

AS DIGITAL TELEVISION CONTINUES ITS FRUSTRATING NONEMERGENCE, INTEREST IN INTERIM TECHNOLOGIES THAT MAKE CURRENT VIDEO SOURCES LOOK THEIR BEST IS ON THE RISE. THESE ENHANCEMENTS MAY OBSOLETE HDTV BEFORE IT GETS OFF THE GROUND.



Illustration by Daniel Guidera

Video improvements obviate big bit streams

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THE REASONS BEHIND the slow-as-molasses rollout of digital terrestrial-television programming are well-documented and frequently discussed (**Reference 1**). Expenses for this technology include the high cost of equipment both at the video-capture, editing and encoding, and broadcast stages, as well as the nearly five-figure price tag for a full-blown digital television with tuner. Broadcast modulation schemes are hotly debated, although the FCC's late

January reaffirmation of the 8-VSB system for terrestrial broadcast may have finally resolved this issue. Also, Hollywood paranoia over the potential for illegal, lossless duplication of broadcasts has slowed the rollout of compelling video and film content (**Reference 2**).

However, many consumers have either seen or heard secondhand about the audible and visible wonders of next-generation television. Even if they haven't, it would be foolhardy to underestimate the marketing power of the word "digital" (**Reference 3**). TV manufacturers, who by now had hoped to be selling a lot of expensive new sets with tuners, have instead switched to a bridge sales strategy.

They're promising consumers the best reproduction of existing video sources via new progressive-scan televisions, and they're providing for future digital TV reception via provisions for off-board tuners. Camcorder, satellite-receiver, set-top-box, and DVD-player suppliers are also using the same pitch to upgrade consumers' video-generation equipment.

How much of this image improvement is actually possible, and how much is marketing hype? What can you do to translate quality-enhancement *potential* into *reality* and at what incremental bill-of-materials cost? To fully understand next-generation television, you should first make sure you understand today's

TV technologies, such as NTSC, PAL, and SECAM, and how these standards came about.

DISPLAY PROGRESS(IVE)

Early televisions used imprecise, slow electron-scan guns, and video transmission and reception bandwidth was scarce and expensive. As a result, the NTSC defined a 525-line video frame, which refreshed 30 times/sec and consisted of two interlaced 262.5-line fields of odd and even lines (**figures 1a** and **1b**). Field updates occurred 60 times/sec for the initial black-and-white broadcasts, slowing to 59.94 fields/sec (or a 15.734-kHz line frequency) when the NTSC added color (chroma) information to the broadcast signal (**Figure 2**). The NTSC system uses approximately 45 lines of each two-field frame for synchronization, vertical-rectangle-blanking, and closed captioning, which leaves approximately 480 lines to carry actual per frame image data.

PAL defines a two-field, 625-line-per-frame interlaced signal, which refreshes at a 50-Hz field rate and is equivalent to a 25-Hz frame rate or 15.625-kHz line frequency; SECAM uses PAL-like timings and vertical resolution but employs unique chroma-handling techniques. This article uses NTSC-based terminol-

AT A GLANCE

▶ Enhancement technology helps today's video look its best and may make HDTV unnecessary for most consumers.

▶ Deinterlacing video material and viewing it on a progressive-scan display especially improves the visual quality of objects in motion.

▶ Inverse telecine reverses most of the "damage" done to film in adapting it to interlaced displays.

▶ Upscaling and downscaling algorithms transform incoming image resolutions and aspect ratios to match output devices, but you must ensure they don't blur details or add objectionable distortions.

▶ See part 2 (*EDN*, June 7, 2001) for more on video quality, specifically color, noise removal, and edge enhancement.

▶ Part 2 also includes a hands-on shootout to separate propaganda from picture perfection.

ogy. If you live outside of the United States, or if you live within the United

States but, in search of maximum-possible vertical image resolution, have invested in a PAL-compatible DVD player, movies, and display, use 25 frames/sec and 50 fields/sec instead of 30 frames/sec and 60 fields/second, respectively.

All but the latest generation of TVs are interlaced, so until recently, all video cameras also captured interlaced images—first all odd lines in the frame, followed by even lines $\frac{1}{60}$ sec later. And, in an era in which televisions that measured more than 20 in. diagonally (the largest size for which the 1939 black-and-white television specification was intended) were unimaginable, interlacing worked well. However, a field-refresh rate of 60 Hz isn't fast enough to prevent the onset of visible phosphor decay between redrawn lines. The television freshly redraws one set of lines, even or odd, as the other set fades. This step helps minimize the phosphor-decay problem, because your eyes and brain interpolate across scan lines and recreate some semblance of the missing information. However, the result is an overall softening of the image, along with flicker that's particularly noticeable in a dark room.

Interlaced-image capturing produces acceptable results if the subjects you videotape are still. But if the subjects

HIGH-QUALITY VIDEO MEETS THE INTERNET

Just as large-screen televisions are motivating consumers to purchase high-quality video-output equipment, large CRT and LCD progressive-scan computer displays, coupled with high-bandwidth Internet connections, are stimulating an increasing focus on streaming and download-and-play-video quality. Look at any of today's modern video-editing programs or lossy video encoders. You'll find the same sorts of quality-improvement capabilities as those for TV.

For example, consider the RealVideo format. Since the development of version 7 of the RealProducer video encoder, RealNetworks has included a suite of editing filters, such as deinterlacing, inverse telecine, and low and high noise reduc-

tion. By lowpass filtering high frequencies, high noise reduction tends to eliminate fine image detail. Any good lossy video encoder automatically discards redundant frame-to-frame information, so an inverse-telecine filter may not dramatically reduce the compressed bit rate, but it will improve the quality at that bit rate. Multipass analysis increases encoding time but enables the algorithms to tune their functions to the exact characteristics of the source material. VBR (variable-bit-rate) video encoding, as with VBR lossy audio, enables encoders to intelligently allocate bits across frames as necessary (**Reference A**).

RealVideo 8 introduced a new video codec that RealNetworks based on Intel's H.263 research.

And although RealProducer optionally downscales incoming video as part of encoding, it doesn't support upscaling, for a good reason. Why ship more bits than you need from the server to each receiving client? Instead, the RealPlayer decoder handles on-the-fly upscaling, otherwise known as a *zoom* function. RealProducer provides another interesting feature—a video-quality index, which can help you find out whether your encoded bit stream is insufficient to meet your resolution, frame rate, or other quality expectations. It also indicates whether you've created an unnecessarily large bit stream that will take too long to download or require an excessively fast Internet connection and large burden on the

server (**Reference B**).

