

Optimizing standard-definition video on high-definition displays

THE AVAILABILITY OF LARGE-SCREEN HD LCD TVs AND PLASMA DISPLAYS IS DRIVING THE POPULARITY OF DIGITAL-TV BROADCASTS AND HD-SIGNAL INTERFACES. HOWEVER, THE ABILITY TO SUPPORT LEGACY SOURCES WITH THE HIGHEST QUALITY REMAINS AN ESSENTIAL REQUIREMENT. THE 3-D-COMB VIDEO DECODER IS A CRITICAL PROCESSING BLOCK THAT CAN HEAVILY INFLUENCE OVERALL SYSTEM PERFORMANCE.

When designers initially developed television, it supported only the broadcast and display of images in monochrome—that is, black and white. As technology evolved, TV broadcasts also supported color, but they still needed to maintain backward compatibility with monochrome-TV-display equipment. They needed to accommodate color information within the avail-

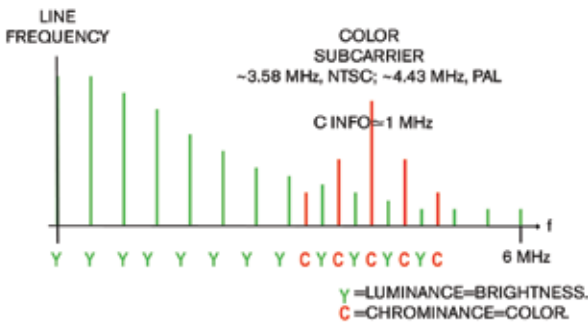


Figure 1 Luminance and chrominance information shares the same spectrum in a composite video signal.

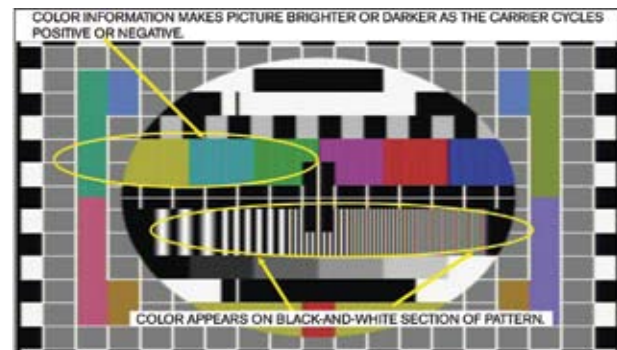
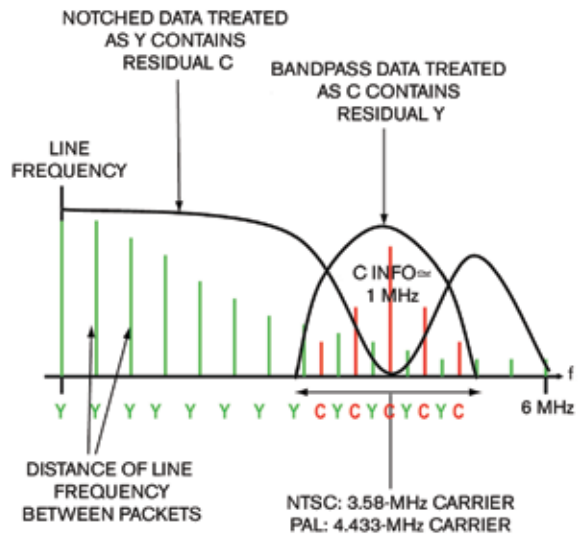


Figure 2 An image with no luminance and chrominance separation contains numerous artifacts.

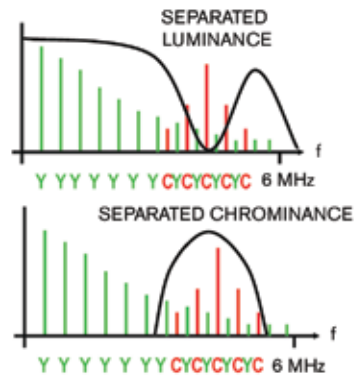


Figure 3 Notch filters and bandpass filters separate the luminance and the chrominance.

