Power Consumption Reductions in CCFL Backlight System

Overview

This paper investigates the potential for power savings in LCD backlights by using CEYX's lamp control system and related design improvements. The baseline calculations consider a backlight assembly with 16 inverters driving 16 cold-cathode fluorescent (CCF) lamps. The lamps are 26.25"in length. The improved design drives the same lamps, but uses two inverters as explained below.

Power savings was analyzed in six main areas. Each area is made possible through the use of the CEYX Software Enabled Controls System. There is interdependency between the design areas, that when combined as a whole, enables significant power savings. For purposes of analysis and computation, the areas are broken out and presented individually: I. II. III. IV. V. VI.

I. **Inverter Reduction** Increase ratio of lamps-to-inverter from 1:1, to a minimum of 4:1, or to 8:1 (dependent upon application type)
II. **Best Practices**. Industry best practices for efficient inverter operation
III. **Lamp Equalizers** Circuit and control firmware that enables a low power and cost efficient way stabilize individual lamp current.
IV. **Continuous Servo Contro** Power reductions made possible with CEYX's Software Enabled (S-E) Control System through precise and efficient control.
V. **Adaptive Strike Process** Planned improvement to the S-E controls systems which improves lamp strike voltage timing resulting in additional power savings
VI. **Digital Drive Synthesis** Planned improvement to the S-E controls system, which improves transformer power timing.

Power Savings Summary

The following table summarizes the power savings from each of the elements, which are further explained in detail:

Savings Area	Power Savings Watts	Power Savings %
Inverter Reduction	5.10	6.50
Best Practices	4.04	5.15
Lamp Equalizers	0	0
Continuous Servo Control	10.69	13.63
Adaptive Strike Process	0.52	0.66
Digital Drive Synthesis	0.78	0.99
Total	21.13	26.9 %

I. Inverter Reduction Power Savings

The improved inverter design reduces the number of inverters from 16 to 2 in the 16-lamp system. Thus, each re-designed inverter will drive 8 lamps. The analysis focused on one of the inverters; for a 16-lamp system, two inverters would be used, and the wattage calculations (both use and savings) can be doubled.

a. Inverter System Basis

The basis to determine power savings is the 30" LCD TV Backlight system with 8 commonly used inverters controlling 8 CCFL lamps. Each lamp requires a nominal 6.86 Watts, therefore total power required for 8 lamps = 54.9 Watts. The Inverter manufacturer specified the circuit as 70%

efficient in delivering power to the lamps. Given the inverter efficiency, to determine the actual power required to drive the lamps:

Where P_o = power out
Where P_i = power in
Where power efficiency is defined by: $P_o/P_i = 0.70$
Therefore, power in P_i required to light 8 lamps = $P_i = P_o / 0.7$ => 54.9 W / 0.7 =>
Where P_i = 78.43 Watts.

The calculation shows 23.53 Watts (78.43 W - 54.9 W = 23.53) of power is consumed by the 8 inverters in order to drive 8 lamps.

We calculated the power consumption of an improved design to be 18.43 watts. This was determined by a component level accounting of power consumption for the new design, combined with elimination of redundant circuitry and use of a CMOS controller rather than the power-hungry bipolar controller in the original inverter design.

This is a <u>5.10 W power savings </u>(calc: 23.53 – 18.43 = 5.10) or; % Power savings = 5.10/78.43 W* 100= 6.5%.

II. Best Practices Power Savings
The CEYX control system complements the use of Best Practices even though it does not directly enable the Practices. Good inverter designs consider the following:

- Improved transformer with low flux densities, better core material and low resistance windings
- Improved Mosfet devices
- Regulated DC power source of 24 volts
- Non-dissipative snubbers
- Use of “class D” topology for primary transformer circuit

A part-by-part accounting for a system that uses 1 inverter for 8 lamps was done. The results show that the inverter made using best practices (as opposed to the original design methods and parts of the baseline inverter) further reduces power consumption from 18.43 W to 14.39 W for a <u>power reduction of 4.04 W</u>.

