Tape Formats Compared

How do DV formats measure up with Betacam SP and 601?

Digital Video Magazine evaluates the image quality of major video production tape formats.

by Jim Feeley

Digital Betacam looks better than DV. That's no surprise. But just how much better does it look? How does DV compare to Betacam SP? What about the 50Mb (megabit) DV-based formats, DVCPRO50 and Digital-S? And how does each format's image quality compare to ITU-R BT.601 video?

Although anecdotes and informal evaluations abound, *Digital Video Magazine* wanted to compare image-quality differences among leading digital and important analog video formats. That's what we do here.

In our evaluation, we used a 525-line 601 signal as our ultimate reference. We didn't evaluate HDTV formats. It's difficult to compare a 4:3 image to a 16:9 image. More important, the vast majority of current video production and viewing still occurs in 4:3.

We evaluated Digital Betacam, Digital-S, DVCAM, DVCPRO, Betacam SP, Hi8, and 3/4-inch U-Matic VTRs. To ensure consistent results, we used top-of-the-line VTRs to evaluate each format. We wanted VTRs with the highest-quality components in order to minimize errant measurements. Where possible, we used VTRs with SDI I/O to carry the 601 test video to the VTR and to carry the processed video out of the VTR. The specific VTR models are listed on page 42. We also tested an Accom DDR. Together these devices cover a large range of current production formats.

There are several formats we didn't evaluate. We didn't test DVCPRO50, but we expected that the results would match those of Digital-S,a format based on the same 50Mb DV data stream as DVCPRO50. We didn't include S-VHS or VHS VTRs.

Illustration by Jeff Berlin

We expected S-VHS would generate results similar to those of Hi8. We assumed VHS would perform even worse.

We didn't include a standard DV VTR because we needed SDI I/O for our core evaluation, and we didn't have an SDI-to-1394 converter. However, we assumed that standard DV would perform similarly to the other 25Mb formats, DVCAM and DVCPRO.

We tested a DV-based format—DVCAM—with SDI input and Y/C output, and again with Y/C input and Y/C output. These results will interest those who shoot or edit DV-based video who don't own a 1394/FireWire or SDI-equipped NLE yet.

We also didn't perform multigenerational tests. We measured only first-generation tapes made from 601 source video. With the advent of pure digital clones, generation loss is less of a factor in digital video production. Testing first-generation video let us determine each format's best-possible video quality.

We conducted our tests in the online suite at the Bay Area Video Coalition (BAVC; www.bavc.org). All of the decks had been expertly maintained and had moderate drum hours. The DV-based VTRs all had under 700 hours on their recording drums. The Digital Betacam and analog decks had more (but still acceptable) hours.

Drum wear can affect performance, but that effect is minimal if the VTR is carefully maintained and drum wear isn't excessive. Drum wear didn't play a significant factor in our results.

The analog VTRs didn't have SDI input or output, so we converted between the SDI signal and analog with several devices. Depending on the format, we chose a combination of an AJA Video D10C SDI-to-analog Component converter, an AJA Video D10A analog Component-to-SDI converter, a DPS-210 Transcoder, and a Prime Image HR600+ time-base corrector. We also relied on our eyes and our years of experience viewing video.

While abstract "codec buster" test signals and scenes have value for engineers designing and debugging systems, we wanted to know how the tape formats perform in the real world. We chose video sequences with content, detail, and motion similar to that encountered in everyday video production. Specifically, we chose three standard test sequences: CCIR 36 Ferris Wheel, CCIR 30 Mobile and Calendar, and CCIR 16 Susie.

While abstract "codec buster" test signals and scenes have value for engineers designing video systems, we wanted to know how the tape formats perform in the real world.

Many other factors play a role in the final image quality of a video: camera and lighting, possible transcoding errors in bringing video into an NLE that may not natively support the same production tape format, and even different quantization tables for the same video format in a VTR and NLE. However, our tests shed light on one key factor affecting the overall image quality of digital video production.

