Lighting Systems
Part II

The Sun is Setting on the Incandescent Light Bulb

LED efficiency and lower cost will illuminate the future

With all the benefits of higher efficiency in a technology that has come on in leaps and bounds, LEDs are already a natural choice for many applications. Modern LEDs and their associated IC drivers have become more sophisticated than their early predecessors.

By Tony Armstrong, Product Marketing Manager, Power Products Group, Linear Technology Corp.

The sun is about to set on the use of the incandescent light bulb as a primary light source. This is being fueled by the proliferation of the light-emitting diode (LED) as a solid-state lighting source. A LED is a semiconductor device that emits incoherent narrow-spectrum light when electrically forward biased, resulting in a form of electroluminescence. In other words, the direct conversion of electric energy to light by a solid phosphor subjected to an electric field. The color of the emitted light depends on the chemical composition of the semiconductor material used, and can be near ultraviolet, visible or infrared.

LED technology has increased significantly over the past couple of years. Higher brightness levels, higher efficiencies, longer lifetimes and decreasing costs have spun out from the many advances made in terms of heat dissipation, packaging and processing. Unlike incandescent light bulbs, LEDs do not have a filament that will burn out and they tend to run cooler. Incandescent light bulbs waste 95 percent of the energy they consume as heat.

High-energy efficiency LEDs use only 10% of the electrical energy required to power traditional incandescent bulbs and give of less heat with similar light output levels. Furthermore, LEDs offer extremely long life – typically ten years or more, twenty times longer than the best incandescent bulbs. In addition to solid-state reliability, the shape of the LED package allows light to be focused. Incandescent light sources often require an external reflector to collect light and direct it in a usable manner.

However, despite these significant advances, more can be done in terms of the efficiency of energy conversion, thermal management and production costs. For example, LED efficiency has made dramatic gains. These improvements resulted from better light generation within the chip and a better means of extracting the light from the chip and its package. Similarly, the selling price of 20mA white LEDs have dropped dramatically. When initially introduced, volume prices were a nominal $1. Today, it is possible to purchase these 20mA white LEDs for less than 25 cents in high volume.

LEDs are driven with a constant current where the DC current level is proportional to LED brightness. To vary the LED brightness, there are two methods of dimming the light by controlling the LED current. The first method is analog dimming, in which the LED DC current level is reduced proportionally to a maximum of 10:1 ratio by reducing the constant LED current level. Reducing the LED current further than this can result in a change in LED color or inaccurate control of the LED current. The second method is digital or pulse-width-modulation (PWM) dimming. PWM dimming switches the LED on and off at a frequency at, or above 100Hz, which is not perceivable to the human eye. The PWM dimming duty cycle is proportional to LED brightness, while the on-time LED current remains at the same level (as set by an LED driver IC), maintaining constant LED color during high dimming ratios. This method of PWM dimming can be used with ratios as high as 3000:1 in certain applications.

Of course, all of these advances have not only fueled the adoption of LEDs as a lighting source in different applications, but have also simultaneously driven the demand for LED driver ICs with which to power them. To understand the obstacles for the design and manufacture of these LED driver ICs, it is necessary to understand what a white LED requires in order to produce light. As already stated, a white LED must be driven by a constant current source so that the white point of the light is uniform (that is, it does not shift). Furthermore, since the white LED is a diode, its internal forward voltage (Vf) drop has to be overcome. This Vf varies with the current rating of the white LED and will also change with temperature. A typical 20mA white LED has a Vf that varies between 2.5V and 3.9V over the entire operating temperature range. Most applications use more than one white LED and can also have these LEDs configured in parallel, in series, or a combination of both – for example parallel strings of LEDs in series. This means that white LED driver ICs must be capable of delivering sufficient current and voltage for the specific configuration of LEDs, and in a conversion topology which satisfies both the input voltage range and required output voltage and current requirements.

Applications for LEDs are commonly found in displays and indicators for automotive and aircraft dashboards, traffic signals, cell phones, police take-down bars, othoscopes, flat-panel-display backlighting, miner's lamps, architectural and outdoor stadium lighting. Nevertheless, the single largest market driver for LED growth now, and for the next couple of years, is the backlighting of flat-panel-displays. These displays come in the form of liquid crystal displays (LCDs) used for TVs, navigation systems, portable media players, digital signage and computer monitors. However, one of the challenging technical hurdles for LED adoption is the concern over thermal management. Although LEDs do not radiate as much heat as other light sources, depending on the output power, they may need appropriate heatsinks so that light output and lifespan do not decrease. For example, a high-brightness LED with 25-lumen output typically consumes more than 1W. This means that the white LED driver IC must have high efficiency conversion so that it is not a major contributor to this thermal issue. Also, as seen by the wide range of applications, in many instances there are space limitations. This means that the LED driver IC must be able to accommodate a compact solution footprint and also be low profile.

