Intelligent Backlighting System for LCD TV

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Abstract

A new current control technique called Amplitude Shift Modulation (ASM) for cold cathode fluorescent lamps (CCFL) has been developed. This new technique sets and continuously controls the current of each individual CCFL in an LCD backlight lamp array.

Introduction

Traditionally, backlights have been implemented using one inverter for each cold cathode fluorescent lamp (CCFL). To address market requirements, recent designs have simplified circuits by using one inverter (and one transformer) for an array of CCFLs. Driving an array of CCFLs from the same inverter results in a lack of uniformity. The reduction in uniformity occurs because each CCFL exhibits unique characteristics and the single inverter treats all CCFLs the same. When this occurs, the current in each CCFL will be different and the corresponding light output from each CCFL will generally be different from the output of others in the array.

Analog CCFL Current Balancing Approaches

Various balancing methods can restore light uniformity across the panel. Most CCFL current balancing methods rely on analog circuits[1,2]. For example, a popular implementation uses one current balancing transformer per CCFL. This approach still requires numerous transformers and uses additional PC board space. Accuracy of current balancing also suffers since there is no practical way to guarantee repeatability and matching of transformers to obtain an error below 10 to 20 %. Features such as aging, automated manufacturing test, and backlight blinking are not properly supported to obtain high performance. Future requirements of power conservation and video coordination will require intelligence in the backlight which most analog approaches do not support.

Amplitude Shift Modulation

Amplitude Shift Modulation (ASM) is an alternative method used to obtain light uniformity and intelligence in an array of CCFLs. ASM is a digital technique used to set and balance CCFL currents which relies on switching transistors and digital servo control systems.

The ASM waveform for current (see figure 1) is comprised of two sinusoids. One sinusoid has a large amplitude and the second has a small amplitude. Total root mean square (RMS) current for the CCFL is related to how long we apply the large sinusoid current versus the amount of time that we apply the smaller sinusoid current. The total RMS current is related to the duty cycle. Percent duty cycle is defined as follows:

$$ASM\ \%\ Duty\ Cycle = \left(\frac{T_{ON}}{T_{ON} + T_{OFF}}\right) \times 100 \qquad 1)$$

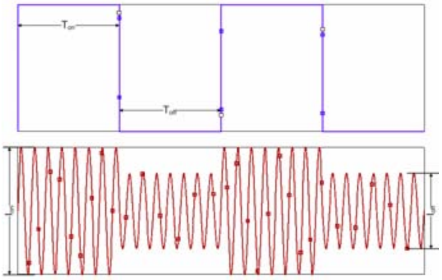

Figure 1. *ASM current waveform*

The RMS current for an arbitrary waveform is defined as follows:

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt} \qquad 2)$$

Since the ASM waveform consists of two sinusoids repeating over a period of time T, the RMS value is:

$$I_{RMS} = \sqrt{\frac{1}{T}\left(\sum_{i=0}^{n-1}\int_{\theta_i}^{\theta_{i+1}} i_1^2(\theta)\,d(\theta) + \sum_{i=n}^{m-1}\int_{\theta_i}^{\theta_{i+1}} i_2^2(\theta)\,d(\theta)\right)} \qquad 3)$$

Where $\theta_0 = 0$, $\theta_1 = \pi$, $\theta_2 = 2\pi, \ldots, \theta_n = n\pi$, $\theta_{n+1} = (n+1)\pi$,

or, using time domain expressions:

$$I_{RMS} = \sqrt{\frac{1}{T}\left(\sum_{i=0}^{n-1}\int_{\theta_i}^{\theta_{i+1}} I_H^2 \sin^2(wt)\,dwt + \sum_{i=n}^{m-1}\int_{\theta_i}^{\theta_{i+1}} I_L^2 \sin^2(wt)\,dwt\right)} \qquad 4)$$

Where I_H is the peak amplitude of the large sinusoid, and I_L is the peak amplitude of the small sinusoid.

Figure 2 shows a circuit used to implement ASM. The circuit consists of a ballast capacitor C_B, and a switch comprised of the parallel combination of a MOSFET Q with a capacitor C, a resistor R, and a diode D. An AC voltage source V_S is applied to the circuit, while a PWM generator drives the MOSFET from fully on to fully off. Resistor R is typically a very small value and smoothes out the current waveform when the MOSFET is switched. Diode D is used to bypass the switch during the negative part of the applied sinusoid voltage.