In each of our image quality tests, the Accom DDR, Digital Betacam VTR, and Digital-S VTR finished first, second, and third, as you would expect. 3/4–inch and Hi8 consistently trailed behind. The middle of the pack is where it gets interesting.

BEHIND OUR TESTS

The measurements

Our measurements reveal each tape format's fidelity when reproducing several 601 reference video sequences. We made our measurements with a Tektronix PQA-200 system. The system compares a reference 601 sequence to the same sequence as encoded by the test VTR. The PQA-200 measures horizontal and vertical shifts in luma and chroma, as well as gain and level changes in luma and chroma. It also measures luma cropping.

We measured many parameters on each VTR. The most significant of these were the peak signal-to-noise ratio (PSNR) and the Picture Quality Rating (PQR) measurement.

The PSNR measures differences in the luminance component of the reference and the encoded video. PSNR gives every difference equal weight, without regard to the human visual system. With the PQA-200, we determined PSNR by finding the ratio of the peak signal to Root Mean Squared (RMS) noise between the reference video and the encoded test video. The PSNR values for each field are averaged to give an overall PSNR measurement for each test video sequence on each VTR. The higher the PSNR, the more signal and the less noise you have. A device that copies and plays back the 601 reference without changing the values of any pixel will have an infinite PSNR.

PQR measurements

The PQA-200 makes picture quality measurements using the Just Noticeable Difference (JND) algorithm developed by the Sarnoff Corporation. Sarnoff designed JND to accurately emulate the perceptions of the human visual system. (See "How To Measure Video Quality" on page 28 for more on the PQA-200 and JND.)

Tektronix's PQR rating uses the JND model to correlate the quality ratings given by observers viewing the scenes from a distance four times that of the screen heights.

For each sequence, the PQA-200 makes a series of image measurements and establishes a PQR based on the JND measurements of four fields, starting with field four of the test sequence (see Figures 1 through 3). For every subsequent PQR measurement, the system ignores the JND values for the oldest field and adds those of the next. The overall PQR rating for a scene is an aggregate of the sequential PQR values.

The PQR luminance measurement analyzes only a video signal's brightness information; the PQR luminance and chroma measurement measures errors in both the brightness and color channels. Shifts in luminance have a greater impact on a scene's perceived image quality, and thus play a bigger role in establishing a device's PQR score.

The lower the PQR, the fewer observers will notice the difference between the processed sequence and the 601 reference. A device with perfect 601 capture and playback will generate a PQR of 0.00. PQR ratings of 1.00 indicate degradations with a small perceptual impact. PQR ratings of 3.00 indicate mild (but observable) image ➢

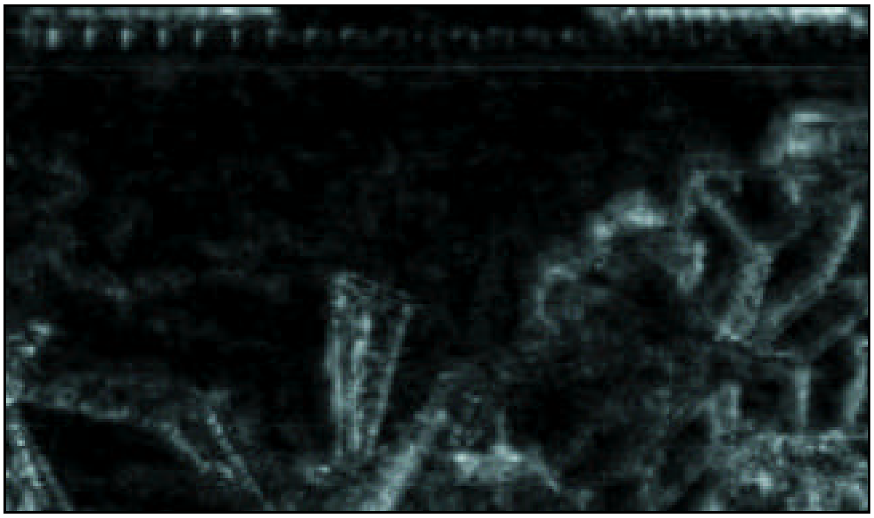


Figure 1—Hi8 PQR luminance map.

