LCD Backlight Life

Introduction

Except for certain mechanical issues, the backlight life is mainly determined by the lifetime of the lamps. All Landmark backlights and sunlight readable LCD modules use cold cathode fluorescent lamps (CCFLs). In general, there are two major lifetime issues with CCFLs.

1. The light output of a CCFL decreases as the lamp ages. Most of the CCFL manufacturers specify a half brightness lifetime of 20,000 hours. That is, the light output of the lamp decreases to 50% of its initial value after 20,000 hours of accumulative operating time. Usually, the half brightness life is specified at a given lamp current such as 5 mA.

2. The starting voltage of a CCFL increases as the lamp ages. In general, we can minimize the impact of this effect by using an inverter that delivers a starting voltage significantly higher than the voltage required to start the lamp.

In addition, lamp aging also happens after many turn on and turn off cycles. Fortunately, for normal LCD backlight applications, this phenomenon seldom occurs since it takes more than half million on/off cycles before any significant aging effect can be observed.

So, the dominant lifetime issue is the decrease of the backlight brightness as the lamps age. The aging effect that causes the brightness decay accelerates when the lamp is driven at a higher current. On the other hand, when the lamp current decreases, the aging effect slows down. A rule of thumb relationship between the half brightness life and the lamp current is shown in Fig. 1.

From the curve, the lamp half brightness life is 20,000 hours at 5 mA lamp current. At 6 mA lamp current, the life decreases to 12,000 hours. However, if we reduce the lamp current to 4 mA, the half brightness life increases to 35,000 hours.

Lamp Life Tests

Actual life tests conducted at Landmark Technology on the lamps used in our backlights indicate that the lifetime figures specified in the rule of thumb curve is rather conservative. Some of these test results cumulated in the past 6 years are presented in Fig. 2 and Fig. 3.

The first figure (Fig. 2) shows the test results of two lamp samples at 5 mA rated current. The test started on April 2, 1992. The brightness of the lamps were monitored at intervals of a few hundred hours during the first year then of a few thousand hours afterward. At the last monitor point of 52,359 hours (5.98 years), the brightness of both lamps were still more than 50% of their initial values. However, it becomes difficult to start sample #2 with the inverter used in the test.

The second figure (Fig. 3) shows the test results of three lamp samples at 7 mA lamp current. This is about 40% higher than the 5 mA rated current. Thus, this represents a stress test.

At 7 mA current level, the lamp half brightness life predicted by the rule of thumb curve is about 7,000 hours. However, at

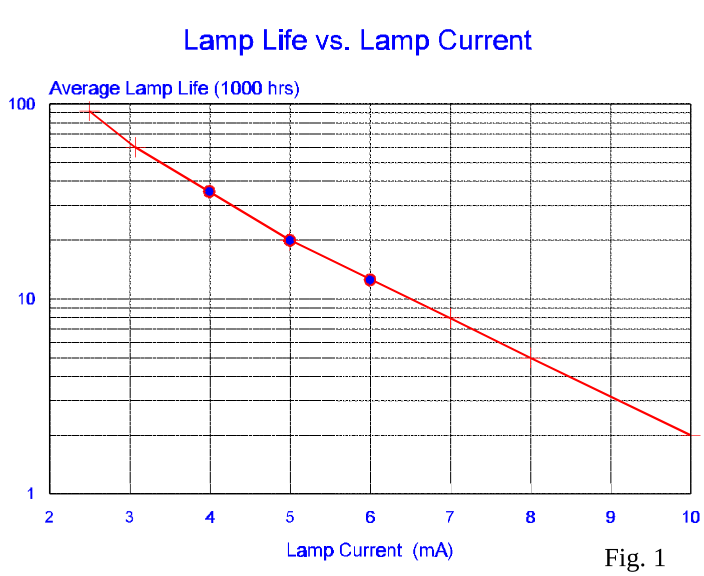

Fig. 1

42,104 hours, the brightness values of two of the lamps are still slightly higher than 50% of their initial values.