As an example, consider the cellular phone. Most of today's cellular phones have a built-in digital camera capable of high-resolution still and video images. Gains in camera performance have also created the need for a high power white light source for camera use in-doors or in dim ambient light. White LEDs have emerged as the primary light source in cellular phones equipped with cameras. Since they possess a desirable combination of features for the modern cell-phone designer: small size, high light output, and the ability to provide both "Flash" and continuous "Video" subject lighting. High output power LEDs have been developed specifically for use as integrated camera lights.

Just about any handheld battery-powered device uses a color active-matrix LCD to display the different types of information and data needed by the user. However, manufacturers are faced with the challenge of ensuring that a user can read the information from these displays in any type of environment. To achieve this, they must provide the color LCD with the correct amount of backlighting. This backlighting is normally provided by white LEDs. This created the demand for a compact, efficient and low noise methods to power these LEDs.

In this specific area of white LED driver ICs, Linear Technology has a number of solutions available. The use of either a low noise inductorless DC/DC converter (more commonly known as a charge pump) or a DC/DC converter – the main difference between these being the need for an inductor (magnetics). Inductorless DC/DC converters are an ideal choice for space-constrained applications where low to moderate load currents must be supplied. Furthermore, they come in small packages and require very few external components, typically as few as three ceramic capacitors. Most boost DC/DC converters are specifically designed to provide high efficiency and constant-current drive for white LED backlights.

High brightness (HB) and super HB LEDs can be found in LCD TFT backlighting in high-end TVs, industrial lighting, automotive navigation displays and projectors. One popular area is for instrument panel backlighting, interior lighting, and the brake lights of many automobiles and trucks. Luxury automobile manufacturers are increasingly taking advantage of the latest technologies in solid-state LED lighting to enhance the aesthetics of their future model vehicles by relying on these lighter, smaller, and more durable devices for interior and exterior illumination. It is clear that LEDs promise lower long-term cost and longer life which are among many advantages over incandescent light bulbs for interior lighting.

However, driving LEDs at high current requires the DC/DC converter to accurately regulate the current to ensure uniform light intensity and color integrity as well as to protect the LEDs. Furthermore, a significant challenge is to power one or several strings of LEDs from a battery voltage that can be less than, equal to, or higher than its load voltage. Yet another concern is to efficiently dim the LEDs over a large dimming ratio while preserving their chromatic characteristics at both low and high brightness levels. And lastly, efficient operation of the DC/DC driver is a crucial requirement, especially in driving HB (high brightness) LEDs, since all the power not emitted as light is dissipated as heat.

Driving LEDs from a car battery requires a DC/DC converter to accurately regulate the LED current to ensure uniform light intensity and color integrity as well as to protect the LEDs. Moreover, the DC/DC regulator should be optimized for specific power requirements depending on the intended use of the LEDs. Also, a difficult challenge is to power one or several strings of LEDs from a battery voltage that can be less than, equal to, or more than the load voltage. Another concern is to efficiently dim the LEDs over a large dimming ratio while preserving their chromatic characteristics at both low and high brightness levels. Efficient operation of the DC/DC driver is a crucial requirement, especially in driving HB LEDs, since the power not converted into emitted light is wasted through heat.

It is clear that the trend to utilize white LEDs as a primary lighting source will continue for many decades to come. Their long life, reliability and efficient energy conversion when compared to the incandescent bulb are too compelling to dismiss. At the same time, their continued adoption will fuel the demand for the LED driver IC that are necessary to power them.

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High Quality TFT Monitors Need Optimized Design

Liquid crystal characteristics and driving circuits

Today's consumers and a large proportion of the business world demand top quality displays for their TVs, Computers or the new Information displays we are seeing at airports. The control and driving circuits are a critical function and require close attention

By Oliver Nachbaur, System Engineering Manager, Display Power, Texas Instruments

Liquid crystal displays using active matrix thin film transistors (TFT) are used across many applications and often determine the success of the end product on the market. The main technology driver is the large screen LCD (liquid crystal display) TV panel, which requires superior picture quality to compete with CRTs (cathode ray tubes) and plasma panels. This article gives more insight into the latest TFT LCD characteristics and its control circuits. It focuses on the dot inversion driving method as used for notebook, monitor, TV and public information displays.

Construction of a Liquid Crystal pixel

Figure 1 shows a twisted nematic (TN) cell, which has a 90° crystal twist. Such a cell is commonly used in active matrix displays and contrasts with the super twisted nematic (STN) cell, which has a twist of 270° and is mainly used in passive matrix displays.

