Why Do South Facing Digitals Age Faster Than North Facing Digitals - Considerations for Display Longevity

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***Abstract*— It is a widely observed trend in North America's Digital Out Of Home advertising industry that digital billboards installed with a south-facing orientation tend to have a shortened lifespan and degraded reliability compared to those that are north-facing. The primary reason behind this trend is of course the Sun. However this whitepaper describes the basics of the mechanisms, considerations and possible mitigations against accelerated aging due to the Sun. The relevant mechanisms are heat degradation, UV degradation and thermal expansion/contraction. Media Resources VISIONiQ products are specifically designed with these challenges in mind.**

I. INTRODUCTION

LED Digital Billboards technology has matured significantly over the last twenty years. The industry as a whole, both operators and manufacturers, have learned a great many things through their experiences of how these electronic systems work in the real environment. One observation universally noted by the top North American operators is that LED Digital Billboards installed facing south tended to age worse than those facing north. Varying reports exist but the consensus is that given a product made by a top-quality manufacturer, many south-facing digitals de-facto require replacement after only 7-8 years due to degrading visual and reliability performance, while most north-facing digitals easily survive 10+ years. Common intuition tells us that the Sun is the culprit. This is true yet the degradation mechanisms relating to the sun are many-fold, and a proper understanding of these mechanisms will help us to understand the factors affecting longevity. Since longevity is potentially the single most important aspect of a digital product when it comes to operator Return On Investment, we believe operators need a clear understanding of the considerations around lifetime.

II. SOLAR RADIATION

Solar radiation is broad spectrum electromagnetic energy arising from the sun that provides all of the light and heat for the Earth. The power of the solar radiation should therefore never be underestimated; after all, all heat in the environment originated from the Sun. The measurement for Solar radiation power is called Solar Irradiance, the amount of radiant flux on an area, in units of W/m^2. The values of Solar Irradiance in North America range from 500-1000 W/m^2, or roughly 46-93 W/ft^2. As shown in Figure 1, Solar Irradiance is comprised of 3 distinct bands: Ultraviolet, Visible, and Infrared.

The impact of solar radiation on equipment placed in sunlight introduced a considerable number of stresses.

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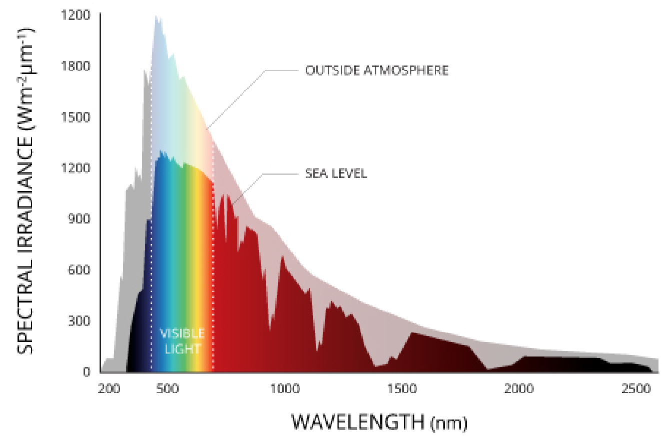


Fig. 1. Solar Spectrum showing Ultraviolet, Visible Light and Infrared (Heat) wavelengths.

A. Ultraviolet Radiation

While most of the solar energy reaching the ground is visible (which can be seen) or infrared (which can be felt as heat), there remains an ultraviolet (UV) component which is well known to cause chemical damage to organic materials including plastics. UV radiation is absorbed into certain chemical bonds, breaking them into chemically-reactive free radicals. Long term UV exposure in this way can cause a multitude of issues including fading, color-shifting, brittleness/cracking or warping of plastics. In the case of digital displays, each of these issues when applied to the Light Emitting Diodes optics or the plastic housings of modules are detrimental to product performance. While some plastics are naturally better than others in resisting UV damage due to their composition (for example polycarbonate versus polypropylene), UV resistance can be imparted by the addition of UV stabilizers which preferentially absorb UV photons and convert them into heat instead of releasing free radicals. For module housings, the choice of a high quality outdoor-use plastic polymer such as a GE/SABIC LEXAN™ polycarbonate with UV stabilizers greatly increases the performance longevity. Unfortunately, lower cost polycarbonates or other plastics with inadequate UV stabilization are still widely used in the industry and can be usually identified after a few years by faded blacks and a repeating pattern of blotchiness on the LED display caused by warped louvers.