When the MOSFET is off, the CCFL current I_L will flow into the series capacitor and resistor as shown in Figure 2. When the MOSFET is turned on, the entire CCFL current flows through the MOSFET channel.

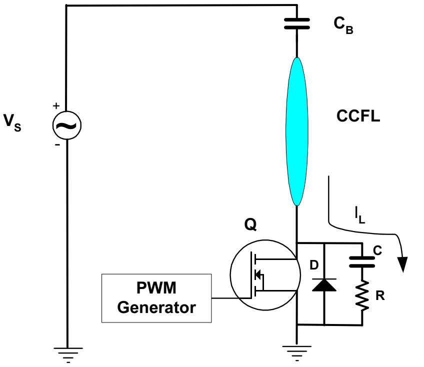

***Figure 2**: ASM circuit*

The resulting current waveform for the MOSFET in the circuit of Figure 2 has the form of a half wave rectified sinusoid.

The RMS power consumption through the MOSFET is given by:

$$P_Q = I_{RMS}^2 \, RDS_{ON} \qquad 5)$$

where I_L^2 is the square of the CCFL RMS current when the MOSFET is on and RDS_{ON} is the resistance of the MOSFET channel when the transistor is fully on. For a half wave rectified sinusoidal waveform, the RMS value is given by Equation 5.

$$I_{RMS} = \sqrt{\left(\frac{1}{T}\right)\left(\left(\int_0^{\left(\frac{T}{2}\right)} I_H^2 \sin^2\theta \, d\theta\right) + 0\right)} \;=\; I_{RMS} = \frac{I_H}{2} \qquad 6)$$

The power consumed in the MOSFET is then:

$$P_Q = \frac{I_H^2}{4} RDS_{ON} \qquad 7)$$

As an example of power consumption in the MOSFET, consider the circuit of Figure 2. Assume the voltage source V_S applies a continuous sinusoid (100% Duty cycle ASM) of 60 KHz and an amplitude of 7.07 mA peak. Furthermore, assume that the RDS_{ON} for the MOSFET is 200 Ω, then the power consumed in the MOSFET is:

$$P_Q = \frac{\left(7.07 \times 10^{-3}\right)^2}{4} (200) = 2.5 \ mW \qquad 8)$$

The relatively small power consumption allows the use of semiconductors to replace functionality previously addressed with transformers. The small amount of power consumption also allows for integration of circuits used for ASM into a single chip.

Note that slight modifications of EQ 3 will allow the calculation of MOSFET power consumption for the case where the ASM duty cycle is different from 100%.

Potential Cause of Flicker	**Flicker Prevention Measure**
Not enough current	Restrict current range for ASM modulation to the appropriate value for the CCFL so that fluorescent processes are not disturbed.
Not enough voltage	Design inverter circuits to ensure that the CCFL modulation does not change the CCFL voltage to a value that would cause flicker.
Poor inverter regulation	Design the inverter and, in particular, the power transformer to ensure the CCFL voltage does not sag.
Conducted interference	Create inverter PC layout using well-understood practices to prevent conducted interference from logic or power circuits from coupling into the inverter control system.
Low frequency modulation	Operate ASM so that there are no modulation harmonics of < 90Hz.
Optical cross modulation	Synchronize inverter operation frequency with the ASM waveform.

***Table 1**. Flicker prevention measures for ASM applications*

Crest Factor Considerations

Crest factor of a waveform is defined as a ratio of the peak current to the RMS current.

$$CF = \frac{I_P}{I_{RMS}} \qquad 9)$$

A variety of applications use crest factor as a metric to describe certain properties of a waveform in the system. In mechanical engineering, crest factor is a measure of the amount of impact stress during operation of gears. Power supplies need to consider crest factor of inrush currents in order to ensure satisfactory voltage regulation.

