Tweaking LCDs to tune in television

By Dick McCartney
Chief Technologist
Flat Panel Displays
National Semiconductor Corp.
E-mail: dick.mccartney@nsc.com

Active-matrix liquid-crystal displays (AMLCDs) are establishing themselves as central contenders for large-screen TVs in the living room. This is no easy feat, given the demands of the consumer TV market for high performance at an affordable price. For AMLCDs to expand market share, panel manufacturers must find new ways to improve performance while reducing cost.

There are several performance challenges in display electronics when LCDs are applied to TV. First, there is the issue of sheer size and format. The 14-inch, XGA format (1,024 x 768 pixels) dominates the notebook PC, while the 17-inch SXGA format (1,280 x 1,024) dominates the LCD desktop monitor application. The entry point for large-screen LCD-TVs is the 30-inch-wide XGA plus (1,366 x 768); while at the higher-end of the market, at 40 inches and larger, is true HDTV (1,920 x 1,080). The HDTV format requires more than 2.5 times as much data per image frame as the wide-XGA plus format.

As XGA and SXGA applications for LCDs took root, the need for a solution with lower power consumption and reduced EMI was provided largely through the use of differential signaling and data transmission lines. Transmission-line theory treats the signal path as a waveguide rather than wire connections, which allows the signal shape to be preserved as it travels. The technology was introduced to move digital pixel data to each column line driver at the rates required to write all the pixels in a typical 1/60-of-a-second frame time.

TV requires signal integrity as much as laptop and monitor applications do, but the larger formats and sizes put new demands on the signal. Larger panel sizes associated with TV require signals to travel over longer distances, which translates into more opportunities for impedance-mismatch artifacts and cross-coupling. Also, at 30 inches or so, the column board that normally runs the full width of the display must be built as two separate boards to accommodate the size limits of PCB manufacturing. This adds more discontinuity to the signal path and corruption of the signal. It also complicates the efforts to minimize space through efficient signal routing. Furthermore, the current trend is to refresh the display at 90-120Hz to reduce the effects of motion-blur inherent in the scan-and-hold nature of AMLCDs.

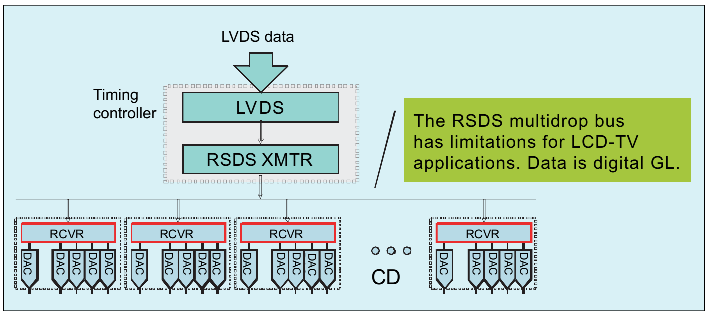

Figure 1: Multidrop differential bus operates across transmission lines to move digital video data into the column drivers.

Aside from these added strains on signal integrity, high-performance TV requires more gray scale per pixel than do computer applications. LCD-TV requires a 30bit pixel (10bits of gray scale per RGB color) rather than the 24bit pixel used in computer applications. This is necessary to eliminate contour boundaries that can develop in shallow luminance gradients, which exist in images such as a sunset sky or an ocean scene. The quantization of luminance across a spatial gradient can produce an objectionable visible line. This effect is exaggerated in TV because of the generally higher-contrast design.

In addition to the intrinsic reasons for additional gray scale, color and contrast, image-enhancement processing produces images with 30bit precision due to luminance scaling. An LCD's dark-ambient contrast is limited because the display cannot fully shut off the light valves that form each pixel—in short, the light valves leak. Contrast for a high-end LCD-TV today is approaching 1,000:1, while conventional LCD-TVs are only closer to half of that. To make up for this limitation, image processing has been developed to examine an image frame-by-frame and expand the range of the dominant luminance component. This allows images that have a narrow dynamic range of luminance (low contrast) to be scaled so that a larger number of gray levels can be seen.