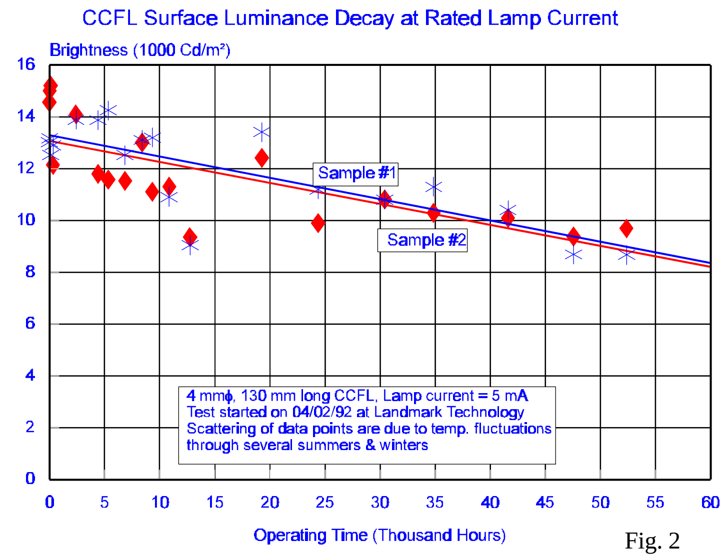

Fig. 2

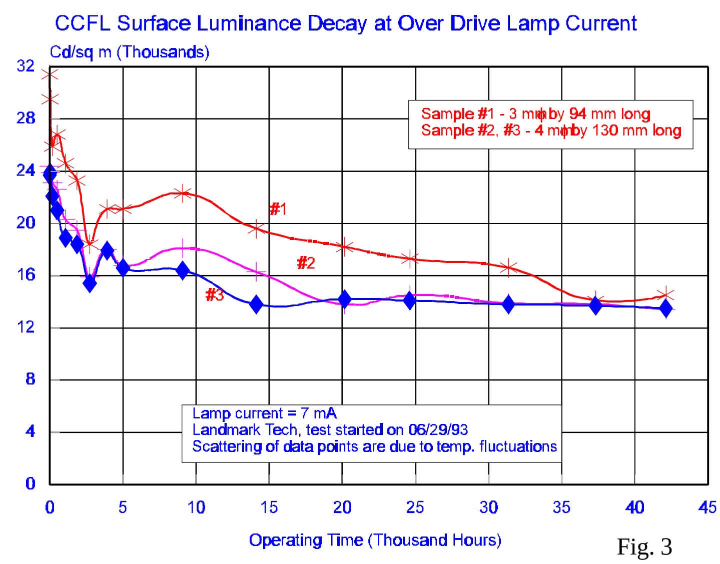

Fig. 3

The data points in these two tests show a wide spread on the brightness scale. This is particularly serious within the first 10,000 hours of testing time. We noticed this phenomenon and attributed it to the room temperature fluctuations as weather condition changes and the effects of summer and winter seasons. At the beginning of the test, we did not quite realize that the temperature effect would be so large. In order to have more precise data, in later monitoring points, the lamp brightness values were mostly measured with the room temperature controlled within ±1^{O}C.

Life Tests of Landmark Backlights

The above data shows the test results of the lamp life. Our experiences have indicated that the luminance (brightness) decay in backlights is usually faster than those of the lamps. This is caused by the fact that the backlight materials (i.e. diffusers, light pipe, etc.) usually turn darker as time goes by, contributing additional decay in backlight brightness. So, how about the half brightness life in an actual Landmark backlight?

Fig. 4 shows the actual operating life test of Landmark C033 very high brightness (VHB) backlight. C033 is an early VHB backlight produced during 1994 - 1995 period. Its basic optical design has been implemented in later VHB backlights such as C053C, C053G and sunlight readable LCD modules such as C073B.

The life test started on September 07, 1995. The backlight was driven at 6 mA lamp current with 5 commercial inverters made by TDK. At the recent monitoring point of 22,388 hours (2.6 years), the luminance decreases to 7,590 nits from its initial value of 12,400 nits. As a result, the backlight luminance is down to 61.2% representing a 38.8% decay after 22,388 hours of continuous operation at full lamp current. This test indicates

