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STEVE MULLEN ON PROGRESSIVE SCANNING

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Progressive: What You Need to Know

As new products with progressive scan options hit the market, it's critical to understand the basics behind this technology.

By Steve Mullen

PRIOR TO NAB, PANASONIC'S NEW AG-DVX100 MiniDV camcorder generated major buzz on the Internet. The feature that caused so much excitement was the ability to shoot at 24fps.

As I read email and later talked with videographers after the NAB exhibits opened, I noted several things. First, the intensity of the comments. Some folks were certain 24p was nothing more than a marketing gimmick. Others were equally convinced that the DVX100 would usher in a whole new world of videography and DV filmmaking. But what caught my attention the most was that for all the passion, there was an amazing lack of knowledge about progressive video.

Progressive video is a much broader topic than the new Panasonic MiniDV camcorder. If you want to shoot with progressive scanning, you can choose a product to match your budget. The DV-based AG-DVX100 is an entry-level 24p camcorder. (For an AG-DVX100 users' guide, check out *www.mindspring.com/~d-v-c.*) If you want to shoot with native 16:9 CCDs, the AJ-SDX900 can be used at 24p with the DVCPRO25 codec. If you need minimally compressed, 4:2:2 video, then switch the AJ-SDX900 to DVCPRO50.

Need to shoot HD? Then shoot with the DVCPRO HD AJ-HDC27 at 720p24 (or at any frame rate between 4fps and 60fps). Apple and Panasonic have announced joint technology developments that mean it will be possible to transfer all of these formats via FireWire into Final Cut Pro for editing.

Previous experience has taught me that launching directly into an explanation of progressive scanning, especially 24p, would not be productive. An understanding of progressive scanning depends on understanding interlace scanning. And, because Panasonic and Canon's Frame Modes are so often confused with progressive scanning, there is no way to avoid digging into them as well.

Need to shoot HD? The Panasonic AJ-HDC27 lets you shoot DVCPRO HD at 720p24 (or any frame rate between 4fps and 60fps).

Interlace Scanning

Our NTSC system is based upon interlace scanning. Before CCDs, the imaging tube, transmission system, and viewing tube all used interlaced scanning. Modern cameras use CCD chips that are progressive scanning devices. A CCD captures 481 rows of information during a time period determined by the camera's shutter-speed setting. The CCD is then read out as an analog signal, from the top row to the bottom row — during 1/60th of a second. From the *upper* 480 rows read-out, one interlace field is obtained. To capture a frame's field-mate, once again the CCD captures the image during the shutter exposure time, and then in the next 1/60th of a second, the *lower* 480 rows are read out.

Because an NTSC recording system can accept only 240 lines in 1/60th of a second, what is done with the information from the 480 rows read out from the CCD? One obvious option would be to simply discard all odd CCD rows during an *even* field and all even CCD rows during an *odd* field.

Engineers abhor the idea of tossing out information. And two significant benefits arise from using the seemingly unnecessary information. First, a CCD is made 6dB more sensitive to available