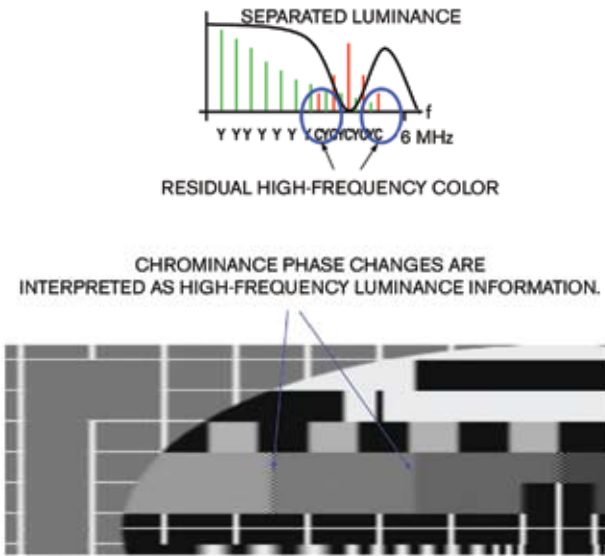


Figure 4 The TV falsely interprets residual color within the luminance path as luminance information, resulting in an undesirable dot-crawl effect.

able bandwidth and in such a format that earlier TVs would continue to show undistorted black-and-white displays.

In a composite video signal, color information shares the same bandwidth as the available luminance information. A sine wave with varying amplitude and phase represents the chrominance content of any transmitted image (Figure 1). You must therefore separate the chrominance and luminance from each other to correctly display the picture.

Chrominance information resides at the high end of the frequency spectrum and at multiples of the line length. The challenge on the display side is to correctly extract the lumi-

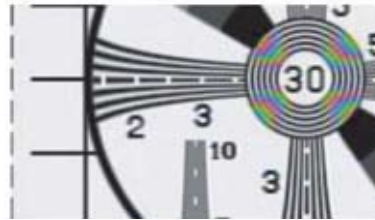


Figure 5 Residual luminance within the chrominance path causes cross-color artifacts.

nance and chrominance information and to maintain the full bandwidth without causing display artifacts. If no luminance-versus-chrominance separation occurs, color information makes the picture brighter or darker as the carrier cycles positive or negative.

Color information also incorrectly appears within black-and-white sections of the image (Figure 2).

Using a simple notch or bandpass filter to separate luminance and chrominance results in residual chrominance in the luminance signal path, and vice versa (Figure 3). The residual information that remains can result in severe image artifacts, such as “dot crawl” (Figure 4). Residual luminance information within the chrominance path can also cause artifacts such as “cross color” (Figure 5).

A comb filter adds a delayed version of a signal to itself, causing constructive and destructive interference. The frequency response of a comb filter comprises a series of regularly spaced spikes, giving the appearance of a comb. A 2-D comb filter provides higher video-decoder performance than that of notch and bandpass filters (Figure 6). It operates on the principle that, if an image has similar lines above or below the line of interest, you can more completely separate the chrominance and luminance. In the case of NTSC (National Television System Committee), the chrominance sine wave changes 180° from line to line. If any two consecutive lines are added together, luminance content doubles and chrominance content cancels. Conversely, if two lines are subtracted, the luminance content cancels and the chrominance content doubles. In an example with full-frame color bars, every active line is visually identical. At a given signal level, the luminance content of each line is the same. Apart from the phase changes, the chrominance content of each line is also the same.

Video decoders, such as those from Analog Devices (www.analog.com), use a five-line, 2-D comb filter, which provides better performance on NTSC and PAL (phase-alternating-line) sources. The comb processor must determine, depending on the complexity of the image, whether to combine the current line with the previous line or with the next line. It cannot perform any line combinations for certain images, and, in this case, it may instead notch the current line. An adaptive 2-D-

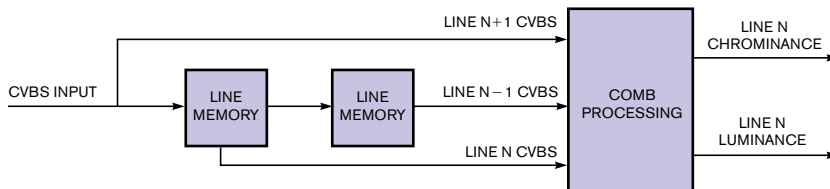


Figure 6 A three-line, 2-D comb would introduce a one-line delay from input to output.