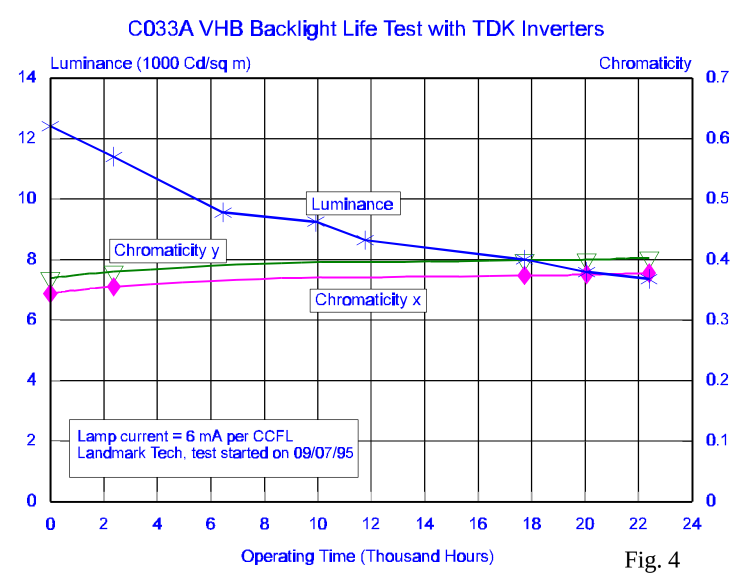

Fig. 4

that the half brightness lifetime of C033 backlight is longer than 20,000 hours.

Fig. 5 below presents the test results of VHB backlight C053C. This backlight was introduced in September 1995 and has been our most popular product in the past three years. The test is conducted with a pair of Landmark

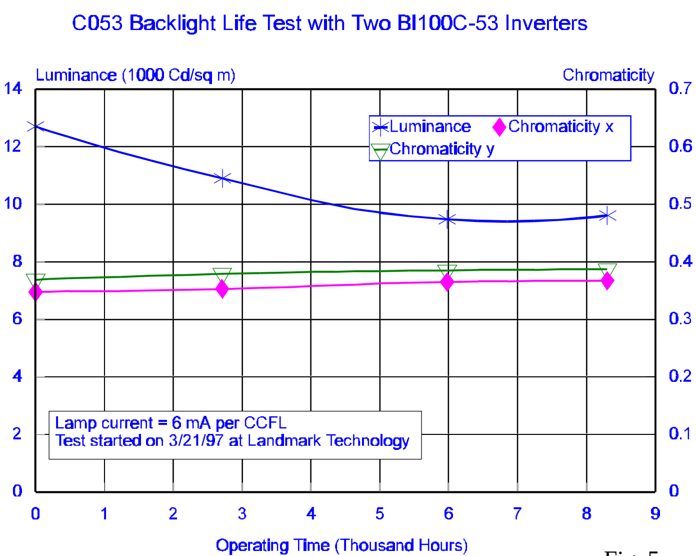

Fig. 5

BI100C-53 inverters. These inverters have the dimming capability that can adjust the backlight luminance down to about 3% of its full value.

The C053C test started on 3/21/1997. The backlight was run at its full brightness throughout this test. The initial (0 hour) luminance of the backlight is 12,700 nits. After 10,632 hours of operation, the luminance value dropped to 9,260 nits or 72.9% of its initial value. The decay in luminance is therefore 27.1%.

It is interesting to compare the test results of C033 and C053C. The C033 test data closest to the last monitor point of the C053C test is the point at 11,780 hours. At this point, the luminance of C033 decreases to 8,640 nits from its initial brightness of 12,400 nits representing a 30.3% decay. This value comparing to the 27.1% decay for C053 at 10,632 hours, is amazingly close and remarkably reproducible, indicating that lamp and backlight life are virtually not effected by the inverters used to drive them.

The Color Shift Issue

By mid 1995, we had accumulated over 20,000 hours life test data on some of the early single CCFL edge-lit backlights manufactured for a major US. customer in 1992. We noticed that all the backlights under test became more yellow in color than the non-operated control unit. As a result of this, we started to monitor the backlight chromaticities (x, y) on all the life tests conducted after summer of 1995.

The C033 test reveals a noticeable backlight chromaticity shift toward yellow at as early as 2300 hours. This yellow color shift increases as time goes by, becoming quite serious at about 5,000 hours and then the rate of increase slows down.

The yellow shift in backlight color may cause some concern in LCD applications where the color fidelity is important. A major portion of the yellow shift is caused by the yellowing (or darkening) of the backlight materials. These include diffusers, reflectors, adhesives and some others. By analyzing and isolating the “bad materials”, Landmark has reduced this yellow color shift problem significantly in the last three years.

