

# Contemporary DTV Acquisition—Some Perspectives on the Related Standards, the Technologies, and the Creative

By Laurence J. Thorpe

*The arrival of digital television (DTV) has created a curious maelstrom of tentative engineering excitement, business anxiety, creative skepticism, and spotty consumer anticipation. In light of the imminent debut of new DTV services, lingering technical debates on DTV formats are no longer helpful, and, in the larger scheme of things, they are already anachronistic. In the context of the front end of the new television system, DTV image acquisition, technical debate certainly still swirls unchecked. This paper will attempt some perspectives intended to urge a move to the next and most important phase of this inter-industry DTV movement, namely, proactive implementation by the creative program production community. The present technical status of DTV image acquisition will prove to be better than many believe. It is suggested that the rigorous implementation of Standards should be subservient to the paced and incremental march of Technology, and that it is the Creative community that best drives the pace of advance of the latter. At some point, it becomes essential for the realities and subjectivity of digital program creation to supplant misguided engineering rigor. Resolution will be central to much that is examined here. There is surely no technical performance parameter that is so carelessly bandied, and so grossly misunderstood, particularly when it comes to the realities of widescreen standard-definition television (SDTV) and high-definition television (HDTV) picture acquisition.*

The industry is entering a new era of television. The enhanced performance transparency promised by digital delivery media calls for a thoughtful review of both technical and creative priorities in digital program origination. The latter may be acquired on motion picture film originated (with subsequent digital transfer to HDTV/SDTV); it may be direct electronic acquisition by digital camcorder or some separate camera-recorder combination; or, computer generated.

Image acquisition has become the focal point of most contemporary discussions relating to the implementation of various DTV production standards.

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Above all of the current furious discourse on DTV scanning parameters and digital sampling structures, there hovers a central preoccupation with image resolution. The industry needs to come to grips with the multidimensional aspect of picture quality and recognize that there can be such a thing as enough resolution—within any given SDTV and HDTV video format. It will be argued that only the creative production community can impart the requisite perspective on this issue.

## DTV Image Acquisition

The underpinnings of DTV image acquisition equipment are:

- Technical standards that prescribe all basic parameters of production video formats.
- Technologies that are mobilized to implement those standards.

- The Creative community that spearheads the multiplicity of applications of image acquisition and ultimately determines the pace of advance of product design.

Reference will be made to the Acquisition Triad as shorthand for the combined dynamics of these three entities (Fig. 1). Sometimes not understood, or widely accepted, are the intricate relationships between the three, and the order that should define their individual importance over time.

At some stage in the evolution of the first two, there arises the need for engagement of the third element, the Creative—those producers, cinematographers, technical directors, and video shooters who ultimately embrace the new acquisition products. The timing of this passing of the baton from the engineering to the production community is critical to the ensuing pace of development.

## DTV Acquisition Triad—An Orderly Relationship

A good production standard might be described as one that stretches acquisition technology in the early days, but inherently spurs an unrelenting pursuit of full realization of that standard. This can, as will be noted, take some time. To a degree, therefore, a good standard is inherently "future-proofed." A proactive creative community, taking over at an appropriate time following early implementation of a formalized standard, should lead the paced evolution toward the full promise of that standard.

The Creative is a more crucial part of this Acquisition Triad, particularly when it elects to become more proactively engaged than is perhaps appreciated. Arguably, this is more so in acquisition than in other parts of the televi-

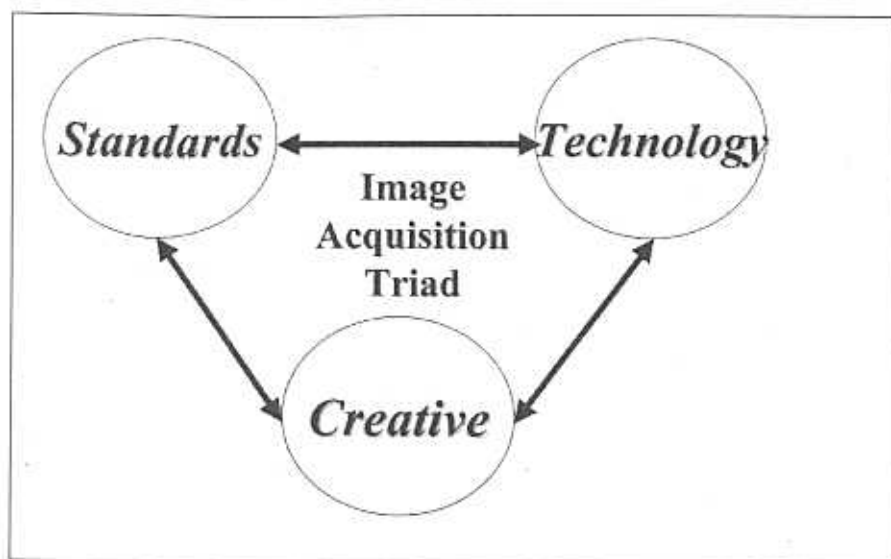


Figure 1. The three underpinnings of DTV acquisition product design.

sion system. One interesting (and even important) case history of a paced yet energetic interplay between these three elements on the emergence of DTV acquisition was the evolution of the now famous 601 Production Standard.

#### Birth of SDTV Acquisition—Pursuit of the Elusive 601 Standard

In 1982 the new Y/R-Y/B-Y digital component video set was defined by the seminal collaborative work of SMPTE and the European Broadcasting Union (EBU) on a digital studio origination standard. The global International Radio Consultative Committee (CCIR) Recommendation (now International Telecommunications Union Radio Communications Committee (ITU-R BT) 601-5) that emerged shortly thereafter was surely a standard ahead of its time, certainly in terms of digital acquisition. It would be 4 years before this digital production format could even be digitally recorded (the D-1 videotape recorder). It would be 12 years before this video format could be realized in terms of direct acquisition by a digital camcorder. It is noteworthy, however, to recall that this 1982 standard did ignite instantly the technological impetus to march toward a final realization of the standard (Fig. 2).

The original Betacam format (1982) was specifically designed around that still very new Y/R-Y/B-Y component video set. Yet, this implementation was wholly analog. This was, after all, the

state of the art at the time in camera processing and video recording. In addition, the bandwidths of that original Betacam video component set fell quite short of those prescribed in the 601 Standard—being a mere 4.1 MHz for Y, and 1.5 MHz each for R-Y and B-Y. If such signals were digitized they would have fallen short of the 3:1:1 component set. Yet even today, this analog format (now somewhat extended to 4.5 MHz in luminance) constitutes the largest source of program acquisition for the largely digital post-production that operates according to the full 601 Standard.

These shortcomings, however, constituted no barrier to the subsequent

phenomenal success of digital 601 production. This was because while Betacam represented true state-of-the-art video recording at the time, it also fulfilled a Creative need. It brought to the industry a camcorder that facilitated the acquisition of pictures in component video form, and had a subjective quality beyond anything else available at the time. It spurred adoption of component video thinking within an entrenched NTSC composite environment. It would only be a question of time before technology would support practical implementation of an all-digital system in full compliance with that far-sighted standard.

This was a case of the Creative element taking over in a timely fashion, and engaging instead in highly proactive use of the early products. Even then, it would be another 12 years before technology would catch up with the written standard in terms of acquisition. In 1994 the Digital Betacam format arrived, and with it, the world's first all-digital camcorder<sup>1</sup> originating SDTV program material in full compliance with the 10-bit version of the 4:2:2 601 Standard. The Acquisition Triad worked splendidly, but it was paced by technology.