One of the most important qualities of TV today is its color rendering. Consumers often choose TVs based on this feature. Consequently, much consideration is given on how to map the best image colors into the color space produced by a given LCD panel. This processing results in more RGB precision than what is present in the original image. Consequently, 10bit gray scale (30bit pixel) is required to properly render the image without truncation artifacts.

LCD users might find it surprising that LCDs are too slow for video applications. However, computer applications are very forgiving of slow pixel-response times. Broadcast TV is another story. Each frame—or each half-frame in the case of interlacing—is captured in less than 1/60 or 1/50 of a second. The moving component of the image is captured in sharper detail than a movie film frame; also, it must be rendered on the display screen at faster rates than frames are presented in movie theaters. This high presentation rate means that response time is much more of an issue for TV than for most other video sources, and it is particularly important for HDTV.

LCD-TVs require a response-time-compensation (RTC) overdrive block to compensate for the slow optical response of the LCD. The RTC block resident in the timing controller (TCON) intercepts the digital video stream and compares the previous gray-level command to each pixel with the current gray-level command. It then chooses a predetermined alternative gray level from a look-up table (LUT). The alternate value programmed into the LUT is experimentally chosen to bring luminance to the target value at the end of one frame. If the new gray level is lighter than the preceding one, a command is sent for a gray level that is initially lighter still. If the new gray level is darker, an exagger-

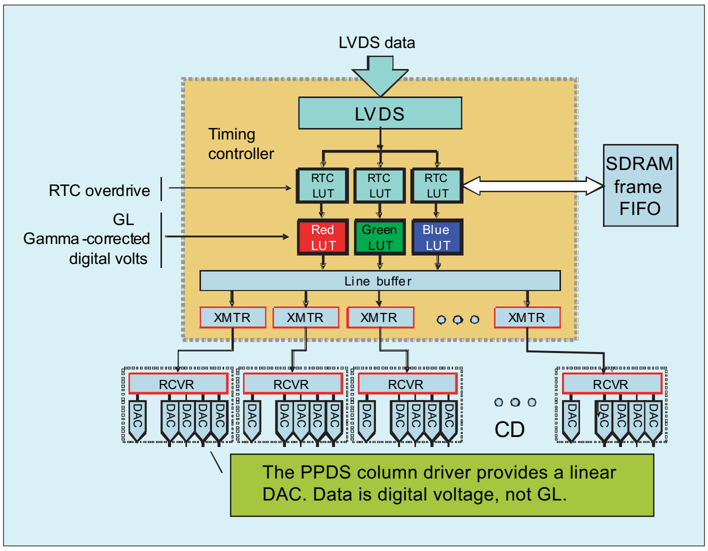

Figure 2: The PPDS architecture involves a system of separate point-to-point links instead of the conventional multidrop bus.

atedly darker command is initially sent.

Electronic architectural solutions that worked well for LCD monitors and laptops fall short when confronted by the additional demands posed by LCD-TV applications (**Figure 1**). The multidrop differential bus architecture operating across transmission lines to move digital video data into the column driver is heavily taxed by the LCD-TV application. The quality of the signal wave shape must be maintained to support the required faster data rates. To address these issues, some companies are exploring a cascade solution in which the conventional bus enters one end of a column driver, is buffered, and retransmitted to the next column driver. This converts the conventional bus into a point-to-point solution that has much higher signal quality, but it does so at the expense of additional column-driver I/O and circuitry. Remaking the bus architecture through cascading to improve signal integrity does not, however, address the broader requirement to provide more gray-scale precision, improved contrast, color management and other advanced features.

First, delivering cost-effective, 10bit per-color gray scale is a daunting challenge for the conventional resistive-string, digital-to-analog converter (RDAC), column-driver architecture. In the RDAC approach, which has been the exclusive solution for notebook and monitor applications to date, digital gray levels are sent to the column driver across a differential transmission-line bus. The column driver maps these values to one of the voltage nodes on a series resistance string. The column-driver design predetermines the required voltage at each of these nodes to command the LCD to the brightness associated with the particular gray level.