Backlight Life at Reduced Lamp Current

Landmark Technology introduced a series of long life (40,000 hours) high brightness backlights in late 1995 for the industrial display market. The lamps inside these backlights were run at a reduced current, typically, 4.2 mA per lamp instead of the normal 6 mA current. From the curve in Fig. 1 and the accumulated lamp lifetime test data at the time, we were quite confident that these backlights would indeed have a half brightness life of 40,000 hours. Subsequent actual life tests on these backlights tend to support this claim.

Fig. 6 on the next page presents the test data on C054 backlight with BI100C-54 inverter. The backlight contains 5 lamps with each lamp running at 4.2 mA current. The initial luminance of the backlight was 5,100 nits. Please note that the data shows some increase in luminance value at 1,152, 2,088, and 4,872

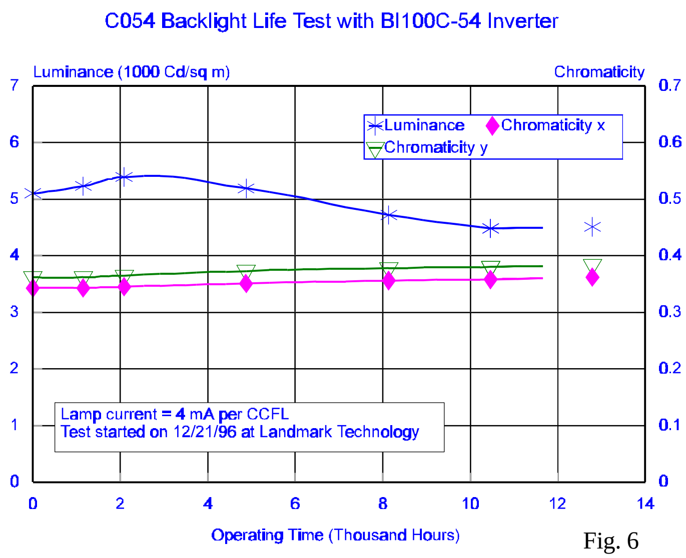

Fig. 6

hours. This was caused by room temperature rises beyond our control due to an early arriving spring and summer.

At the last monitor point of 12,792 hours, the luminance of the backlight decreased to 4,510 nits (88.4%), corresponding to a merely 11.6% decay from the initial value. Comparing to the C053 and C033 test results at about the same operating time, the C053 shows a 27.1% decay at 10,632 hours and the C033 shows a 30.3% decay at 12,400 hours. Both these numbers are much higher than the 11.6% decay observed on the C054. Therefore, the actual test data with reduced lamp current tends to support the fact that the C054 will have a lifetime much longer than 20,000 hours.

From the test data cumulated with the lamps and the early single CCFL edge-lit backlights, the luminance decay curves all show a slow down trend beyond the first 10,000 hours. Since the luminance decay of C054 is less than half of the C053 and C033 decay, it is very reasonable to predict a 40,000 hours life based on the existing C054 test data.

For Landmark high efficiency (HE) backlights and sunlight readable LCD modules, we recommend an S-mode operation where the lamp current is reduced to about 2/3 of the normal value. The S-mode operation provides the advantages of power saving for less thermal management issues and longer backlight life. In fact, the specified S-mode lamp current for most of the HE backlights and modules is about 4 mA. Therefore, the backlight half brightness life under S-mode operation is 40,000 hours. So far, the existing C054 test data (lamp current = 4.2 mA) tend to support this lifetime claim. In the meantime, C054 test continues and we will complete the 40,000 hours test and confirm the predicated lifetime by August 2001. Stay tuned!

The PWM Inverter Issue

The backlight luminance can be adjusted by pulse width modulating (PWM) the lamp current at a repetition rate high enough to prevent LCD screen flicker. Within each PWM cycle, the lamps are turned fully “ON” for a fraction of the cycle time. The human eyes, being very slow with respect to the PWM rate, response to the average light produced over