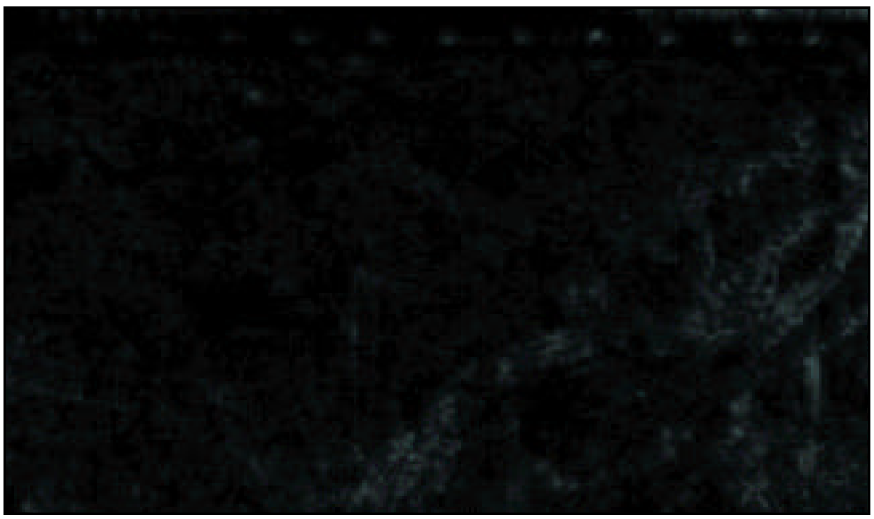


Figure 2—DVCPRO PQR luminance map.

Figure 3—DDR PQR luminance map.

For each device we tested, the PQA-200 generated a series of PQR maps. These maps graphically show visible differences in brightness in the encoded test video when compared to the 601 reference video (the system generates a separate series of maps for the luma and chroma measurement). The more visible the difference to a human observer, the brighter the PQR map. These maps from the Ferris Wheel test sequence reveal that Hi8 (Figure 1) shows significant image degradation, while DVCPRO (Figure 2) shows less degradation. The pure-black DDR PQR map (Figure 3) shows that the DDR imparted no image changes to our 601 test signal.

degradation. PQR ratings above 10.00 indicate clearly observable image degradation.

Test analysis

The Ferris Wheel test sequence —CCIR 36—has an abundance of luminance and color detail in a scene with high motion. The cars in the video whip around, but most of the tape formats handled the motion well.

The DDR transparently captured and played back the 601 test video sequence, resulting in an infinite signal-to-noise ratio and no image degradation. Among the compressed tape formats, Digital Betacam's 1.6:1 compression introduced the least image degradation, with aggregate PQR scores below 1.00 for both luma, and luma and chroma measurements. Digital-S, with its 50Mbps (megabits per second) data rate and 3.3:1 compression (nearly twice the compression ratio of Digital Betacam), produced PQR scores about twice those of Digital Betacam.

