SONY

SONY HDCAM: PICTURE SHARPNESS - Issues of Image Resolution

24P TECHNICAL SEMINAR #2

by Laurence J. Thorpe

CINEALTA

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

ABSTRACT

On the surface, the published technical specifications of resolution for a 35mm motion picture film negative would appear to decisively eclipse the resolution specifications of a contemporary 24P digital HD camcorder. It is important, however, that the final comparison between the two media be made on a common large screen (in either the film domain or the digital HD domain). A considerable body of comparative testing over the past couple of years shows that large-screen viewing of two 35mm release prints, one produced from the film negative, the other derived by a transfer from digital 24P capture of the same scene, reveal a resolution equivalence that is remarkably close.

To understand this apparent anomaly, it is important to consider resolution from the practical perspective of what is actually perceived by the human visual system when viewing imagery on a large screen. Picture Sharpness is a term long used by film manufacturers. It is a very good term, and it implies much more than merely expressing "resolution" in another way. In order to assess the difference in perceived Picture Sharpness, we must account for the tolls taken on resolution by each element of the film processing system and the 24P digital acquisition system.

INTRODUCTION

In drawing the comparison between digital 24P HD and 35mm motion picture film, no aspect engenders more spirited discussion than that of their relative Resolution. Indeed, in a perverse twist of television history, the prevalent methodology for specifying the resolution performance of professional video cameras has evolved to a point where the published specifications of all leading camera manufacturers are no longer useful in describing the picture sharpness of the final viewed image.

The formal specification of resolution is the Modulation Transfer Function (MTF) -- the curve depicting signal output level versus the spatial frequency of a pattern of alternate black and white lines. MTF can be used to separately specify the lens, the digital camera, and motion picture film. When appropriate, MTF can even be specified separately for the horizontal and the vertical domain.

Our discussion must begin by recognizing a fundamental difference between what is recorded on a 24P tape in the digital camcorder and what is captured on the negative emulsion in the film camera.

Digital 24P is a bandwidth-limited resolution system. Analog 35mm film is a grain-limited resolution system. In this simple distinction are sown the seeds of an endless technological dialectic.

Simply stated, this fundamental difference between the two media means that, in the case of the digital 24P camera, the high MTF created by the 1920 x 1080 spatial sampling is abruptly truncated by the sharp digital filters inherent to the digital recording process. Motion picture film, being an analog medium, suffers no such truncation, and its formidable MTF characteristic extends to very high frequencies before tailing down gracefully into the film grain. This essential MTF disparity introduces considerable difficulty when we attempt to compare resolution between the two media. In fact, we can only resolve this difficulty if we reach some agreement on precisely what is being compared.

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

A MAN FOR ALL MEDIA

Identifying the "what" in "what is being compared" was superbly done in the 1950-60s by Otto Schade, Sr. He worked at the RCA Princeton Research Labs, and produced a legendary body of work on Image Quality [1] in the comparison between photographic film and television systems. Schade brilliantly resolved the dilemma by pointing out that a distinction must be made between Picture Sharpness and Resolving Power when assessing image resolution. He based this distinction on the interesting results uncovered following his long and close study of the behavior of the human visual system. Schade emphasized that the ultimate perceived picture sharpness of an image on a screen, whether created by film projection or television display, was a complex concatenation of the multiple MTFs inherent to both systems.

PICTURE SHARPNESS

Picture Sharpness is closely linked to the behavior of the human visual system when viewing imagery from a distance -- a form of viewing that encompasses both theatrical cinema and television. Perceived picture sharpness depends on maximizing the detail contrast within the optical pass band of the human visual system. This process is intimately related to the MTF within the range of detail frequencies that can actually be discerned at a specific viewing distance. MTF itself describes the behavior of the contrast of progressively increasing spatial frequencies.

Schade's seminal work, both mathematically and subjectively, defined the crucial importance of the shape of the MTF curve, especially at the lower end of the human visual pass band. This was shown by Schade to be radically different from the visual pass band when viewing imagery at close quarters -- where, for example, the human eye can readily discern extremely high frequency detail even when the signal level is almost buried in the film grain, especially if a magnifying glass is used. This form of viewing includes close study of reconnaissance photography, microfilm work, and examination of graphic detail content on a computer screen. In these examples, Resolving Power clearly has a very special priority. It has a lesser priority in the realm of entertainment program production.

FIGURE 1 simply summarizes the essential portions of a given MTF curve as they bear on Picture Sharpness and Resolving Power.

