# New CCFL Power Supply Expands Automotive Applications for Back Lit Liquid Crystal Displays

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## Abstract

*New backlight inverter features pioneered by Microsemi are solving major problems in automotive LCD back lighting applications. The problems and their solutions, along with actual laboratory data, are presented in this paper.*

## 1. Introduction

Automotive displays must operate over the temperature range of –30 to + 85 °C and at the same time be viewable in direct sunlight or in total darkness. This requires a light source capable of very intense light that can also be dimmed to less than 1% of its maximum. Recent developments in cold cathode fluorescent lamp technology improve light output at cold temperature, but have higher operating and strike voltages than standard lamps. Operating voltages and efficacy are also quite non-linear over temperature. These load requirements, coupled with the eight to sixteen volt range of a car battery present considerable challenge to a CCFL inverter that must be able to provide flicker free lighting from more than 400 to less than 1 Nit.

## 2. CCFL Temperature Characteristics

CCFL light output is dependent on ambient temperature and on temperature rise of the lamp itself. Lamp manufacturers usually measure temperature on the outside surface of the bulb, midway between the electrodes, but for most applications it is more convenient to mount a thermistor closer to one end. For ease of measurement and more precise correlation to the actual application, all CCFL light output and voltage data presented in this paper was taken with lamps mounted in LCD panels designed for automotive use. A variety of lamps with temperature sensors mounted near one end instead of centered between the cathodes were used. Therefor, data may not directly correlate with lamp manufacturer data.

Lamps are normally rated for peak output at 30 to 40 °C rise above a 20 °C ambient. At lower temperatures light falls rapidly, as shown by figure one below. In standard CCFLs, output is virtually unusable below 0 degrees, since the small amount of light they do put out is often of pinkish or purple color, far from the perfect white light needed for good color rendition in an LCD panel.

Recently available 'self heating' lamps increase white light output significantly at cold temperatures, and flatten the curve over the higher temperature range as well. These lamps provide good display quality over the wide thermal operating environment of automotive displays.

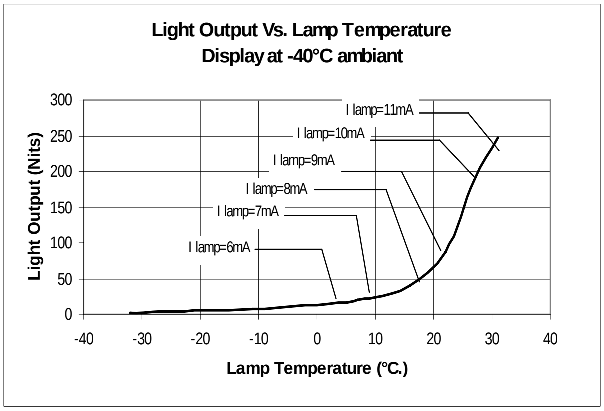


Figure 1

**Over Driving Lamps Decreases Warm-up Time and Increases Output at Cold Temperature**

Warm up time to full brightness from ambient is an exponential function. Figure two is a plot of measured lamp brightness versus time for a 5 inch LCD panel when the panel is held at a constant –40°C. The lamp in this display is nominally rated at 9 mArms (10 mA maximum), but is driven up to 15 mA to show the increase in overall light output and the decreasing rise time of light with current overdrive. What would normally be a 2 minute warm up to 80 Nits output with nominal rated drive current is accomplished in less than 30 seconds when driven at 15 mA.

It is also clear from figure two that over driving can dramatically increase absolute light level at low temperature. In this case, 50% overdrive yields three times the light output with a corresponding rise time of one third. The results of overdrive are obvious and dramatic. The concern is how overdrive will impact lamp life.

It will take a lengthy testing effort to prove any hypothesis about lamp life and low temperature overdrive. Just the same, a simple calculation using data we already have can give a reasonable prediction. Lamp life is related to two major issues: mercury consumption, which is directly proportional to lamp current level, and operating bulb temperature. Lamp life is reduced exponentially as bulb temperature drops below optimum. It is estimated to be about 1/10th as long when bulb temperature is 0°C compared to 65°C.