The same consideration is also relevant for the optical epoxy used to package LED diodes. In particular, the blue dye used in blue LED packages are susceptible to yellowing,

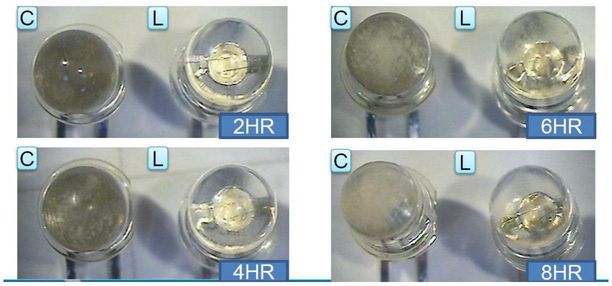


Fig. 2. Comparison of two water clear LED package materials under high-power UV test. Note the fading and yellowing of the C sample even after 2 hours of testing. The L sample uses a superior UV stabilizer.

which then reduces the blue light output resulting in a pinkish tint on LED digital billboards. In the current state of the industry, one of the most important factors affecting cost and quality of optical encapsulations is the longevity of UV stabilizer.

B. *Heat Irradiance*

In the context of a digital billboard, the power of Solar Irradiance can be 2-3 times the maximum heat generated by the electronics themselves. Since LED modules are intended to provide high contrast, the surfaces are black by necessity. This also means that the majority of visible light and infrared light is not reflected but instead absorbed by the face materials of the display. The solar heating of a digital billboard could be the vast majority of all heat experienced by the electronics. When highly directional solar loads are applied to the face of LED modules, the front surface can rise to very high temperatures and therefore prevent any effective dissipation through that surface, since heat will only conduct from higher to lower temperatures. In such a situation, the only effective paths to dissipate heat are through the edges or rear of the LED module, therefore adequate heat removal through the cabinet is a critical aspect of thermal management.

Since this heating is highly directional, creates thermal gradients, and forces different heat dissipation paths than situations with no solar load, it cannot be accurately represented through testing setups only with elevated ambient temperature. In order to test properly, designers/manufacturers can use the Military's MIL-STD-810 Method 505 standard or Automotive DIN 75220 in a laboratory, or for a more full-scale test, perform careful in-situ testing with real solar load. Media Resources has validated the thermal performance of the VISIONiQ system using 12 actual install sites with full scale digital billboards and monitoring the data of internal module temperatures under different solar conditions. As a test, active cooling via fans was disabled on 2 installations which resulted in significant spikes of module temperatures in those installations when solar load was applied, but less significant differences when there was no sun. This clearly demonstrated the importance of fan-based cooling in the cabinets.

Fig. 3. Solar load testing apparatus in a laboratory that induces stresses similar to real application with the full UV, visible and infrared spectrum

C. *Diurnal (Day and Night) Cycles*

The last major element of stress arising from the Sun comes from exacerbated thermal cycling during diurnal cycles. South facing displays will encounter a far wider range of temperature swings than equivalently located North facing displays. This creates mechanical stresses due to differences in the way each material expands, and if managed improperly will introduce many types of problems including damage to module side-walls (causing future leakage and corrosion), snapping of faceplate mounting bosses, flatness of modules (causing visual tiling), broken solder joints and jamming of modules during service calls. These effects happen due to the differences in the CTE (Coefficient of Thermal Expansion) between various materials of the display including Aluminum, Module plastic casings, FR-4 fiberglass printed circuit boards (PCB), potting and solder. Each combination between materials needs to be considered with some care, for example the PCBs with module plastic casings. The most common FR-4 material of PCBs has a relatively low linear CTE at 12-14 ppm/C while standard polycarbonate has 65-70 ppm/C. In a scenario where the daytime temperature due to sun exposure is 40C/72F more than night time, e.g. in Nevada in winter, this difference in CTE can result in a relative difference in expansion of 0.65mm (25 thou) between a module casing and the internal PCB, putting many stresses on fasteners and bonds between these two materials. The result, as some manufacturers have experienced, could be the fracture of screw bosses used to hold the faceplates on the modules and subsequent peeling of those faceplates. This is only one of several types of stresses caused by the thermal cycling that results from day and night cycles.

