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APPLICATION NOTE 5591

Ensure Long Lifetimes from Electrolytic Capacitors: a Case Study in LED Light Bulbs

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Abstract: Electrolytic capacitors are notorious for short lifetimes in high-temperature applications such as LED light bulbs. The careful selection of these devices with proper interpretation of their specifications is essential to ensure that they do not compromise the life of the end product. This application note discusses this problem with electrolytic capacitors in LED light bulbs and provides an analysis that shows how it is possible to use electrolytics in such products.

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Hot LEDs and Short-Lived Electrolytic Capacitors

Several years ago, I worked on a few designs for LED light bulbs. Very early on, it became clear that the temperatures of components in such light bulbs can get quite high. I personally measured component temperatures as high as +130°C in light bulbs purchased at local retail stores. Now admittedly, these were early LED bulb designs. Manufacturers now understand that, even though these LED bulbs consume substantially lower power than those they would replace, they still must have good thermal engineering. This is the only way to get the lifetime of the electronics to match the lifetime of the LEDs themselves.

I found it disturbing that many of these hot designs contained electrolytic capacitors, which are notorious for short lifetimes at elevated temperatures. I expected that the lifetimes of these capacitors would severely compromise the lifetime of the products, and not allow them to reach the 30,000 to 50,000 hour capability of the LEDs themselves. With common electrolytics rated at 2000 to 5000 hours at +85°C, I vowed not to use an electrolytic in any LED bulb designs.

In talking to LED bulb manufacturers at that time, I found that many did not understand the limitations of electrolytic capacitors. It was common for them to point out, for example, that they had used a part rated for +105°C and had measured the temperature of this part to be +100°C. Surprise was often their reaction when I pointed out that their +105°C-rated capacitor was only guaranteed to meet spec after 2000 hours at +105°C.

Temperature and the Endurance Spec for Electrolytic Caps

It is important to understand both the “endurance” spec of electrolytic capacitors and how temperature affects it. There is always a time of operation associated with the temperature rating, typically between 1000 and 10,000 hours. The maximum temperature ratings are typically +85°C or +105°C. It is a common and largely valid rule of thumb that capacitor lifetime increases by a factor of 2 for every +10°C reduction in temperature. Conversely, lifetime decreases by a factor of 2 for every +10°C increase in temperature. Therefore, at +100°C, the endurance of the 2000 hour, +105°C-rated capacitor mentioned above would be $2^{1/2}$ × 2000, or about 2,800 hours. Even if you assume that, on average, the capacitor operates at +95°C, its lifetime only increases to 4000 hours. This is hardly the 30,000 to 50,000 hours desired for LED light bulbs.

It is no surprise, therefore, that many of these early LED bulbs had overly optimistic lifetime ratings due to the manufacturers’ misunderstanding of the ratings of their electrolytic capacitors. I took apart several such bulbs that died after less than 1000 hours of operation. Nearly all of them had a failed electrolytic capacitor.

Power Factor and Ripple: a Trade-Off

The more cost-effective LED light bulb designs back in those years all utilized single stages. All of the single-stage architectures of which I am aware produce either good power factor or low-output 120Hz (100Hz) ripple. Not both…unless you use at least one large-valued capacitor. To get capacitor values large enough to allow a design to deliver both, electrolytics must be used.

At that time, many manufacturers accepted products with substantial 120Hz ripple, as long as the power factor was high. I did several designs without electrolytics that had substantial 120Hz ripple in the LED current.

Designing for Lifetime

As time passed, LED bulb manufacturers became more sophisticated and low ripple is now desired. A good solution involves two-stage designs with a front-end power factor correction (PFC) circuit followed by a separate regulator, typically a flyback. The cost of a two-stage design can be prohibitive for some applications, so I took another more serious look at using electrolytics in my single-stage designs.

We can get both good PFC and lower output ripple by adding a large output capacitor to many single-stage designs. In typical designs, this capacitor has to be several hundred microFarads and rated for voltages in the 25V to 100V range, depending on the number of series LEDs used.