Encoding tools from other proprietary codec developers such as Apple, in partnership with Sorenson, and Microsoft are beginning to include similar capabilities, as are utilities for industry-standard codecs, such as Ligos Technology's GoMotion and LSX-MPEG encoders. You also have the option of enhancing quality prior to encoding, using tools such as Adobe's Premiere, Media 100's Cleaner, and Sonic Foundry's Vegas Video.

REFERENCES

- A. Dipert, Brian, "Digital audio breaks the sound barrier," *EDN*, July 20, 2000, pg 71.
- B. Dipert, Brian, "Hot & streamin'," *CommVerge*, April 2000, pg 28.

move, their locations within the frame shift between the time that the camera captures one set of lines (for example, odd) and when it captures the other set (even) (**Figure 3**). Look closely at an interlaced display, and you can see artifacts, which go by names such as feathering, jaggies, twitter, judder, and line crawl. Keep in mind that although the dimensions of the average home and, therefore, the distance from the television screen to the sofa in the living room haven't grown significantly in the decades since NTSC's unveiling, the average screen size *has* grown. Videophiles with front-projector systems and large screens were the first to notice NTSC's shortcomings. However, the deficiencies are becoming widely known, particularly as consumers grow more familiar with the high-resolution,

ACRONYMS

ATSC: Advanced Television Systems Committee

DCDI: directional correlational deinterlacing

DLP: digital light processing

DTV: digital television

DVD: digital versatile disk

DVI: Digital Visual Interface

EDTV: enhanced-definition digital television

FCC: Federal Communications Commission

HDTV: high-definition digital television

PAL: phase-alternation line

RGB: red, green, blue

SDTV: standard-definition digital television

SECAM: Sequential Couleur Avec Memoire

USB: vestigial sideband

XGA: extended graphics adapter

fast-refresh, and progressive-scan capabilities of their computer monitors and experience their first digital-ready TV demonstration at their local electronics stores.

Part of the solution to the video-quality problem involves employing a progressive-scan display, such as a computer-monitor-like CRT, an LCD, a DLP, or

a plasma unit. Progressive-scan displays refresh all of the scan lines consecutively, from top to bottom (**Figure 1c**). The CRT phosphor-decay problem is even more critical with progressive-scan displays than with interlaced displays, because you don't have fresh, even scan lines to visually reinforce fading odd lines and vice versa. So the entire progressive-

WHAT'S NEXT?

This article focuses on video-quality improvements primarily related to scan lines and, therefore, vertical resolution. Numerous other enhancement opportunities also await your inspection, including improvements in color decoding and luma/chroma separation to maximize horizontal resolution and decrease cross-color and

cross-luminance artifacts, with proper signal interconnection between video-generation and -display devices. Detection and elimination of both analog and digital noise and compression artifacts is possible, as is color augmentation and object-edge enhancement, or sharpening. Part 2 of this article in *EDN's* June 7, 2001 issue will

explore these topics in depth.

Nearly all vendors claim to support quality features, such as video deinterlacing, scaling, and inverse telecining that only one or a few companies once provided. But are these features *really* present, or are they just marketing hype? If they do exist, how well do they work? To answer these questions, in part

2 I also put a number of video products under the microscope in a hands-on shoot-out (**Table A**). As a result of this work, I'm hoping to understand whether and when it makes most sense to put video-enhancement technology in the source, in the destination, or somewhere in between.

TABLE A—VIDEO-GENERATION, -ENHANCEMENT, -DISPLAY AND MEASUREMENT PRODUCTS IN HAND OR ON THE WAY

Video-generation equipment	Video-enhancement equipment	Video-display equipment	Video-evaluation hardware and software
<p>Audio Authority 09A60 VGA to component video adapter</p> <p>Ayre Acoustics D-1 DVD/CD Player with VR2 progressive-scan video option</p> <p>Canon ES4000 Hi-8 camcorder</p> <p>Intel Pentium 4 1.5-GHz PC, including Nvidia GeForce3 graphics subsystem (with S-Video, DVI, and analog RGB outputs); 3Dlabs VX1-1600SW graphics subsystem (with LVDS and analog RGB outputs); Terk TV35 and TV50 digital-television antennas; Teralogic Janus DTV decode board; software DTV decoders from InterVideo and Raviscent Technologies; BroadLogic DTV tuner board; and DVD decode software from Cyberlink, MGI Software, InterVideo, Mediamatics, and Raviscent</p> <p>Panasonic PV-DV101 digital camcorder</p> <p>Toshiba SD2108 DVD video player (interlaced output) and SD9200 DVD audio player (progressive output)</p>	<p>DVDO (Silicon Image) iScan Pro</p> <p>Faroudja/Sage FLI2200 evaluation board</p> <p>Focus Enhancements QuadScan Elite</p>	<p>Apple Cinema Display 1600×1024 pixel 16:9 LCD</p> <p>Mitsubishi MegaView Pro 27 29-in. 4:3 CRT</p> <p>NEC E1100 21-in. 4:3 CRT computer monitor</p> <p>Princeton Graphics AF3.0HD 32-in. 16:9 CRT</p> <p>Silicon Graphics 1600SW 1600×1024 pixel 16:9 LCD</p>	<p>DisplayMate Technologies Multimedia with Motion</p> <p>Joe Kane Productions Video Essentials</p> <p>Kayye Consulting edition of DisplayMate for Windows</p> <p>MadOnion.com VideoMark 2000</p> <p>Ovation Software Avia Guide to Home Theater</p> <p>Sage/Faroudja test pattern DVD</p> <p>Sarnoff JNDmetrix-IQ</p> <p>Score CP290 Color Analyzer and VP300 Video Generator</p> <p>THX Optimode and WOW!</p> <p>Unapix Entertainment Ultimate DVD Platinum</p>

scan CRT frame refreshes at 60 Hz. Progressive-scan displays based on LCD, DLP, or plasma technology aren't subject to the same phosphor-decay problem as CRTs and can refresh more slowly. However, they're still subject to the approximately 24-frame/sec minimum refresh rate required to fool your eyes and brain into thinking that consecutive still frames are actually continuous motion.