Power savings translates into an additional reduction above basis:
4.04W/78.43 W* 100 = 5.15%

III. Lamp Equalizers
LCD manufacturers assume that when every lamp is run at the same current, each will have the same resulting luminance, which has been the driving force behind one-lamp: one-inverter designs.

The typical practice today to obtain equal currents in a backlight system that uses one inverter per lamp, is to use a potentiometer in series with the current sensor. If all 8 lamps are driven out of one inverter, the individual lamp currents will be different unless additional controls are installed. A potentiometer cannot be used to set individual lamp currents when 1 inverter is used to drive 8 lamps.

An improvement over potentiometers uses a power switch. However, this approach consumes power and is very expensive.

CEYX has developed an improved proprietary design that uses a lamp current “equalizer” consisting of switched capacitors and control firmware in a configuration that equalizes lamp currents with no addition of power.

The net effect is a zero power savings. The elegance of this approach however, is the equalizer is an enabler for inverter reduction combined with individual lamp control without adding any power requirements to the inverter circuit.

IV. Continuous Servo Control

The CEYX Software Enabled Controls is a control network that collectively monitors, senses, and controls or enables control of an (operating) environment for a particular purpose. Dynamic Lamp Servo is one key element of the controls firmware because it applies the principles of continuous performance regulation. Electronic components used in backlighting systems exhibit significant amounts of part-to-part variations. Component variability has a direct impact on system performance, especially power consumption. Continuous performance regulation eliminates the impact of component variability and the resulting power waste.

The following discussion accounts for the variations in component characteristics, and shows the power savings as a result of applying continuous servo control.

a. Power Savings to ”Fixed” Variability Portion of Inverter Electronics

Component variations are broken into two classifications for this discussion. The first set of variations is classified as “fixed” variability. In traditional analog inverter designs, this set of parametric variations is adjusted to null by using a manual potentiometer to establish set points during manufacturing. We have seen this approach used for inverter-to-lamp ratios of 1:1 and higher (e.g. 1:4). In the higher ratio designs, one potentiometer is used to simultaneously set all lamps to one point rather than each individual lamp being set to an optimized point.

In the higher ratio designs, it becomes impractical to install a separate potentiometer for each lamp circuit; hence, the design default of one set point is used for all lamps regardless of inherent variability. To compensate, lamps are generally pre-selected through a quality control process, or changed on the manufacturing line if they are perceived to be outside of established parameters. Another approach is to establish set points above the nominal power to ensure all lamps reach sufficient voltage. In any case, the CEYX Dynamic Lamp Servo automatically establishes the perfect lamp set point for individual lamps, regardless of its location in the manufacturing error distribution, thus allowing the manufacturer to avoid some of the QC steps and realizing power savings as described below.
The “fixed” variables are:

a. Lamp-to-lamp manufacturing variations: +/- 8.41
b. Lamp Transformer assembly variations: +/- 5 %
c. Primary drive circuit variations: +/- 0.5%

Manufacturing variations of the lamp are approximately +/-8.41%, which means a lamp can require up to an additional 0.577W of power in order to operate with the correct amount of luminance. In addition, the transformer manufacturing variation was estimated to be +/- 5% and the primary drive circuit variations: +/- 0.5%. Statistically, not all of the variations occur at the same time. To compensate for the randomness of variation, customary design practices recommend use an RMS computation of the variations 1a -1c above. The result is:

RMS = square root ($8.41^2 + 5^2 + 0.5^2$) =9.8%

The variations mean that the inverter must be designed not only to supply additional amounts of power for a more demanding lamp, but also to compensate for manufacturing variations, which would result in a “weaker” transformer and primary drive circuit. The process of transporting power through the primary drive circuit and the transformer to the secondary circuit causes power consumption in the components used.

The additional amount of power is: 9.8%(Sustaining voltage)* (lamp current) = % added power in secondary shows: 0.098(1143)*6 mA= 0.673 Watts per lamp or 5.38 Watts in an 8 lamp system. Since the system used as a basis is 70% efficient, then Efficiency = Power Out/Power in $=P_o/P_i = 5.38/P_i=0.7\ P_i = 7.69$ Watts

Since the CEYX Dynamic Servo automatically establishes the perfect lamp set point in light of component manufacturing variations, only the amount of lamp power required will be consumed. This results in power savings of 7.69 Watts. In reference to the basis:

% Power savings = (7.69W/78.43 W) *100 = 9.8%

B. Power Savings to "Dynamic" Variability Portion of Inverter Electronics
The second set of parameters represent "dynamic" variables, which means they change over use, time and temperature. However, the potentiometer set points remain fixed from time of manufacture and cannot compensate for aging or temperature variations of the lamp.