As a voltage is applied across the cell, the crystalline structure is aligned along electrical field. Since the polarized light is also oriented along the crystalline structure, the polarizer on the other side of the pixel blocks the light causing the pixel to appear black. If no voltage is applied, then the polarized light passes through the cell as it travels along the crystalline structure with a 90° twist.

When applying a voltage across the cell it is important to apply an AC (Alternating Current) signal instead of a constant DC (Direct Current) voltage. This is because any DC voltage applied for a longer period of time is destructive to the liquid crystal.

Active Matrix Displays allow high resolution and contrast ratios

In order to achieve high contrast ratios, active matrix displays are used. With such a matrix each pixel is controlled by its own TFT. For a colour display, each pixel consists of 3 subpixels using different colour filters to generate red, green and blue. Each sub pixel typically has 256 grey scale levels (8Bit) allowing all the different colours to be generated.

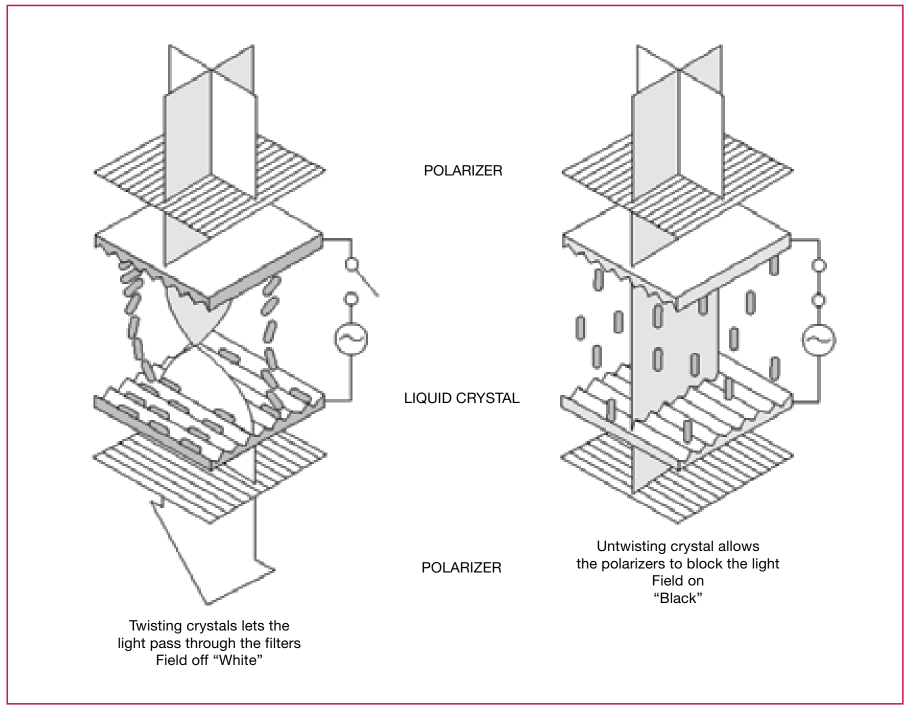

Figure 1: Basic construction of a liquid crystal cell.

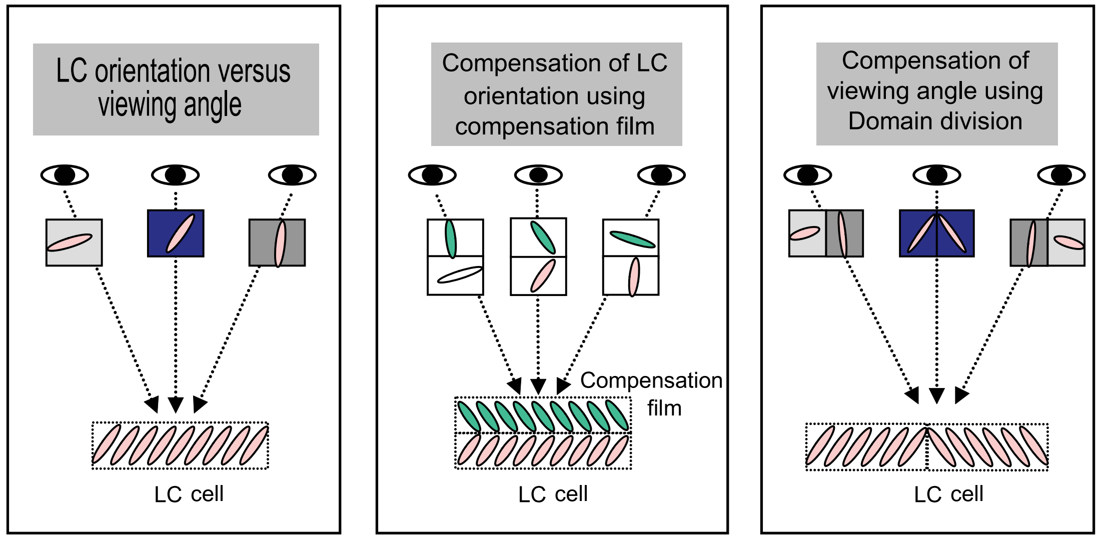

Figure 2: Crystalline orientation influences the reflection of light.

