

Design Challenges in Backlighting LCD TVs

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Designers of circuits for driving cold-cathode fluorescent lamps used to backlight LCD-TV sets must understand the various architectures available and the benefits and drawbacks of each to optimize the design for cost and performance.

Liquid crystal displays (LCDs) are becoming a popular display technology for televisions. According to the research firm IDC (Framingham, Mass.), the number of LCD TVs will grow to 50-million units in 2007. LCD panels are actually electronically controlled light valves that require a backlight source in order to produce a visible image. LCD TVs typically use cold-cathode fluorescent lamps (CCFLs) for this purpose. Other technologies such as light-emitting diodes (LEDs) are being considered, but high cost has limited their adoption. This article focuses on the design challenges in driving and controlling multiple CCFL lamps for backlighting large LCD panels like those used in LCD TVs.

CCFL Lamp Basics

CCFLs are long sealed glass tubes with small diameters that are filled with inert gases (Fig. 1). When a high voltage is placed across the tube, the gases ionize, creating ultraviolet (UV) light that, in turn, excites an inner coating of phosphor, creating visible light.

CCFLs have many desirable features, including:

- Excellent white light source
- Low cost
- Long life (>25,000 hr)

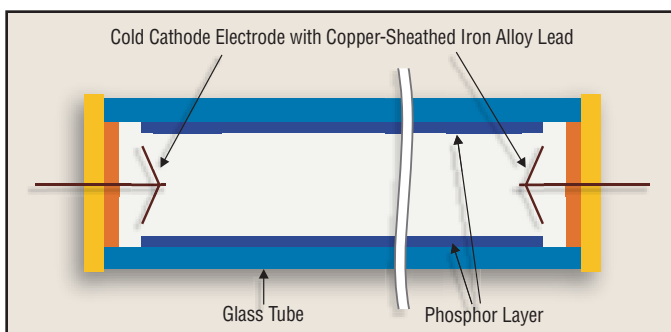


Fig. 1. CCFL lamps are glass tubes filled with inert gases.

- High efficiency (light output versus electrical power input)
- Stable and predictable operation
- Brightness can be easily varied
- Light weight.

However, CCFLs do have some unique characteristics that must be accounted for to maximize their efficiency, life span and usefulness, and these characteristics add to the design challenges. For example, to maximize the life of the lamps, they need to be driven with an ac waveform. Any dc component can cause some of the gases to accumulate at one end of the tube and create an irreversible light gradient where one end of the tube is brighter than the other. Also, to maximize their efficiency (power in to light out), the lamps need to be driven with near sinusoidal waveforms. To accomplish these tasks, CCFL lamps typically require a dc-to-ac inverter that transforms a dc supply voltage to a 40-kHz to 80-kHz ac waveform with an operating voltage of 500 Vrms to 1000 Vrms.

A typical arrangement of CCFLs in an LCD TV is to place the tubes horizontally across the screen equally spaced across the LCD backplane to provide the best possible light distribution. It is important that all of the lamps are operated at the same brightness level. Although there is a light diffuser placed between the CCFL lamps and the LCD panel to help evenly distribute the backlighting, uneven lamp brightness can still be visible and detract from the quality of the TV image. Depending on the size of the LCD panel, up to 30 or even 40 CCFL lamps may be required.

Design Challenges

Because LCD TVs are consumer items, the overriding design factor is cost, yet a certain minimum level of performance must be maintained. The CCFL inverter must drive the lamps in such a fashion that it will not dramatically shorten the lamp life. And because high voltages are gener-

Drive Architecture	Advantages	Disadvantages
Royer	<ul style="list-style-type: none"> • Least expensive 	<ul style="list-style-type: none"> • Cannot control the lamp current or frequency tightly • Requires tight dc supply regulation • Requires a special transformer winding • Requires a ballast capacitor • Low efficiency
Full bridge	<ul style="list-style-type: none"> • Does not require a center-tapped transformer • Works over a wide dc supply range (greater than 3-to-1) 	<ul style="list-style-type: none"> • Requires four MOSFETs • May require p-channel MOSFETs, which are higher cost and lower efficiency
Half bridge	<ul style="list-style-type: none"> • Requires only two MOSFETs 	<ul style="list-style-type: none"> • May require p-channel MOSFETs, which are higher cost and lower efficiency • Requires a higher turns ratio transformer, which increases cost
Push-pull	<ul style="list-style-type: none"> • Requires only two n-channel MOSFETs, which are lower cost and higher efficiency than p-channel MOSFETs • Easily scales to higher dc supply voltages (up to 120 V) • Low transformer turns ratio 	<ul style="list-style-type: none"> • Lower efficiency when the dc supply goes beyond a 2-to-1 range

Table. A comparison of CCFL drive architectures.

ated in driving the lamps, safety must be considered. Three key design challenges must be considered in driving multiple CCFL lamps in LCD-TV applications.