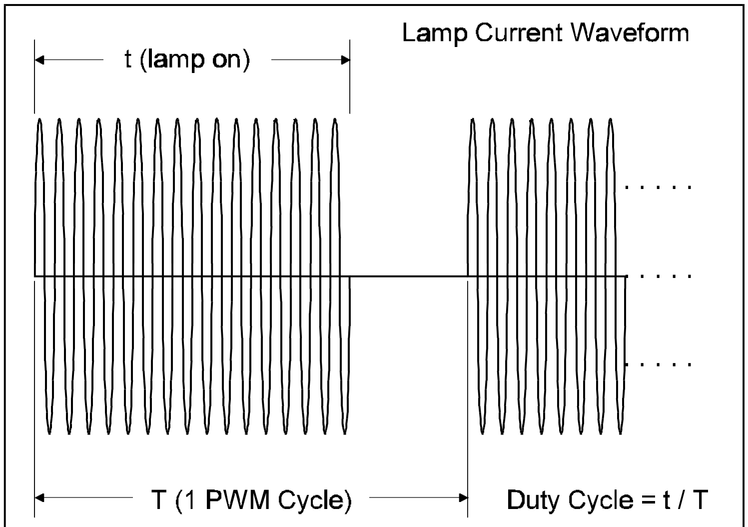

Fig. 7

the PWM cycle. Consequently, the luminance of the backlight and/or the LCD screen is approximately proportional to the duty cycle of the PWM waveform.

In general, inverters with PWM dimming have a very wide luminance adjustment range. For example, we specify our BI200A PWM inverter with a dimming ratio up to 200:1. That is, the luminance of the backlight or the LCD screen can be adjusted from 100% to 0.5%. Moreover, with a well regulated power supply, the BI200A can achieve a dimming ratio about 3,000:1 (100% to about 0.03%).

In the introduction section, we briefly described the lamp aging phenomenon due to repeated lamp turn on and turn off cycles. Typically, this type of aging phenomenon seldom occurs in normal LCD backlight applications since it takes more than half million on/off cycles before any significant aging effect can be observed.

With our BI200A PWM inverter, the lamps in the backlight are turned "ON" and "OFF" at about 250 cycles per second. As a result, it takes only 2,000 seconds (or about 33 minutes) to accumulate a half million on/off cycles. So, how about the lifetime issue?

From the theoretical point of view, when a cold cathode fluorescent lamp is turned off, the gas plasma (a collection of positive and negative ions) in the lamp takes more than 10 msec to die. If the PWM frequency is 250 Hz, each PWM cycle is only 4 msec. As a result, the lamp is turned "ON" again way before the plasma dies completely. Consequently, there is no "cold start" or "hard start" of the lamp at each PWM cycle and therefore no life time issue.

A theory remains a theory until it can be proven by actual experimental data. For this reason, we conducted tests as soon as the laboratory prototype BI200A PWM inverter became available. The backlight used for the test is a C074 prototype with 8 lamps. These lamps use a new phosphor to produce an LCD color tone very close to those of the sunlight. All Landmark standard products introduced in 1997 and after use lamps with this phosphor. Therefore, the test also becomes very important to reveal any possible abnormal lifetime behaviors due to this new phosphor.

The prototype BI200A inverter was set at about 90% duty cycle to turn "OFF" the lamp for 10% of the time in each PWM cycle. At this setting, the average lamp current is about 5.8 mA. The test started on 10/30/97. The result is presented in Fig. 8. At the last monitor point, we have accumulated 7,225 test hours for a total of 6.5 billion PWM cycles or "soft" lamp turn on/off cycles.