Crystalline structure influences the LCD viewing angle

One of the first challenges to be experienced when using LCDs was their limited viewing angle, but especially when used for TV panels, a wide viewing angle with no change in contrast or colour is required. The first picture in Figure 2 shows the dependency between viewing angle and reflected light. Due to this, the contrast and colour change depend on the viewing angle.

One of the first solutions to overcome this problem used an optical film to compensate for the LC orientation and this technique is still used, mainly for low cost monitor applications. More advanced solutions are used for TV panels utilising vertical alignment (VA, PVA) or Inplane Switching (IPS). The picture on the right in Figure 2 shows one example using vertical alignment. Other technologies such as IPS and FFS (Fringe Field Switching) use additional electrodes in the panel to align the crystalline structure horizontally. Use of these technologies allows viewing angles up to 180° with minimum degradation of contrast ratio and colour gamut. Each technology (TN+Film, VA, PVA, IPS, S-IPS, FFS) has its specific advantages and characteristics that should be chosen depending on the end application. Some offer faster response times, while others offer wider viewing angles, or higher immunity against image sticking.

The backlight sets the possible colour gamut

Colour saturation and colour gamut depend mainly on the LCD backlight. The colour gamut of the screen is referenced to the colour gamut possible with the NTSC standard set as 100%. A standard CCFL (Cold Cathode Fluorescent Light) typically used for LCD backlight has a colour gamut of only 31%. Consequently, panels using RGB LED backlights are of interest because they give a much higher colour gamut. Unfortunately, this is at a higher cost compared to CCFL lamps, although that might change in the near future as RGB backlight becomes more commoditized. However, new CCFL lamps were recently introduced offering a colour gamut of 90%, which is a big step forward and closes the gap with RGB LED backlight systems.

Using these technologies allows good picture quality. Another important parameter is the response time of the liquid crystal pixel to avoid motion blur.

Fast response time avoids motion blur

At the beginning of the LCD era, the response time was specified as black to white response time. While most of the displays have very fast black to white response times, the more important

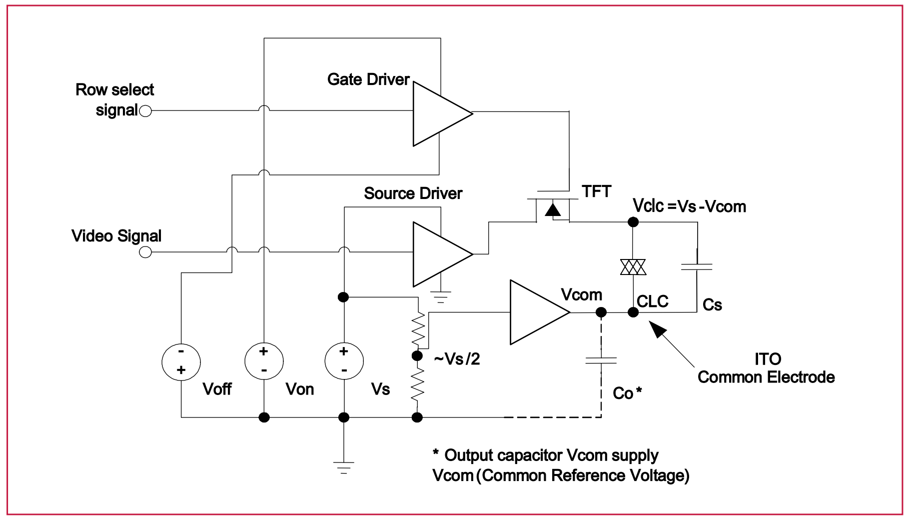

Figure 3: Implementation of the TFT, LC pixel and its driving supplies.