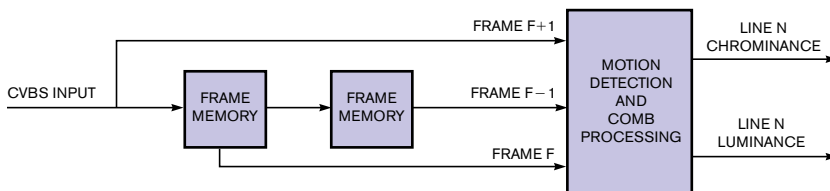


Figure 7 A typical 3-D-comb decoder architecture supplements the previous-generation 2-D comb's spatial implementation with added temporal cognizance.

comb video decoder can provide an acceptable level of performance. However, when consecutive lines are dissimilar, the 2-D comb cannot properly work and reverts to a notch filter to separate the luminance and chrominance for that area of that line.

Although it's important to successfully achieve luminance and chrominance separation without introducing image artifacts or bandwidth limitations—which translate into soft images—many other aspects of the video signal, such as a poor timebase or weak, nonstandard RF signals, also present challenges. Artifacts or image imperfections that were acceptable on smaller CRT displays become unacceptable on the new generation of LCDs and plasma displays. Due to higher resolutions, larger sizes, and greater display contrast ratios, even small image imperfections are now noticeable.

ADAPTIVE 3-D-COMB TECHNOLOGY

The combination of HD (high-definition) source material, a digital interface, and a high-resolution display provides an outstanding viewing experience. However, with the press of a channel change or input button, a user can go from viewing a beautiful HD image to viewing a legacy CVBS (composite-video-broadcast signal). Dramatic improvements in SD (standard-definition)-composite-video-image quality are achievable with the implementation of high-quality, adaptive 3-D-comb technology (Figure 7).

A 3-D comb is similar to a 2-D comb in that it separates luminance and chrominance by combining pixels from certain lines. The major difference is that, whereas a 2-D comb combines pixels from consecutive lines of the image, a 3-D comb combines pixels from the current line with pixels from the same line in a time-delayed version of the image (Figure 8).

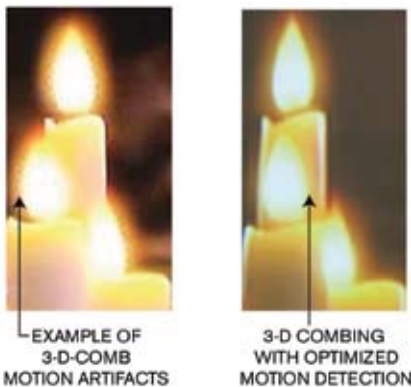


Figure 10 Combing images with motion introduces egregious artifacts.

The implementation of 3-D-comb video decoding delivers superior video. This approach can virtually eliminate objectionable image artifacts, such as dot crawl, “hanging dots,” and cross color. In addition, owing to the manner in which 3-D-comb video decoding separates the luminance and chrominance, the approach maintains the full bandwidth of both luminance and chrominance data packets. Full luminance bandwidth maintains the high-frequency content, providing sharp, clear images that allow the user to distinguish fine detail. Full chrominance bandwidth ensures brighter and better-defined colors.

Although 2-D combing relies on processing the adjacent ac-

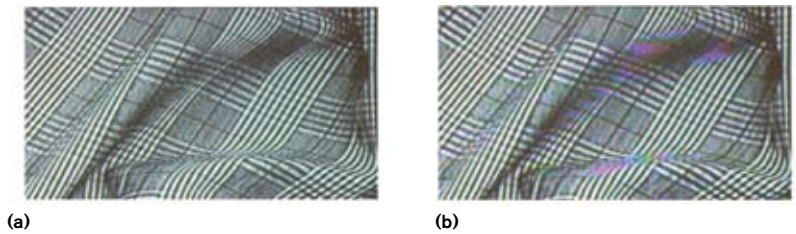


Figure 8 Adaptive 3-D-combing (a) results visibly improve on 2-D-only combing (b).

