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Multi-physics reliability simulation for solid state lighting drivers

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ABSTRACT

This paper is introducing a multi-physics reliability simulation approach for solid state lighting (SSL) electronic drivers. This work explores the system-level degradation of SSL drivers by means of applying its components reliability information into a system level simulation. Reliability information of the components such as capacitor, and inductor, defines how a component electrical behavior changes with temperature, and also with time. The purpose of this simulation is to understand the thermal–electrical behavior of SSL electronic drivers through their lifetime. Once the behavior of the device during its lifetime is understood, the real cause of the failure can be distinguished and possibly solved.

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1. Introduction

In this paper a new system level methodology to study the reliability of SSL drivers is introduced. It provides a way to build in reliability into the design phase. It integrates all aspects of an SSL driver together in order to be able to understand the behavior of the device through its lifetime and eventually being able to predict the device's lifetime. In this paper this methodology is applied in a multi-physics simulation which involves electrical and thermal analysis.

This work is introducing a multi-physics simulation approach in order to understand the thermal–electrical behavior of solid state lighting (SSL) electronic drivers through their lifetime. It is a computer aided reliability assessment tool which applies components reliability information into the system electrical and thermal analysis. The outcome of this simulation on an SSL driver is which component will fail first and due to which of electrical or thermal conditions. This method also can define which part(s) of the device is the most responsible for the electrical or thermal condition which lead to the device's failure.

One of the common approaches toward reliability assessment of SSL drivers is using handbook methods such as MIL217 [1]. These methods have been criticized for several reasons, such as providing no information about failure modes and ignoring the effect of the system's components over each other's reliability [2]. Using tests such as lifetime test on devices is one of the other approaches of reliability assessment. After lifetime test or other tests such as HALT or temperature cycling tests [3], failed devices are examined in order to explore the failed component(s). This component(s) is being replaced with a more robust types of the same component in order to improve reliability of the device. This is a trial and error way towards having a more reliable device. Even if the result is satisfactory, the final product may become more expensive or bigger in size.

There are many circuit level reliability simulation and prediction tools, some examples are FaRBS [4], RELY [5], BERT [6], ARET [7], HOTRON [8]. These tools attempt to access one or more failure mechanism focusing on VLSI [1] circuits/transistors. FaRBS is one the most recent introduced methods. It is a failure rate based SPICE reliability model which makes use of handbook methods benefits [4]. It adds the correlation of failure rates with transistor electrical operating parameters into a SPICE model.[2] The above mentioned circuit level reliability simulation tools have limitations for SSL drivers such as:

- They cannot take passive components into account. SSL drivers are low-power power converters where passive components play a very important role in their reliability, thus the existing tools cannot be used.
- These tools do not provide information about device's behavior during its lifetime.

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[1] Very-large-scale integration (VLSI) is the process of creating integrated circuits by combining thousands of transistors into a single chip.

[2] SPICE (Simulation Program with Integrated Circuit Emphasis) is a general-purpose analog electronic circuit simulator. It is a program to check the integrity of circuit designs and to predict circuit behavior [9].

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This work explores the system-level degradation of SSL drivers due to the components' specification degradation through time [10]. It is multi-physics simulation tool which helps understanding the electrical/thermal behavior of SSL drivers in its lifetime. This method can be a good complementary tool for experimental tests such as lifetime test. In this method components reliability information is used which defines how a component electrical behavior changes with time and temperature. The value of the components are constantly updated with respect to their new status in time.

This method helps understanding the fact that interactions play an important role in the reliability of an SSL driver. The component which fails first is not always the source of the problem. The source of the problem can be in other component which contributes the most to produce the over-stresses on the failed component. This method not only can help with predicting the lifetime of the circuit, but also can provide valuable feedback to the designer about the sensitivity of the device electrical and thermal characteristics to its components. In the following sections first the methodology is introduced, and then it is applied on a case study. At the end of the paper the results are discussed about the advantages and also limitations of our proposed method.