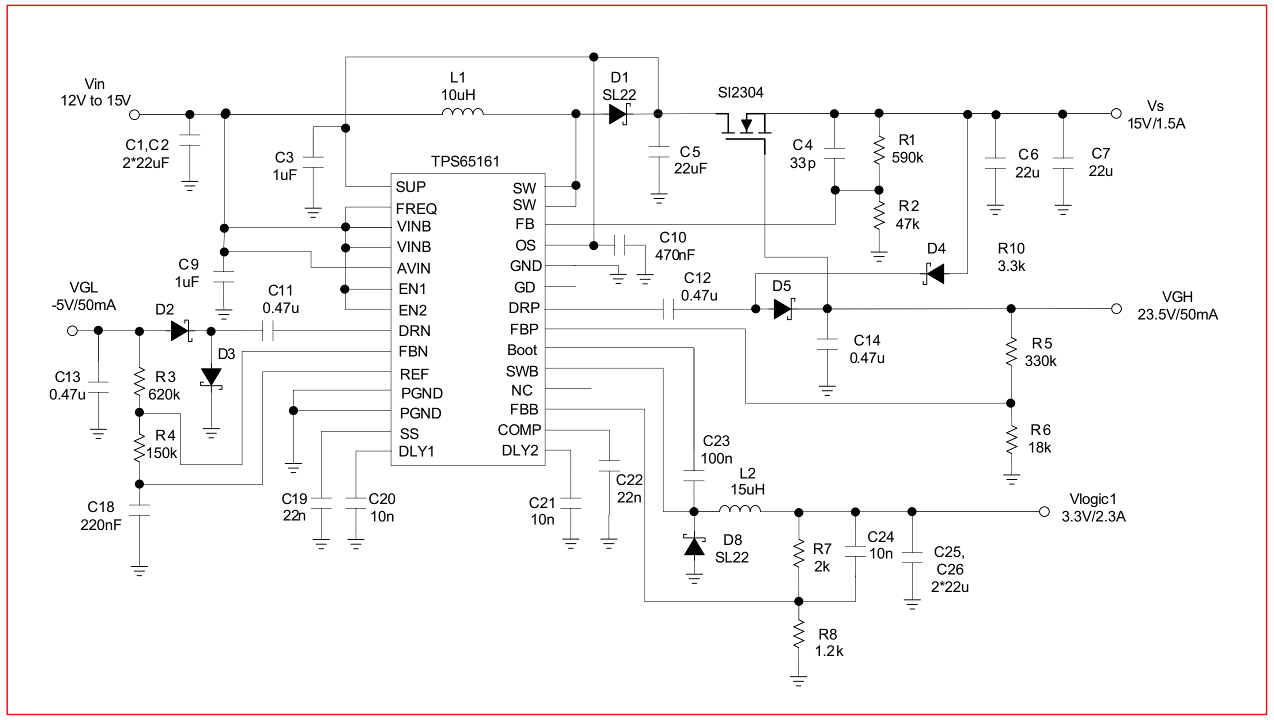

Figure 4: Compact LCD bias supply circuit.

parameter is the grey to grey level response time that is usually much slower. To improve the grey to grey level response time, liquid crystal materials with faster response times are being used. In addition to that, voltage overdrive of the TFT is applied and response times of 4ms and faster are currently achievable. (Some vendors already claim 2ms).

To support all the features discussed, specific power management and control ICs have been developed by semiconductor IC suppliers. The next section outlines the principal circuit to drive a LC pixel and an appropriate power supply and control solution.

Implementation and structure of TFT LC Displays

The implementation and principal structure of an active matrix display using the dot inversion driving method is shown in Figure 3.

Figure 3 shows the principal implementation of a LC pixel and the TFT. To drive the pixel and TFT, the following voltage rails are required:

a) Turn on voltage (Von or VGH) for the TFT in the range of 20V to 30V
b) Turn off voltage (Voff or VGL) for the TFT in the range of -5V to -7V
c) Source driver voltage (VS or AVDD) for the video signal and gamma reference voltages in the range of 7V to 18V
d) Common reference voltage Vcom. Vcom≈Vs/2

The common reference voltage Vcom is used to implement an AC signal across the LC cell. To implement a positive and negative swing across the LC cell, the video signal Vs is an AC signal with a swing between 0V and its nominal voltage e.g. 15V. The Vcom reference voltage is selected to be half of the source voltage (Vs). This implements a virtual ground and forces a positive and negative voltage across the cell. The Vcom reference voltage is implemented with a buffer (Operational Amplifier) to be able to source and sink current. To implement these different voltage rails, dedicated power supply ICs are used.