This dual-purpose RDAC function is highly efficient in a 64 gray-level (6bit) system. However, with the additional gray levels of a 256-level (8bit) system, the column-driver die area needed to bus both polarities of each of the 256 voltages from one end of the chip to the other, along with the circuitry required at each output to decode and select the voltage, dominates the die area. All things being equal, the die area at 1,024 gray levels (10bits) is just too large for this to be an effective solution.

At National Semiconductor, we made a departure from the conventional RDAC approach and created a column driver that uses a linear, cyclic DAC. This DAC is characterized by its small die area, which makes it possible to locate two copies of the DAC at each output–one for each polarity. While one DAC is busy converting incoming data for the next line, the other DAC is driving the line with the voltage converted during the previous line. A key feature of this DAC is its ability to scale to more bits of precision. More resolution simply requires more cycles of the same DAC circuit rather than more die area. With this architecture, we are able to provide a 10bit gray-level capability with a cost-effective die size. The die-size of a typical 10bit PPDS column driver is less than half the die size of a typical 8bit, RDAC column driver.

Figure 3: In PPDS architecture, the gamma tables that reside in the timing controller allow picture-in-picture windows to have different mappings.

Another advantage of this approach is that the inverse gamma function is decoupled from the DAC circuit. This means that each column-driver output directly converts digital voltage values into analog voltage values. The conversion from digital gray levels to digital voltages takes place upstream in the TCON. In other words, the inverse gamma function is provided in an LUT resident in the TCON, which provides great flexibility in mapping each gray level to brightness on the LCD panel. In fact, a separate LUT for each color is possible; real-time updates to accommodate different image sources, contrast expansion, color management and temperature changes are possible.

The column-driver architecture in **Figure 2** is part of the broader architecture called point-to-point differential signaling (PPDS). As the name implies, PPDS is not a multidrop bus, but a system of separate, point-to-point links–a single channel per column driver. This channel carries column-driver control information and digital voltage values that are converted into analog by the column driver. In the conventional bus architecture, data arrives at the column driver in burst mode. Only one column driver receives data at a time, using the bus as a shared, global resource. In the PPDS system, all the column drivers simultaneously receive their data. So even if there is a single differential channel supplying each column driver with data, the channel is used during the whole line time. Hence, clock frequencies between the two systems are significantly different.

In a PPDS system, column drivers can be individually controlled through the packet header sent to each column driver, line by line. This type of embedded control is needed because it eliminates the individual dedicated signals running between the column driver and TCON, saving space and cost. Flexible control of the column driver makes it possible to implement special waveform control. Successful driving of large-format, large-size TVs must include control of the panel-driving waveforms to optimize signal propagation and pixel-charging ratios.

The ability to provide independent RGB gamma tables allows the TCON to precisely correct the color temperature of each gray level. Independent RGB gamma LUTs allow each color to be gamma-corrected independently, providing constant color temperature across all gray levels and extending the acceptability of the technology to higher-performance applications. Direct access to the gamma LUTs allows gamma characteristics to be dynamically or adaptively adjusted in real-time, depending on the content, as determined by an image-processing unit in the TCON. Future configurations will be able to provide different gamma transfer functions in different windows of the display (**Figure 3**). A computer operating system could provide window boundary coordinates to the TCON and then have the it choose a different gamma LUT, depending on the region of the display being written.

Cinema-quality TV is one of the goals of large-screen TV manufacturers. One of the keys to cinema-quality images is gray-scale precision and color management. The PPDS architecture can support a full 30bit color precision from input to display surface. This precision, combined with the features derived from independent gamma LUTs, allows image processing that enhances the viewer experience. Color and contrast enhancement of an image results in higher gray-level precision in the image. The independent gamma LUTs provide a means to directly control the image quality without the need for dithering or other methods of approximating the desired luminance in each pixel.

In monitor and notebook applications, LCD-module electronics stayed in the background, taking in gray-level commands and providing control signals to produce exactly those gray levels. TV requires the panel electronics to provide added front-of-the-screen performance with more color depth, improved color balance, dynamic contrast, response-time compensation and controlled color temperature. With these innovations, many of which are enabled by the PPDS architecture, there is little doubt that the LCD TV may become the consumer's technology of choice. □