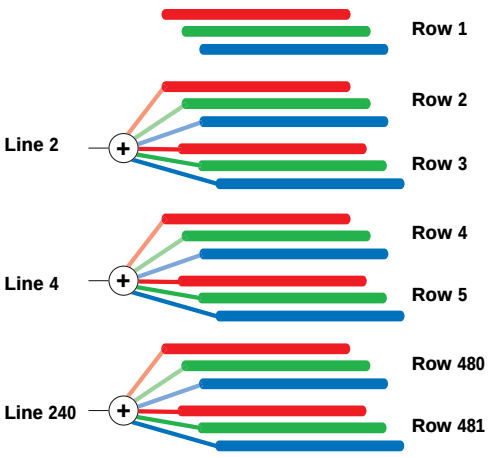

Figure 1: Even-Field Row-Pair Summation

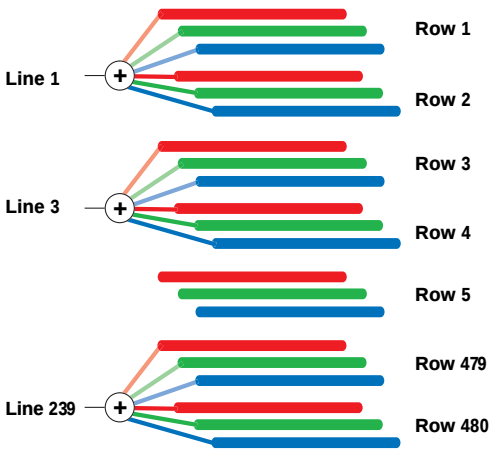

Figure 2: Odd-Field Row-Pair Summation

light with no decrease in S/N ratio. And second, interline flicker is reduced. Interline flicker is "aliasing that occurs when horizontal image detail (signal frequency) approaches that of the CCD row-structure (sampling frequency)." In plain English, this means that when sharp horizontal edges are imaged, you will see a 30Hz flicker on these edges. Flicker can be reduced if the edges are softened by a low-pass filter.

A simple low-pass filter can be created by averaging two data samples. And that's exactly what engineers decided should be done with the 480 rows. By adding data from two successive rows (row-pairs) together, a low-pass filter is created that smoothes horizontal edges. In the process, the signals from two CCD elements are summed, thus increasing signal strength. The process is called row-pair summation. Appropriately, the filter outputs 240 lines — all that can be recorded during an NTSC field-time.

Within an *even* field, the red, green, and blue signals for video lines 2, 4, through 240 are obtained by adding the row 2 RGB signals (delayed by one "line-time") to the row 3 RGB signals; in like manner, row 4 is added to row 5; and row 480 to row 481.

Figure 1 displays how even-field signals are obtained for lower (even) field dominant DV recording. Within an *odd* field, the red, green, and blue signals for video lines 1, 3, through 239 are obtained by adding the row 1 RGB signals to the row 2 RGB signals; row 3 to row 4; and row 479 to row 480. Figure 2 displays how the information for an odd field is obtained.

Unfortunately, a price must be paid for the benefits of row-pair summing. The filter decreases image vertical resolution by about 25% — to 180 lines per field. Thus, the effective vertical resolution of an interlaced frame is reduced to about 360 lines. (The recording system continues to record 480 lines, but it's carrying less information than it can.)

With interlace scanning, the second field of each frame is captured 1/60th of a second later in time than the first. If there are rapidly moving objects, they will be spatially displaced in the second field. If both fields are displayed as a still — or when non-interlaced multimedia productions are created — such objects often display "combed" edges. This is an interlace scanning artifact.

Frame-Mode Scanning

Panasonic's AG-EZ1 and AJ-D215, and Canon's XL1 and GL1 all have a menu item that offers Frame Mode. When this mode is not selected, these cameras use interlace scanning. When Frame Mode is selected, the green elements in row 2 (delayed by one "line-time") are added to row 3 green elements. This process is repeated for rows 4 and 5 through rows 480 and 481. Light sensitivity is increased by 6dB from row-pair summation.

At the same time, red and blue elements in row 2 — also delayed one line-time — are added to their pair-mate red and blue elements from row 1, which have been delayed two line-times. This process is repeated for row 3 and row 4, through rows 479 and 480. Sensitivity is increased by summation. (See Figure 3.)

As the CCDs are read out, 240 lines of RGB data are processed. Because the green-row data were obtained from the rows between the red and blue rows, for grayscale objects there are 480 luminance estimates per CCD column. (Don't confuse row-offset with the CCD chip's horizontally offset green elements that increase horizontal resolution.)

These estimates do not, however, carry 480 lines of vertical information. First, row-pair summation has decreased vertical information by 25%. And second, the estimation process itself reduces vertical resolution further — yielding a video frame with about 320 lines of vertical resolution. The CCD read-out is recorded as an *even* field to tape, and is also stored in a buffer. During the next field-time, the contents of the buffer are recorded as an *odd* field. Thus the recording is interlace, yet each video frame contains no interlace artifacts.