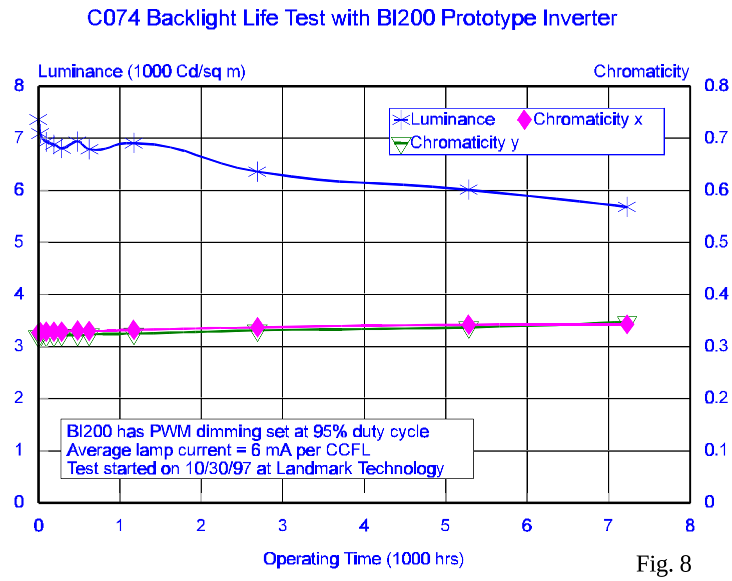

Fig. 8

We observe a luminance decay of 22.8% after 7,225 hours. This decay is quite normal comparing to the C033A life test data (22.9% decay at 6,456 hours and 25.4% decay at 8,850 hours) and the C053C life test data (24.3% decay at 8,304 hours) presented in the previous section. Therefore, we can conclude:

1. The soft lamp turn on/off cycle with PWM inverters does not cause excessive lamp decay.

2. The amazingly close luminance decay figures in three totally independent tests conducted at different time frames make us believe that the lamp life depends very likely only on the average lamp current.

3. There is no difference in backlight life behavior with the new lamp phosphor.

Miscellaneous Life Issues

1. Lamp Infant Mortality Issue

During the past six years, our backlight manufacturing group as a whole have consumed a few million lamps supplied mainly by two major Japanese lamp manufacturers. We have experienced an average lamp infant mortality rate of less than 0.02%. That is, on average, 1 out of 5,000 lamps shipped to us has a shorter than normal life due to various pre-mature failures.

At the backlight level, since early 1995, Landmark has experienced a return rate within the warranty period of about 0.1% due to failures of one or more lamps in multi-lamp backlights. Most of the failures are due to mechanical reasons such as lamp breakage, leakage of gases, etc.

2. The MTBF Issue

In a multi-lamp backlight, if N is the number of lamps used and T is the mean time between failure (MTBF) of the lamp, then the mean time before having at least one lamp fail is,

$$Tn = T / N$$

This equation is often mis-interpreted in applying it to the MTBF of a multi-lamp backlight. The mis-interpreted argument is that the lifetime of the lamp is 20,000 hours and therefore the MTBF of an 8-lamp backlight is 20,000/8 = 2,500 hours. First of all, the stated 20,000 hours lamp life is the half brightness life. That is, at 20,000 hours, the lamps are all functional but at half their initial light output. In a matter of fact, the MTBF of a CCFL is so long, it is seldom a factor to effect the LCD backlight life.

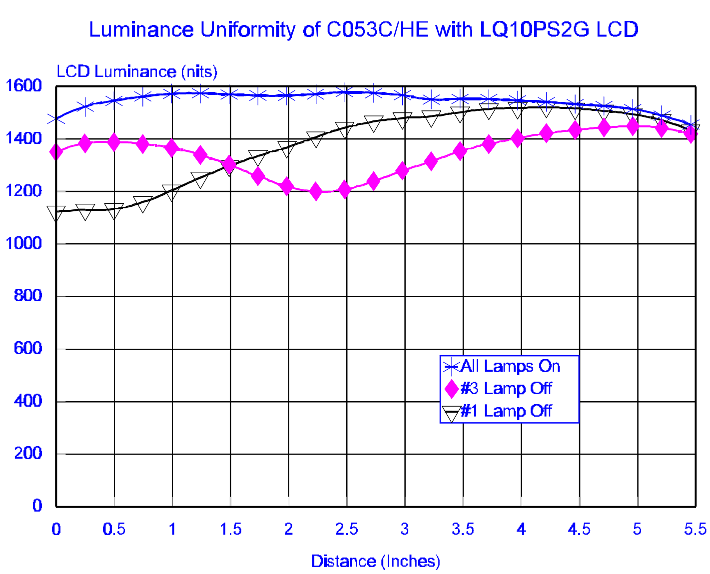

Fig. 9

One of the major advantages of a multi-lamp backlight is that if one of the lamp fails, the backlight and the LCD remain readable with slight sacrifice in luminance uniformity. We conduct the experiment with a Landmark C053C/HE backlight mounted on a Sharp LQ10PS2G SVGA LCD. This backlight has 8 main lamps placed along the horizontal direction. The lamps are spaced to cover the vertical active area of the LCD (about 6.3"). First, we scan the LCD luminance every 0.25" distance along the vertical direction (i.e. in the direction perpendicular to the lamps). Then turn off #3 lamp (which is in the middle section of the LCD) and repeat the luminance scan. Finally, we turn off #1 lamp (which is at the top edge of the LCD) and repeat the luminance scan. The test results are presented in Fig. 9. From this figure, it is obvious that if one of the lamps is off, a luminance dip centered at the lamp position is created and also the entire LCD luminance is reduced. If we follow the equation below to measure uniformity:

$$\text{Uniformity} = (\text{Lmax} - \text{Lmin}) / (\text{Lmax} + \text{Lmin})$$

where Lmax and Lmin are the maximum and minimum luminance measured in the scan. Then the uniformity figures of the LCD module (with C053C/HE backlight) are:

Condition	Uniformity
All lamps are on	4.1%
#3 lamp fails	9.3%
#1 lamp fails	15.1%

With a single lamp failure, the uniformity figures are not bad at all. The LCD is fully readable. However, the viewer can see some luminance non-uniformity when the screen displays the white or some single color such as green. The non-uniformity becomes far less noticeable when the screen displays a graphics and/or an image.

3. The uniformity issue as lamp ages

Some customers have a concern that in a multi-lamp backlight, one or more of the lamps may age at a much faster rate than the rest and therefore causes a degradation in backlight uniformity. As a result of this concern, we investigate into the uniformity issues associated to the backlight aging. Since the C033 backlight has gone through more than 22,000 hours of life test, it is a best candidate to conduct studies on potential uniformity issues due to lamp differential aging.

The results are shown in Fig. 10. At the time of this test, the cummulative operating time on C033A backlight was 24,980 hours. We measured the luminance at two different brightness levels (full brightness and 50% dimming) along a direction perpendicular to the 8 main lamps. It is quite obvious from the curves in the figure, the backlight uniformity is quite good after 24,980 hours of operation.

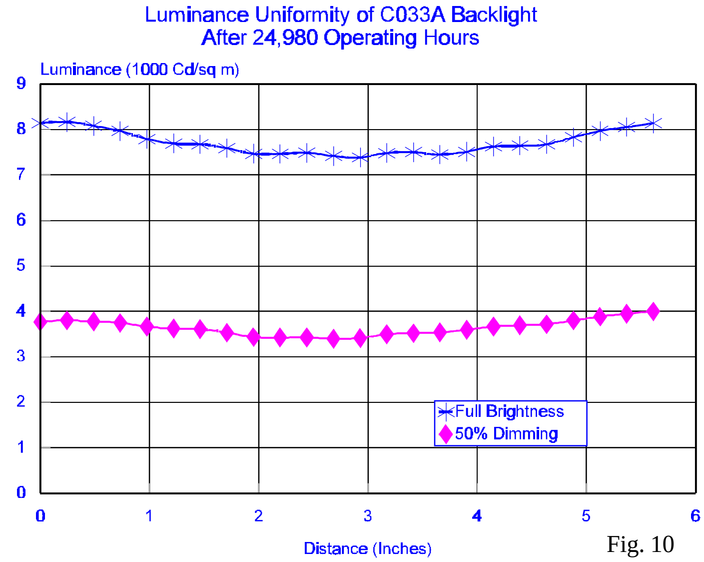

Fig. 10

It is interesting to investigate whether the CCFLs have a differential aging rate.. Again, we use the well seasoned C033 backlight to conduct the test. The diffusers on the C033 were removed to expose the lamps. Then the surface luminance of the 8 main lamps were measured. The lamps were driven at 6 mA current. The results are listed below.

Lamp #	Luminance Y	Chromaticity x	Chromaticity y
#1	17,900 nits	0.361	0.382
#2	18,200	0.364	0.385
#3	17,500	0.361	0.382
#4	17,400	0.363	0.382
#5	18,200	0.364	0.384
#6	17,500	0.365	0.383
#7	18,100	0.363	0.382
#8	18,000	0.361	0.383
Average	17,850	0.363	0.383

We observe a suprisingly small (less than ±3%) spread in lamp surface luminance after 24,980 hours of operation. Therefore, the data do not show any evidence of lamp differential aging. On the other hand, the average lamp luminance is much too high than expected from the luminance decay data of the C033A backlight. In addition, the chromaticities of the lamp do shift toward yellow but at a much less degree than what is observed on the backlight.