The "dynamic" variables are:

a. Lamp variations with temperature: +/- 3.7%
b. DC supply to inverter variation (as battery discharges, DC power used by the inverter will change): +/- 1%

As mentioned above, a common approach to avoid lamp variation through time is to use an initial current setting that is higher in value than what is actually needed in order to have margin for the parameter change. This approach is inefficient since it uses more power than it is necessary. The CEYX dynamic lamp servo uses feedback measurements such as lamp voltage and current to determine fluorescence. This means that the servo does not need to rely on additional production of power to ensure lamp is properly driven given the component variations such as aging, battery power change and changes in the lamp requirements due to temperature. At no time does the CEYX system transport additional power through the primary driver and transformer to the secondary circuit containing the lamps.

Statistically, not all of the variations occur at the same time. To compensate for the randomness of variation, customary design practices recommend we use an RMS computation as described above. The result is a power loss of 3.83%.

The significance of this variation is that the inverter design will need to be made in such a way that the primary drive circuit and the transformer in the inverter will need to provide the additional power (3.83%) to the secondary circuit containing the lamp. The process of transporting power through the primary drive circuit and the transformer to the secondary circuit causes power consumption in the components used. The additional amount of power is:

3.83%(Sustaining voltage)* lamp current = % added power in secondary shows:
0.0383(1143)*6 mA= 0.263 Watts added per lamp or 2.1Watts in an 8 lamp system.

Since the system used as a basis is 70% efficient, then the amount of additional power that needs to be provided is:

Efficiency = Power Out/Power in$=P_o/P_i = 0.7 = 2.1W/P_i\ P_i =$ 3 Watts

Since the CEYX Dynamic Servo automatically establishes the perfect lamp set point in light of lamp temperature variations and DC power supply variations, only the amount of lamp power required will be produced. This results in power savings of 3 Watts (in reference to the original basis): % Power savings = (3 W/78.43 W) *100 = 3.83%

V. Adaptive Strike Process

This is a planned future improvement. A full 48 Watts of power is required for full luminance of all 8-lamps. In an average large screen LCD application, lamps are sometimes dimmed to 75% luminance during typical operation in a darkened room. Dimming can be achieved by a pulse width modulation (PWM) waveform with a duty cycle of 75% (this means the lamp is on 75% of the time, and off the other 25%). In order to effect dimming without the observer seeing the on-and-off operation, the total cycle time for the PWM is usually set to ~2.5 ms, which is below the observer's ability to detect on-off cycling. The 2.5 ms setting corresponds to the following sequence: turning on the lamps for 1.875 ms then turning off the lamps for 0.625 ms.

Each time the lamps are turned on there is the need to re-apply the strike voltage. The strike voltage is a 2000+/-volt sinusoid at 60 KHz. The strike voltage corresponds to twice the operating voltage of 1000 volts. Strike voltage must be applied until the lamp switches to the fluorescent state. At that point in time the lamp voltage is reduced to sustaining voltage.

Analog controllers will typically be designed with a current control loop having a frequency response of a few hundred Hertz. This means that it will take the controller a significant amount of time to detect when strike has occurred. Using a highly optimistic value of response time for an analog controller, let's assume the analog controller can detect current and will reduce the lamp voltage from the strike value to the sustaining value within a response time in the order of 32 microseconds. A sampling and learning technique used by the CEYX software control system can determine fluorescence and reduce the lamp voltage to the sustaining value within ~50 nanoseconds.