TPS65161 Compact LCD Bias IC

To simplify the LCD bias and control circuit and to minimize total solution costs, Texas Instruments provides several Compact LCD Bias ICs dedicated to specific end applications. TPS65161 is one example from a fast growing portfolio of Compact LCD Bias Supplies. The device runs from a 12V input voltage rail and provides all voltage rails as outlined in Figure 3. In addition a step down converter is integrated providing a 3.3V supply rail to power the timing controller (TCON) of the panel. Special care is needed in respect of power on sequencing of the different supply rails as well as high power supply efficiency in order to allow such high levels of integration for power supply circuits. The boost converter itself delivers 15V@1.5A. As an example, Figure 4 shows the TPS65161 optimized for high resolution large size LCD TV panels.

Conclusions

This article outlined the key requirements and display characteristics for modern LC panels as used in Notebook, Monitor and TV applications. However, to achieve an excellent picture quality the entire monitor or TV set has to be optimized. The power supply and control circuit discussed usually comes with the panel. For a complete system the graphic controller with its video scaler has a major impact on the overall picture quality as well. Therefore panel technology and driving circuits, as well as the graphic controller provided by the set maker, have to be optimized to achieve superior picture quality.

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Building Backlighting Solutions for LCD Displays

The proper choice of light source

Designers face three key choices when building backlighting solutions for today's wide variety of LCD displays: which light sources to use for the lamps, how to drive them, and how to improve quality and power efficiency using visible light sensors for automatic brightness control.

By Roger Holliday, Vice President, Strategic Business Development and Dr. Xiaoping Jin, Senior Systems Engineer, Microsemi Analog Mixed Signal Group

Designers face three key choices when building backlighting solutions for today's wide variety of LCD displays: which light sources to use for the lamps, how to drive them, and how to improve quality and power efficiency using visible light sensors for automatic brightness control.

Since the backlight unit consumes the most power within the display subsystem, these choices are not trivial. The right decisions can significantly improve battery life in portable products, while in the wide variety of other display applications the backlight design is critical for optimizing display brightness, contrast and viewer ergonomics.

Picking a Light Source

Most large LCD display backlight systems use either cold cathode fluorescent lamps (CCFL) or external electrode fluorescent lamps (EEFL) to provide the high-intensity illumination required for displaying full-motion video. Also in mass production are U-shaped CCFL and EEFL backlight configurations; however, since both require higher driving voltage than CCFL, their application is currently limited to screens below 32 inches.

Light-emitting diodes which produce a specific light within a narrow spectrum are providing another promising lamp source for backlight units. LEDs offer greater mechanical stability than CCFLs or EEFLs. Their short switching time and, by using a pulsed light source, can eliminate "smearing" effects of fast-moving images in LCD displays.

LED backlights can utilize single-color, multi-color or white LEDs. (Monochrome white LEDs actually mix blue and yellow light to create their white light.) Multi-color red/green/blue solutions, when available, promise to leverage advanced packaging techniques to significantly increase color options and color mixing.

Powering the Lamps

After selecting a light source, the next step is to power the lamps. To do this, backlight inverters must be able to drive backlight systems with high efficiency, low interference, reliable start-up and protection, and tight control of lamp current distribution under multi-lamp environments.

Most LCD backlights use straight lamps which, in low-cost screens below 20 inches, are generally mounted at the top and bottom edges of the panel. In larger panels, this approach risks problems with intra-lamp cross-coupling, uniformity of illumination, and heat concentration, so the preferred approach is to space the lamps evenly behind the panel.

In general, a lower-cost, single-ended wiring scheme is the most popular for screens below 32 inches. The drive voltage is applied only to the hot end of the lamps, with the other end grounded to the chassis. The voltage on the hot end can be a common single phase, or multiple phases. Better picture quality is possible by using an interleaved two-phase design, in which voltages between adjacent lamps are alternated by 180 degrees. The high voltage field is largely localized between two adjacent lamps, significantly reducing interference to the LCD display. Fig.1 shows a typical configuration using CCFLs.

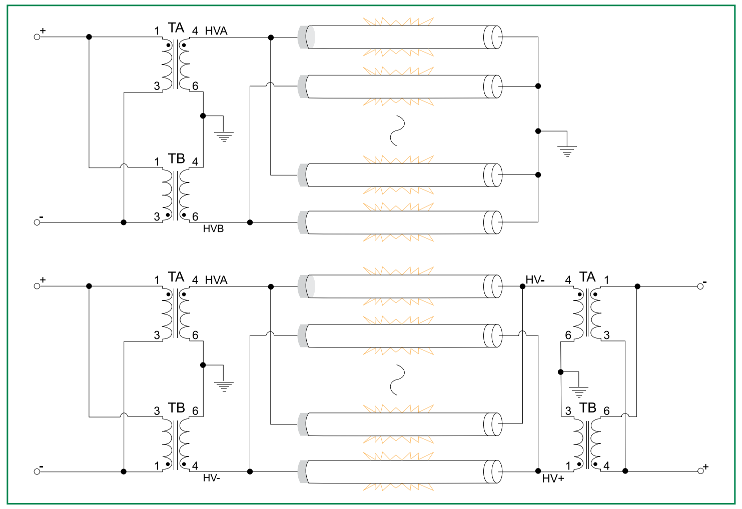

Figure 1: Typical Multi-CCFL Architecture.