The following discussion estimates the probable effect on lamp life where the goal is to get the lamp to optimum temperature as quickly as possible without exceeding 50% overdrive. A bulb temperature feed back system is assumed that returns lamp current to nominal upon reaching optimum bulb temperature.

Assuming an automobile display must perform for 250,000 miles at average speeds of 25 miles per hour, then 10,000 hours of lamp life are required. All CCFLs used in LCD applications are rated for 10,000 hours as a minimum, with new types rated up to 50,000 hours. If a lamp is turned on an average of once every 10 miles during its life, or 25,000 times, and overdriven by 50% for 30 seconds each time, it would see 208 hours at overdrive during its 10,000 hour life. The additional mercury consumed is about 1.04% of that required to sustain 10,000 hours at nominal rated current. Life reduction due to mercury consumption of around 100 hours can therefor be expected.

On the other hand, 208 hours of overdrive results in saving about 416 hours of operation at low bulb temperature. This is because overdriving reduces warm-up time to 1/3 that of nominal drive. Since operating at reduced temperature has the largest detrimental effect on lamp life, it is reasonable to expect that lamp life in automotive applications can actually be *improved* simply by overdriving at turn on. If it can be shown that overdriving to 150% of rated current is not detrimental to lamp life, so long as optimum bulb operating temperature is not exceeded, then ambient light output levels at cold, as well as response times at all temperatures can be optimized with a simple temperature feed back system.

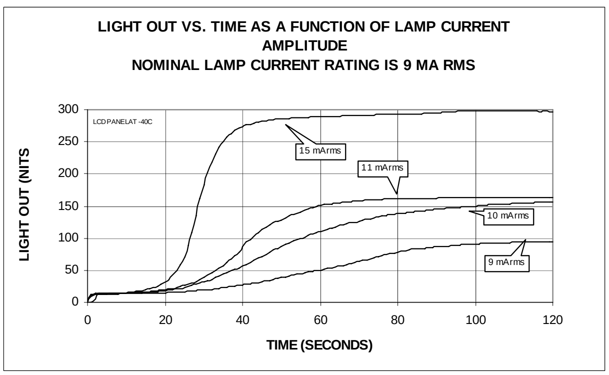


Figure 2

**Resistance Wire Heating**

It has been popular in military applications to pre-heat cold cathode fluorescent lamps to improve light output, enhance dimming range, and reduce strike potential. Resistive wire coiled around the lamp is effective in accomplishing this task, and is a possible substitute for self heating lamps. A significant problem with resistance wire heating in automotive and portable applications is related to their small size. LCD's designed for these applications are very thin, requiring 2 – 3 mm diameter lamps. Lamp drive electronics must also be made small, requiring higher operating frequencies. Wire coiled around the bulb creates a large parasitic capacitance between the lighted lamp and chassis ground, making it difficult to properly drive the lamp in the 60 to 80 KHz range required. Resistance wire heating is less efficient and more expensive, making self-heating lamps the preferred technology.

## 3 Driving Self Heating Lamps

Self-heating lamps are made by using new gas formulations and increased gas pressure. This results in higher operating and striking voltages and in higher operating power. In order to get more light on the display surface; more lamps or longer 'formed' lamps are used. Formed lamps can be in 'L' or 'U' shapes to wrap around two or three edges of the panel. The bends in these lamps tend to increase voltage requirements and make high ratio dimming more difficult. Multiple straight lamps are easier to drive but demand that current in all lamps be made extremely close to equal to prevent uneven lighting across the display. Note in figure two the strong dependency of light output on current level. In this case, a +20% change of current resulted in 55% increase in light output.

There are really only three ways to drive a 2 lamp system; use one complete and separate inverter for each lamp, or use a single inverter to drive both lamps, either in parallel or in series. The single inverter case is desired because of its lower cost. Driving two lamps in parallel is common, but has the main drawback that lamp current sharing is very difficult. The series configuration is preferred because lamp current sharing is inherent.