#### Technology—and Contemporary Digital Image Acquisition

Astonishing strides have been made in all of the core technologies associated with electronic acquisition. In both imaging (the picture shoot) and

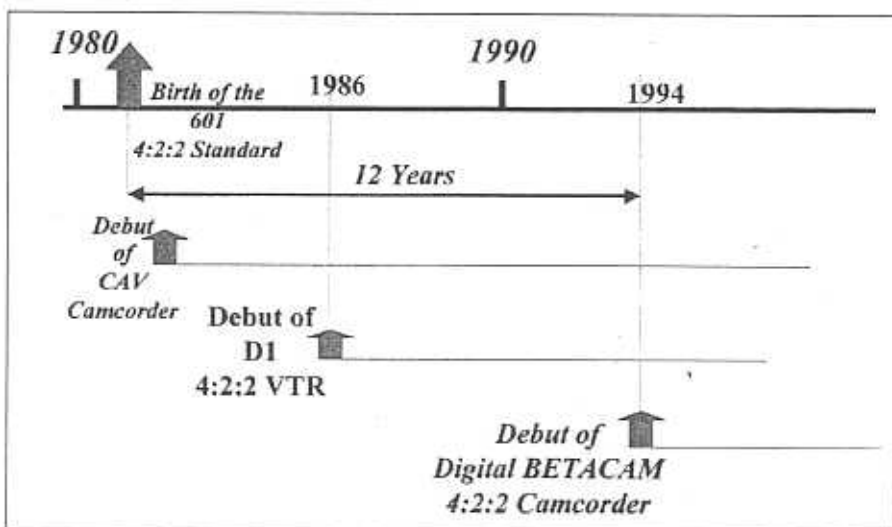


Figure 2. The early emergence of the 601 Standard led to a paced evolution toward the final realization of a 4:2:2 digital camcorder.

recording (the picture capture), the technologies of image sensors, digital recording on both tape and disk, and digital signal processing, have all advanced with extraordinary rapidity. Indeed, they have dramatically accelerated over the past half-decade.

One consequence of this is that the old film-video debate has become an entirely new (and far more constructive) discussion in the past three or four years. Technically, SDTV electronic digital acquisition can squarely rival the picture quality of 35mm film transfers (to SDTV) for many television programs and commercial applications. Perhaps of greater significance to the independent film community is the fact that today's electronic acquisition, combined with the reverse transfer to film, has also become a visible new reality in lower budget motion picture theatrical release.

HDTV, on the other hand, still significantly challenges both the Technical and the Creative. The former encompasses some daunting technical realities in today's optics: charge-coupled device (CCD) imagers, recording technologies, digital signal processing (DSP), digital image manipulation, and most especially, high-definition (HD) displays. The Creative challenge is, however, the more troublesome. The still frenetic debate on HDTV standards and related video formats regret-

tably perpetuates a sense of a lingering prototype phase that is clearly discouraging many within the production community. And, overshadowing the entire matter of marketplace success or failure of HDTV, there looms the crucial issue of HD equipment costs.

There has never been a greater need for an energetic and immediate engagement of the Creative element of our triad, to provide the guidance that will stimulate a paced and sustained evolution in HD product development.

### State of the Union of the SDTV Acquisition Triad

*Standards—Firmly in Place  
Technology—Highly Mature  
Creative—Widely Experienced*

The state of this union, for SDTV, is very good. The past five years have witnessed an unprecedented flurry of technological activity, centering around developments in imaging technologies, digital signal processing (DSP), and the emergence of a potpourri of digital recording formats tailored to various tiers of the video marketplace.

The now long-established ITU-R BT 601-5 international standard prescribes the basic parameters for production according to the 4:2:2 digital parameters. Direct acquisition according to the

601 signal format then was considered a far off technological dream, totally unnecessary within an entrenched analog composite NTSC environment. It is worthwhile to take a brief look at how well this standard is presently being met by contemporary origination equipment. We will examine a present-day 525-line widescreen SDTV studio camera.

### Studio Camera

A new 12-bit DSP camera (having about 1.7 million gates of DSP circuitry) combines advanced digital processing of the red, green, and blue (RGB) video with a new CCD imager. In terms of traditional camera operating performance specifications, the careful matching of these two core technologies<sup>2</sup> in the BVP-900/950 series has produced a significant improvement in all of the following:

- Signal-to-noise ratio: 65 dB
- Horizontal resolution (MTF): 80% @ 400TVL/ph
- Dynamic range: 82 dB
- Vertical smear: -145 dB

In terms of camera resolution, the technologies of CCD and DSP are married in a novel fashion. This union mobilizes the high CCD sensor count and optical low-pass filter to create an impressive MTF across the useful operating videoband (e.g., 6.75 MHz for a 16:9 image) while simultaneously employing a novel digital signal processing technique to circumvent the normal Nyquist sampling limitation (Fig. 3).

This technique facilitates an increase in MTF within the useful videoband, extends the limiting resolution of the camera to 750 TVL/ph for the 16:9 widescreen mode, and to about 950 TVL/ph for the standard 4:3 CCD, while virtually eliminating any associated aliasing.

For the standard 4:3 image format, the band edge of the 4:2:2 luminance signal is 5.75 MHz (as determined by the SMPTE prescribed filter template). This studio camera has a specified horizontal depth of modulation (DoM) of 80% (with no image enhancement applied) at the 5-MHz (or 400 TVL/ph) point, retaining a band-edge DoM of about 74% at 5.75 MHz. For the widescreen case, this reduction becomes 65% DoM at the 400 TVL/ph

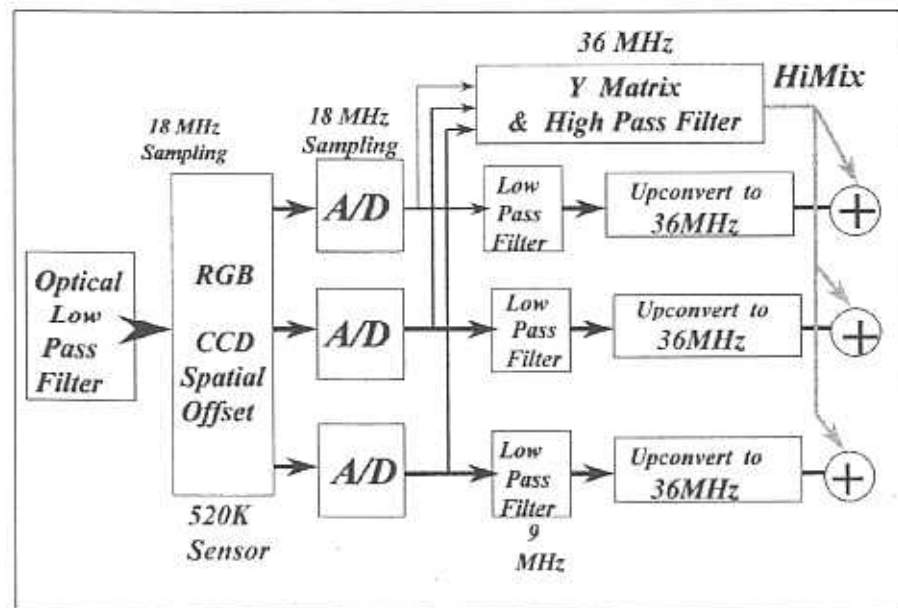


Figure 3. A combination of CCD precision spatial offset, optical prefiltering, and DSP processing used to optimize a balance between horizontal MTF and aliasing.

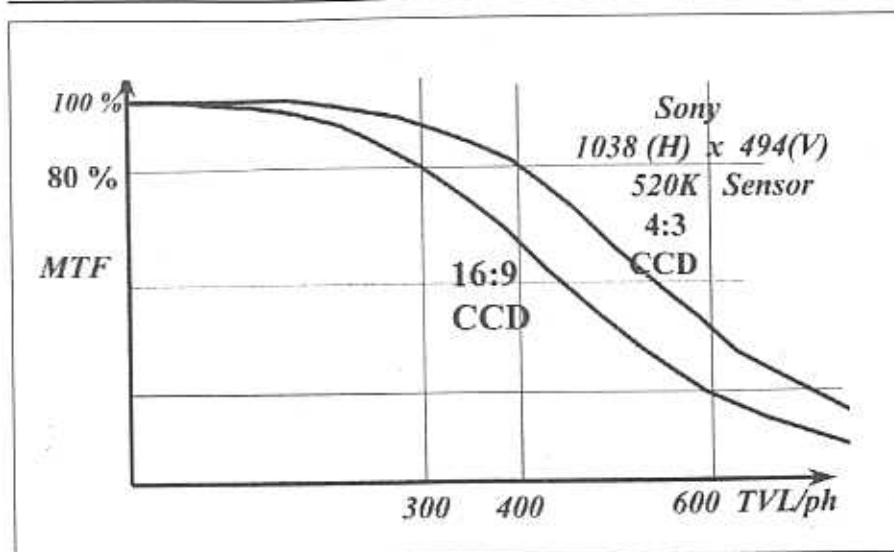


Figure 4. A 1000-element CCD with special DSP processing can produce an unprecedented MTF in the 4:3 image format and a very high MTF when switched to the widescreen 16:9 mode.

(or 6.75 MHz) boundary. These are unprecedented resolution capabilities.