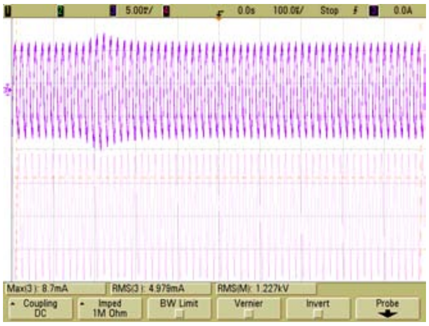

Figure 3. *Typical ASM waveforms*

Top trace: CCFL current waveform at 5% ASM. Bottom trace: CCFL voltage waveform at 5% ASM. Note that there is no sharp change in both the current and voltage waveform.

In communications engineering, crest factor affects the operating point of power amplifiers in order to maintain efficiency and to prevent radiation out of the allowable band of transmission frequencies.

In CCFL display applications, crest factor has been traditionally used to estimate performance in two areas: current to light conversion efficiency and life.

To understand these two performance metrics, we looked at current to light power conversion characteristics. Figure 4 shows the results of an experiment to determine current to light power relationship for a CCFL. Note that beyond 6 mA, a saturation region of the characteristic is reached and additional amount of current does not appreciably produce an increase in Illuminance. (1 LUX=lumen/m^2 =1/680 W/m$^{2)}$. For this experiment, the voltage across the CCFL is maintained at a constant RMS value.

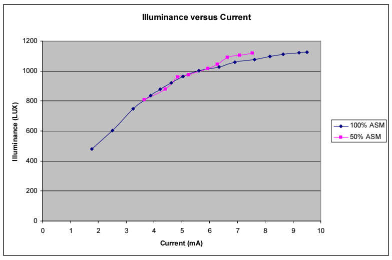

Figure 4. *Current to light conversion characteristic for a CCFL*

Figure 5 illustrates two current waveforms that can be applied to the CCFL under study. The two waveforms have equivalent values of RMS current. One current waveform is sinusoidal; the other current waveform has a high crest factor. The high crest factor waveform will not deliver significant light power when the values of current are beyond the saturation region of +/- 6 mA. Most of the current beyond the start of the saturation region is known to simply produce heat and not light. Thus, the current to light conversion is inefficient.

High currents in a CCFL cause reduction in life. If driving currents consistently exhibit excursions beyond the start of the saturation point, the lamp is being operated at higher currents than necessary to obtain the needed illumination. Thus, life is negatively affected and current to light conversion will be inefficient.

It is believed that discretion is necessary when using crest factor as a measure of performance in a CCFL current regulation scheme. If a pure sinusoid is applied to a CCFL, the crest factor will have a value of 1.414, which could be construed as an ideal value. Consider that if the peak amplitude of the sinusoid exceeds the saturation point of the CCFL characteristic, then efficiency and life will be negatively affected even though a seemingly acceptable value of crest factor was obtained. As long as efficiency and life are achieved, crest factor becomes an irrelevant metric.

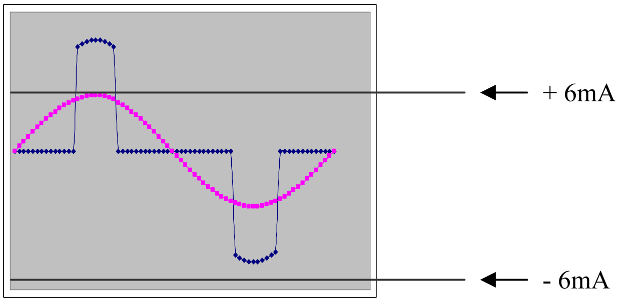

Figure 5. *CCFL crest factor illustration*

ASM contains two sinusoids. Each individual sinusoid has a crest factor of 1.414. If the duty cycle is 100% then the overall crest factor is 1.414; if the duty cycle is 10% then the crest factor is 2.0.

ASM has been adapted to operate with precision servo controls. At no time is the current allowed to have excursions into the saturation region. In this manner, efficiency and life goals can both be achieved even though crest factor values increase from 1.414 to 2.0. The crest factor metric did not anticipate the invention of ASM and thus becomes irrelevant for digital applications.

Power Consumption Efficiency

A test was conducted to determine efficiency. Figure 6 shows the test setup.