1. *Picking the best drive architecture.* Creating the

high-voltage ac waveform needed to drive the CCFL lamps can be realized via several architectures, including Royer (self-oscillating), full bridge, half bridge and push-pull. The table lists the advantages

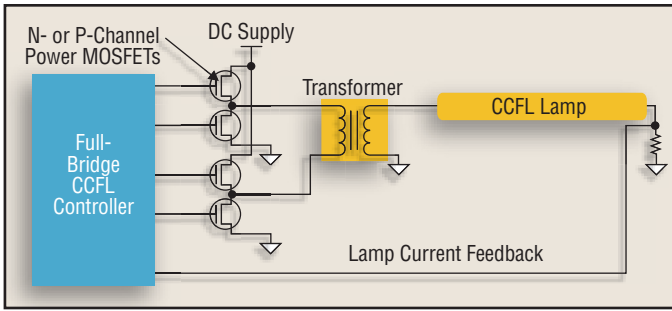


Fig. 2. Full-bridge drives work well over a large dc-inverter supply range.

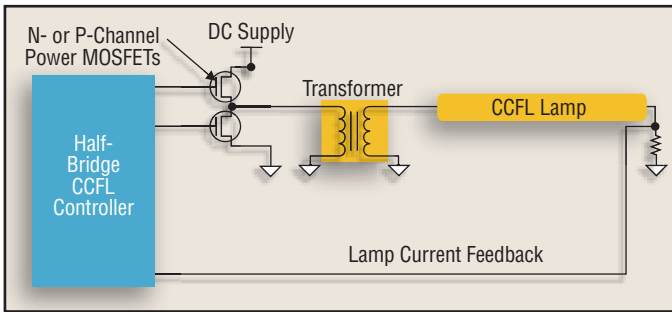


Fig. 3. Half-bridge drives require two fewer MOSFETs than full-bridge drives.

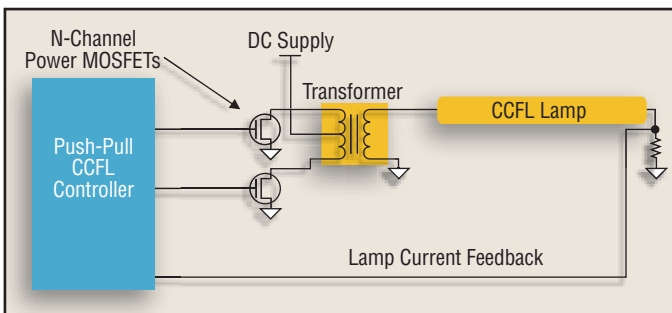


Fig. 4. Push-pull drives are simple yet provide accurate control.

and disadvantages of these four architectures.

Royer architecture. The best application for the Royer is designs in which the lamp frequency and brightness do not have to be tightly controlled. Because the Royer is a self-oscillating design, it is difficult to control the exact lamp frequency and lamp current—which directly affects lamp brightness—because of variations in component values. For these reasons, the Royer architecture is almost never used in LCD-TV applications, even though it is the least expensive of the four to implement.

Full-bridge architecture. The full-bridge architecture is best suited for applications that require a very wide dc supply voltage range (Fig. 2). Almost all notebook PCs use a full-bridge approach because of the wide dc supply range. The inverter dc supply is tied directly to the notebook's main dc power source, which can vary from 7 V—low battery—to 21 V—ac charging. Some full-bridge implementations do require p-channel MOSFETs, which are more expensive than n-channel MOSFETs. Also, p-channel MOSFETs are less efficient because of their inherent higher on-resistance.

Half-bridge architecture. The biggest advantage of the half-bridge architecture is that it requires two fewer MOSFETs

per drive channel than the full-bridge architecture (Fig. 3). However, it does require a transformer with a higher turns ratio, thus increasing the cost of the transformer. And like the full-bridge architecture, the half-bridge architecture may require p-channel MOSFETs.