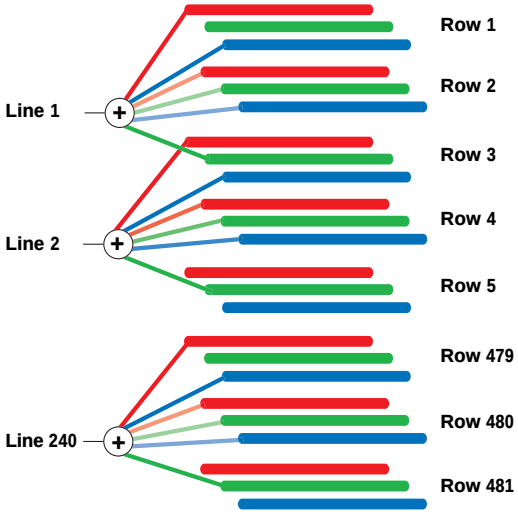

Figure 3: Frame Mode Scanning

Progressive Scanning

Progressive scanning achieves maximum vertical resolution while also eliminating interline flicker and interlace artifacts. There are three commonly used progressive scan capture rates, each with its own nominal shutter-speed: 24p (1/48th sec), 30p (1/60th sec), and 60p (1/120th sec). The CCDs are read out as usual, from the top row to the bottom row — during 1/24th (for 24p), 1/30th (for 30p), or 1/60th (for 60p) of a second. Row-pair summation is not used, so sensitivity is not enhanced. Depending on the format, CCDs capture 480 rows, 720 rows, or 1080 rows.

While progressive capture is simple, recording the captured image to tape is usually more complex. The simplest recording method copies all rows from the CCDs directly to tape each 1/60th of a second. Using 1.1-megapixel CCD chips, Panasonic's DVCPRO HD AJ-HDC27 camcorder can capture 1280x720 pixel resolution frames. This camcorder records using the 720p60 HDTV format standard.

There is an NTSC compatible progressive system, 480p30. Panasonic's new MiniDV AG-DVX100 and DVCPRO/DVCPRO50 AJ-SDX900 camcorders can be switched to this format. In 480p30 format, each captured 480 line frame is recorded as two 240-line fields. This format is perfect for multimedia productions that will be played on such displays as progressive scan computer monitors, because 480p30 has no interlace artifacts.

Now let's look at 24fps video. Sony's CineAlta was the first of the currently available 24fps formats. Sony records 24p by lowering the clock-rate of a 1080/i50 VTR to 1080/i48. The 24p frames are then recorded as even and odd "fields" at 1080/i48. Sony calls this 1080/24PsF, Progressive Segmented Frame recording. Sony has announced no plans to transfer 1080/24PsF via FireWire.

Panasonic offers three 24p-capable camcorders: the MiniDV AG-DVX100 (480p24), the DVCPRO/DVCPRO50 AJ-SDX900 (480p24), and the DVCPRO HD AJ-HDC27 (720p24). When shooting 24p with the AJ-HDC27, as sequential frames are read out from the CCDs, 2:3 pulldown is performed. Pulldown converts every four progressive video frames to 10 progressive video frames. (See Table 1.) Over the period of one second, six sets of four frames are converted to six sets of 10 frames. Thus, 24 frames are converted to 60 frames. The result is a 720p60 recording of a 720p24 capture. (Reverse 2:3 pulldown can be used to obtain the original frames.)

Panasonic's AJ-SDX900 and AG-DVX100 must use a slightly different system because they are NTSC camcorders. As sequential frames are read out from the CCDs, pulldown must be performed to convert every four progressive video frames to five interlaced video frames. Assuming the use of industry standard 2:3 pulldown, two "judder" frames would be generated. Judder frames contain one field from one frame and one field from an adjacent frame. (Red text in Table 2.)

Over the period of one second, six sets of four progressive frames

Table 1

Frame A		Frame B			Frame C		Frame D		
Frame 1	Frame 2	Frame 3	Frame 4	Frame 5	Frame 6	Frame 7	Frame 8	Frame 9	Frame 10

2:3 Pulldown (AABBBCCDDD cadence) for 60p

Table 2

Frame A		Frame B			Frame C		Frame D		
A-even lines	A-odd lines	B-even lines	B-odd lines	B-even lines	C-odd lines	C-even lines	D-odd lines	D-even lines	D-odd lines
Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd
Video Frame 1		Video Frame 2		Video Frame 3		Video Frame 4		Video Frame 5	