The 'ballast' impedance of a capacitor in series with each lamp must control lamp currents in a parallel arrangement. Since lamp impedance is negative, e.g., lamp voltage increases as current decreases; ballast impedances must be very high and closely matched to insure current matching. Lamp operating voltage must also be closely matched and must track as the lamps age. In the parallel arrangement, the inverter current regulation loop can only sense the sum of the two lamp currents, and therefor cannot help control matching.

In a series connected arrangement, the inverter regulates the series current that flows through both lamps, and therefor plays the major part in establishing matched currents. Lamp operating voltage in this case is double a single lamp, but when using direct drive inverter topology, is still not greater than the sum of lamp voltage added to ballast voltage required in the parallel case. When operated in series, lamp voltage matching and aging are no longer critical.

Strike voltage in a series configuration is higher than for parallel, and requires the high voltage transformer be more robust. Figure three shows measured individual strike voltages of the two lamps in a series connected arrangement with a third plot of total strike voltage for the two connected in series. The good news here is that total strike potential generated by the inverter is only about 1.5 times, rather that twice an individual lamp. The dynamics of striking two lamps in series is not totally understood, but experimentation shows that one lamp will always strike just before the other due to unequal voltage drops around the system. It is suspected that lamp and panel parasitic capacitance's facilitate this behavior. The net result, however, is total applied voltage to strike two lamps in series must be equal to run voltage plus strike voltage.

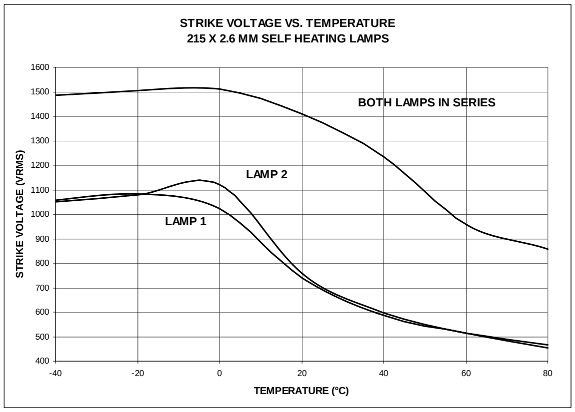


Figure 3

# 4 Wide Range Dimming

A moving vehicle can quickly drive from direct sunlight to very dim light as when entering a tunnel, or it can travel through total darkness in uninhabited areas at night. Dash mounted displays must quickly adjust emitted light in these situations to prevent temporary night blindness for the driver. This is an absolute safety requirement.

There are two ways to dim a CCFL. The conventional method is called analog dimming, where lamp current amplitude is adjusted. Fluorescent lamps emit light directly proportional to the current that flows through them, but they have a very limited current range. The maximum allowed current divided by the minimum allowed is usually a ratio of three to one. On the upper end, the lamp can saturate so that increasing current no longer increases light output. On the lower end, the lamp will begin to extinguish from one end, resulting in a severely uneven output along the tube. The other method is digital dimming, where the lamp is operated at its optimum current amplitude, but switched on and off at a relatively low frequency “burst rate”. During each burst, an adjustable number of higher frequency lamp current cycles are permitted. Control of the number of cycles is via a PWM (pulse width modulated) input signal. The duty cycle of this signal can vary from nearly zero to 100%, with corresponding lamp output varying from almost no light to its maximum. Figure four shows light output vs. duty cycle over the automotive temperature range for a self-heating lamp. Note that lamp output vs. duty cycle is linear compared to analog dimming shown in figure one.