For an analog controller, power is calculated by determining the energy delivered to the lamp during strike, adding the result to the energy delivered to the lamp during sustaining operation and dividing the total by the PWM cycle of 2.5 milliseconds:

$$P = (P_1T_1+P_2T_2)/T,$$

Where P_1 is the amount of power applied to the lamp during strike
T_1 is the amount of time strike voltage is applied
P_2 is the amount of sustaining power applied to the lamp after strikes
T_2 is the amount of time that sustaining power is applied to the lamp
T is the total cycle time for the PWM operation = 2.5 ms

Since we have a 75% duty cycle, $(T_1+T_2)/T * 100 = 75\%$
Strike voltage= 2000 Volts
Sustaining voltage= 1143 Volts

Once strike occurs, the analog controller will reduce the voltage to the sustaining voltage. Assume that once strike occurs, the fastest that the analog controller can reduce the strike voltage to sustaining voltage is 32 microseconds = T_1 >> $P= [(2000)*(6x10^{-3})*(32 \text{ x } 10^{-6}) + (1143)(6 \text{ x } 10^{-3})(1.875 \text{ X}10^{-3} -32x10^{-6})]/2.5x10^{-3}$ = 5.21 Watts, or 41.67 Watts for an 8-lamp system.

For the CEYX control system, power is calculated using the same formula. Using the CEYX approach, the lamp voltage is reduced from the strike value to the sustaining value in ~50ns= T_1 => $P = [(2000)*(6x10^{-3})*(50 \text{ x } 10^{-9}) + (1143)(6 \text{ x } 10^{-3})(1.875 \text{ X}10^{-3} -50x10^{-9})]/2.5x10^{-3}$ = 5.14 Watts, or 41.15Watts for an 8-lamp system.

The reduction in the application of adaptive strike process results in a calculated power savings of 0.52 Watts (41.67W-41.15W) above basis.

% Power savings= 0.52W/78.43 W) *100 = 0.66%

VI. Digital Drive Synthesis

A significant amount of power in an inverter is consumed in the primary circuit, specifically in the Mosfets used to switch power into the transformer. Ideally, the process would switch the Mosfets on and off with zero time spent in the transition region between the off- and on-state. If Mosfets could be switched with the transition region at zero time, the operation would avoid the high resistance of the transition region, which consumes significant amounts of power. Although the time can never be zero, minimizing the time by matching the timing to the characteristics of the actual components in the primary drive circuits used saves power.

Use of an analog controller results in a timing process that can only be changed by, desoldering and changing the associated passive components surrounding the analog controller. As a result, the timing cannot be easily adapted to manufacturing variations of the primary drive circuits.

In contrast, digital synthesis of the primary drive allows for the control system to be adaptive to manufacturing variations and changing conditions. The CEYX Digital Drive Synthesis uses an adaptive drive for the Mosfet drive circuit such that the drive is operated in an appropriate manner to minimize power consumption. As an example, a calculation of power savings can be made relative to the Mosfet switching time.

In a typical inverter, the typical time for ½ of the oscillation period is calculated: (½)*1/60K=8.33 microseconds. In our 8-lamp system, we need to switch approximately 78.43 Watts into the transformer. If we use 24 Volts in the primary circuit, this corresponds to switching 2.5 Amps. If we have a 1/100th of a cycle variation in switching the Mosfet, then we can approximate Mosfet power consumption as: (1/100)* 78.43W= 0.78W power savings. % Power savings= (0.78 W/78.43 W)*100 = 0.99 %

VII. Total Savings Potential

Comparison of system efficiency "before" and "after" the improvements shows:

Power Requirements Comparison of "Before" & "After" Improvements

P in	P out	Inverter Power		Efficiency
Before	78.43 Watts	54.9 Watts	23.53 Watts	70 %
After	57.3 Watts	54.9 Watts	2.4 Watts	95.8 %

Thus, we can see that the sum of savings is quite material for any CCFL backlight system. One of the issues in large area LCD TVs is the generation of excess heat, which can effect the operation and lifetime of other components in the TV as well as objects in close proximity. Since the backlight is the main source of the heat, which results from high power consumption, reducing it is of prime concern.

These power savings are undoubtedly extendable to other size screens. Of particular interest is power savings that may be obtained in portable devices such as laptop computers. CEYX is doing further work in this area to validate the savings calculated in this paper and to quantify the potential savings for other sizes and configurations of screens.