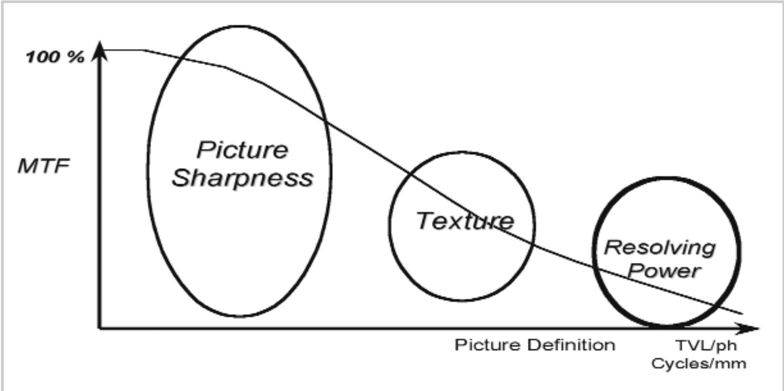


FIGURE 1 The Modulation Transfer Function (MTF) encompasses three key regions in relation to the human visual system

RESOLVING POWER – AND LIMITING RESOLUTION

On both the cinema screen and the home television screen, the upper spatial frequencies are totally invisible to the viewer. Consequently, Limiting Resolution specifications have little bearing on perceived picture sharpness. For close viewing, on the other hand, these upper spatial frequencies can have a very significant effect. This is especially significant as the eye-brain can, at close scrutiny, discern a very low level of detail contrast in these upper regions of the MTF curve, even in the presence of considerable noise or film grain.

Schade indicated that in many images there is, in essence, a "texture" overlaid on the essential image sharpness impressed upon the eye-brain. Texture is fine detail, and is a function of the lower amplitude detail contrast in the upper portion of the human visual pass band. It is extremely variable with viewing distance. This texture can be quite apparent at relatively close viewing distances -- but becomes virtually invisible at longer viewing distances.

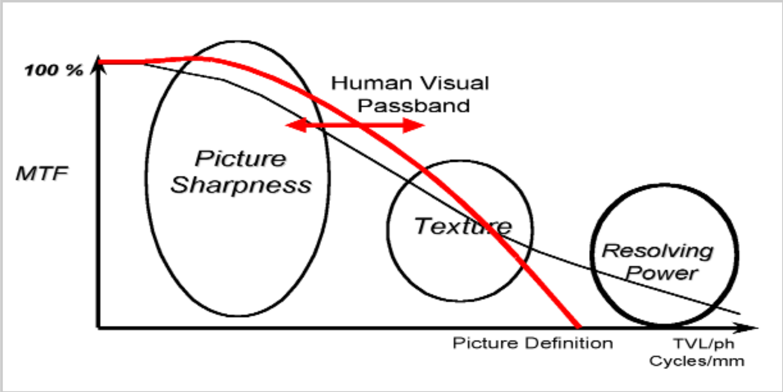


FIGURE 2 Superimposition of the variable human visual passband (variable with viewing distance) upon the MTF curve of a specific acquisition medium.

ASSESSMENT OF PICTURE SHARPNESS

Schade's work on assessing picture sharpness of both photographic film systems and television systems showed that a crucial weighting was evident in the disparate MTF curves produced by both systems. His work demonstrated that the square of the area under the MTF curve in question -- when normalized -- produced that weighting. He showed unequivocally that picture sharpness was directly proportional to that squared area.

FIGURE 3 indicates the concept for an arbitrary MTF curve.

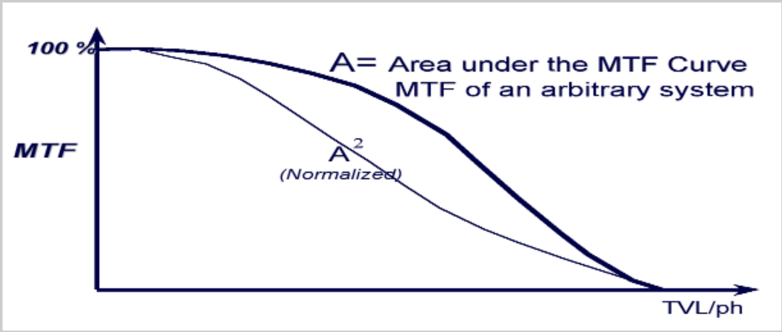


FIGURE 3. Showing the normalized Squared Area curve of Schade; as it relates to the system MTF curve -- indicating the weighting of perceived picture sharpness toward the lower spatial frequencies.