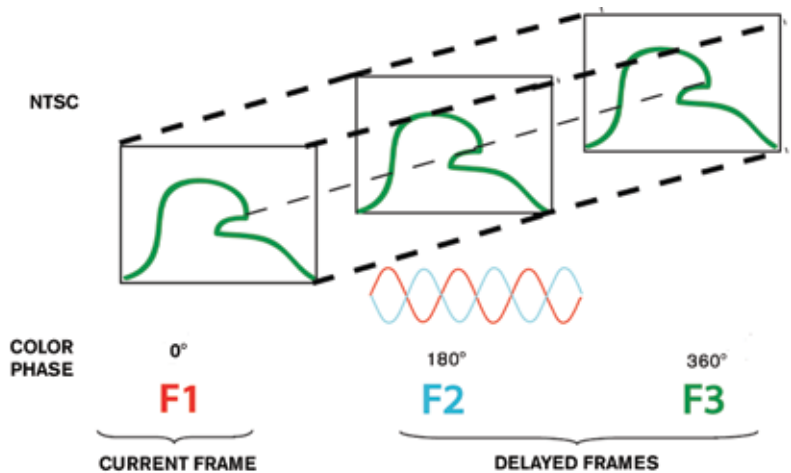


Figure 9 A typical NTSC frame sequence showcases the 3-D-comb filtering technique.

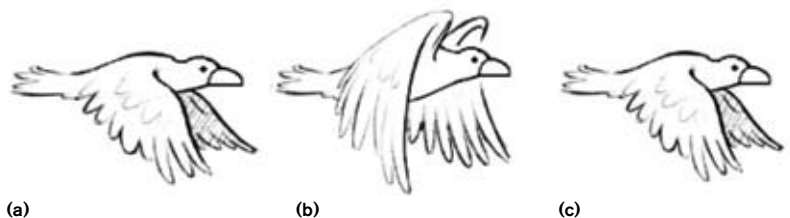


Figure 11 Adaptive 3-D combing relies on the ability of the decoder to correctly detect motion. This sequence is the normal order of events as a bird flaps its wings—the down position (a), the up position (b), and returned to the down position (c).

tive video lines, analyzing them, or both, 3-D processing compares frame-to-frame video-pixel information (**Figure 9**). It compares data from the current frame with data from a previous frame in memory. If you add both frames together, chrominance information for each pixel cancels, whereas luminance pixel data doubles. Likewise, if the previous frame subtracts from the current frame, luminance pixel data cancels, whereas chrominance information doubles.

Despite the advantages of 3-D-comb processing, designers must address its performance limitations and challenges. A 3-D comb allows perfect separation of luminance and chrominance in images that would cause legacy 2-D comb or notch filters to fail. However, it can achieve that goal only if the pixels in the image are absolutely still. Conversely, if the image is moving, and, hence, pixel data from two consecutive frames differs, you cannot use 3-D combing on the image (**Figure 10**). It is critical for the video decoder to examine each pixel, comparing it with previously stored pixel data, to determine whether motion has occurred and then decide on which type of comb to implement.

Because motion detection is complex, the approach you use must analyze every active pixel from the current and stored frames to determine which type of separation method to use. The 3-D-combing technique combs pixels with no motion, 2-D combing works on areas that are not complex with motion, and notch filters work on areas that are complex with motion. The key challenge of a 3-D-comb decoder is not the

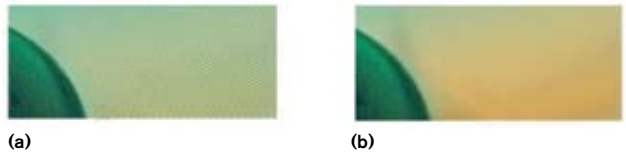


Figure 12 An invalid determination of 3-D-combing relevance results in visible mesh artifacts (a). With the corrected motion, no mesh artifacts occur (b).

3-D-combing process itself, but the complex motion detection and adaptive switching between 3-D, 2-D, and notch.

WHEN GOOD COMBS GO BAD

Adaptive 3-D combing relies on the ability of the decoder to correctly detect motion. Failing to do so causes the comb to incorrectly process pixel data, resulting in motion artifacts (**Figure 11**). The bird's wings are in the down position in **Figure 11a**. In **Figure 11b**, the wings have moved to an up position, and, in **Figure 11c**, the wings have returned to the down position. This sequence is the normal order of events as a bird flaps its wings.

Many 3-D-comb decoders examine frames 1 and 3 and, finding them the same, incorrectly assume that no motion has occurred. Therefore, they decide to 3-D-comb the data (**Figure 12**). High-performance video decoders with 3-D combs,

in contrast, use many frame memories to more accurately detect motion between all of the frames. Using a large number of frames is necessary for the decoder to make accurate decisions about where and when to apply the 3-D comb.