### Standards and Numerology

#### The Current Industry Angst Relating to 16:9 Widescreen Horizontal Resolution

Where a great deal of understandable confusion reigns today is in the attempt to apply old and familiar rules of thumb to ascertaining resolution in a television camera. One of the oldest industry yardsticks is to get a snapshot of the horizontal MTF performance of a camera in terms of the DoM at a given reference frequency. The reference spatial frequency that has become the norm for the standard 4:3 525-line television system is 400 TVL/ph. This translates to 5 MHz for this 4:3 system (Appendix).

The present widespread confusion arises because camera manufacturers are reluctant to quote the DoM at the same 400 TVL/ph for their 16:9 widescreen cameras. Within the competitive environment, we craftily quote the DoM still at 5 MHz, in the anticipation that engineers will not realize that in the new widescreen domain this now means 300 TVL/ph, and not the old 400 TVL/ph!

The bottom line is that a given CCD imager, with a fixed number of horizontal sensors, will produce less resolution in the widescreen SDTV mode than it does in the standard 4:3 mode (Fig. 4).

This is a fundamental that is totally independent of the different readout mechanisms employed by competing manufacturers. It is an inescapable fact in all current switchable 16:9/4:3 cameras. The big question then becomes: does it matter? To acquire a better sense of reality on this resolution dilemma, we need to look a little more closely at resolution and what really constitutes visual picture sharpness.

### Picture Sharpness and MTF

MTF is the curve depicting video signal output level versus the spatial

frequency produced by imaging a pattern of alternate black and white lines in a given dimension. Horizontal and vertical MTF is by far the most important and relevant measurement of picture sharpness. The oft-quoted limiting resolution (certainly in the context of camera specs) tells nothing about perceived picture sharpness. In that sense, contemporary camera specs is somewhat deceptive. We have become victims of a narrow decades-old myopic focus on the horsepower race of horizontal limiting resolution in competitive specifications.

As Schade showed in his seminal work on camera and film resolution,<sup>3</sup> the apparent picture sharpness (as seen by the viewer) is a two-dimensional quantity, and is directly related to the square of the area under the MTF curves in both the horizontal and vertical domain. Thus the shape of those curves are a greater determinant of picture sharpness than their point of limiting resolution. This is particularly important in the new DTV world where the television system is sharply bounded by many cascaded digital filters. Of prime importance in DTV acquisition is that the very first digital recorder that captures that original picture introduces the first brick wall filter.

Today, a television camera can easily demonstrate in excess of 900 TVL/ph of horizontal limiting resolution. However, the very first digital

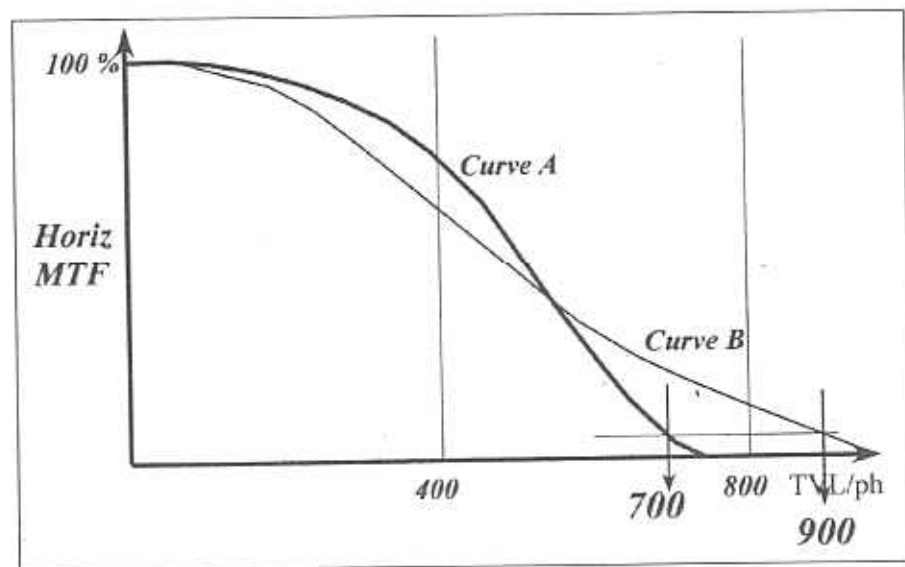


Figure 5. Two MTF curves having different depth of modulation over the passband and quite different limiting resolution. Which provides the sharper picture?

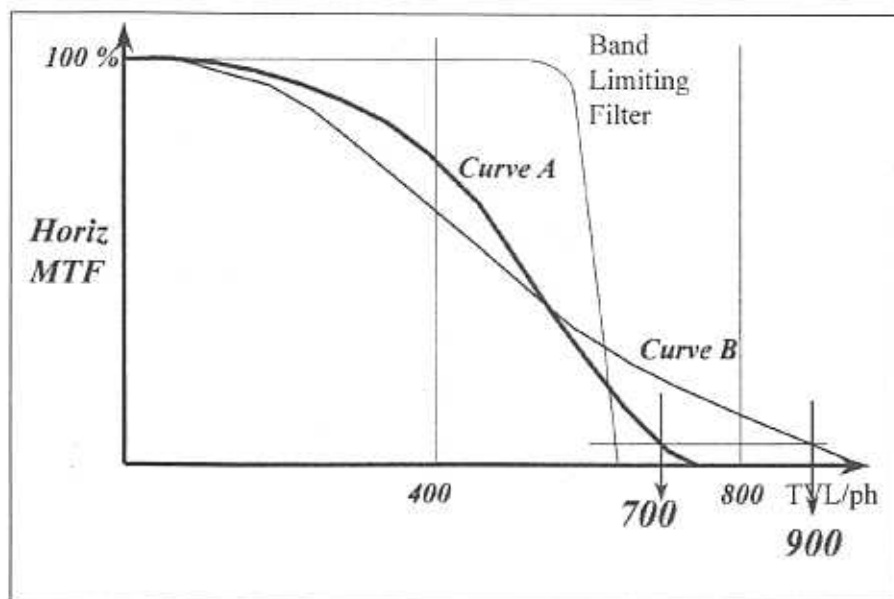


Figure 6. The introduction of a bounding digital filter into the acquisition system will truncate the MTF responses and more effectively expose the effective sharpness difference.

videotape recorder (VTR) that actually captures this video, quickly and ruthlessly truncates it to a number more in the region of 500 TVL/ph. Consider Fig. 5, which shows two different camera horizontal resolution profiles (that is, two different MTF curves).

Curve A has a limiting resolution of about 700 TVL/ph. Curve B has a limiting resolution in the neighborhood of 1000 TVL/ph. Clearly, the shapes of the two curves are quite different. Which would produce the sharper image, as seen by the human visual system?

To ascertain this, Schade would square the area under the two curves, integrate these results, construct two rectangular MTF curves (having equivalent areas as the squared curves but two different boundaries), and assign the higher sharpness to that with the resultant higher boundary number (a number he designated  $N_e$ ). In the case shown, it is not immediately apparent which curve encompasses the greater area. But, if the two cameras are now both subjected to the first digital filter in the television system, arbitrarily chosen as that shown in Fig. 6, then the picture sharpness difference becomes readily apparent. Curve A will produce the decisively sharper image.

The key question remains, however, the significance of the lower 16:9 resolution compared to the 4:3 image for-

mat. It will be demonstrated that in terms of overall picture sharpness it is actually a total nonissue.

### Standards and Specifications

#### The Historical Fixation on Camera Horizontal Resolution

Sometimes forgotten is just how much horizontal resolution has improved over the best of the former 30mm Plumbicon pickup tubes (circa 1985). Then, a 50% DoM at 400 TVL/ph was considered the very best possible (when the beam was adjusted for minimum astigmatism, which was crucial to good vertical resolution). With CCDs now typically providing 70 to 80% DoM, it is arguable that SDTV horizontal resolution has definitively passed a point of diminishing returns in terms of contributing to overall picture sharpness, which is a complex integration by the human visual system of the portrayed two-dimensional picture. While improved since the advent of the CCD imager, the still relatively substantial resolution shortfall in the vertical direction, a consequence of the inherent SDTV 480-line sampling shortfall, creates a significant weighting that depresses overall picture sharpness. Beyond a certain point, in normal program material no amount of increase in horizontal resolution can compensate for this.

### Standards and Technology

#### When are there Enough Sensors in the CCD Imager for SDTV?

Of more than passing interest is that while almost all contemporary HDTV cameras have CCD imager-sampling lattices that precisely coincide with the digital sampling structure prescribed by SMPTE 274M standard, this was never the case with 525 or 625-line SDTV. To illustrate a marketplace-driven technological progression, Fig. 7 summarizes the well-known CCD spatial sampling lattices that have emerged since the dawn of that first RCA broadcast-quality imager in 1984.