Schade then introduced a beautifully simple concept for reducing any complex MTF characteristic to a simple assessment of its relative picture sharpness. To achieve this, he superimposed upon the squared area curve a rectangle having an area equal to that of the normalized squared area curve. Where the rectangle intersects the horizontal frequency axis, Schade labelled this frequency Ne -- and he used that Ne number (quoted in TVL/ph) as a relative measurement of picture sharpness. He called Ne the Sharpness Rating.

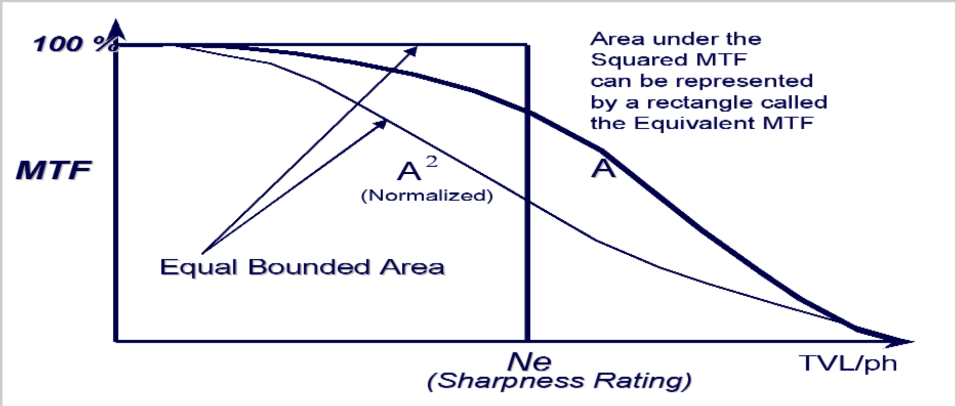


FIGURE 4 Schade's proposal for assigning a singular rating to the picture sharpness of a system having a given MTF characteristic.

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

PICTURE SHARPNESS OF THE 24P SYSTEM AS COMPARED TO 35MM FILM

To compensate for its inherent bandwidth limitation, the 24P acquisition system effectively ignores the upper spatial frequencies and instead maximizes the contrast of all frequencies within the human pass band (for normal cinema and television viewing). This dispels the difficulty of making technical comparisons between the original 24P digital capture and the original recording on the 35mm film negative. It is more useful instead to examine the relative picture sharpness of the two media in two real-world contexts:

(a) The Film Domain -- where the digital 24P capture is transferred to a positive release 35mm film print that is directly compared to the positive release print derived from 35mm origination.

(b) The Digital Domain -- where the digital HD transferred from 35mm film on an HD Telecine is directly compared to 24P acquisition.

24P cannot yet produce the resolving power recorded on the 35mm film negative. It cannot do so because the technology of today will not support affordable digital acquisition at that level of picture resolution -- in terms of both the camera imaging and the associated digital recording data rate required to sustain that image capture. Contemporary 24P capitalizes upon the fact that nobody views the film negative. Before being viewed in the cinema, the film negative must undergo a complex series of opto-chemical processes to produce the requisite positive release film print. These processes collectively make a considerable alteration to the final MTF of the viewed positive release print. Similarly, when viewed as HD, the film negative is transferred by an HD Telecine, a different process that involves its own complex convolution of system MTFs.

MTF AND MTF AND MTF...

We will now look more closely at these two real-world approaches to comparing 24P and motion picture film. These comparisons reflect the many tests conducted by numerous workers over the past eighteen months. Some researchers were interested in assessing the potential of 24P for moviemaking -- including final theatrical release on 35mm film. Others focused on comparing the two media in the digital domain, to assess the potential of 24P as an alternative to 35mm film for high-end television production. In both cases, we will examine the individual system elements involved in producing the final imagery required for comparative viewing. And here we will quickly become immersed in the multiple MTFs of those system elements.

