the return rate of the failed products. But with the amount of LED drivers sold and the family approach (read: buckets), we managed to obtain a significant amount of data. Table 2 lists the results of the validation. It is seen that the Field Call Rates (FCR) for the scoped drivers are (much) lower than the predicted rates within the time frame analyzed. Apart from that, in the last ten years, no significant failure modes, or issues were observed in field returns related to Elcaps or solder joint wear-out.

TABLE 2: COMPARISON OF ERT WITH FIELD RETURND DATA FOR 4 TYPICAL LED DRIVERS. FIT OR PPM/1KHRS.

Driver	Market [yrs]	Field FIT Nominal	90% upper bound	ERT FIT
A	1.0	130	148	520-790
B	2.0	342	528	622-945
C	4.5	278	299	440-668
D	5.7	333	356	921-1119

4. CONCLUSION

Reliability is an important asset for LED drivers, especially when it comes to service contracts. As product maturity increased, customers and original engine manufacturers have the right to ask for the rationale behind the derivation of specifications. Leading companies can differentiate by giving this transparency as a customer delighter.

This paper describes an industrial approach for the prediction of electronics reliability by combining a handbook-based reliability tool (ERT) with field return data. From our investigations we conclude that it remains worthwhile devoting resources to experimental validation testing and modeling of new LED and driver platforms. These can provide the basis for calculators backed up by powerful physics of failure (PoF) models and a FIT repository. The presented approach will be indispensable in case modelling will be enhanced by feed-back loops made possible by IoT and big data analytics. In future the presented calculation tool will be made fit-for-use for such analyses.

ACKNOWLEDGEMENTS

This project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 876659 [iREL4.0]. The JU receives support from the European Union’s Horizon 2020 research and innovation programme and Germany, Austria, Slovakia, Sweden, Finland, Belgium, Italy, Spain, Netherlands, Slovenia, Greece, France, Turkey.

REFERENCES

[1] Frost & Sullivan, 2020 Annual Update of Global LED Lighting Market, September 2020.

[2] W.D. Van Driel, X.J. Fan (editors), Solid State Lighting Reliability: Components to System. 01/2013; ISBN 978-1-4614-3067-4 Springer New York.

[3] W.D. Van Driel, X.J. Fan and G.Q. Zhang (editors), Solid State Lighting Reliability: Com-ponents to System Part II. 06/2017; ISBN 978-3-319-58174-3 Springer New York.

[4] Navigant Consulting, Inc., Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, report prepared for the U.S. Department of Energy, September 2016.

[5] Estimated LED penetration of the global lighting market from 2010 to 2030, available at link (last visited on 8/25/2016).

[6] Market penetration predicted for white light, freely available at link (last visited on 10/16/2020).

[7] Reliability and lifetime of Outdoor LED systems, Signify Whitepaper, 2019, available at: link (last visited on 04/28/2021).

[8] S. Tarashioon, An Introduction to Driver Reliability, In: W.D. Van Driel, X.J. Fan (editors), Solid State Lighting Reliability: Components to System. 01/2013; ISBN 978-1-4614-3067-4 Springer New York.

[9] IEEE std 1413.1-2002, IEEE guide for selecting and using reliability prediction based on IEEE 1413, IEEE standard coordinating committee 37.

[10] MIL HDBK217-E, Notice 1, Reliability Prediction of electronic Equipment, Military Handbook, 1990.

[11] Telcordia Technologies Special Report, Reliability prediction procedure for electronic equipment, SR332, 2001.

[12] Lahyani, A., et al., Failure prediction of electrolytic capacitors during operation of a switch mode power supply. IEEE Transactions on Power Electronics, 1998. 13(6): p. 1199-1207.

[13] W. Engelmaier, Solder Joint Reliability - Theory and Applications, ed. J.H. Lau, Van Nostrand Reinhold, New York, (1991), 545.

[14] J. Jones, J. Hayes. A comparison of electronic-reliability prediction models. IEEE Trans. Reliability, 1999; vol. 48(2), pp. 127–134.