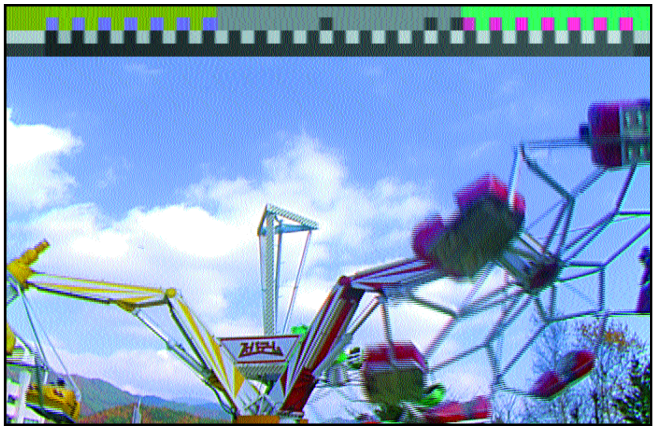
The 25Mb DV-based formats—DVCAM and DVCPRO—both compress the 601 signal twice as much as Digital-S does, and, predictably, had PQR scores twice those of Digital-S. With this particular video sequence, DVCAM produced a PQR score slightly better than that of DVCPRO, but the small difference wasn't visible to our observers.

With the test video, Betacam SP produced images essentially equal in quality to those of DVCPRO and DVCAM, even though its PSNR was lower.

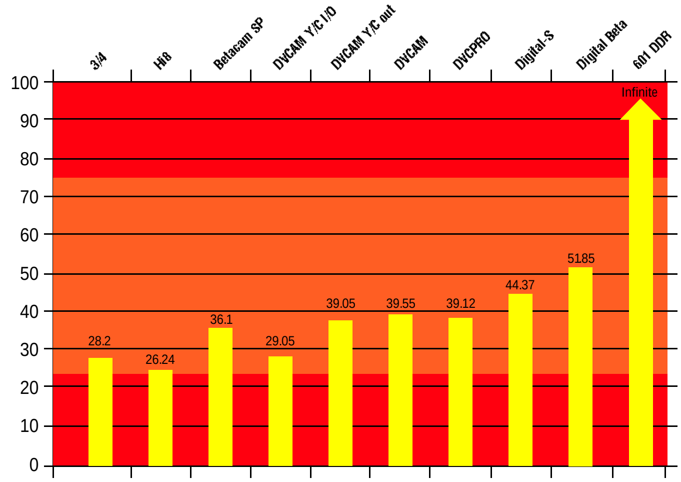
DVCAM with Y/C output performed only about 0.5 PQR worse than DVCAM and DVCPRO with SDI out—an impressive result, suggesting little added degradation. The non-Component analog formats—3/4-inch and Hi8, as well as DVCAM when receiving and outputting a Y/C signal—produced the most visible degradation. Hi8's video was clearly impaired compared to the 601 source.

Using this high-motion video, all the digital formats (except DVCAM with S-Video I/O) and Betacam SP produced very acceptable video.

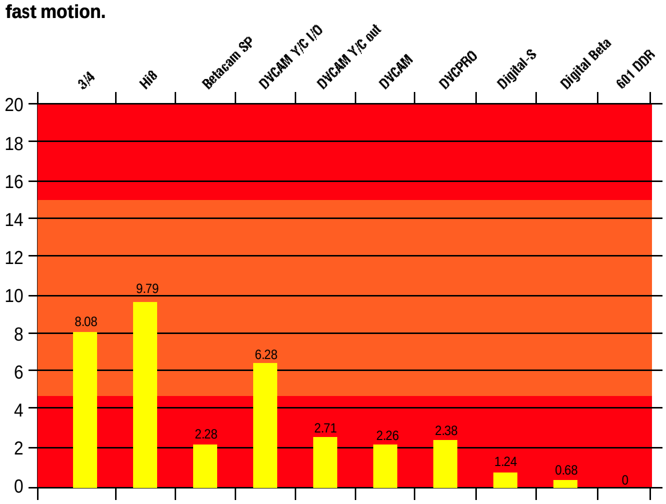
The Mobile and Calendar test sequence—CCIR 30—provides detailed, colorful objects and backgrounds. Several of the objects move in different directions, and the camera moves in a slow pan. This test proved the hardest for all the tape formats to capture, with the non-Component suffering visible image degradation. The DDR introduced no image degradation. ➢