BOB AND WEAVE

Once you have a progressive-scan display, how are you going to present interlaced-captured 60-field/sec content on it? If the objects in the image are at rest, the deinterlacing, or line-doubling, solution is simple (Figure 4a): You stitch the odd and even fields together, in a technique commonly called *weave*. But how rare and boring is a still-life video sequence? If objects are in motion, particularly as fast as objects in sporting events and music videos, for example, you have a problem: If you simply combine the odd and even fields, you end up with motion artifacts.

An alternative approach involves doubling up the odd scan lines to form an entire frame, then duplicating the even lines to form the next frame (Figure 4b). This approach, often referred to as *bob*, eliminates many of the motion artifacts but

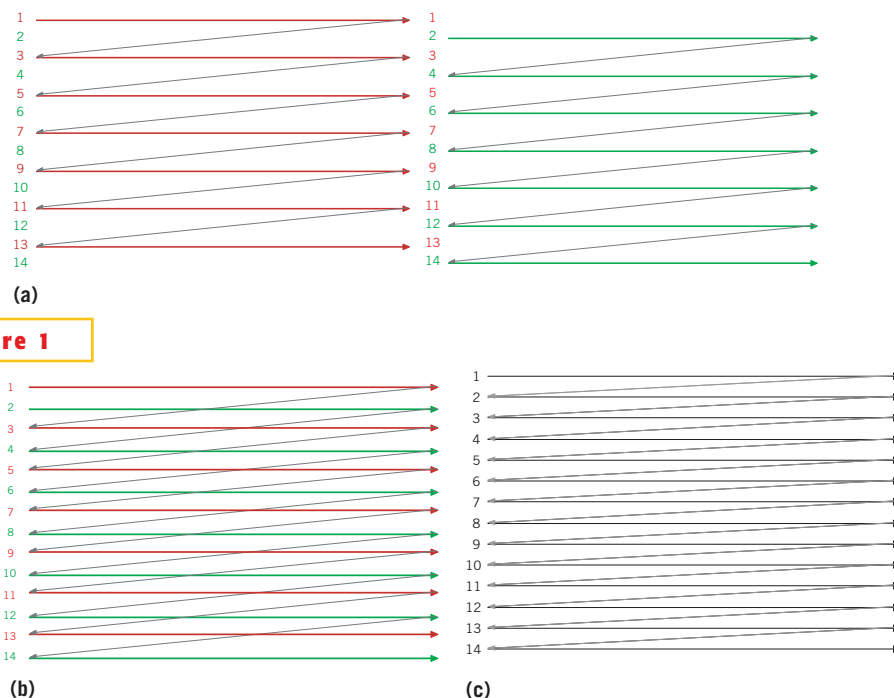


Figure 1
Interlaced television outputs odd and even fields (a) 1/60 sec apart to create a complete frame (b). Progressive displays, in contrast, sequentially output all scan lines in one pass (c) (courtesy Silicon Image).

induces its own problems. Objects' horizontal edges that align with one of the original interlaced scan lines, or stripes one scan line thick, appear and disappear from frame to frame, causing annoying flicker. By using only one field's scan lines to create the entire frame, you effectively halve the vertical resolution of that

TABLE 1—ATSC BROADCAST OPTIONS AND THEIR REQUIRED DISPLAY-LINE FREQUENCIES AND UNCOMPRESSED VIDEO BANDWIDTHS

Common name	Horizontal resolution (pixels)	Vertical resolution (pixels)	Total per-frame pixel count	Aspect ratio	Frame frequency (Hz) (progressive) or field frequency (interlaced)	Required horizontal-scan frequency (kHz) ¹	Required video bandwidth (MHz) ²
1080i (D3)	1920	1080	2,073,600	16:9	59.94 (interlaced)	33.72	37.09
					29.97 (progressive)	33.72	37.09
					23.98 (progressive)	26.98	29.67
720p (D4)	1280	720	921,600	16:9	59.94 (progressive)	44.96	37.09
					29.97 (progressive)	22.48	18.54
					23.98 (progressive)	17.99	14.84
480p (D2)	704	480	337,920	16:9	59.94 (progressive)	31.47	13.5
					29.97 (progressive)	15.74	6.75
					23.98 (progressive)	12.59	5.4
				4:3	59.94 (progressive)	31.47	13.5
					29.97 (progressive)	15.74	6.75
					23.98 (progressive)	12.59	5.4
	640	480	307,200	4:3	59.94 (progressive)	31.47	12.59
					29.97 (progressive)	15.74	6.29
					23.98 (progressive)	12.59	5.04
480i (D1)	704	480	337,920	16:9	59.94 (interlaced)	15.74	6.75
				4:3	59.94 (interlaced)	15.74	6.75
				4:3	59.94 (interlaced)	15.74	6.29

¹ Horizontal-scan frequency includes scan lines needed for blanking interval.

² Assumes 4:2:2 chroma sampling. Lower video bandwidths reduce the displayed horizontal resolution.

frame. And where field-to-field pixel variations are a result of diagonal edges and not object movement, the edges end up with indistinct, distorted appearances.

More elaborate versions of bob and weave interpolate the missing scan-line information in each artificially constructed frame, either from nearby pixels in the same field's scan lines or from pixels at identical locations in past and future fields (Figure 4c). The number of pixels that the interpolation process uses and the proportional priority given to the information in each of these pixels differentiates the alternatives. The more complex the algorithm, the more logic gates or lines of code you need to execute it and the faster those gates or the processor running that code needs to operate. Also, the more pixels you use in the interpolation process, the more buffer memory you need to hold the pixels' respective scan lines.

The best approach to deinterlacing combines the best aspects of both bob and weave. Motion-adaptive deinterlacing selects a temporal or spatial-interpolation algorithm for moving and stationary objects, respectively (figure 5a and 5b). The selection occurs either on a field-by-field, pixel-group-by-pixel-group, or, ideally, pixel-by-pixel basis, because different sections of the image of-

ten move in different directions and at different speeds. How can you tell whether a pixel is in motion? The answer to this question represents the black-magic proprietary technology that no developer is willing to publicly divulge. The Faroudja division of Sage, for example, touts its DCDI, which, according to the company, works well on diagonal edges.