MAXIMIZING FEATURES

For a 3-D comb to properly function, memory buffers store the frames of video-pixel data for analysis and processing. Decoders such as Analog Devices' ADV7802 12-bit SDTV/HDTV video decoder with a 3-D comb filter and a graphics digitizer maximize memory usage by using it for other non-3-D-combing tasks, such as advanced temporal-noise reduction. As with 3-D combing, the ADV7802 uses techniques that compare pixel data from the current frame with previously stored data to filter and remove noise from the image.

External memory can also find use in implementing advanced timebase correction. Frame-based timebase correction ensures that the decoder always outputs a fixed output clock, a fixed number of samples per line, a fixed number of lines per frame, and the correct field sequence. Although this feature is not normally a requirement for TV applications, an increasing number of manufacturers are moving much of the receiver

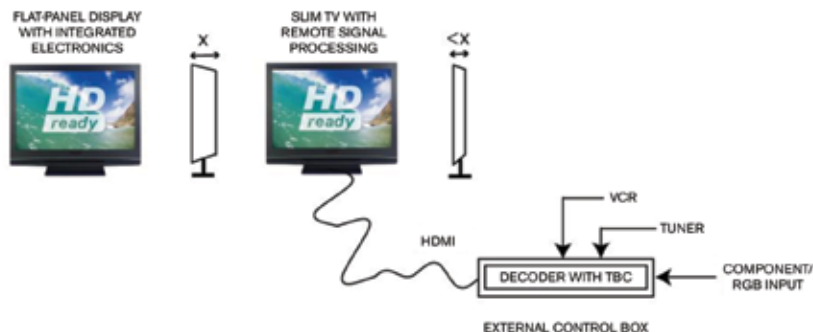


Figure 13 A low-profile display panel moves receiver and control electronics into a separate unit.

and control electronics into separate remote boxes to minimize the display panel's depth. This type of design also limits the number of cables you need to interface directly with the TV, which might be in a location in which wiring is awkward or difficult (Figure 13).

The remote box feeds the display through an HDMI (high-definition multimedia interface) or similar link. For this type of link to work, the TV requires stable pixel and clock data. Since timebase correction allows direct connection between the video decoder and the link's transmitting device, the decoder provides solid timing and pixel data even for nonstandard inputs.

Apart from luminance and chrominance separation, many other aspects of composite video processing directly influence display quality. The performance of the input ADC is critical to the overall video quality the display receives. Professional-quality video decoders, such as the ADV7802, deliver better than 62-dB SNR (signal-to-noise ratio) using a 12-bit ADC. It is important to note that the differential-phase and -gain figures for performance-driven applications can exceed 0.45° and 0.45%, respectively. Cost-sensitive applications may use a video decoder with nine-bit ADCs, such as the Analog Devices ADV7180.

The decoder must also be able to process nonstandard and weak broadcast-signal sources. TV customers and manufacturers continue to put great emphasis on these requirements. Consumers who have just purchased a new, high-end, large-screen plasma or LCD TV may continue to connect it, for example, to a 12-year-old VCR and an analog-RF-ca-

ble system. They expect at least the same level of performance from their HDTV when using their VCR as they had with their old CRT TV. This requirement means that the video from the VCR should be stable and continue to maintain lock even in “trick modes”—that is, when a user pauses, fast-forwards, or rewinds it.

Weak RF signals should also remain synchronized with color lock, even when the input signal drops below 25 dB μ V. Low-level RF signals and video signals with old, nonstandard systems present decoder designers with numerous challenges. The algorithms implemented are important considerations when you are benchmarking the quality level of the decoder. Many manufacturers market their capability to successfully process such signal sources. Analog Devices, for example, uses technology in its video decoders that incorporates synchronization detection and extraction, resampling, and advanced back-end FIFO management.

Intelligent filter algorithms, such as those in the ADV7802, use PLL (phase-locked-loop) blocks along with HSYNC (horizontal-synchronized) and VSYNC (vertical-synchronized) processor blocks to ensure the correct extraction of the synchronization information. The filters ensure that the decoder gates the time period in which it looks for synchronization information. The synchronization PLL blocks and processor blocks ensure the correct alignment of the detected synchronization. **EDN**

AUTHOR'S BIOGRAPHY

Frank Kearney is an applications-staff engineer with the advanced-TV segment of Analog Devices. He received a degree with distinction in electronics and telecommunications from the Limerick School of Engineering (Limerick, Ireland). Kearney has worked for the last seven years on customer applications involving high-performance video encoders, video decoders, video DACs, video codecs, and, more recently, silicon TV tuners.