In larger screens, the simplified, single-phase approach is often inadequate. A better solution is a floating lamp structure in which the high voltages are applied to both ends of the lamp, with a 180-degree phase difference of their fundamental frequency.

Regardless of whether a single-phase or floating lamp structure is used, inverter designers also must solve technical challenges related to lamp current balancing, striking, fault detection and synchronization.

Proper lamp current balancing ensures even brightness over the screen. This is difficult because the lamp's negative operating impedance and positive current-temperature characteristics accelerate current imbalance. Additionally, the lamps can exhibit unmatched parasitic parameters, especially the parasitic capacitance, which also can lead to lamp-current imbalance.

Striking is equally important and challenging, especially when multiple lamps are powered from a common output. When multiple lamps are paralleled, the voltage can be clamped to the lamp operating voltage of the struck lamps, thus preventing other lamps from successful striking. It takes careful design to guarantee reliable striking.

The third challenge is reliable fault detection. To ensure safety, each lamp' s open condition must be detected. In multi-lamp systems where lamps are powered from the same source, the transformer voltage may not rise when a single lamp is open.

Finally, the operating frequencies of multiple inverters must be synchronized in order to eliminate cross frequency interferences. Also, the phase relationship of inverter outputs must be controlled to ensure the desired driving voltage polarity. For high picture quality, inverter frequencies also must synchronize with video scanning frequencies to avoid an optical beating effect that appears as a moving bar on the screen.

There are several ways to meet these challenges with available circuit topologies while optimizing both performance and cost efficiency. The three basic topologies for LCD TVs are push-pull, half- bridge, and full-bridge.

The high total impedance of both push-pull and half-bridge circuits makes it difficult to get satisfactory lamp current waveforms over a wide input range. Full-bridge topologies perform better by using soft switching to minimize the interruption to circuit resonance characteristics. If a floating lamp architecture is used with a full bridge topology, system costs are increased since, as mentioned earlier, separate inverters are usually needed at both ends of the lamps. A patent-pending Microsemi soft-switching architecture illustrated in Fig. 2 achieves excellent performance with only half the power components by using two-switch inverter stages at each side of the panel to provide opposite phase voltages with separate transformers.

Microsemi also has a patent-pending soft-switching strategy for split-bridge architectures. Its advantage is that the waveforms on the two ends of the lamps always remain in 180-degree phase difference, compared with the varying phase angles of the phase-shifted method, resulting in improved current balancing in the presence of parasitic capacitances.

Once the topology has been selected, the designer must choose either an active or passive balancing scheme. Passive schemes rely on impedance-matching of the lamp circuit by purposely introducing more impedances into the system. This can be achieved with a ballast capacitor, shunt capacitor, inductor, or high leakage inductance of the transformer. While less costly, these solutions may be inadequate when imbalance is severe. Active balancing schemes work better because of their active self-correction mechanism. Balun is one example – when balanced, the flux generated by the two branch current cancels each other and the balun behaves like a pure DC resistance. When an unbalanced condition occurs, an error flux is generated to resist the unbalance condition. The inductance of each winding works like the open loop gain of a control system, and more turns are needed to minimize the balancing error.

Microsemi has developed a more versatile and cost-effective method called Jin balancing. As illustrated in Fig. 3, each balancer has two windings. During operation the circulation current in the secondary winding loop maintains the balance of the lamp current. Under balanced conditions, the magnetizing force from primary and secondary current cancel each other out. The effective magnetizing current is essentially zero. Flux is only generated under unbalanced conditions where the difference of the primary and secondary magnetizing force will induce a correction voltage in the balancer winding, thus forcing the current to balance.