Push-pull architecture. The final architecture to be considered is a push-pull drive scheme (Fig. 4). This scheme has a number of advantages. First, it only uses n-channel MOSFETs, which lowers the cost and raises the efficiency of the inverter. Next, it easily scales to higher dc-inverter supply voltages. Using a higher dc-inverter supply voltage only requires selecting a MOSFET with the appropriate drain-source breakdown voltage. The same CCFL controller can be used no matter what voltage the dc-inverter supply is. This is not the case for full-bridge and half-bridge architectures using n-channel MOSFETs. The biggest disadvantage of the push-pull drive scheme is that the dc-inverter supply range should be less than 2-to-1; otherwise, the efficiency of the system will drop because the ac waveforms will have a high crest factor when the dc-inverter supply voltage is high. This makes the push-pull drive scheme inappropriate for notebook PCs but ideal for LCD TVs where the dc-inverter supply voltage is regulated to within $\pm 20\%$ or less.

2. Driving multiple lamps. CCFL lamps have been used for several years in notebook PCs, digital cameras, navigation systems and other equipment with smaller LCD screens. These types of equipment typically only have one CCFL lamp and, as such, the traditional technique is to use one CCFL controller for the lamp. With the advent of large LCD panels where many CCFL lamps are needed, some new approaches have been necessary. One possible approach is to use a single-channel CCFL controller to operate multiple lamps.

In this approach, the CCFL controller monitors the lamp current through only one of the lamps and then drives all of the lamps in parallel with approximately the same ac waveform. There are several shortcomings with this approach, however.

The first problem is maintaining equal brightness across all of the lamps, so that no bright or dull spots are apparent to the viewer. Driving all of the lamps with the same waveform can cause uneven brightness because of differences in the lamp impedances and in their ambient temperatures. The brightness of CCFL lamps varies with the current driven through the lamps. Each lamp is likely to have a slightly different operating impedance when lit; and therefore, driving all the lamps with the same waveform causes each lamp to have a different current driven through it and hence a different brightness. Furthermore, the brightness of CCFL lamps also varies with temperature (Fig. 5). Because heat rises, the lamps at the top of the panel will be hotter than the lamps at the bottom of the panel, causing uneven brightness.

The second disadvantage with using a single-channel CCFL controller to drive multiple lamps is that a failure in a single lamp—like lamp breakage—will cause all of the lamps

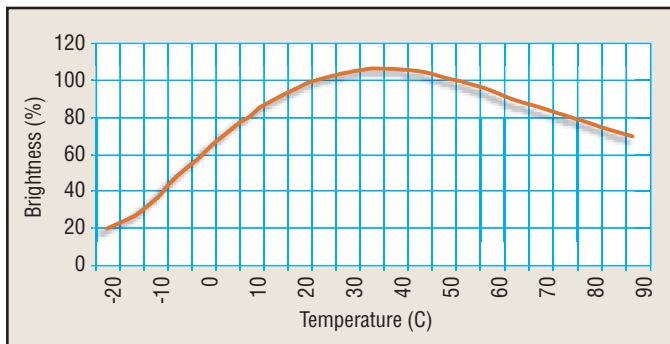


Fig. 5. The brightness of CCFLs varies with ambient temperature.

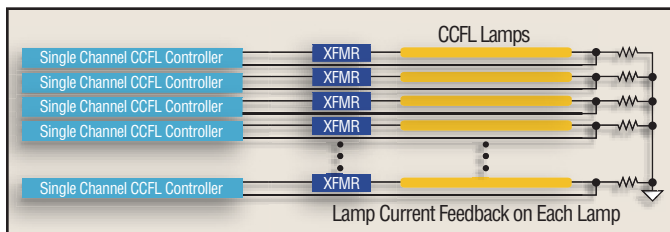


Fig. 6. Using a single-channel controller for each CCFL lamp is not cost effective.

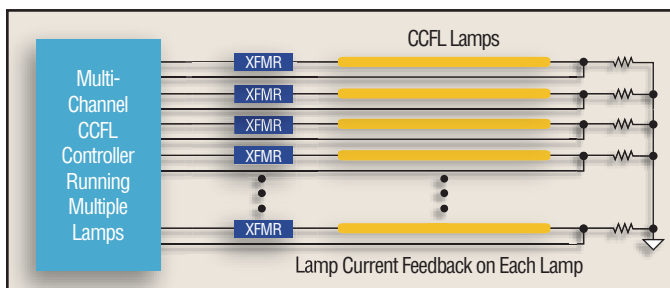


Fig. 7. Controlling multiple CCFL lamps with a multichannel controller is ideal.

to turn off. A third disadvantage is the fact that since all of the lamps are being driven in parallel and turned on and off at the same time, the dc-inverter supply must be more heavily decoupled with bulk capacitance, which raises the cost of the inverter.

One way to solve these problems is to use a separate CCFL controller for each lamp (Fig. 6). The big disadvantage to this approach is the extra cost created by adding more CCFL controllers.