PICTURE SHARPNESS – COMPARISON IN THE FILM DOMAIN

Many workers chose to examine relative picture attributes in the film domain on large screen optical projection systems. While each test had its own variants, they all basically reduced to the test system depicted in Figure 5. We will examine both "paths" of this system and assess the effect of the cascading of their system MTFs.

by Laurence J. Thorpe

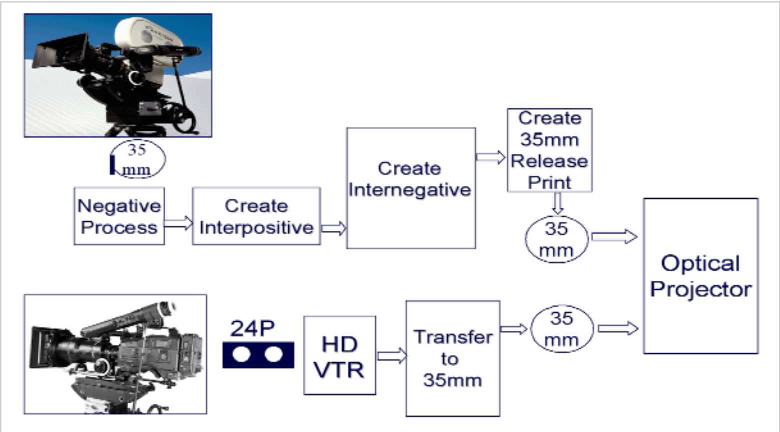


FIGURE 5 Shows the comparative testing of 35mm film and 24P picture attributes – as assessed on large screen film projection.

SYSTEM MTF – FOR THE 24P SYSTEM

Schade placed great importance on identifying and accounting for all of the system elements that ultimately formulate the final MTF -- in both the horizontal and the vertical domain (this being particularly important for the digital 24P system). In the case of the 24P system, most of these MTFs are embedded within the camera system. In the discussion to follow, we make the assumption that digital image enhancement is switched to zero in the 24P camera. Thus, the camera's DSP processing circuits make no contribution in the form of another MTF curve (the assumption being that they have a flat frequency response to the 30 MHz limit specified by the ITU 709 production standard). Figure 6 outlines the separate MTF contributions within the digital camera section of the 24P acquisition system.

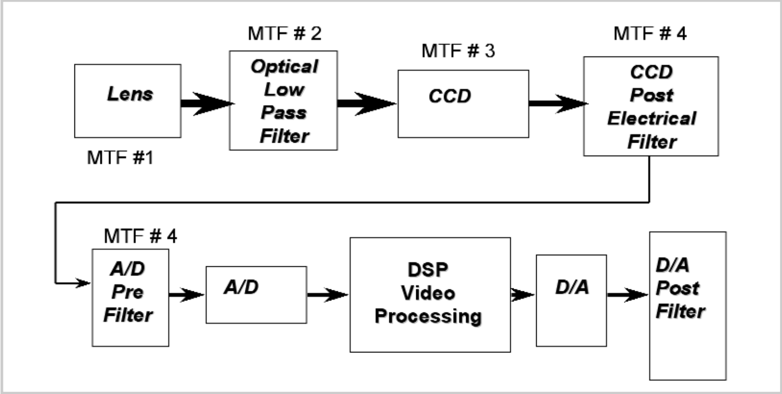


FIGURE 6 Showing the separate MTF elements that convolute to the final horizontal MTF of the 24P camera

FIGURE 7 below summarizes the collective effect of these MTFs, showing the final convolution of a camera system MTF as the bold curve.

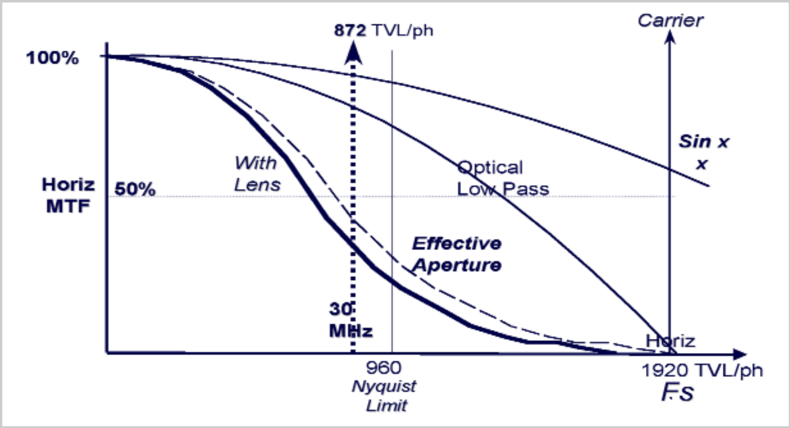


FIGURE 7 Showing the final horizontal MTF of the 24P camera with a generic HD lens (the latter is, in practice, a system MTF variable).

The system MTF will vary depending upon the quality of the lens used -- and the various tests to date do show interesting variations between the lenses of the many manufacturers involved. Each lens exhibits its own variation in how MTF characteristics alter with aperture setting. It is important to note that this lens MTF variability applies also in the case of the film camera.

