IEEE Reliability Society

Annual Technical Report 2009

1. INTRODUCTION

This annual technology report of the IEEE Reliability Society is based on material submitted by the technical activity segments of the Society, statements from experts in the field, industry reviews, and current special interest groups working in the current field.

Technical activities is the technical arm of the IEEE Reliability Society in the primary areas of technology operations that encompass the society's fields of interest. Its charges are:

- Help incubate new conferences
- Foster ways to get more technical information to our members through:
  - Annual Technical Report that comes out each January
  - Enable a content rich web site that will provide IEEE RS organizational data, technical reports and data, and tools. These capabilities are under development.
  - Publicize state of the art work in the IEEE Transactions, Spectrum magazine, our web site, and discussion groups.
  - Enhance the RS promotional flyer with technical activities content.
  - Build templates, guides and resources to guide and mentor new members of the society and profession
  - Interface with other technical societies and collaborate on joint ventures to gain synergy
  - Deliver technical information through: classes, tutorials, DVD's, and online collaboration (meetings)

The flagship reliability publication of the Society is "IEEE Transactions on Reliability" which addresses all aspects of reliability science. The Transactions is published quarterly on topics related to semiconductor, software, network, human factors, manufacturing, theory, optimization, modeling of system reliability, maintainability and others. Over the past 57 years, the Transactions have published many historical articles on reliability theory and practice, which have been widely applied by many theoreticians, engineers, and system users. Selected ATR articles contained herein are published each year in one issue of the Transactions.

SynJet® Thermal Management Technology Increases LED Lighting System Reliability

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Introduction

Electronic system reliability is typically a function of ambient temperature [1]. In many systems, an increase in temperature by 10 °C to 20 °C will cut the lifetime in half. LEDs in solid state lighting are subject to the same decrease in lifetime and also their light output quantity and quality are more negatively affected by higher temperatures [2].

For example, a MR16 form factor light fixture with a heat sink in natural convection may have a thermal resistance from sink to ambient of 5 °C / W. Therefore, a 15 W heat load will result in an increase of 75 °C LED heat sink temperature over ambient when the unit is powered on.

In the same example, active cooling will reduce the thermal resistance to 2 °C/W, resulting in 30 °C rise in heat sink temperature over ambient. Proportionally, the die temperature is always a few degrees above the heat sink temperature. The difference in die temperature between active and passive cooling is then at least 40 °C, drastically increasing the lifetime when actively cooled.

While adding a fan to a system will decrease component temperatures and therefore increase their lifetime, the limited fan lifetime with well-known failure modes will increase the system failure rate and reduce the maintenance cycle on the light fixtures.

A novel air moving device, called SynJet®, based on an oscillating membrane with no parts moving in friction, provides the necessary cooling capacity to reject tens of Watts from heat sinks to the ambient in typical applications. With SynJet Technology the design engineer has the opportunity to increase the overall system reliability by increasing component lifetimes at lower temperatures without adding much to the reliability allocation. Typical SynJet products have minimum L10 lifetimes of 100,000 hours at 50 °C and some models have demonstrated 300,000 hours of L10 at 60 °C, exceeding typical LED lifetimes. A typical example of a LED light reliability block diagram is shown in Figure 1.