The light bulb manufacturers, fortunately, also quickly refined their thermal designs. Over time, LEDs have also gained in efficacy; more of the consumed power goes to generating light rather than heat. As a result, the component temperatures in light bulbs dropped, giving us more “breathing room” in component selection. There are quite a few families of electrolytics rated for 5000, 7000, or even 10,000 hours at +105°C or even +125°C. Many of them, particularly the +105°C-rated parts, are not much more expensive than the common 2000-hour rated parts.

Because of the better thermal conditions, I determined, in consultation with others, that I could keep the electrolytic capacitor temperature at +90°C or below. I knew that I could use a device rated at 7000 hours at +105°C. Taking into account the "rule of thumb" factor-of-2 for a ±10°C change in temperature, I also knew that my capacitor would be good for 20,000 hours. Better, but that was not good enough. I wanted this LED light bulb to last from 30,000 to 50,000 hours.

I decided to dig further into the meaning of the "endurance" rating for electrolytics. I picked a 330µF, 50V device rated for 7000 hours at +105°C, the Nichicon® UHE1H331MPD, which has a "cousin" capacitor made by UCC that is nearly identical in specifications and is the same size and footprint, the EKY-500ELL331MJ25S.

The UCC data sheet states the following for the endurance specification:

> The following specifications shall be satisfied when the capacitors are restored to 20°C after subjected to DC voltage with the rated ripple current is applied (the peak voltage shall not exceed the rated voltage) for the specified period of time at 105°C.

- Capacitance change ≤ ±25% of the initial value
- D.F. (tanδ) ≤ 200% of the initial specified value
- Leakage current ≤The initial specified value[1]

This description means that if this part is operated at the rated maximum ripple current of +105°C for 7000 hours, the capacitance will change by less than 25%. Similarly, the dissipation factor, and thus the ESR, will be no more than double the original spec. Finally, the leakage current will still meet its original spec.

This is not exactly the end of life for that part.

I built a couple of prototypes and placed a much lower-valued ceramic capacitor right at the output and our larger electrolytic further away where it was not near the heat-generating components. I verified that the capacitor was not exposed to temperatures over +90°C under any anticipated operating condition.

Next, I calculated the ripple current that the capacitor would have to handle, noting that the "endurance" time would increase if the capacitor did not operate at full ripple current. This happens because ripple current causes self-heating. It was easy to show that the selected capacitor had a rating of several times the worst ripple current that it would experience. Moreover, performance data demonstrated that lower self-heating meant that the capacitor would operate at roughly +10°C lower than if it were subject to the maximum ripple current. The upshot of all this? The endurance doubles to 40,000 hours.

There was, however, something else to consider. It was also important to examine the reduction in capacitance over the time that the endurance spec implied. The output voltage ripple still had to be low enough to meet the functional spec with a 25% reduction in capacitance, which the endurance spec says is the worst case. In my application, 220µF would have been adequate, so I chose a 330µF part.

Endurance to 40,000 hours, however, is not the desired 50,000 hours. But again, remember that 40,000 hours is not the end of life for the capacitor. Rather, it is the point at which it will have reduced specs. Since I had overspecified the part, these reduced specs would not adversely affect the circuit operation. The capacitor should thus operate well beyond the adjusted endurance rating of 40,000 hours.

With this analysis, I was comfortable with a conservative 30,000-hour rating for the lifetime of the LED bulb. I have since used several of these bulbs around my house for over 3 years (about 30,000 hours), including a couple that are on all the time. None have failed. The manufacturer also reports no problems with the longevity of these designs.

What Larger Lesson Have We Learned?

This is a good example of the importance of fully understanding the details of component specifications. We have seen how a cursory look at an electrolytic capacitor's specifications led to dramatically shorter product lifetimes than desired. It is simply not good enough to pick a part whose temperature rating is above the highest temperature that it will experience—one must also look at the underlying endurance spec.

Ultimately, we must dig deeper into the meaning of specs like endurance for electrolytics, and then wisely choose parts with substantial margin relative to the conditions under which they will operate. Only then can we get substantial product lifetimes.

The bottom line is all too familiar. It is always wise to read the data sheet and understand what each important spec means. What they *really* mean.

Reference

1. See the data sheet for the UCC EKY-500ELL331MJ25S electrolytic capacitor at www.chemi-con.com/components/com_lcatalog/uploaded/9/8/8/16196364517194fed52ea.pdf.

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