2:3 Pulldown (AABBBCCDDD cadence) for 24p

Table 3

Frame A		Frame B			Frame C			Frame D	
A-even lines	A-odd lines	B-even lines	B-odd lines	B-even lines	C-odd lines	C-even lines	C-odd lines	D-even lines	D-odd lines
Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd
Frame 1		Frame 2		Frame 3		Frame 4		Frame 5	
after dropping the judder frame									
Frame A		Frame B				Frame C		Frame D	

2:3:3:2 Pulldown (AABBBCCCDD cadence)

Panasonic's DV-based AG-DVX100 — and its ability to shoot at 24fps — created quite a buzz on the Internet just before NAB.

are converted to six sets of five interlaced frames. Thus, 24 frames are converted to 30 frames — with 60 fields. To be NTSC compatible, the progressive frame rate is actually 23.98fps (23.976fps) to yield an interlaced video frame rate of 29.97fps.

What does this video look like when it is played back? In terms of temporal characteristics, it has the "look of film that's been transferred to video." If you want a film look, 24p with 2:3 pulldown will work fine. Progressive, 24p provides greater vertical resolution for both grayscale and color objects than does Frame Mode. The combination of low frame-rate and slow shutter-speed yields more fluid motion handling than does Frame Mode. Because it is 24.97fps interlaced NTSC video, any NLE can be used to edit 2:3 pulldown video.

I Don't Need Film Look — I'm Making a Film

Panasonic's AG-DVX100 and AJ-SDX900 have you covered. Selecting Cine Mode records to tape using an alternate pulldown scheme. Tapes made in Cine Mode will play on NTSC equipment just like 2:3 pulldown video. Material shot with this mode is intended to be transferred via FireWire or an SDI-equipped VTR into an appropriately configured NLE where it can subsequently be edited at 24fps in 480-line progressive native resolution.

Panasonic has not released details of the Cine Mode recording method. However, it's not difficult to anticipate the process needed to get 23.98fps video and audio onto tape and then to a hard disk.

First, to make capture more efficient, the data flow should contain only a single judder frame. There are three pulldown schemes that meet this requirement: 3:3:2:2 (AAABBBCCDD), 2:3:3:2 (AABBBCCCDD), and 2:2:3:3 (AABBCCCDDD). After transfer, the judder frame can be dropped and the 48kHz audio samples "re-mapped" from 1,601 to 2,002 samples per frame. Table 3 shows a 2:3:3:2 pulldown sequence that might be used.

Delivering Progressively

After editing progressive video, there are two fundamental export possibilities: export as progressive video or, after applying pulldown, export as interlaced video. As the AG-DVX100 and AJ-SDX900 use NTSC recording they cannot record native 24p video signals directly, so the NLE must add some form of pulldown before transfer back to these camcorders — or to a VTR. Note that before transferring interlaced exported video to film, reverse pulldown must be applied to recover the original progressive frames.

My Production Has to be Widescreen

There are two paths to widescreen HD and film release if you shoot with an inexpensive camcorder like the AG-DVX100, which has neither 16:9 CCDs nor electronic anamorphic. You can use an optical anamorphic adapter, but be prepared for its limitations.

Alternately, you can process your production using a Panasonic AJ-UFC1800 Universal Format Converter after editing in 4:3 aspect 480p24. The image will lose 25% of its vertical detail from the applied 16:9 (1.78:1) aperture. The converter will then upscale the 720x360 pixel (letterbox) image to 1280x720 (720p60) or 1920x1080 (1080/i60 or 1080p24).

Because progressive video offers 480 lines of vertical resolution, the 16:9 letterbox yields an image with an effective vertical resolution of 360 lines. This is the same vertical resolution provided by interlace scanning an NTSC 4:3 image. Thus, 16:9 progressive video should appear to have no less vertical resolution than 4:3 interlace video.

Of course, you really want progressive to deliver more resolution. And, in its own way, it does. Progressive scanning offers more real-world resolution than measured by static resolution charts. A study by William E. Glenn showed that apparent progressive image resolution is almost twice that of interlace image resolution for moving objects ("Understanding Camera Resolution," *Broadcast Engineering*, August 1999).

Progressively scanned video, whether with a low 24fps temporal rate or with a high 60fps rate, promises to be the next big thing in production. In conjunction with FireWire transfers and software codecs, the post scene will change dramatically over the next few years. Might be time to retire your interlaced shoes.

feedback

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