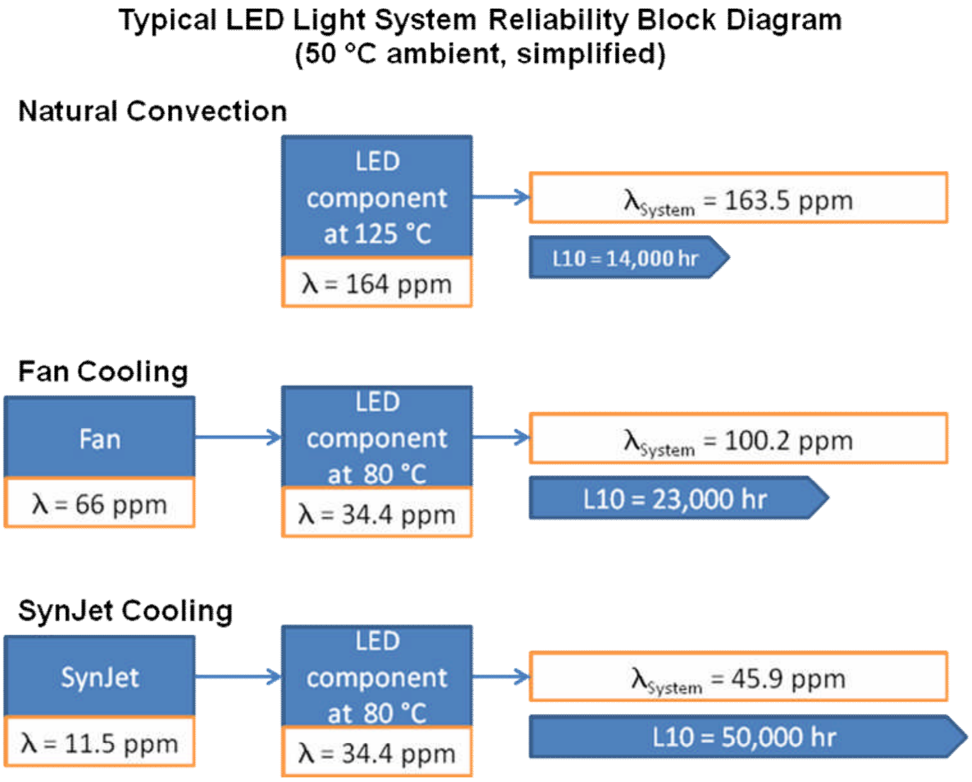

Figure 1: Typical Reliability Block Diagram for LED Light with and without active cooling.

SynJet Technology

SynJet technology, a patented active cooling solution from Nuventix, Inc. [3], offers a new option for thermal management utilizing synthetic jets. The SynJet module was designed specifically to address the limitations of current air movers, i.e. fans. A synthetic jet is a turbulent pulsating flow of air with greater cooling efficiency and lower power, while also offering high reliability and near silent acoustics. The rapid-fire pulses of turbulent air, typically 30 to 200 pulses/second, break up the thermal boundary layer and increases heat transferred from the heat source to the ambient. Aside from enhancing the small-scale mixing near the heated surface, the vortex-dominated synthetic jet flow creates a mean flow, which enables system level heat removal along with localized heat transfer (see Fig. 2). In addition, multiple synthetic jets can be created from a single oscillating diaphragm, generating unique simultaneous multidirectional airflow [4].

Synthetic jets are powered by an oscillating diaphragm in a cavity, usually via an electromagnetic actuator. The downstroke of the diaphragm slowly draws air into the synthetic jet, and then the air pulse is rapidly expelled during the diaphragm upstroke. Only relying on ambient air for cooling allows for a synthetic jet solution to be wholly contained, with no outside venting required. This enables cooling for difficult form factor applications. [5]

Besides LED lighting, current SynJet solutions enable DVR/DVD boxes, disk drives, and chip cooling solutions.

SynJets modules can be designed to offer extremely low acoustics as well, perfect for CE devices or set-top boxes/home-entertainment components. SynJet airflow can even be tailored to accommodate psychoacoustic perceptions. The SynJet module is routinely developed for solutions under 22 dBA.

With early adoption in the LED industry, synthetic jets are ushering in a new era in thermal management, turning to unsteady, turbulent air to effectively cool. SynJet modules offer higher heat transfer coefficients, excellent acoustics and an extremely flexible form factor, all while being the most reliable air mover in the industry. Thermal management has always been a constraint to designers, but synthetic jets are removing the previous restraints, enabling innovative design across many industries.