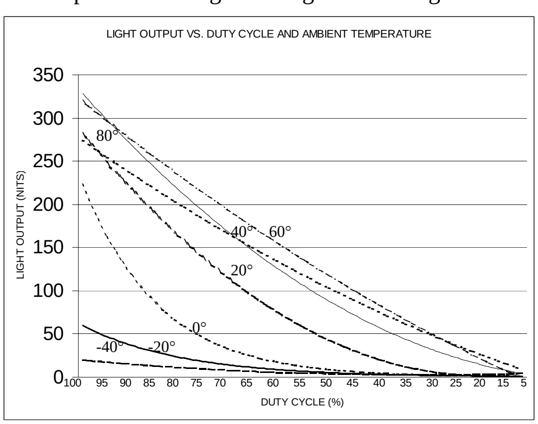


Figure 4

Digital dimming techniques have been used in military applications for a number of years, but until recently have been too expensive for commercial applications. During the last two years Microsemi has shown digital dimming is an effective, low cost, and reliable method for achieving high dimming ratios. Over 3 million lamp x hours of life testing combined with numerous installations in commercial monitors and automotive displays confirm lamp reliability is not degraded by digital dimming.

# 5 Techniques for Wide Dimming Range

### Lamp Current Shaping

Dimming ratios of 100:1 are relatively easy to obtain by careful lamp current wave shaping. Lamp current frequency is usually in the 70KHz range, while burst frequency is in the 100 to 300 Hz range. It is important when operating at very low duty cycles, e.g., less than a dozen lamp current cycles per burst, to carefully shape the turn on of lamp current. Providing 20 to 40% overshoot of the first few cycles will insure the lamp lights instantly over its full length so light gradients do not appear on the display screen. Figures five and six show optimized lamp current wave shapes at 50% and 2% duty cycle.

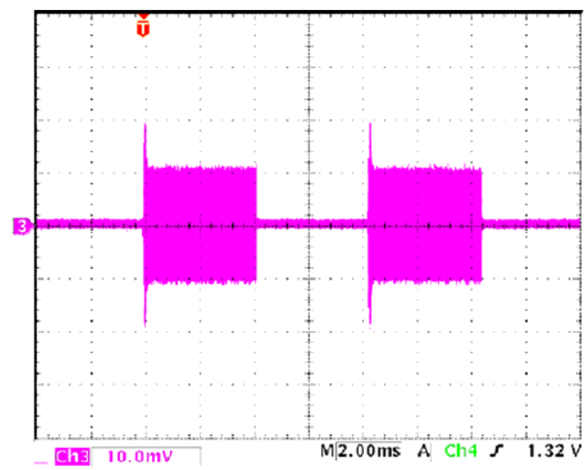


Figure 5

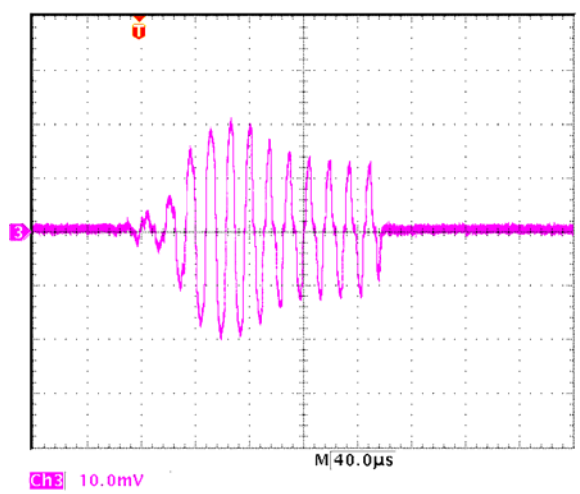


Figure 6

**Preventing Flicker**

Flicker is the singular symptom of many lighting problems and is therefor difficult to diagnose. The human eye can detect less than a 1% change in light intensity when it occurs at frequencies of less than 90 Hz. For this reason, burst rate must be above 90 Hz and care must be taken to insure optical beating at less than 90 Hz can not occur, but most importantly, the average current to the lamp during each burst must be identical.