This concept succeeds because of its active electro-magnetic coupling mechanism. Also, because the secondary winding is free from the lamp circuit, the signals from the secondary winding

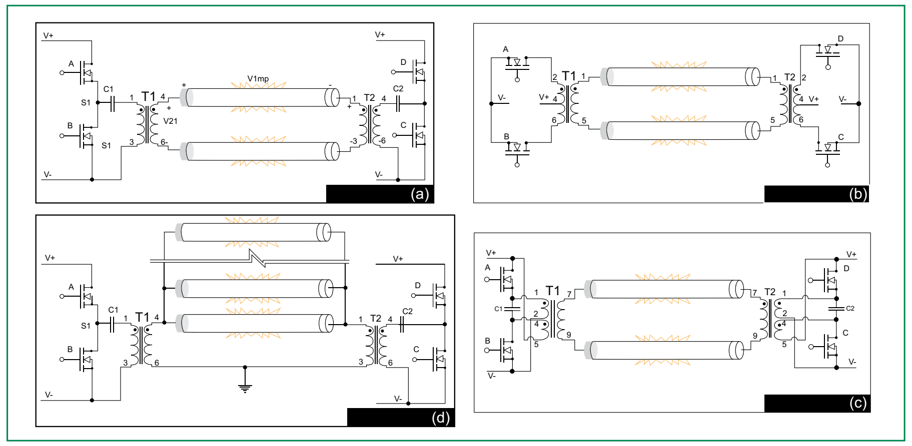

Figure 2: Split Phase Inverter Configurations For Floating lamp Structure.

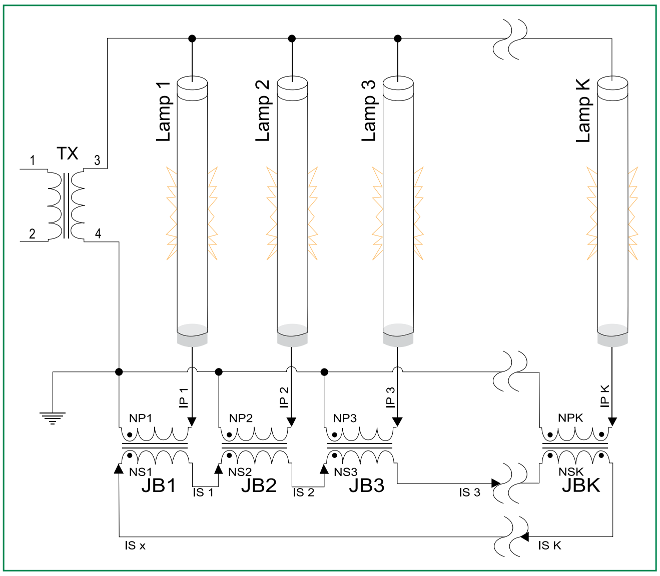

Figure 3: Jin Balancer Concept.

can be used anywhere in the system without restriction on the placement of primary winding. Jin balancing offers significant cost savings and design flexibility in multiple-lamp systems.

Automatic backlighting

In addition to selecting a light source and choosing an inverter design, it is important to consider automatic backlighting technology. Portable devices roam between vastly different ambient lighting conditions. Without automatic backlight control, users either tolerate poor-quality displays or must manually adjust the brightness setting. Automatic backlighting improves ergonomics and also drives substantial incremental power savings. For example, backlight power required for optimum display readability in a typical office environment is 0.73 watts less than in sunlight conditions.

Integrated circuit visible light detectors enable these automatic backlight control applications. These devices consist of an array of PIN diodes on a single substrate. The overall spectral response of the diodes within the array closely approximate that of the human eye. Their benefits can be realized whether the systems are backlit by CCFL or LED lamps.

One of the most challenging applications for automatic backlight control is the automobile, where CCFLs are the preferred choice because of their superior brightness capability. Automotive displays are used in both bright, sunlit ambient environments and at night. This requires outputs in excess of 600 candelas/m^2 (nits) during the day, or about four times the brightness of a typical laptop computer, and three to five nits at night. Dimming ranges must be in the ranges of 225:1, or more than 10 times those of the best typical computer displays.

There are two basic automatic backlighting control approaches. The first is simply to reverse the display contrast under software control, as ambient light changes to preset levels, but this is of only limited effectiveness and will not work with the increasing number of video-based applications. A better approach is based on integrated circuit control. In the case of automotive applications, this is done using a wide-range CCFL dimming control technique. It allows night-time display brightness to be reduced to less than one percent of its maximum daytime levels, and provides true, flicker-free uniform lamp-dimming across the extreme range of ambient light. In addition, integrated circuit control operates at much lower power levels and can be achieved with no incremental cost penalty.

Today's automatic backlight control systems can extend the battery life more than one-half hour in a typical laptop, and provide up to 20 more minutes of talk time for a cellular handset. Additionally, this approach reduces stress on the LEDs or CCFL lamps that illuminate the displays and can often improve lamp life by as much as three times.

Conclusion

The LCD display market is continuing in rapid growth, powered by increasing affordability and superior performance in a variety of applications, from the harsh, demanding environment of the automobile, to the complex demands of big-screen LCD TVs. The proper choice of light source, inverter technology and automatic brightness control solutions will result in the optimal implementation for the given application.

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