Note that for the first two years the CCDs had a somewhat under-sampled structure horizontally; yet even with the 403-element CCD (of RCA) many at the time noted the distinct subjective sharpness improvement (over the then contemporary small-format pickup tubes). This was largely attributable to the distinct improvement in vertical resolution introduced by the CCD, together with the absence of imager astigmatism and imager corner defocusing.

It took only a decade for SDTV CCDs to rapidly advance to oversampled horizontal structures, with today's horizontal sensor counts approaching twice the number of the digital sampling structure. The advantage of ever-increasing MTF over the useful 5.75-MHz bandwidth, and the attendant lowering of horizontal aliasing artifacts, in one sense, argues for a continuation of the current competitive drive to indefinitely increase the sensor count. However, despite this apparent logic, we at Sony have come to a quite different conclusion.

#### Horizontal Resolution in Context with the Multiple Dimensions of Image Quality

This conclusion is based upon the recognition that, as in most engineering tasks, there comes a point of diminishing returns. There are two other important weighting factors in CCD design that must be borne in mind:

- The undersampled vertical in the 480-line (525 system), and the consequence of that weighting on overall picture sharpness.

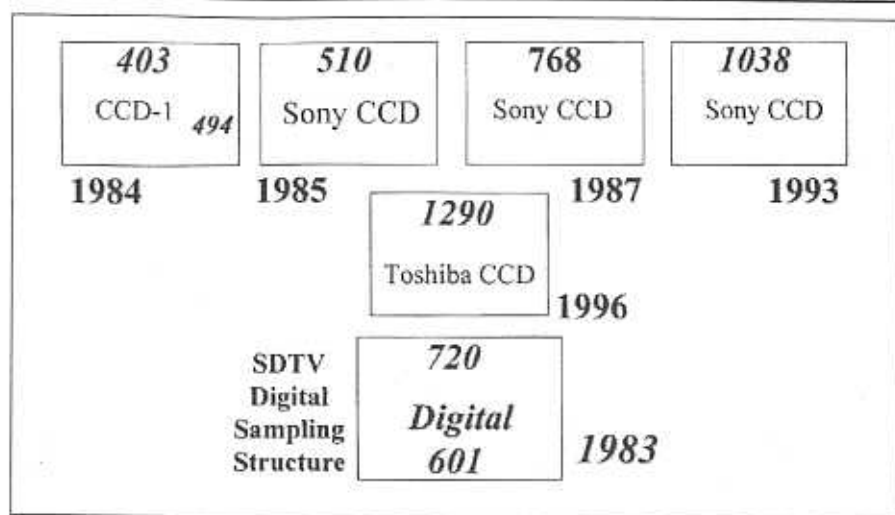


Figure 7. A historical profile of the paced evolution of SDTV CCD imagers in terms of the increase in their horizontal sensor count.

- The reduction in size of the sensor that accompanies any increase in horizontal count, and the consequence of that on the overall imaging quality of the sensor.

- The new digital processing capabilities offered by DSP that permit previously unheard-of enhancement to video images following the CCD opto-electronic transformation.

As shown somewhat simplistically in Fig. 8, the increase in resolution offered by the continuing increase in horizontal sensor count is ultimately counterbalanced by the more complex deterioration that sets in on the inherent quality of the sensor and the attendant increasing difficulty of high quality control in manufacturing. The separate picture quality attributes that are uniquely determined by the individual sensor are:

- Sensitivity.
- Colorimetry.
- Exposure latitude (dynamic range).
- Tonal reproduction (gray scale).

They are the other "dimensions" of image acquisition that are essential to the reproduction of excellent overall picture quality (Fig. 9).

There are also CCD imaging artifacts that are negatively affected by a continuing reduction of the image sensor size:

- Noise.
- Vertical smear (on intense high-lights).
- Dark current (and RPN).

There is more than adequate latent horizontal resolution in today's SDTV acquisition cameras, for 16:9 and cer-

tainly for 4:3 imagery. The sophistication of modern digital image enhancement systems can further augment this to meet any creative taste. In terms of adding any significant improvement to overall SDTV picture sharpness, however, it is the vertical shortcoming that must be dealt with. In directly addressing this vertical limitation, the 480 Progressive scanning system constitutes the most promising advance in decades. It does three important things:

- Elevates the inherent vertical MTF.
- Restores a greater equality between the horizontal and vertical MTF curves. This in itself is desirable to the human visual system.

- Eliminates the flickering 30-Hz alias associated with interlace scanning.

### State of the Union of the HDTV Acquisition Triad

*Standards—Firmly in Place  
Technology—Maturing Creative—Skeptical and Hesitant*

*The Long March—the Parallel Advance of HDTV Production Standards and Image Acquisition Technologies*

The development of the famous ATSC Table 3 (delineating recommended DTV transmission video formats) and the subsequent splintering of the broadcast industry in terms of deployment of most of those formats, has raised some interesting new challenges to the production and post-production communities intending to service the "DTV food chain."

HDTV image acquisition has evolved through no less than four successive product design cycles and three successive production standards, before reaching the contemporary SMPTE 274M standard that describes a wide-range of format variations, all centered around the high-resolution 1920 x 1080 sampling structure and 74.25 MHz sampling frequency.

SMPTE 274M is a very far-sighted standard, one that will carry HD television imaging far into the next millennium particularly in terms of present

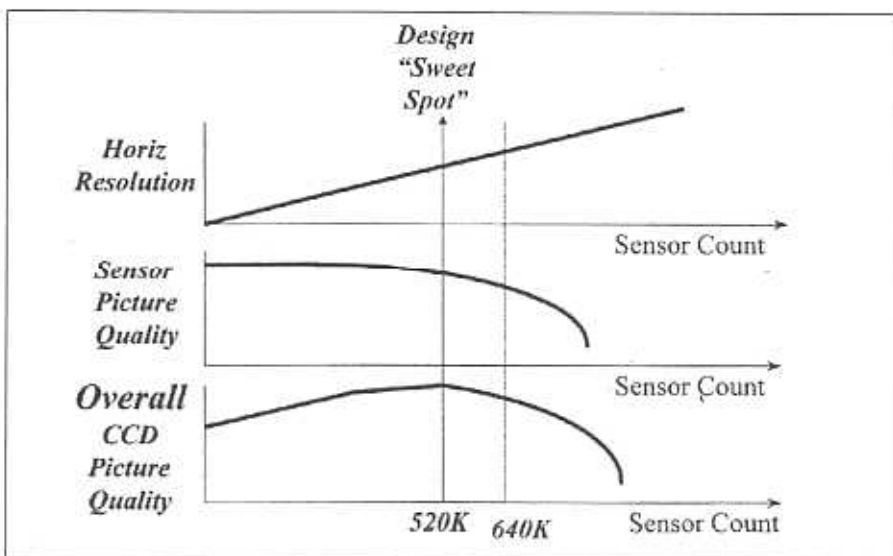


Figure 8. The relationship of CCD horizontal sensor count with both horizontal resolution and the aggregate dimensions of other key picture quality attributes.

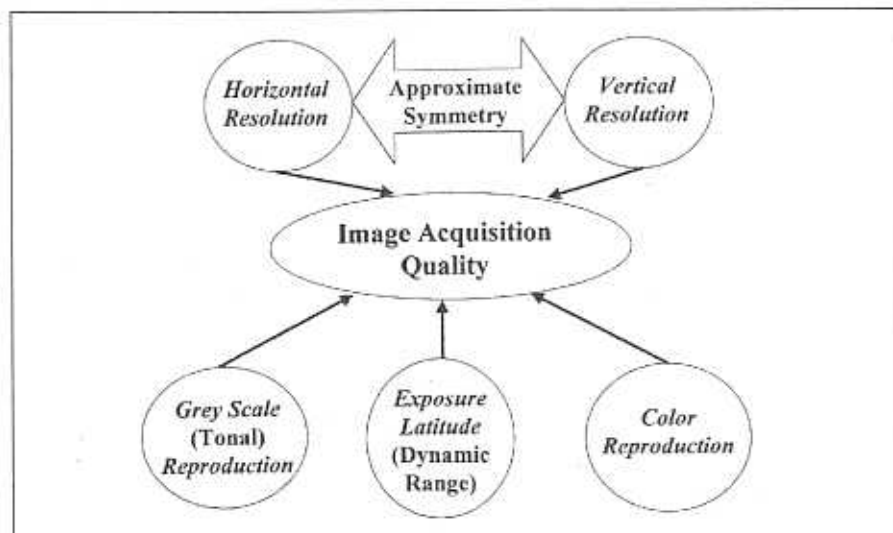


Figure 9. The multidimensional aspect of image acquisition quality.

realities in electronic acquisition, including the HD telecine electronic transfer of 35mm and Super 16mm motion picture film. Unlike its SDTV counterpart, where core technologies in imaging and recording have "caught up with," or indeed outstripped, the strictures of their written production standards, the dawn of the DTV era sees HDTV production standards straining the technologies of image acquisition and image display.