If the deinterlacer resides within a DVD or DTV decoder chip prior to the digital-to-analog video-conversion step, you may think it can use the MPEG motion vectors; some first-generation deinterlacers have exclusively employed this technique. Reliance only on motion-prediction vectors is, however, of questionable benefit. Motion vectors do not always correspond to actual motion; rather, they are useful for mathematical expediency. A motion-vector shift may, for example, reflect nothing more than a change in scene lighting that creates a better block-to-block match elsewhere, even with no object motion present.

The deinterlacing-algorithm selection represents a balance of quality and cost. National Semiconductor's Mediamatics DVD decoding chips, for example, use flag-controlled deinterlacing algorithms, and the company's software DVD decoders employ bob and weave techniques. National plans to migrate to three-field motion-adaptive deinterlacing for next-generation devices and software revisions. Videophiles would probably insist on more sophisticated techniques; whether they can see the difference between the low-cost and more expensive deinterlacing alternatives, except perhaps on test patterns, is debatable. However, National Semiconductor's fu-

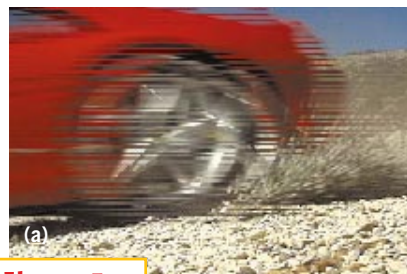


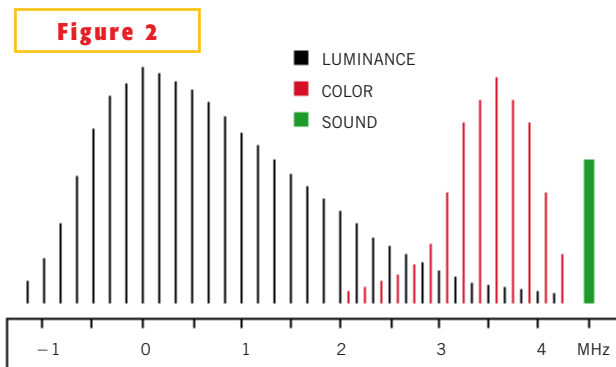
Figure 3



Interlaced-captured video of objects in motion produces fringing effects (a), which mimic the artifacts seen after telecining film content. Interpolation to deinterlace video and inverse telecining of film create a more accurate image presentation (b) (courtesy Faroudja subsidiary of Sage).

ture approach will likely be adequate for the mainstream DVD players and PCs that use the company's chips and software. ATI Technologies' Radeon graphics architecture similarly represents one of the first appearances of hardware-accelerated motion-adaptive per-pixel deinterlacing in PCs.

Remember, too, that DVD decoders, like DTV decoders and graphics accelerators, employ a unified memory architecture and that they use memory not only for deinterlacing but also for audio and video decoding, scaling, and other functions. The choice of deinterlacing algorithm hinges not only on available memory density but also on available memory bandwidth and on the number of functions simultaneously contending for that bandwidth. Graphics accelerators integrated in core-logic chip sets tend to offer limited features and performance compared with stand-alone high-



Composite video, such as the video standard used in NTSC broadcasts, intermingles chroma information with high-frequency portions of luminance and places it nearby audio data.

TABLE 2—OPTIONS AVAILABLE TO DTV BROADCASTERS FOR EACH FCC-ALLOCATED CHANNEL

In 19.4-Mbps bandwidth, a broadcaster can provide*:

- One HDTV signal (1080i or 720p) plus data,
- three EDTV signals (480p, 60-Hz refresh) plus data,
- six EDTV signals (480p, 30-Hz-refresh) plus data, or
- six SDTV signals (480i, 60-Hz-refresh) plus data.

* Compression efficiency depends on both source-material characteristics and desired visual quality. The actual number of EDTV and SDTV signals per broadcast channel may be lower than these estimates.

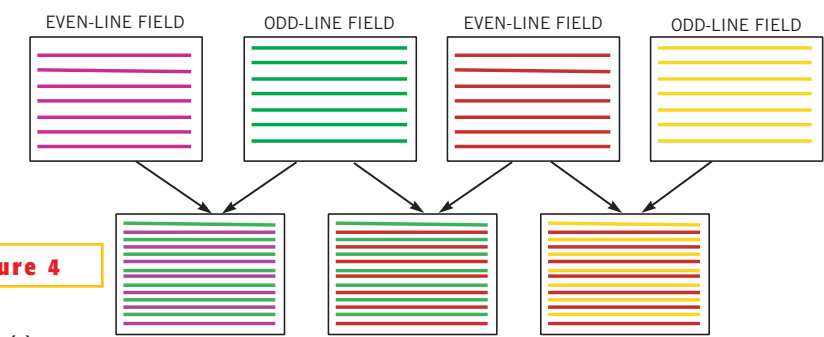
end graphics chips, and similarly, you can't expect an integrated deinterlacer to match the quality of a separate chip tuned for that purpose.

FORMATTING FILM

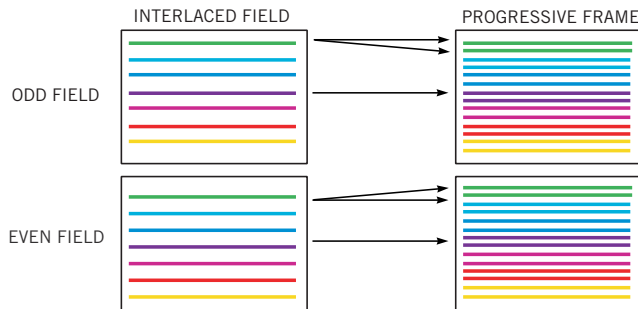
Extracting maximum quality from an interlaced video source for output to a progressive display involves a lot of work. Many video sources, however, aren't interlaced. Examples include progressive-scan video cameras, film, and computer graphics. Theoretically, it should be much easier to progressively display this material. However, reality is more complicated, specifically if the video creators assume their products will appear on an interlaced display. For example, consider a DVD player.

To encode 24-frame/sec film onto a DVD, movie studios put the film through a video-conversion process called telecining, also called 3:2 pulldown (Figure 6a). Not all of the resultant fields are stored on the DVD video disc; embedded control flags instruct the DVD decoder chip to repeat_first_field and put top_field_first, for example. Note, though, that use of these flags, as well as picture_structure=frame, picture_structure=top field, picture_structure=bottom field, and the self-explanatory progressive_frame, is optional. If the flags are absent or if they're incorrectly coded, interlaced display is relatively unaffected. But missing or incorrect flags can cause havoc for an inverse telecine algorithm.