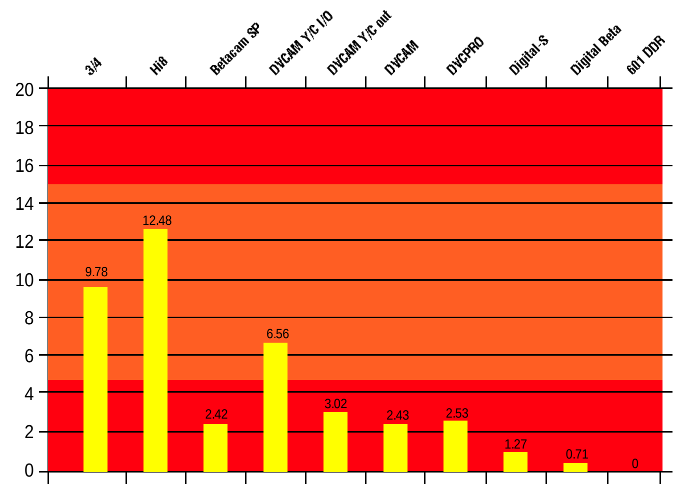
The Ferris Wheel test sequence—CCIR 36—provides color detail and fast motion.



Peak signal-to-noise ratio. Longer bars are better.



PQR-Luma. Shorter bars are better.



PQR-Luma & Chroma. Shorter bars are better.

Digital Betacam was again the tape format with the least-degraded image, though its (and every other format's) PQR scores were higher (thus worse) than on the Ferris Wheel test. Digital-S, DVCAM, and DVCPRO each produced PQR scores about twice as high as their Ferris Wheel scores, with DVCAM and DVCPRO showing impairments that were noticeable, but slight.

DVCAM had PQR scores slightly lower than DVCPRO; but again, the differences were insignificant.

The Mobile and Calendar's highly detailed content proved to be less of a challenge for Betacam SP, which yielded PQR scores approximately one point better than those of DVCPRO and DVCAM.

For this highly detailed and colored video, Betacam SP produced slightly, but visibly, superior results to the 25Mb digital formats. The non-Component formats—Hi8 and 3/4-inch—showed strongly degraded images. Only the uncompressed DDR produced the same results it did in the easier Ferris Wheel test.

The Susie test sequence —CCIR 16— plays a talking head shot with slow, smooth motion as the subject leans forward. The closeup of a human face, along with the skin and hair detail, make an image that demands careful compression. Several, but not all, of the tape formats produced their best images when encoding this test video.

Digital Betacam and Digital-S, the two digital tape formats that apply the least compression, produced the best PQR scores for tape. However, these scores and the image degradation weren't as low as their Ferris Wheel scores.

DVCAM and DVCPRO both scored within one-half PQR point of Digital-S and within one PQR point of Digital Betacam—impressive results considering their lower data rates and higher compression. In this test, DVCPRO produced slightly better scores than DVCAM; but as in the other tests, the differences between these two weren't noticeable.

Betacam SP produced good images, but not as good as the 25Mb DV-based formats, DVCAM and DVCPRO. However, both Betacam SP and the 25Mb DV formats produced their best images when encoding this talking head shot. All the above formats produced slight to no perceptual image degradation.

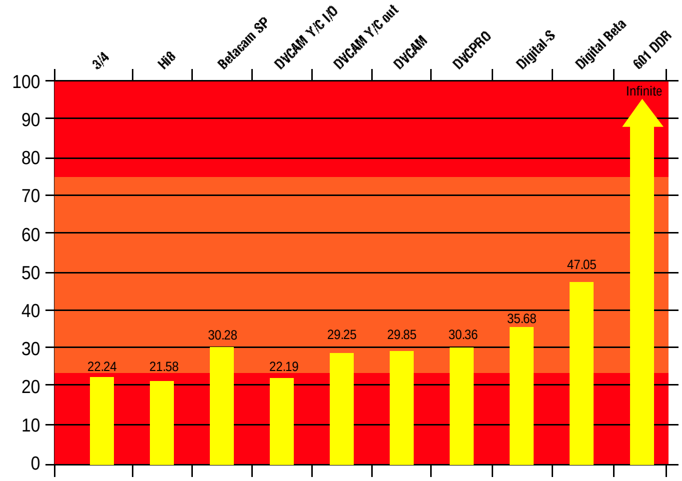
When DVCAM output a Y/C signal (after receiving an SDI signal), the degradation was noticeable, but not annoying. 3/4-inch and Hi8 both produced video with significantly impaired image quality. For this talking head video, all the digital formats and Betacam SP produced acceptable images.