The SMPTE 274M standard prescribes potential picture information content that is beyond the present-day capabilities of optics, imagers, digital recording, and HD display. This is particularly true of compact mobile HDTV cameras and recorders; at the other extreme of the television system, it is especially true of present-day CRT-based HDTV studio monitors. As will be shown, it will take some years before HDTV image capture can realize the equivalent degree of performance of their current counterparts in 4:2:2 SDTV. The central question then arises as to the present performance status of HDTV acquisition relative to the real needs of program production.

### A Creative Query on Image Specmanship versus Picture Creation

#### How Good is HDTV Acquisition Today?

It is remarkably good. Measured in terms of what a camera creates in overall

resolution, and how much of that is actually captured on the companion recorder, current HD is far better than NTSC was at its beginning, in terms of how it filled the allotted 4.2 MHz. It is better, too, than SDTV in the early 1980s, at the birth of the 601 Standard, in terms of how it filled its allotted 5.75 MHz. This is argued on the basis of the perceived picture sharpness of the first generation recording made of an HDTV camera's video, in combination with how well the other dimensions of the image are being acquired.

At the height of analog NTSC Type-C recording (around 1981 to 1986), the depth of modulation at 4.2 MHz of the

typical 30mm PbO camera of the time was about 45 to 50%, and for the portable 2/3-in. cameras it was only 25 to 35%. Vertical behavior of these pickup tubes was so bad that it simply was not spoken about (a consequence of astigmatic beams). By 1990 a good 2/3-in. CCD camera was producing a 60% depth of modulation at the 5.75 MHz recording limit of a D-1 recorder, though very few first-generation recordings were ever produced in that format.

HDTV image acquisition is, as will be shown below, better than in the early days of component SDTV, but it still has a way to go in terms of the degree of fulfillment of its own SMPTE 274M production standard before achieving parity with contemporary digital SDTV.

### Standards and Technology

#### The Issue of the HDTV CCD Imager

To understand the current state of the art in implementing the highest resolution HDTV standard, the 1920 x 1080 sampling structure, it is useful to scrutinize the core technology that bears directly upon the HDTV acquisition: the CCD imager. Almost without exception, all current 1080 HDTV imagers have a spatial sampling lattice of 1920 x 1080 sensors,<sup>4</sup> coincident with the digital sampling structure (Fig. 10).

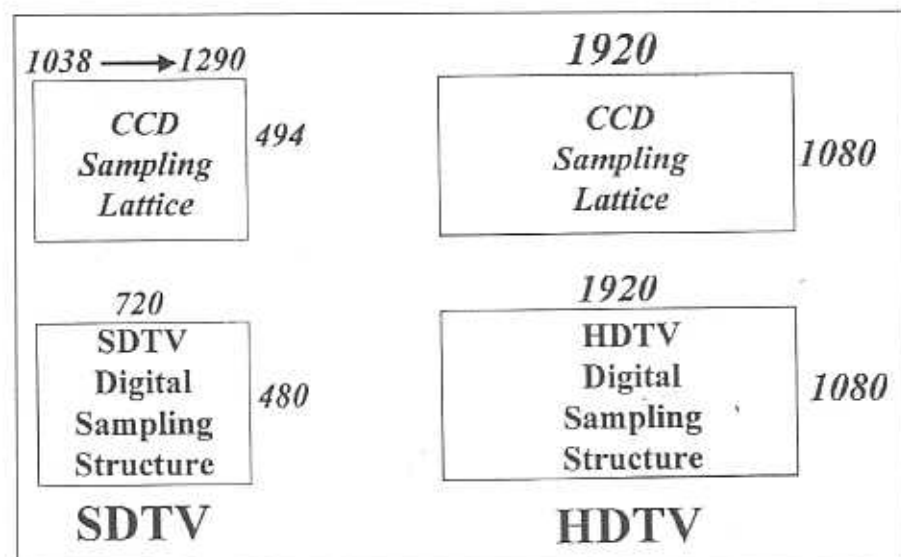


Figure 10. Present HDTV imagers have spatial sampling lattices that are precisely coincident with the digital sampling structure, which is not the case in SDTV.

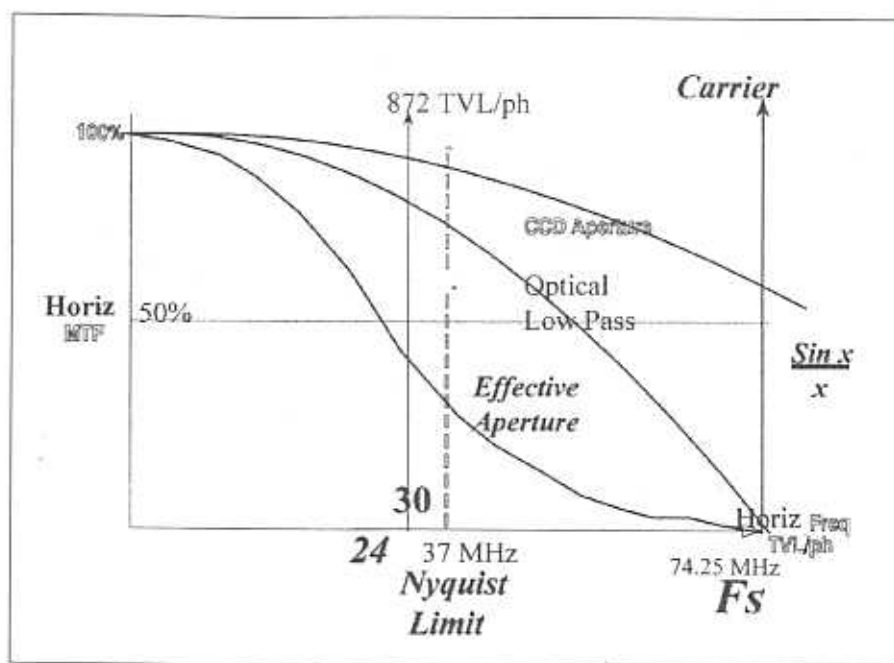


Figure 11. Horizontal MTF curve for the 2/3-in. CCD imaging system in the Sony HDC-700 studio camera and the HDW-700 HD camcorder.

To put a perspective on what this contemporary HDTV CCD means to current HD picture sharpness, Fig. 11 reproduces the horizontal MTF delivered by the 2/3-in. CCD imaging system within our HDC series cameras and the HDW-700 camcorder. Note that at the specified band-edge of 30 MHz (or 872 TVL/ph), the depth of modulation is about 40%. In comparing this with the contemporary 65% depth of modulation of our DVW-700WS 16:9 widescreen camcorder at its band-edge of 5.75 MHz, it is clear that there is considerable room for growth to be anticipated in future HDTV imagers that have higher sensor counts.

### The Issue of the HD Lens

The resolution situation is further compounded by the concatenation of present HD lens performance with that described above for the imaging system. Early HD lenses developed in the mid-1980s strove to achieve the best possible HD performance, and they were astonishingly good. They proved, however, to be inordinately expensive, as indeed were the earlier HD cameras and recorders of that time.

In an attempt to bring down the cost of HD lenses in anticipation of the real DTV marketplace in the late 1990s (and to stay in step with sharply drop-

ping camera costs), lens manufacturers adopted some pragmatic design compromises. As a consequence, current new generation lenses also fall short of the full promise of the 1920 x 1080 two-dimensional sampling of HD. It is important to note that these compromises vary between manufacturers. There are so many variables in lens

design that it is inevitable that different design decisions will emerge.

There is nothing to apologize for on the part of the lens manufacturers. They have made their lens performance (on average) quite reasonably commensurate with the current HD CCD performance (Fig. 12). And the larger voice of the Creative community has been clearly urging lower cost HDTV acquisition products to support a practical launch of the new medium.

### Creative—the Issue of Picture Content

A key variable in the discussion of HDTV program acquisition is the spectral response of the scene content itself. This resides squarely in the domain of the Creative in our triad.