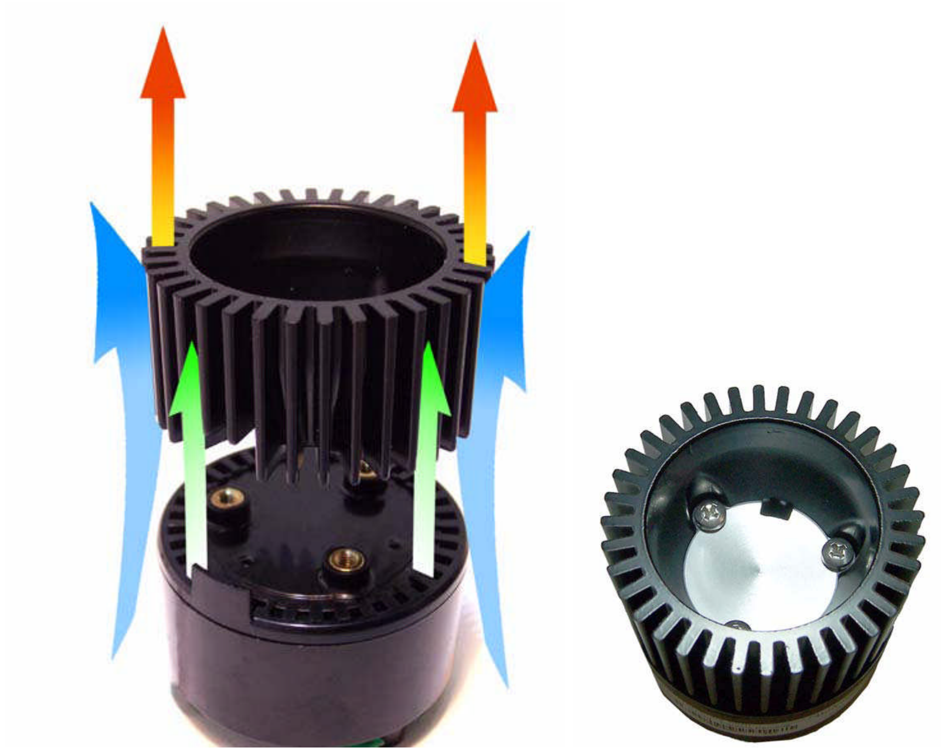

Figure 2: MR16 SynJet® cooling module with heat sink (left). This model is designed for up to 20 W applications. Arrows indicate air flow. Green for pulsating SynJet flow, blue for entrained ambient air, orange/red for rejected heated air from heat sink. Right: LEDs are installed on inside heat sink surface.

Reliability Assessment

Perhaps the greatest benefit of the SynJet module is the reliability of the synthetic jet solution. Thermal management has historically leaned on the fan as the go-to active cooling solution resulting in low mean time to failure (MTTF) and all the well-known reliability issues with bearings, fouling fan blades and electronics drive circuit failures due to high in-rush currents.

The SynJet module reliability has been extensively tested, often with the worst case operating specifications. As lifetime metric the L10 time is measured, at which 90% of the population survive within specifications at the maximum operating temperature of the specified module. Results have shown 300,000 hours L10 at 60° C or 34 years of 24 hour-a-day, seven days-a-week operation at 60° C. Other examples of the SynJet reliability tests are (all with at least 20 samples):

- 500 thermal shocks between -40 °C and +85 °C, 5 min. soak, operating, no failures
- 30,000 power on/off cycles (1 min.) at minimum and maximum operating temperatures, no failures
- 95% humidity at maximum operating temperature for 2,500 hours, no failures.

The reliability success of SynJets is due to several factors. Early on, design for reliability (DFR) methods were implemented with stringent requirements in a stage gate review process. The closed loop of the reliability qualification process cycle, namely environmental testing – performance and failure analysis – corrective actions – design feedback, steadily improved the reliability performance of SynJets. Highly Accelerated Life Testing (HALT) was used to find and improve the weakest links in the design. Ongoing reliability testing for production parts ensures that the reliability performance does not decline.

Lifetime demonstrations are performed on every cooler type with a minimum of 200 units split between two walk-in chambers set at 75 °C and 85 °C, respectively, where they are monitored in operation for 2,000 to 10,000 hours, depending on model and sample size. At the moment of this writing, 3,500 SynJets are operating inside these chambers, split 2:1 between the lower and higher temperatures.

Failure Discussion

Besides demonstrating a long lifetime, the most interesting reliability aspect is to find out what the dominant failure modes are and how they occur. Due to the construction of SynJets with no parts moving in friction, failure modes are very different from fan-like devices. The only two components that exhibit relative motion at all are the flexible membrane and the interconnect wires, making the material selection for those parts most important. The materials of all currently shipping SynJet models materials have been tested in products for over 3 years. Neither in the field nor in reliability testing have any failures of membrane materials of interconnect wires occurred.

Summary

SynJet technology enables many novel technologies and boosts the green efforts in power saving LED lighting designs. The benefit of adding SynJet cooling increases component reliability by lowering component temperatures, typically without net increase of the system reliability allocation, but often even increasing the overall system reliability.

References

[1] LED Magazine, December 2007, http://www.ledsmagazine.com/features/4/12/1

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[3] http://www.nuventix.com

[4] http://www.nuventix.com/technology/papers/

[5] “Thermal Management Using Synthetic Jet Ejectors”, Raghav Mahalingam, Nicolas Rumigny, Ari Glezer, IEEE Transactions on Components and Packaging Technologies, Vol. 27, No. 3, September 2004