The winner is . . .

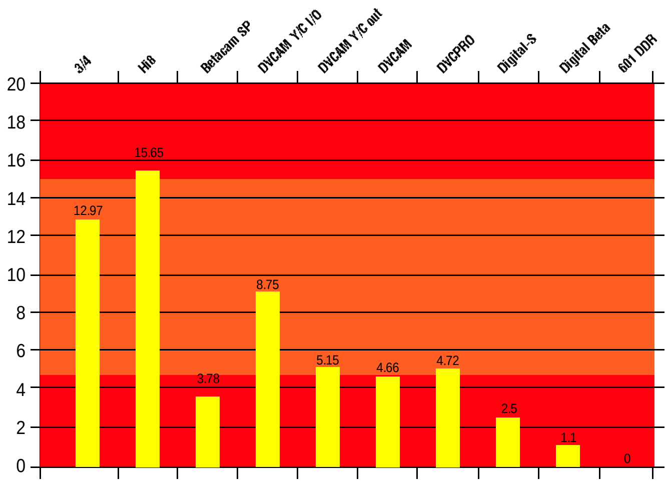
The results of our image quality tests closely matched our expectations. Less compression is better than more compression. Component video is better than Y/C and Composite video. But beyond these obvious conclusions, we made some other observations.

The more detailed and complex the image we played, the greater the benefit of ➢

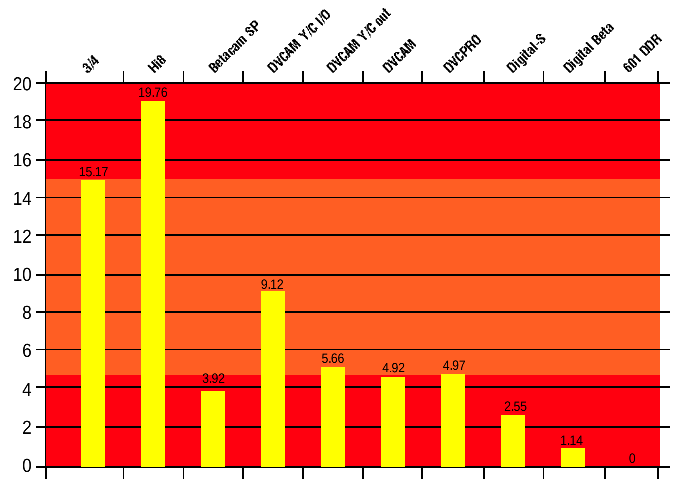
The Mobile and Calendar test sequence—CCIR 36—has lots of detail and motion. It proved the most difficult challenge.



Peak signal-to-noise ratio. Longer bars are better.