Scene content is quite widely variable. The dynamics are heavily dependent upon the angle of view to which the camera lens is set for a given scene, and of course, the specific contents of that scene. In other words, we are referring to the spectral response of the optical information actually captured through the lens for presentation to the CCD imager. This spectral response is largely typified by high-amplitude lower frequencies with a progressive diminution of amplitude of those higher frequencies that might be contained in the scene.

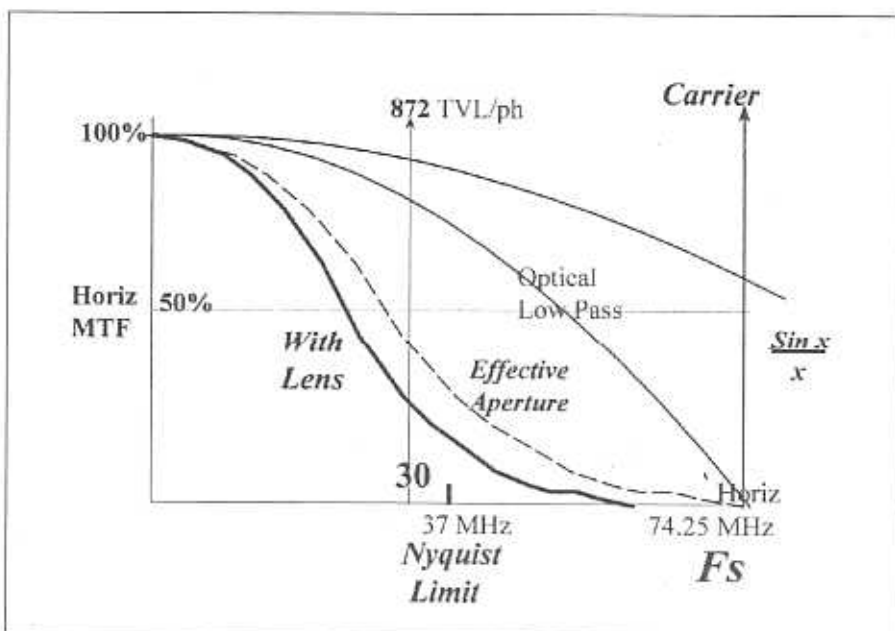


Figure 12. The final camera video MTF (RGB component and matrixed luminance) when the lens and CCD imaging system are concatenated.

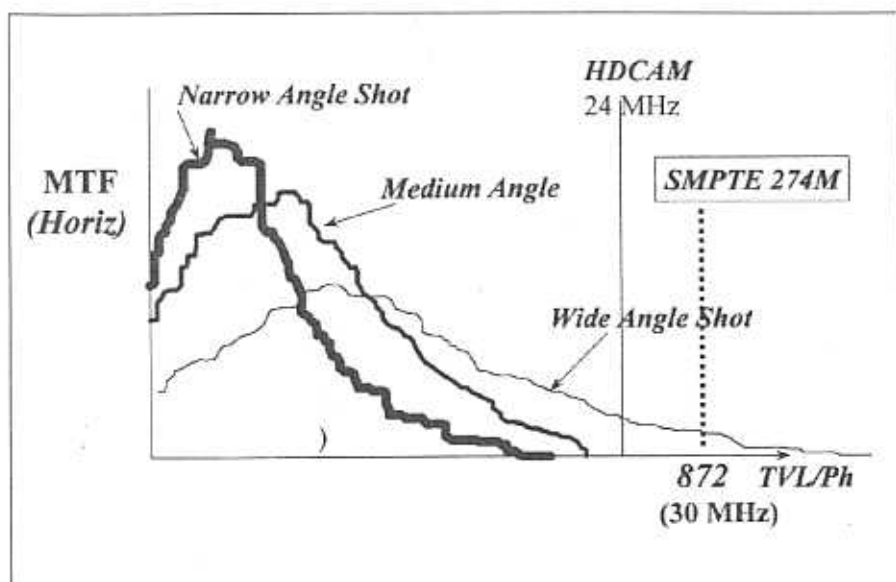


Figure 13. Typical spectral responses of different scenes presented to the CCD as a function of the lens angle of view setting (similar behavior in the vertical domain).

A close-up shot, for example, primarily contains high-amplitude low-frequency energy, both horizontally and vertically (for example, a classic head and shoulders shot), with some low-amplitude high frequencies (such as human hair). A medium shot (perhaps the common framing of a cluster of players on the ball field) will disperse this energy, manifested as lower amplitude low frequencies, and some increase in the amplitude and spread of the higher frequencies. A wide-angle shot (containing perhaps a busy cityscape, a panoramic landscape containing numerous trees, or a ball field and a crowded stadium), will have lower-amplitude low-frequency energy, with the higher frequencies spread over a far broader range, but generally having ever-lowering amplitude (Fig. 13).

The scene's inherent spectral energy is concatenated with the MTF response of the lens (both horizontal and vertical) and camera beam-splitting optics, and this considerably lowers the amplitude of the very high frequencies. The three CCDs now do their best in sampling the optical spectral distribution that are presented to them, but here too, their own effective MTF comes into play.

Sony studied this distribution of energy for a wide range of imagery containing many scenes and many lens settings. It soon became apparent that for the vast majority of images there is presently very little video information

above 25 MHz (what little there is remains buried in noise and aliasing artifacts). This reality was to factor squarely into the technical decisions made on the HD recording format developed for the first generation HDW-700 camcorder.<sup>5</sup>

### The HDCAM Camcorder

#### *The Struggle between the Production Standard and Technology*

No acquisition product exposed the present struggle between the capabilities

of contemporary technologies and the production standard more than the compact one-piece HD camcorder. A particularly high priority was assigned to the development of a product that would be contemporary in size, weight, recording time, operational features, and cost as the current generation of standard 525-line digital ENG/EFP camcorders.

The early creation of a substantial amount of HDTV program material was deemed essential to the successful take-off of DTV. The HDTV large screen format lends itself particularly well to the portrayal of wide-angle panoramic imagery sure to greatly augment the presentation of sports, natural history, drama, special events—all of which require heavy use of battery-operated mobile acquisition equipment. Thus, a new recording system was an imperative. However, to implement a practical and reliable HD camcorder, a hard look at the realities of the HD production standard in light of currently available technologies was required.

### Standards and Technology

#### *The Challenge of the Miniature Digital Recorder*

The HD camcorder became the great dictator in determining the recording system data rate. This had to be low enough to provide the same 40-min

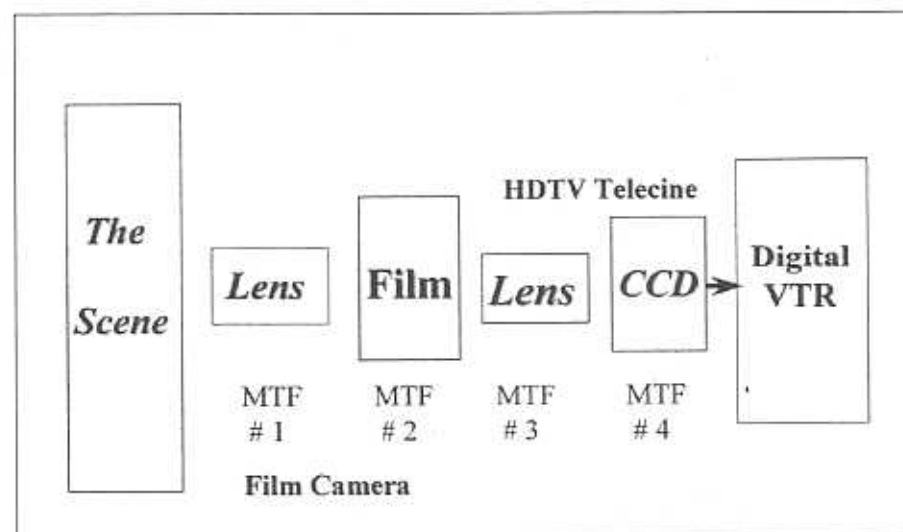


Figure 14. The HD telecine transfer process encompasses the concatenation of numerous MTF characteristics that quickly curtail horizontal and vertical resolution.