The most predominant cause of flicker in very high ratio dimming systems is unstable cycle counts in each burst of lamp current. Synchronizing the lamp current frequency to the burst frequency will eliminate this instability. Additionally, if these two frequencies are synchronized to the video frame frequency, moving horizontal bars caused by slow beat frequencies will be prevented. Two methods to synchronize are available; a phase locked loop (PLL) which locks the burst and lamp frequencies to the external video sync pulse, and a down counter which derives the burst rate from the external video horizontal sync pulse. In this later case, the video horizontal frequency is too slow to produce the high frequency lamp current, so a higher frequency source, such as the video data clock may be used.

Both methods eliminate the inherent one cycle uncertainty resulting from synchronizing two unrelated oscillators with a flip-flop.

Some other sources of flicker are noise on the analog brightness control input, noise on system power supplies, and jitter on PWM ramps and their output pulses.

## 6 Dual Dimming Controls

Previous sections have discussed analog and digital dimming attributes and how they relate to lamp performance. This sections describes a system that simultaneously uses both types of dimming. Since analog current amplitude can be used to help overcome the slow response and low light output of CCFLs at low temperature, the ideal self heating lamp controller would adjust current amplitude as a function of bulb and / or ambient temperature. Duty cycle, via digital dimming, would be adjusted as a function of ambient and display light output as compared with the user brightness setting. Lamp output would feed back and compare to the user setting. To prevent temporary driver blindness, sensors that detect ambient light would automatically override the user input so that brightness quickly adjusts to changing ambient light conditions.

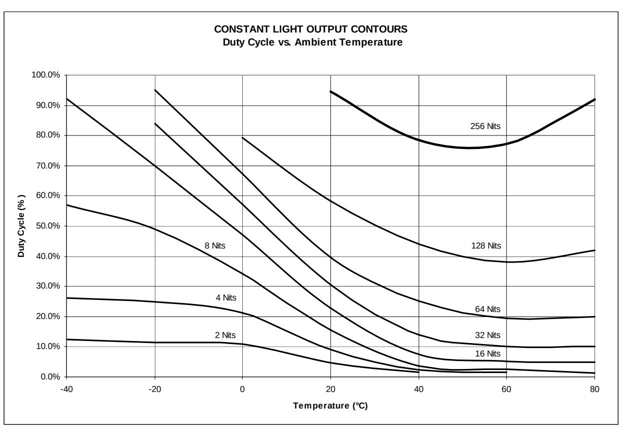


Figure 7

Figure seven shows how lamp current duty cycle must change over temperature to produce constant light output.

## 7 A fully Digital Dimming Control Scheme

CCFL controllers available today are hard pressed to exceed dimming ratios of 100:1. Auto manufacturers, however, are requesting ratios of 1000:1. One thousand to one ratios that vary brightness from ½ Nit to 500 Nits can be achieved with a fully digital control system that derives burst rate and lamp current from a single oscillator. Ideally this oscillator is phase locked to the video controllers vertical sync pulse to prevent video interference from optical frequency beating.

Digital dimming is based on counting current cycles applied to the lamp at each burst so there are no instantaneous random changes in average current. The system interface must be digital so that no analog noise is introduced, and both analog and digital dimming techniques are simultaneously employed as previously described. In the case of analog dimming, a DAC will supply the final reference voltage to the single analog circuit used in the controller, the lamp current error amplifier.

Digital counters and magnitude comparators vs. an analog PWM circuit must be used to control burst duty cycle. The conventional PWM implemented with a linear voltage ramp and comparator must be discarded. These have jitter that cause duty cycle instability because they are dependent on the start and finish levels of the voltage ramp, and they require a DC brightness control voltage be presented to the comparator.

## 8 System Specification Considerations

Extreme dimming at extreme cold temperature is difficult to control without very accurate light and temperature feed back, and may not be necessary considering the brief time the lamp itself needs to heat up. As usual, in severe environment systems, designing for full specifications over the entire operating range will involve trade off in nominal performance, cost, or both. The system designer should give full consideration to specifications that may be relieved to obtain the best overall cost performance ratio.