Fortunately, several options are available to reduce these stresses, starting with creating a better match in CTE between components. For example, Media Resources uses LEXAN^{TM}503R which includes glass fibers and has a reduced CTE of 40 ppm/C, effectively reducing the mismatch with PCB material by half. Secondly, thermal management to reduce on-module temperature under solar load will also reduce the mismatch between day and night conditions and reduce the risk of this thermal cycling damage.

III. HEAT VS ELECTRONICS

A. *Law of Arrhenius*

Predicting lifetime of electronic devices is a difficult and complex task. Fortunately there are basic laws, empirically describing the physics of molecular interactions that are strongly predictive of lifetime. The Law of Arrhenius is the most important of these laws. The concept can be logically described as follows: whenever there is an increase in temperature, there is an increase in the rate of interactions between molecules in a material, as temperature is the measure of the energy in the motion of molecules in a material. The Arrhenius Equation, first described in 1889 and used since as a cornerstone of Chemistry is expressed as follows:

$$K = Ae^{(-Ea/RT)}$$

where k is the chemical reaction rate, and T is the temperature in Kelvin. When A, Ea, and R are constant in the model, the result is that the rate of interaction K, or the rate of aging, is exponential with the temperature T.

The integrity of some materials, and therefore their lifetimes, are directly degraded by the number molecular interactions as the fundamental measure of ”wear and tear”. Therefore, as temperatures increase, interactions increase, and lifetime decreases.

In electronics, the industry has long established the “10C - Twice Law” which applies Arrhenius to electronics components. For approximately every 10C (or 18F) increase in temperature, it doubles the rate of interaction. With a 20C increase, the rate quadruples; with a 30C increase, the rate increases eight-fold, and so forth. Similarly since lifetime can be thought of as some fixed number of interactions, this means that every 10C increase in temperature halves the lifetime of a device. While there are other additional failure modes not accounted for by this model, the model holds generally true for electronics because it is highly relevant in describing most ”age-able” components such as capacitors and semiconductors.

The implications of the Law of Arrhenius are severe: electronics operating way above their normal operating temperature have an exponentially shorter life. If the on-board electronics are not thermally managed, premature failures will tend to begin exhibiting themselves due to the functional loss of stabilizing components such as capacitors. Through good component selection and thermal management design, these stresses to lifetime can be mitigated. For these reasons, Media Resources uses long life-time tantalum capacitors and active cooling to provide the best possible product lifetime.

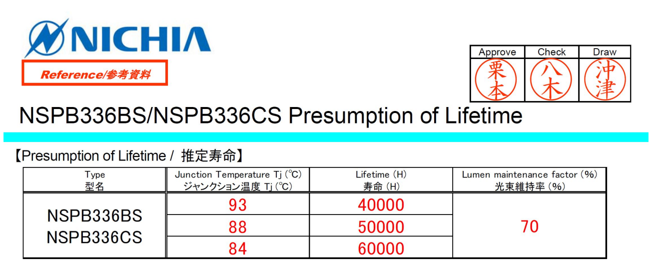
Two major heat-related failure mechanisms in the electronics of LED digital billboards arise from the two above components: capacitors and Light Emitting Diodes (LED semiconductors). As capacitors age and increase in failure rate, so too do the LED modules that rely on them to stabilize the on-board voltage. Failure modes can range from flickering down to complete non-function. Displays with aged capacitors will require increasingly more physical service calls before becoming completely unreliable. A sharp increase over time of module failure rate signifies the end of life of a display. Operating the displays at reduced temperatures will increase the capacitor lifetime in accordance to the Law of Arrhenius, and so Media Resources believes active thermal management vis-a-vis cooling fans are better to increase longevity, even if the displays don’t appear to need them in the first few years of operation.