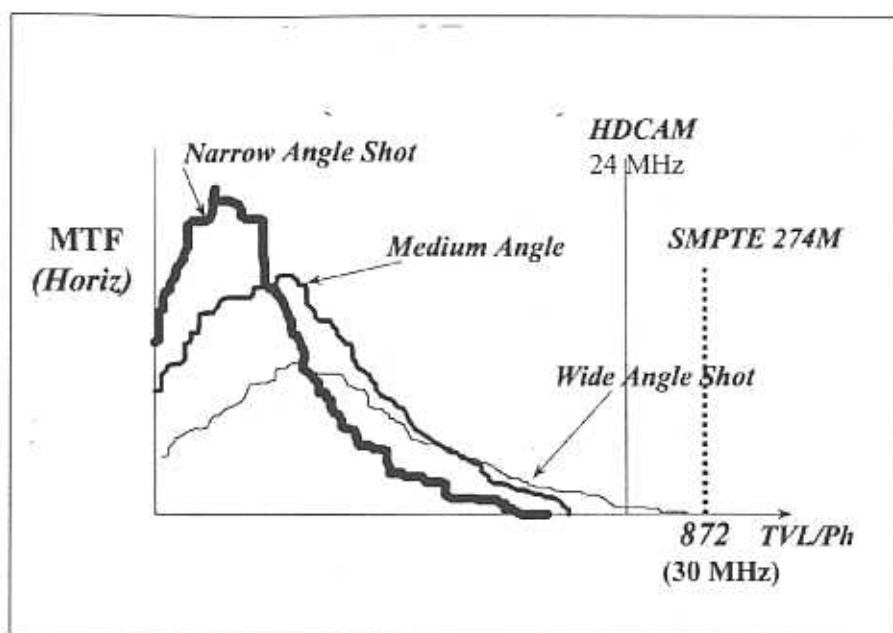


Figure 15. The contemporary HD telecine (regardless of technology) cannot produce horizontal video information (from a 35mm film record) beyond about 25 MHz. Yet again, the HDCAM recording format faithfully captures all the transferred high MTF below 24 MHz.

recording of a Digital Betacam camcorder, and to ensure the same recording integrity. The task now turned to the determination of an appropriate bit-rate reduction (BRR) strategy that could reduce the awesome 996 Mbits/sec of the baseband HD video component set created in the camera to somewhat in excess of 100 Mbits that ensures highly reliable field recording. There are two classic elements to contemporary BRR strategies:

- Digital prefiltering
- Compression

Either technique, or both techniques, can be mobilized to achieve a desired level of BRR commensurate with a desired picture quality (with criteria of multigenerational recording in post-production constituting a key factor in the latter).

Following extensive research that employed close examination of a broad range of taxing HDTV imagery, it was decided that an optimum combination of both techniques would indeed preserve very high subjective HD picture quality while yielding the required 7:1 data reduction. Total video data is reduced to 5/8 of the original 996 Mbits by digital prefiltering, and this is followed by a relatively modest degree of 4.4:1 video compression.

Many ask if the VTR digital pre-

filtering too drastically curtails resolution and negates the camera's capture of a reasonably high HDTV picture sharpness. Actually, it was the realities of present-day HDTV camera (and telecine) video origination, as described above, that aided in the final choice of the prefiltering criteria. The essential engineering design task was

to maximize video capture over the useful passband while minimizing any associated compression distortions over that same passband.

### HDTV Acquisition by Telecine Transfer of Film

The outputs of present telecines actually have less high-frequency energy than their live camera counterparts. This is not surprising given that there are more concatenated MTFs involved; the film camera lens, the film negative itself, film processing, and finally, the telecine's optical system and CCD scanning (Fig. 14).

In addition, unlike the CCD live HD camera, the telecine input is a motion picture film component recording having quite substantial differences in the MTF characteristics of the three color emulsions. In particular, the red emulsion's two-dimensional MTF falls far short of the green, which in turn, is somewhat less than that of the blue. Thus, the critical matrixed luminance signal has considerably less resolution (both horizontally and vertically) across the useful frequency band than that of the live HD camera. None of the measurements made on all the existing HDTC telecines can presently reproduce any discernible and useful picture information above 25 MHz when scan-

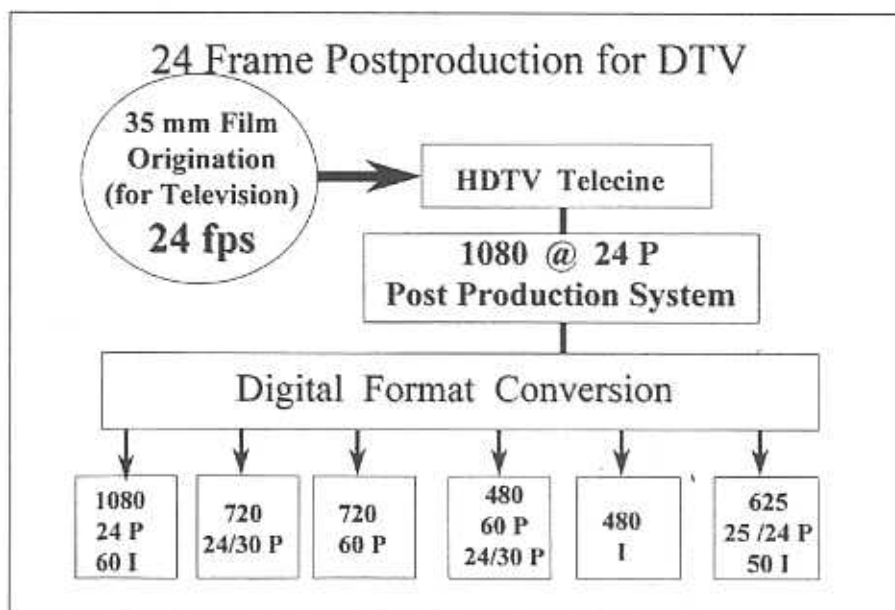


Figure 16. A single highest resolution 1920 x 1080 HD mastering system for 24-frame film originated program material can be digitally downconverted to produce multiple DTV distribution formats at superior quality.

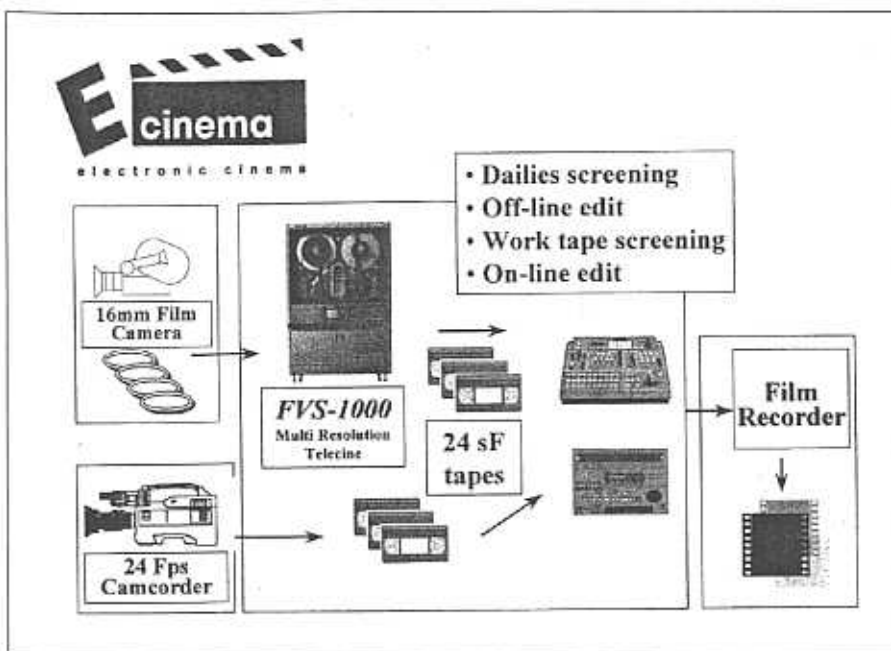


Figure 17. The new 24-frame progressive HD acquisition system (and supporting post-production systems) will extend creative flexibilities in moviemaking.

ning a 35mm test film recording of a multiburst chart (noise and aliasing overshadow what small amount of video might be there) (Fig. 15).

### The Next Step in DTV Image Acquisition

#### Creative and Technology— Industry Desire for a 24-Frame Progressive HDTV System

Throughout the long HDTV standardization process, the creative community was becoming increasingly aware that video quality was advancing with great rapidity and was rapidly converging on that of 35mm motion picture film. While the old debate did heat up in the mid-1980s to early 1990s, today it has settled into a far more constructive dialogue. And, within that discourse an increasing number of the creative folk are calling for better convergence between HDTV and film, based on the common frame rate of 24 Hz progressively scanned.