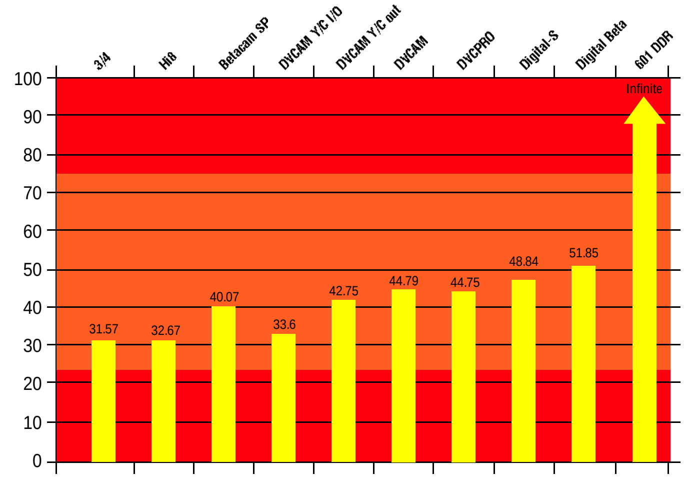
PQR-Luma. Shorter bars are better.



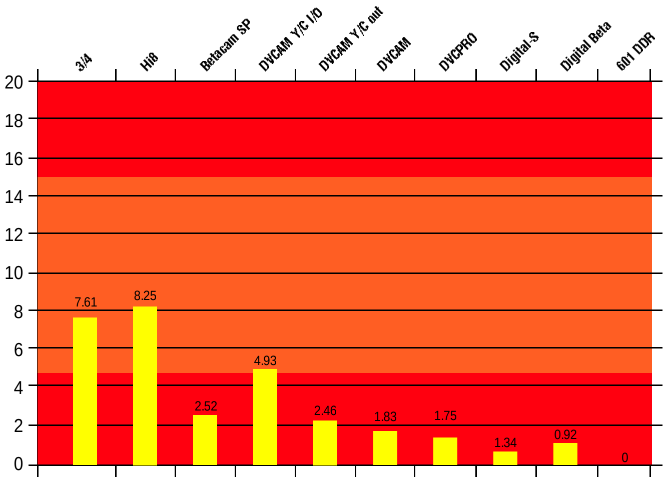
PQR-Luma & Chroma. Shorter bars are better.

Tape Format		3/4	Hi8	Betacam SP	DVCAM Y/C I/O	DVCAM Y/C out	DVCAM	DVCPRO	Digital-S	Digital Betacam	601 DDR
Test	**Source**										
Ferris Wheel	CCIR 36										
PSNR		28.2	26.24	36.1	29.05	39.05	39.55	39.12	44.37	51.85	Infinite
PQR Luma		8.08	9.79	2.28	6.28	2.71	2.26	2.38	1.24	0.68	0.00
PQR Luma & Chroma		9.78	12.48	2.42	6.56	3.02	2.43	2.53	1.27	0.71	0.00
Mobile/Calendar	CCIR 30										
PSNR		22.24	21.58	30.28	22.19	29.25	29.85	30.36	35.68	47.05	Infinite
PQR Luma		12.97	15.65	3.78	8.75	5.15	4.66	4.72	2.5	1.1	0.00
PQR Luma & Chroma		15.17	19.76	3.92	9.12	5.66	4.92	4.97	2.55	1.14	0.00
Susie	CCIR 16										
PSNR		31.57	32.67	40.07	33.6	42.75	44.79	44.75	48.84	51.65	Infinite
PQR Luma		7.61	8.25	2.52	4.93	2.46	1.83	1.75	1.34	0.92	0.00
PQR Luma & Chroma		9.16	13.66	2.66	5.07	2.69	1.92	1.84	1.36	0.99	0.00
Format/VTR Specs											
Color Sampling		Y/C	Y/C	4:2:2	4:1:1	4:1:1	4:1:1	4:1:1	4:2:2	4:2:2	4:2:2
Compression Ratio		N/A	N/A	N/A	5:1	5:1	5:1	5:1	3.3:1	1.6:1	1:1
Compression System		analog	analog	analog	DV-based	DV-based	DV-based	DV-based	DV-based	DCT-based	uncompressed
VTR Model		VO-9850	EVO-9850	CVR-70	DSR-30	DSR-80	DSR-80	AJ-D640	BR-D92U	DVW-500	WSD/2Xtreme
VTR Manufacturer		Sony	Sony	Ampex/Sony	Sony	Sony	Sony	Panasonic	JVC	Sony	Accom
VTR List Price		$13,425	$7900	$39,000	$4800	$9495	$9495	$8495	$20,950	$39,000	$12,900