For more information on electronics failures and lifetime that are not covered in this whitepaper, search online for the topic of ”reliability engineering bathtub curve” which provides excellent supplementary context for anyone with interest in reliability and electronics lifetime.

B. *LED chip lifetime and degradation*

LED lifetime has a similar relationship with temperature, but has a different mechanism of failure that causes luminous output to decrease over time. At the chip level, this degradation occur primarily due to a mechanism called Shockley-Read-Hall (SRH) Non-radiative Recombination, where defects in the semiconductor active layer cause carriers (holes and electrons) to re-combine and create a lattice vibration (heat) without radiating any photon (light). Defects in the LED active layer will increase in density over time as a function of electrical current but also temperature. The increase in defect density for SRH recombination also increases exponentially with temperature following the Arrhenius Equation. Near the end of life for a display, it is a common practice in the LED industry to compensate for some of the light degradation by increasing the electrical power through the LEDs, but this further accelerates the degradation by increasing the electrical current and the temperature at each chip. This practice should only be used with a clear understanding that the display is near the end of its life cycle.

To put some numbers in perspective, see in Fig 4. the strong effect of even small differences in temperature at the junction, highlighting the importance of thermal management: 20,000 hours (2.28 years) lifetime loss for only 9C/16F increase in temperature. While the practical lifetime of the Nichia 336 product is generally well in excess of 60,000 hours, Nichia does not make these claims as the industry standard TM-21 math model used for lifetime prediction does not recommend reporting projections of greater than 60,000 hours.


NICHIA

Reference/参考資料

Approve	Check	Draw
栗本	八木	沖津

NSPB336BS/NSPB336CS Presumption of Lifetime

【Presumption of Lifetime / 推定寿命】

Type 型名	Junction Temperature Tj (℃) ジャンクション温度 Tj (℃)	Lifetime (H) 寿命 (H)	Lumen maintenance factor (%) 光束維持率 (%)
NSPB336BS NSPB336CS	93	40000	70
	88	50000	
	84	60000	

Fig. 4. Excerpt from Nichia reference document on estimated lifetime to reach 70 percent luminous output under different LED internal temperatures.

A high-quality LED chip (such as those of Nichia, the undisputed quality leaders for display LEDs) provides significantly better resistance to the buildup of defect density and extends lifetime even under high temperature stresses. The difference in price between the top tier LEDs such as Nichia and low end LEDs can differ by 10 times but appear to be similar in initial performance.

IV. SUMMARY AND CONCLUSION

In summary of the discussions in this whitepaper, we first looked at issues arising from the Sun and the relative spectral bands of energy.

- Ultraviolet irradiance from the sun causes chemical damage to polymers, requiring careful selection and qualification of materials in both the plastic casings of LED modules and the LED diode packages themselves.
- Heat irradiance from visible and infrared spectra cause a highly directional thermal load, many times larger than the self-heat of electronics that also breaks with conventional testing in high ambient chambers and ultimately forces LED modules to dissipate through the rear.
- Day-night cycles will increase thermal cycling stresses that create multiple challenges around thermal expansion/contraction. Enhanced matching of material CTE and active cooling helps reduce the stresses and the associated risks of damage.

Furthermore we discussed the effects of heat on the lifetime of electronics, starting with Arrhenius Equation and its electronics industry corollary “10C - Twice Law”. The implication is again that active cooling will improve product lifetime, and that thermal induced problems will not appear until such a time when it becomes an an unpleasant and irreversible surprise.

Finally, we provided a high level overview of the degradation that happens within LED chips themselves which depends primarily on electrical current and temperature as is predicted by Arrhenius.

In totality this whitepaper is intended to educate and remind operators that longevity is created through conscious choices in product design and construction, specifically addressing the mechanisms that cause electronics to age. Buyers and operators should avoid making judgment on a product based solely on initial appearance of quality, especially if the price seems unusually attractive. It is important to understand the fundamental causes of degradation and how the manufacturer has sought to solve the problems. South or North Facing, Media Resources VISIONiQ Digital Billboards can be depended on to last.