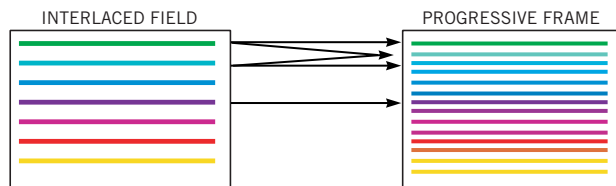
Why bother with inverse telecining? Two out of every five telecine-encoded video frames contain fields from different film frames. Any motion within the scene produces artifacts similar to, but possibly even worse than, the feathering phenomenon. At least with uncorrected interlaced-captured video, you display a series of fields captured in correct chronological sequence—odd field 1, even field 1, odd field 2, even field 2, and so forth. With telecine-converted film, you end up combining even field 2 with odd field 1 and dis-



(a)



(b)



(c)

Video-deinterlacing-algorithm alternatives include weave, which combines fields (a); bob, which replicates fields (b); and interpolating between fields (c) (courtesy Silicon Image).

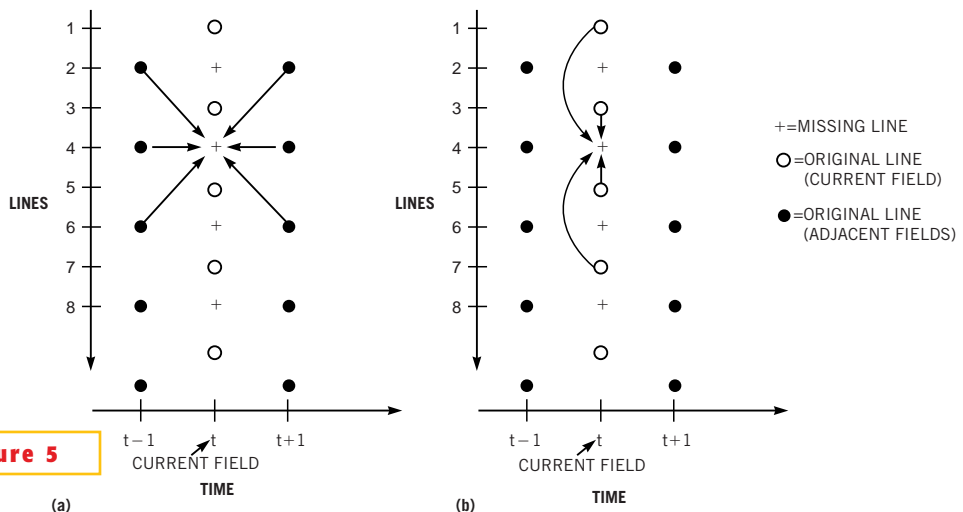


Figure 5

Temporal interpolation (a) works best with objects in motion; spatial interpolation (b) gives the most accurate results for pixels representing stationary objects. Advanced adaptive algorithms work with subfield resolution, ideally at the per-pixel level (courtesy Faroudja subsidiary of Sage).

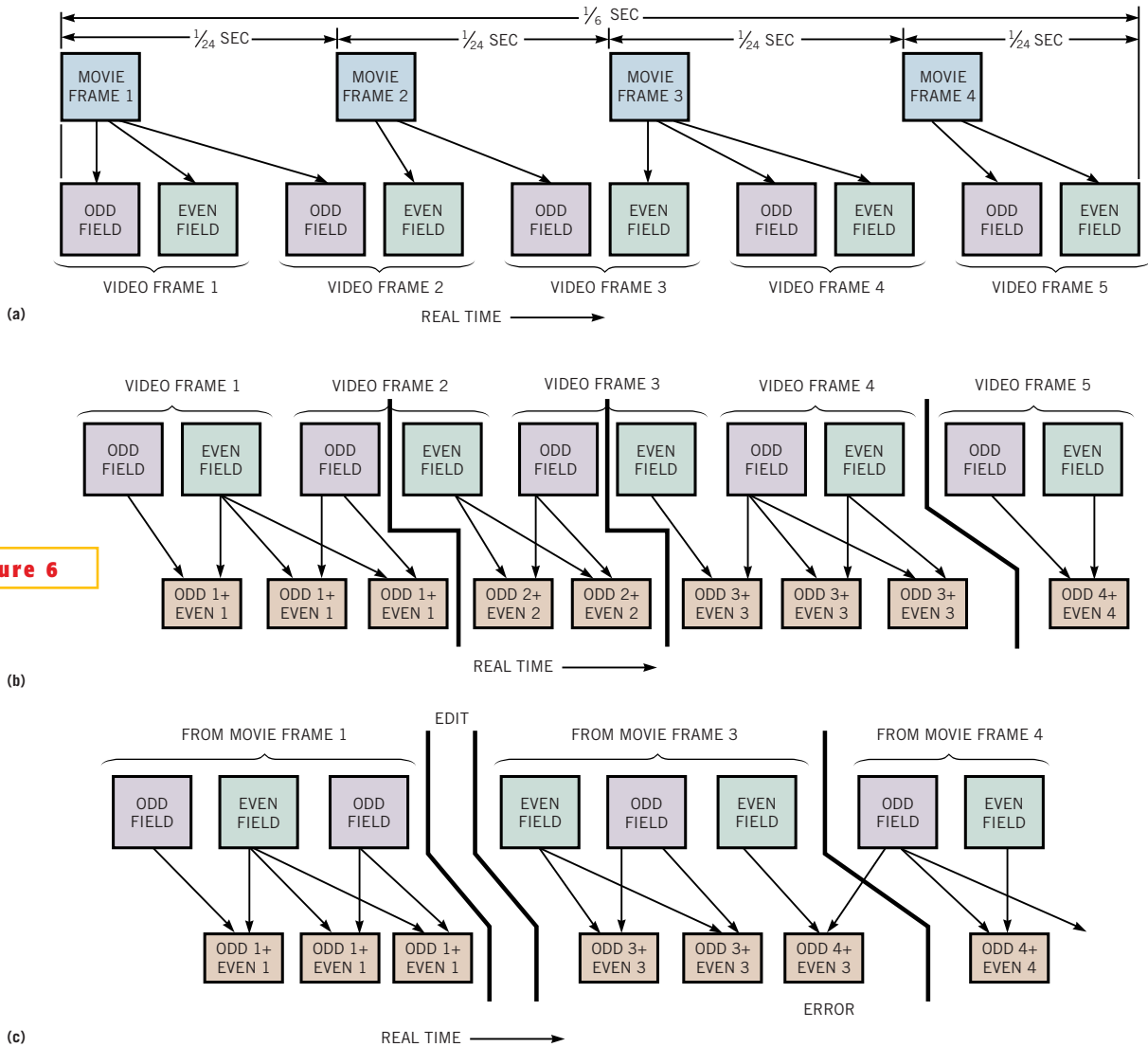


Figure 6

Telecining (a) converts 24-frame/sec progressive film content to 60-field/sec interlaced video, but it creates motion artifacts. Inverse telecining (b) restores a progressive presentation, albeit with repeated-frame stutter. Intermingling film and video content (c) complicates the inverse-telecine algorithm's task (courtesy Faroudja subsidiary of Sage).