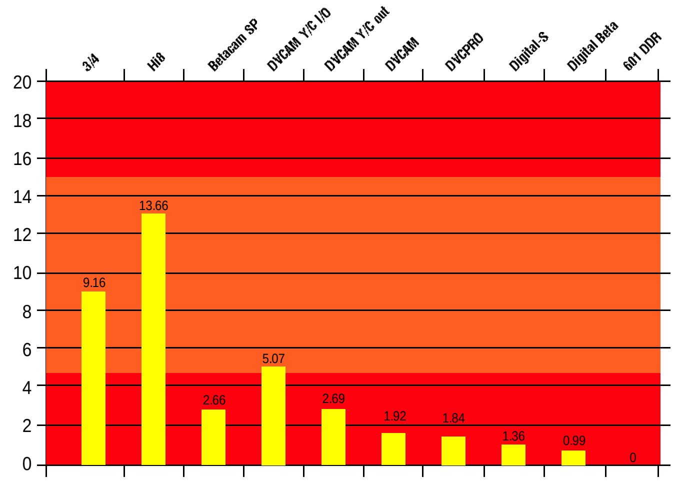
The Susie test sequence—CCIR 16—emphasizes skin and hair detail.



Peak signal-to-noise ratio. Longer bars are better.



PQR-Luma. Shorter bars are better.



PQR-Luma & Chroma. Shorter bars are better.

mild compression. More formats produced PQR scores under 2.00 with the Susie footage than with the Ferris Wheel or Mobile and Calendar footage.

The perceptual difference between Digital Betacam and Digital-S is noticeable; but with the talking head and high-motion image content, the difference isn't very noticeable. With the highly detailed and complex images in the Mobile and Calendar sequence, the difference is greater; but Digital-S still turns in very good-looking video.

As the data rates suggest, 50Mb DV-based formats show about half the image degradation as 25Mb DV formats. We used a Digital-S VTR for our 50Mb DV format, but we expected that DVCPRO50 would exhibit the same image quality improvement over DVCAM and DVCPRO, two 25Mb formats.

DVCAM and DVCPRO perform essentially the same. Extremely detailed and complex scenes provide a challenge for these formats, yielding visibly, but not strongly, impaired video. But with talking head and fast-motion video, the 25Mb DV-based formats look very good. The two format's PQR scores were consistently within one-tenth of a point of each other. We expect standard DV to be capable of images equal to those of DVCAM and DVCPRO, if you can get the signal to and from tape without reducing it to Y/C video.

Perhaps our most interesting finding involves the 25Mb DV-based formats. If you can record to a DV-based format without a Y/C conversion (for example, by recording straight from camera to tape), you can often get a good image off tape even if you output through an analog Y/C connection. 25Mb DV with Y/C out looks good. You will suffer an image-quality penalty compared to Component digital output, but the loss is slight. That's good news if your NLE has neither an SDI nor a 1394/FireWire input.

Betacam SP still holds its own against the low-cost digital upstarts. If you're satisfied with Beta's image quality, there's no reason to abandon the format. But based solely on perceptible image quality, there's little reason not to consider a 25Mb or 50Mb DV-based format. For many uses, the DV formats deliver similar or superior images for the same or less money.

Hi8 and 3/4? Well, each was good in its day, but those days passed a few years ago.

So what format should you choose? Many factors play a role in answering that question. Camera quality, VTR features, and compatibility with your current and future equipment must be considered.

Unless you run a closed shop where your team acquires, edits, and outputs everything in house, you must be able to play from and record to the formats that your production partners and clients require.

More money can buy higher image quality. But our tests show that excellent image quality is no longer the exclusive province of just one tape format. DV

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