The ideal solution is a multichannel CCFL controller that can drive and monitor each lamp independently (Fig. 7). The multichannel CCFL controller resolves the issues of uneven brightness and single-lamp failure and reduces the required decoupling—and does it in a cost-effective manner.

3. Tight control over the lamp and burst dimming frequencies. Since LCD-TV displays are dynamic and continually show moving images, they have some additional requirements that do not exist in static display applications, like computer monitors and notebook PCs. The frequency at which the CCFL lamp is driven can interfere with the visual image displayed on the LCD screen. Slowly moving lines or bars can be created if the lamp frequency is near a constant

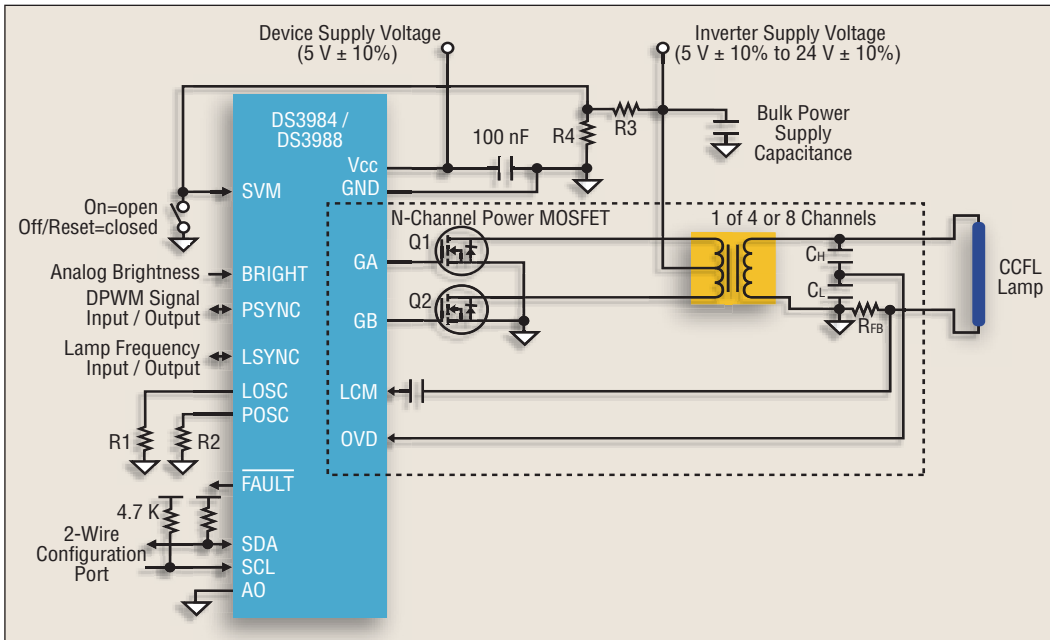


Fig. 8. The DS3984 drives and monitors each lamp independently.

multiple of the video update rates. Tight control over the lamp frequency is required to eliminate these artifacts. If the lamp frequency can be controlled to within $\pm 5\%$, these visual impairments will be eliminated.

The same tight control is required for the lamp burst dimming frequency. The burst dimming is used to adjust the brightness of the lamps. It is a pulse-width-modulated (PWM) signal typically in the 30-Hz to 200-Hz range that turns the lamps off for a short period of time, but not long enough for them to lose ionization. If the burst dimming frequency is near a multiple of the vertical sync rate, rolling lines can be created. Again, control of the burst dimming frequency to within a $\pm 5\%$ level will eliminate this problem. Also, in some

LCD-TV applications, it is necessary to synchronize the slow burst dimming frequency of the CCFL lamps to the vertical sync rate in order to improve the image response of the LCD panel.

CCFL controllers can address all of the design challenges raised in this article. Two examples are Maxim/Dallas Semiconductor's DS3984, a four-channel CCFL controller, the DS3988, an eight-channel version. They can be configured to drive one lamp per channel, as in the case of the DS3984 (Fig. 8), or more than one lamp per channel, which allows users to adapt the design to meet their cost versus performance target. Multiple DS3984s or DS3988s can be easily cascaded to support as many lamps as necessary.

These chips use a push-pull drive scheme that allows the use of lower cost and higher efficiency n-channel MOSFETs, and the dc-inverter supply voltage can be easily scaled to a higher voltage as needed. The individual lamp control and monitoring provides even lamp brightness and reduces the overall component count in the inverter design. With individual lamp control, should a lamp fail, only the failing lamp is disabled. In these controllers, on-chip lamp and burst dimming oscillators are specified to a tight $\pm 5\%$ level, and they can be synchronized to external clock sources as needed.

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