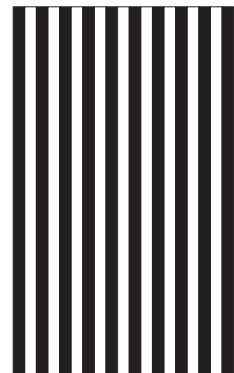
playing it *before* odd field 2, for example. Those artifacts are especially noticeable if you pause playback on one of the affected frames, a situation that the control flags are supposed to preclude but don't always succeed in preventing.

Because the inverse-telecine algorithm can't rely on only control flags it must buffer, analyze, and attempt to match successive fields to detect the presence of 3:2-encoded film material. Remember, if the algorithm's location is after the digital-to-analog conversion step, it doesn't even have access to the flags for use as a guide or sanity check. Note that even if the inverse-telecine algorithm success-

fully rejoins the correct fields into frames, it still needs to repeat two out of every five frames to meet the 30-frame/sec television requirement (Figure 6b). This repetition causes slight display stuttering, which explains why among the 18 ATSC formats, several formats support a native display of 24-frame/sec material (Table 1).

You might think that instead of replicating film frames, you could interpolate intermediate frames between the actual 24 frames to fill the 30 frame/sec rate. And you can. However, the artifacts that this process induces are sometimes more visually unpleasant than either replicat-

Figure 7



Do you see 10 lines or 19? The answer depends on whether your background is in film (10 lines) or video (19 lines).

ed frame-video stuttering or the artifacts that result from not doing an inverse 3:2 pull-down at all. Also, full-frame interpolation is computationally intensive; therefore, it is appropriate only for offline rendering or for low resolution video frames.

Two other huge obstacles await the inverse-telecine algorithm. First, the editing process might have eliminated film frames or, more likely, inserted video material, such as commercials or news clips, between them (Figure 6c). After detecting telecining, if the algorithm blindly executes an inverse 3:2 pull-down on subsequent frames, it incorrectly matches up the wrong fields past the point of the edit break. The algorithm should continuously monitor the frame sequence to prevent artifacts as a result of bad editing.

The more challenging problem is that 24-frame/sec film-sourced and 60-field/sec video-sourced material, both in motion, can coexist *within the same frame*. Consider, for example, a scrolling set of video-created captions at the end of a film broadcast on television or a rotating HBO advertising logo inserted at the film's corner. Two possible interpretation scenarios exist. If the inverse telecine algorithm decides that the frames are *film*, it incorrectly transforms the video material, which leads to stuttered caption or logo motion. If, however, it interprets the frames as *video* and doesn't do an inverse 3:2 pull-down on them, you can end up with visually preferable feathering artifacts.

You might see references to 2:2 pull-downs in video literature. This phrase refers to the conversion of 24-frame/sec film to 25-frame/sec (50-field/sec) PAL or SECAM video. Typically, the telecine algorithm speeds the video and audio by a factor of $25/24$ (1.04) and then interlaces it. Inverse telecining of PAL and SECAM is much simpler than the inverse-3:2-pull-down technique. However, the algorithm must correctly detect whether it's transforming an NTSC or PAL-or-SECAM source and apply the correct pull-down splicing.

BIGGER, SMALLER, TALLER, AND WIDER

Computer-graphics subsystems and LCD controllers need to upscale and downscale horizontal and vertical dimensions of images and refresh rates to match users' resolution settings and dis-



Figure 8

Placing a 16:9 image within a 4:3 frame leaves vertical resolution unused (a), while pan-and-scan editing removes important details (b). Anamorphic transfers (c), when subsequently unsqueezed by video players and televisions, restore the original aspect ratio and deliver maximum detail (d).

play capabilities. Early computers could drive both interlaced and progressive-scan CRT monitors, as well as TVs, but a progressive-scan CRT or LCD is today's dominant PC display option (see sidebar "High-quality video meets the Internet"). Not surprisingly then, video-enhancement technology is coming not only from companies that traditionally focused on home theaters but also from chip suppliers targeting PCs, such as ATI Technologies, Focus Enhancements, Genesis Microchip, Nvidia, PixelWorks, Sage, Silicon Image, and SmartASIC. This trend is accelerating as PCs expand beyond a 2- and 3-D graphics-only platform and process more still- and video-image content.

Most upscaling and downscaling operations stretch or compress both the horizontal and vertical image dimensions by the same multiplication or division factor to prevent distortion. Upscaling tends to be the algorithmically easier of the two operations and is analogous either to how a digital still camera interpolates from a small CCD or CMOS sensor-captured image to create a larger picture or to the digital-zoom feature of camcorders. Because you're inventing pixels that didn't exist in the original image, the downside of upscaling is the inevitable blurring of previously distinct object edges.

Nearest-neighbor, bilinear, and bicu-

bic algorithms all find use in upscaling; nearest-neighbor is the simplest, fastest, and least memory-intensive algorithm, and bicubic produces the most accurate and artifact-free results. To experience upscaling, resize a VGA still image to XGA on your computer; your image-editing software should give you several interpolation-algorithm alternatives. A reconstruction filter that insufficiently bandlimits the interpolated content and, therefore, inadequately suppresses frequency harmonics can cause moiré and jagged edges.