During the past year an additional voice has added to this urging. The post-production community, which is staring into a digital future entailing handling a multiplicity of DTV video formats, now strongly endorses the concept of a single HDTV mastering format based on 24-frame progressive

at the highest 1920 x 1080 resolution that can subsequently be downconverted to all of the 1080 I, 720 P, 480 I/P, and international DVB-related 576 I distribution formats (Fig. 16).

### Standards and Technology

#### The 24-Frame Progressive Acquisition System

SMPTE had wisely included an initial documentation of the 24-frame

progressive variant of the 1920 x 1080 format within the SMPTE 274M standard. In July 1997, Sony formally announced the development of the E-Cinema system, a 24-frame progressive digital acquisition system that would be developed in concert with the moviemaking industry (Fig. 17).

In July 1998, Sony announced a derivative of their present HDVS (1920 x 1080 @ 60 I) system, which would be a 24-frame progressive post-production mastering system to support the multiple DTV format environments (Fig. 18). A 24-frame acquisition camcorder will soon follow.

### Conclusion

Image acquisition for 525/625-line digital SDTV today is very mature and of extraordinary high quality. The move to progressive scan remains the next important technological step that will add any discernible advance in overall picture quality. There is growing marketplace support for this, however, its success is likely to be determined largely by the degree of actual broadcaster commitment to implementing a total progressive system that demands a higher data rate.

Image acquisition for digital HDTV is remarkably good. It has considerable latitude to improve—the written standards ensure that. Yet, it is of more than sufficient picture quality to support the creation of superb quality pro-

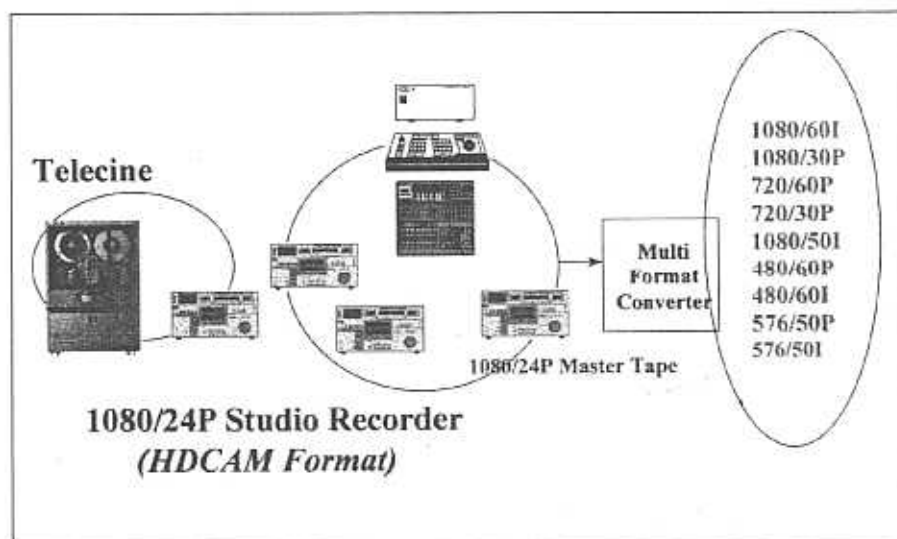


Figure 18. The 24-frame progressive HD post-production system will be a high-end mastering system for 24-frame film originated programming and later for 24-frame electronic acquisition.

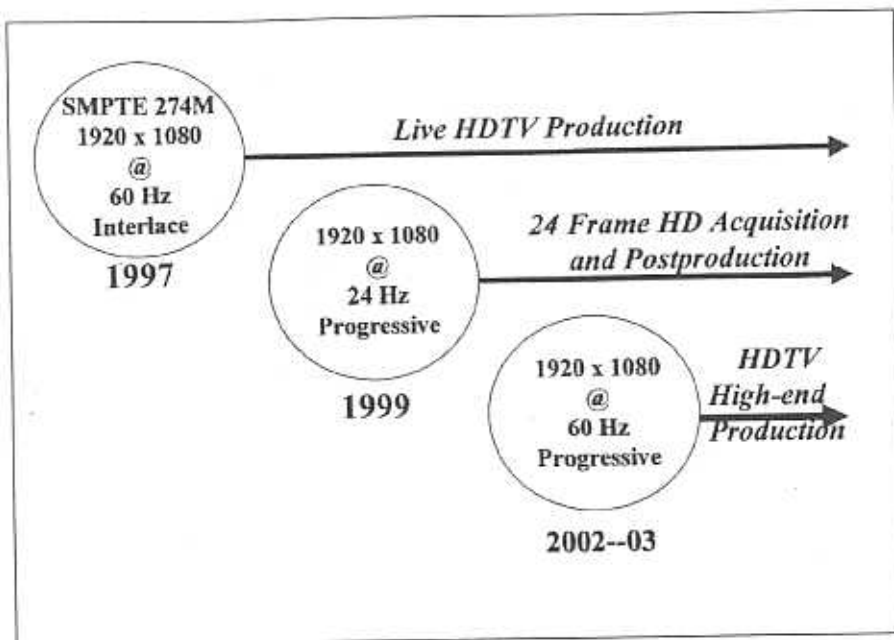


Figure 19. Summarizes the blueprint for one manufacturer that depicts the primary milestones in a planned evolution of HDTV acquisition (with a supporting production and post-production system) into the 21st century.

gramming. The pace of the advance will be determined by a creative community that energetically exercises presently available acquisition systems, and based upon its collective experience, provides the constructive guidance on priorities for progress (Fig. 19).

## Appendix

### Limiting Resolution and Bandwidth in a Multiple Aspect Ratio Environment

The importance of this relationship is that it tells us that for a given scanning period, the relationship between bandwidth and lines of resolution is inversely proportional to the aspect ratio. Put another way, the formula acknowledges the fast nature of the television scanning system. That is, as the aspect ratio widens (within a given scanning timing structure) the faster horizontal scan required to traverse the wider picture (within the same horizontal time period) places a proportional demand on system bandwidth to sustain a given resolution. Thus, it takes more megahertz of bandwidth to sustain a given resolution. This is fundamental.

If we alter the above mathematical relationship as follows:

$$R/Fb = 2 \times Ta/A$$

We soon see that for a 4:3 aspect ratio camera that R/Fb becomes

$$\begin{aligned} &= 2 \times 52.6 / 1.33 \\ &= 80 \text{ TVL/ph per MHz} \end{aligned}$$

Whereas, for the widescreen case

$$\begin{aligned} &= 2 \times 52.6 / 1.78 \\ &= 60 \text{ TVL/ph} \end{aligned}$$

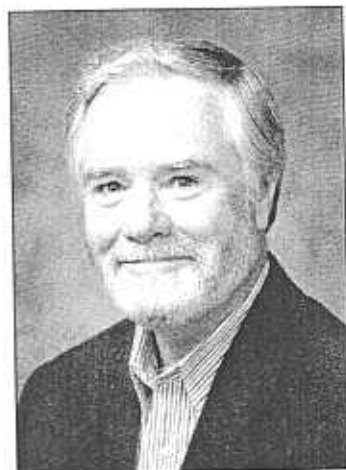
This is true, regardless of how aspect ratio is actually altered (especially in cameras that offer switchable 16:9 and 4:3 operation).

From this relationship is born the rule of thumb that the "Resolution per Megahertz of Bandwidth" is 80 TVL/ph per MHz for the 4:3 system, and 60 TVL/ph per MHz for the 16:9 system.

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## THE AUTHOR



Larry Thorpe is a renowned industry expert in the field of video acquisition, and is generally considered to be one of the leaders of the HDTV movement. His impressive list of accomplishments includes pioneering HDTV market development in the U.S. and ten patents in the field of broadcast development.

Thorpe was promoted to his current position as vice-president of acquisition systems for the Broadcast and Professional Co., Sony Electronics Inc., in 1995. He has business responsibility for all broadcast studio and portable cameras (including HDTV) for the Sony Division.

Prior to his current position, Thorpe was vice-president of production technology for Sony Advanced Systems. He was responsible for HDTV market development and represented Sony on ATSC technology groups, as well as various SMPTE working groups dealing with high-definition electronic production.

Thorpe is a Fellow of SMPTE. He sat on the advisory committees and working groups for ATSC, FCC, and SMPTE in HDTV standards development. In this role, he has published many papers on camera technology and HDTV imaging.

In 1981, Thorpe won the David Sarnoff Award for his innovations in automatic studio color cameras.