2. Methodology

In this section different steps of our new multi-physics reliability simulation methodology are explained. Fig. 1 is the main block diagram of our proposed method. Reliability core processor as the core of this reliability multi-physics simulation tool receives the input data and by integrating three different analysis – electrical, thermal, and sensitivity analysis – produces the output results. Each of these parts will be explained in detail in the following sections.

In each of the steps explained in the following sections the information from light engine part is discussed as well. The reason is, this method of studying reliability focuses on interactions between components of the system in order to be able to make statement about the whole system. Light engine is a part of the system which electrically and thermally[3] affects the SSL driver. Electrically, it is the electrical load for the SSL driver, and thermally its temperature (with respect to its distance) can affect the temperature of the SSL driver. Therefore studying reliability of SSL driver is impossible if we do not take the light engine into account.

2.1. Input data to the reliability core processor

Let's start going to the details of this multi-physics reliability simulation methodology with discussing what input data is required:

- Design information.
- Components non-ideal models.
- The components physics of failure (PoF) information.
- Application field criteria.

Design information: Design information can be obtained from designers of any SSL product. Design information consists of the device electrical and mechanical design information:

- Electrical bill of material (BOM) which is the list of all electrical components with their details from manufacturer. This information consists of the exact type of the device and its operational conditions.
- Electrical diagram or electronic schematics which is a simplified conventional graphical representation of an electrical circuit.
- Mechanical bill of material which is the list of all mechanical components with their details. This consists of mechanical specification of each components. In SSL drivers, electrical components are installed on a printed circuit board (PCB) and PCB is installed in a package which is the enclosure of the device. Information about each part's size and material is included.
- Mechanical diagram which is how different mechanical components are assembled together.

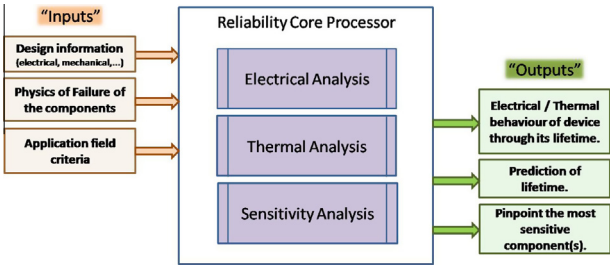

Fig. 1. The block diagram of the proposed multi-physics simulation method to calculate the reliability of SSL drivers.

Components non-ideal models: For the purpose of this multi-physics reliability simulation the electronic schematic of SSL driver should be modified by replacing the ideal model of each component with its non-ideal model. Defining the non-ideal model of components by itself is a very challenging subject. It needs understanding of how a manufactured component behaves in real life and comparing it with the expected behavior from an ideal component. The non-ideal model of each component with respect to its operational conditions may differ. For example the operational frequency can make a big difference in the non-ideal model of components such as capacitors, inductors and transistors [11]. Some of the electronic components manufacturers publish the non-ideal model of their products.

The components physics of failure (PoF) information: One of the essential inputs to the reliability core processor is the reliability information of each component:

- The maximum electrical and thermal stress each component can tolerate, or in the other word electrical and thermal conditions that make the component fail.
- How the the electrical function of each component changes with temperature.
- How the electrical function of each component changes while it degrades with its aging.

The temperature and the degradation models of some of the components can be found in literature, one good reference is the work of I. Bajenescu et al. [12] or B.W. Williams [13]. Components manufacturers also sometimes provide this information as well [14–16]. Although there are plenty of researches about the component failure analysis and their value dependency to different stresses, but still sometimes finding these information for every component can be a huge challenge. But by paying more and more attention to the physics of failure approaches for reliability assessment of electronic devices, it is expected that more of such information will be asked from manufacturers and hopefully it will be more effort from the manufacturers in the future to provide them. The goal of this work is to apply this information into system level and finally to be able to make an statement about the whole system.

[3] In reality light engine can affect of all aspects of the system which are electrical, thermal, mechanical, and electromagnetic. These two are mentioned here because in this work just the electrical and thermal aspects of the system is considered for the reliability study.

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