When you downscale, maintaining good video quality is much harder, for example if you're playing a DVD movie in either a less-than-full-screen window or a window whose native aspect ratio doesn't match the aspect ratio of the display. Good video quality is also difficult to maintain with picture-in-picture applications. Maintaining good video quality is more difficult when downscaling, for example, if you're playing a DVD movie in a less-than-full-screen window or in a window whose native aspect ratio doesn't match the aspect ratio of the display or for picture-in-picture applications. By inadvertently discarding important image details, such as the contours of a human face, you don't want to end up with a presentation that viewers find disagreeable. You also don't want to

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FOR MORE INFORMATION...

For more information on products such as those discussed in this article, go to our information-request page at www.rscanners.ims.ca/ednmag/. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

VIDEO-QUALITY

BENCHMARKING VENDORS:

DisplayMate Technologies

1-603-672-8500
www.displaymate.com
Enter No. 396

Joe Kane Productions

www.videoessentials.com
Enter No. 397

Kayye Consulting

www.kayye.com
Enter No. 398

MadOnion.com

1-416-972-6275
www.madonion.com
Enter No. 399

Ovation Software

1-740-373-6212
www.ovationsw.com
Enter No. 400

Sarnoff

1-609-734-2000
www.sarnoff.com
Enter No. 401

Sencore

1-605-339-0100
www.sencore.com
Enter No. 402

THX Division of LucasFilm Ltd

1-415-492-3900
www.thx.com
Enter No. 403

Unapix Entertainment

1-212-252-7600
www.unapixent.com
Enter No. 404

VIDEO-CHIP AND IP VENDORS:

ATI Technologies

1-905-882-2600
www.ati.com
Enter No. 405

Aurora Systems

1-408-452-5559
www.aurora-sys.com
Enter No. 406

Broadcom

1-905-450-8700
www.broadcom.com
Enter No. 407

C-Cube Microsystems

1-408-490-8000
www.c-cube.com
Enter No. 408

Chrontel

1-408-383-9328
www.chrontel.com
Enter No. 409

Cirrus Logic

1-512-445-7222
www.cirrus.com
Enter No. 410

Cypress Semiconductor

1-408-943-2600
www.cypress.com
Enter No. 411

Divio

1-408-732-1205
www.divio.com
Enter No. 412

Equator Technologies

1-408-369-5200
www.equator.com
Enter No. 413

Focus Enhancements

1-978-988-5888
www.focusinfo.com
Enter No. 414

Genesis Microchip

1-905-889-5400
www.genesis-microchip.com
Enter No. 415

Globespan

1-732-345-7500
www.globespan.net
Enter No. 416

LSI Logic

1-408-433-8000
www.lsil.com
Enter No. 417

LuxSonar

1-510-683-4668
www.luxsonar.com
Enter No. 418

Macronix

03-5786688
www.macronix.com
Enter No. 419

MetaVideo

1-408-354-2525
www.metavideo.com
Enter No. 420

Motorola Semiconductor

1-512-933-6000
www.motorola.com
Enter No. 421

National Semiconductor and its Mediamatics subsidiary

1-408-721-5000
www.national.com
Enter No. 422

NuCore Technology

1-408-919-1820
www.nucoretech.com
Enter No. 423

Nvidia

1-408-615-2500
www.nvidia.com
Enter No. 424

Oplus Technologies

972-4-959-2288
www.oplustech.com
Enter No. 425

Philips Semiconductors

1-408-991-2000
www.philips.com
Enter No. 426

PixelWorks

1-503-612-6700
www.pixelworks.com
Enter No. 427

Sage and its Faroudja subsidiary

1-408-383-5300
www.sage.com
Enter No. 428

Sci-worx

49-0-511-277-0
www.sci-worx.com
Enter No. 429

Sigma Designs

1-408-262-9003
www.sigmadesigns.com
Enter No. 430

Silicon Image

1-408-616-4000
www.siimage.com
Enter No. 431

Silicon Magic

1-408-331-8000
www.simagic.com
Enter No. 432

SmartASIC

1-408-283-5098
www.smartasic.com
Enter No. 433

STMicroelectronics

1-781-861-2650
www.st.com
Enter No. 434

Stream Machine

1-408-435-9166
www.streammachine.com
Enter No. 435

Techwell

1-408-435-3888
www.techwellinc.com
Enter No. 436

Teralogic

1-650-526-2000
www.teralogic-inc.com
Enter No. 437

Texas Instruments

1-800-336-5236
www.ti.com
Enter No. 438

Toshiba

1-949-455-2000
www.toshiba.com
Enter No. 439

Trident Microsystems

1-408-496-1085
www.tridentmicro.com
Enter No. 440

Trimedia Technologies

1-949-455-2000
www.trimedia.com
Enter No. 441

Tvia

1-408-982-8588
www.tvia.com
Enter No. 442

VM Labs

1-650-917-8050
www.vmlabs.com
Enter No. 443

Vweb

1-408-615-1888
www.vwebcorp.com
Enter No. 444

Zoran

1-408-919-4111
www.zoran.com
Enter No. 445

VIDEO-SOFTWARE VENDORS:

Adobe Systems

1-408-536-6000
www.adobe.com
Enter No. 446

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FOR MORE INFORMATION...(continued)

Apple Computer

1-408-996-1010
www.apple.com
Enter No. 447

Cyberlink

1-886-2-8667-1298
www.cyberlink.com.tw
Enter No. 448

Emblaze Systems

972-3-572-2111
www.emblaze.com
Enter No. 449

e-Vue

1-732-590 0102
www.e-vue.com
Enter No. 450

Hantro Products

358-8-815-6300
www.hantro.com
Enter No. 451

InterVideo

1-510-651-0888
www.intervideo.com
Enter No. 452

Ligos Technology

1-415-249-0100
www.ligos.com
Enter No. 453

Media 100 and its Terran Interactive subsidiary

1-508-460-1600
www.media100.com
Enter No. 454

Media Excel

1-512-615-0304
www.mediaexcel.com
Enter No. 455

MedioStream

1-408-452-5500
www.mediostream.com
Enter No. 456

MGI Software

1-905-764-7000
www.mgisoft.com
Enter No. 457

Microsoft

1-425-882-8080
www.microsoft.com
Enter No. 458

National Semiconductor and its Mediamatics subsidiary

1-408-721-5000
www.national.com
Enter No. 459

PacketVideo

1-858-731-5301
www.packetvideo.com
Enter No. 460

QuVis

1-785-272-3656
www.quvis.com
Enter No. 461

Ravisent

1-610-251-9999
www.ravisent.com
Enter No. 462

RealNetworks

1-206-674-2650
www.realnetworks.com
Enter No. 463

Sonic Foundry

1-206-674-2650
www.sonicfoundry.com
Enter No. 464

Sorenson Media

1-801-287-9400
www.sorenson.com
Enter No. 465

OTHER COMPANIES

MENTIONED IN THIS ARTICLE:

3DLabs

www.3dlabs.com

Audio Authority

www.audioauthority.com

Ayre Acoustics

www.ayre.com

BroadLogic

www.broadlogic.com

Canon

www.canon.com

HBO

www.hbo.com

Intel

www.intel.com

Mitsubishi

www.mitsubishi-display.com

NEC

www.nec.com

Panasonic

www.panasonic.com

Princeton Graphics

www.pgr.com

Silicon Graphics

www.sgi.com

Terk

www.terk.com

Toshiba

www.toshiba.com

SUPER INFO NUMBER

For more information on the products available from all of the vendors listed in this box, enter No. 466 at www.rscahners.ims.ca/ednmag/.

distort the image by disproportionately shrinking an object's dimensions.

Envision a picket fence consisting of equal-width boards, a crosshatch grid, or any other sequence of parallel lines. Displaying a downscaled image in which some lines disappear and others end up fatter or thinner than others or in which downscaling alters the spacing of a group of previously equidistant lines won't work. The inverse relationship between time, or in this case location, and frequency requires that the downscaling filter length increase in proportion to the downscaling factor.

A discussion of scaling would be incomplete without a review of resolution as it applies to displays. First, you should make sure your terminology is precise. The phrase "lines of resolution" has different meanings depending on whether you're talking about film, which measures the number of differentiable black lines in an image, or video, which counts not only the black lines but also the white spacing between them (Figure 7). Even though NTSC, DVD, and 480p ATSC can deliver 480 lines of vertical resolution,

few CRT-based direct-view or rear-projection televisions can display them all. Be careful of televisions that claim that they can decode or even display 720p or 1080i HDTV content; the vendors' careful wording might obscure the reality, which is that the vertical resolution you see is actually much lower.

The electron guns inside all but the biggest front-projection CRTs aren't accurate enough to deliver this high resolution. Even and odd scan lines might converge at portions of the screen, or the guns' aim might not exactly match up with the dot pitch of the display, partially illuminating two dots instead of fully illuminating one, for example. This phenomenon is called the Kell factor, and 0.7 is a common value for it. Even if televisions and computer monitors are both progressive-scan devices and cost roughly the same price, they differ in that the TV monitors have larger, brighter screens but with a more relaxed dot pitch than computer monitors; most TV monitors also deliver a slower maximum line-refresh frequency. These factors limit a progressive-scan television's maximum vis-

ible vertical resolution compared with that of a computer monitor.

WHAT'S THE RESOLUTION?

Interlaced displays deliver even lower effective vertical resolution than progressive displays, resulting from phosphor decay at low frame-refresh rates and resultant image softening. Keep in mind that the horizontal display resolutions quoted in specification sheets are for only black, white, and gray-shaded patterns dominated by image luminance. Part 2 of this article explores in depth (see sidebar "What's next?"), most video formats subsample image chrominance to save storage space and transmission bandwidth, a trade-off that decreases the maximum-possible vertical and horizontal color resolution. Also, composite video sources combine luminance, chrominance, and sometimes audio in the same broadcast channel. Inaccurate notch or comb filtering to separate the luminance and chrominance, particularly when object motion is involved, can create artifacts and reduce resolution. Lowpass filtering the luminance infor-

mation to separate it from audio also reduces high-frequency detail.

For a high-end 36-in. progressive-scan (34-in. viewable) television with a 0.77-mm center dot pitch, application of the Kell factor results in a calculated visible resolution of 628×470 . This result closely matches the vertical resolution that a 480p digital television signal delivers (Table 2). Note, too, that the calculated horizontal resolution, although commonly specified in an edge-to-edge fashion, can be inaccurate. Vendors are supposed to specify only the number of lines of horizontal resolution contained within the diameter of a circle whose dimensions don't extend beyond the screen's top and bottom edges. Only the largest, most expensive front-projection CRT systems can deliver all 720 progressive or 1080 interlaced lines of resolution to the screen. DLP and LCD technologies may not match CRT's wide viewing angle and color accuracy. However, they're rapidly improving in both of these areas, and they have an edge in applications that value high resolution.

Why would you want to horizontally upscale or downscale by a different factor than you vertically scale? Consider, for example, the display of a 16:9 movie frame (sometimes called a 1.77:1 movie frame) on a 4:3 (1.33:1) computer monitor or television (Figure 8a). Unless you select the pan-and-scan mode, which discards portions of the image, you may end up with horizontal blank bars at the top and bottom of the screen (Figure 8b). These bars leave unused available vertical-display resolution and can result in permanent CRT damage in the form of burn-in caused by uneven aging of the CRT's phosphors. Similarly, if uncorrected, a 4:3 image creates black bars at the right and left sides of a 16:9 display.

Either simple horizontal or vertical linear stretching causes undesirable fat and short or skinny and tall distortions of objects within each frame. Alternatively, you can nonlinearly stretch the image, with more distortion at the edges of the screen and less distortion at its center, where, theoretically, most viewer attention focuses. Or, if CRT burn-in is your primary concern, you can eliminate the black bars by simply projecting a gray frame or a frame of another color onto the display instead, as Silicon Image does with subsidiary DVDO's iScan Pro.

You may occasionally hear DVDs described as "anamorphic" or "16:9 en-

hanced" DVDs. What do these terms mean? Moviemakers who want to use all of the available vertical resolution of film place on the camera a special lens that squeezes an image's horizontal dimensions (Figure 8c). When a movie theater projects film through a reverse-effect lens, the correct dimensions are restored (Figure 8d). Similarly, instead of placing a wide-screen image within a 4:3 frame as part of the film-to-DVD transfer, thereby throwing away vertical resolution at the top and bottom of the frame, a video engineer can do an anamorphic transfer. The television, along with an appropriately configured DVD player, handles the re-stretching of the frame to correct dimensions, and the resulting image uses all 480 vertical lines of resolution that the DVD video format supports. □



REFERENCES

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3. Dipert, Brian, "As DTV sales stagnate, specs proliferate," *EDN*, Jan 4, 2001, pg 24.
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