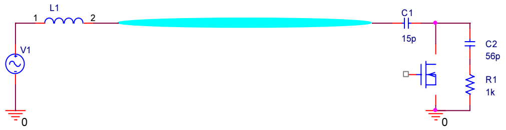

Figure 6. *Efficiency test setup*

The CCFL was connected to an inverter, a ballast capacitor, and an ASM switch MOSFET with ASM switch capacitor. The transistor used to modulate the ASM was switched with several amounts of % duty cycle.

ASM Duty Cycle	VL (RMS)	IL(RMS)	Power (VL*IL) Watts	Illuminance (LUX)	Light Efficiency (LUX/W)	Normalized Efficiency
100%	1.303	6.5	8.4695	1072	126.57	100.00
75%	1.33	6.5	8.645	1118	129.32	102.17
50%	1.36	6.5	8.84	1111	125.68	99.29
25%	1.39	6.5	9.035	1096	121.31	95.84
0%	1.43	6.5	9.295	1112	119.63	94.52

***Table 2**. Efficiency test data*

The tests measured CCFL electrical power and corresponding Illuminance for various percentages of ASM duty cycle. Since the 100% ASM duty cycle was a continuous non-modulated sinusoid, it was used as the reference for normalized efficiency.

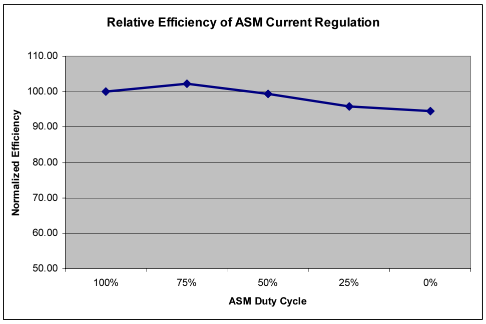

***Figure 7**. Relative efficiency test results*

As shown in Figure 7, even with a drastic modulation range down to 0 % duty cycle, ASM has relative efficiency > 94%. This last value is slightly lower then the efficiency obtained from theoretical calculations due to the presence of leakage currents in the prototype.

Current Regulation Accuracy

Current measurements in the ASM approach are made with digital techniques. An analog to digital converter in an ASIC is used to determine the current in each CCFL connected to the ASIC. Measurements were made with the A/D converter and compared with the measurement using a 1 Kohm resistor and an RMS multimeter. As shown in Table 3, the accuracy error in setting the CCFL current is < 1.9 %.

Test System

Figure 8 shows the system used to test the ASM. The system is representative of a typical application. The MOSFET switches have been fully integrated into an ASIC, that also contains logic and other circuits needed to control an array of CCFLs. Digital controls in the Firmware Engine manage the operation of the ASIC and the inverter operation. The Firmware Engine will adapt the system to various CCFL array applications. The high efficiency of the ASM method enables the large scale integration of functions and the elimination of multiple transformers and discrete components.

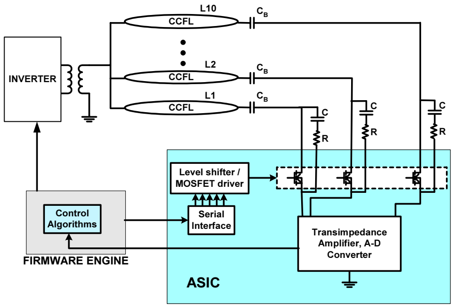

***Figure 8**. Functional block diagram of a backlight using ASM*

ASIC Measurement	Meter	% Error
8.61	8.65	0.42%
7.87	7.93	0.74%
7.15	7.2	0.71%
6.40	6.49	1.44%
5.82	5.89	1.24%
5.49	5.6	1.94%

***Table 3**. Current accuracy setting*

Conclusion

The data presented in this paper shows that for true backlight performance improvement, implementation of a digital control technique like ASM can achieve CCFL current regulation with a < 1.9% error and a power efficiency > 94%.

Use of a digital control technique enables full integration of all lamp current regulation components into a single ASIC. Integration with firmware control methods contributes to power consumption reductions while achieving required performance improvement. Furthermore, features such as age compensation, automated manufacturing and diagnostics tests, and backlight blinking are facilitated by the firmware engine. Digital control for CCFL can be the basis for realizing enhancements independent of lamp count. Digital control can allow synchronization in lamp management for improved video images.

References

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