In summary, the contemporary 24P camera exhibits a typical horizontal depth of modulation in the vicinity of 35% at the specified 872 TVL/ph boundary (equivalent to the 30 MHz spec of the ITU 709 standard). One noteworthy aspect of the 24P system is that progressive scanning, which elevates the vertical MTF curve above its interlaced counterpart (when both are operating at 1080 lines), produces an MTF curve that is very close to the curve shown earlier for horizontal MTF (see Figure 8). Again, no digital image enhancement is involved in either the horizontal or vertical domain. This equivalence is significant in demonstrating that the 24P system is the first video system to have achieved an isotropic imagery. The present 525-line NTSC system is extremely anisotropic, with horizontal MTF far exceeding that of the vertical (which is severely curtailed by the 480 active picture samples and the further penalty associated with interlaced scanning). In producing an unsatisfying perceived resolution, anisotropic imagery plays a greater role than is generally acknowledged -- so this is good news for the 24P system.

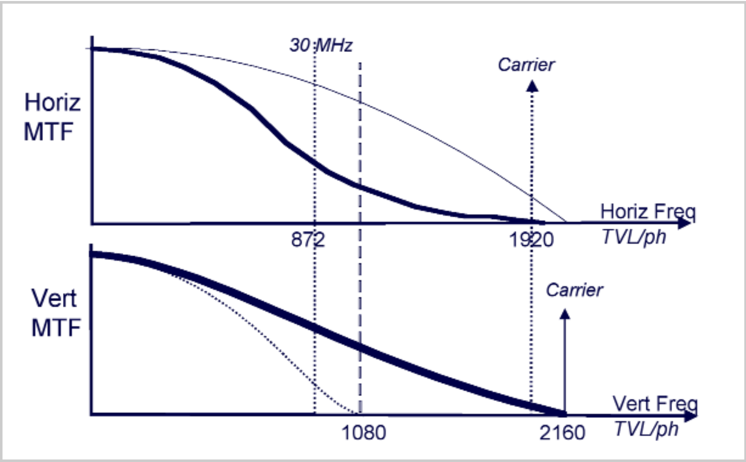


FIGURE 8 The 24P system is the first isotropic video production format

THE 24P CAPTURE PROCESS – THE DIGITAL RECORDER

Thus far, we have described the cascade of individual MTF characteristics that define a typical 24P "shoot" -- that is, the camera performance. We must now deal with the "capture" process -- namely, the digital recording of the camera video. The Sony 24P camcorder utilizes the HDCAM® recording process. Two bit rate reduction strategies are utilized to reduce the daunting 966 Mbps data rate of the camera to the 140 Mbps total sought in the recording section: digital prefiltering, followed by a 4:1 digital compression. A detailed discussion on this strategy can be studied elsewhere [2].

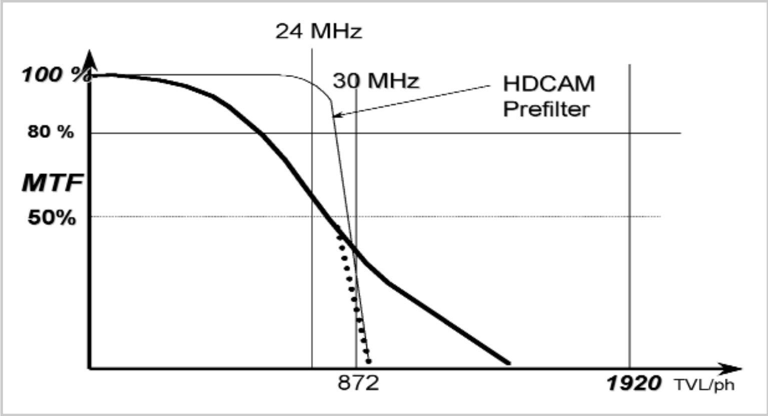


FIGURE 9 The high camera MTF is abruptly truncated by the luminance digital prefiltering in the HDCAM 24P recording; this kicks in at 24MHz

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

The effect of this prefiltering is to leave the camera MTF totally untouched up to about 24MHz. A sharp cut-off filter then comes into play, truncating the camera MTF horizontal curve in the manner indicated by the dotted line in Figure 9.

We opened our examination of the resolution comparison of 24P and 35mm motion picture film by pointing out that the 24P system is a bandwidth-limited resolution system, while the film system is a grain-limited resolution system. Figure 9 graphically depicts the bandwidth limitation of the Sony 24P system. It is important to remember that the recording process has virtually no effect on the relatively high MTF of the camera over the greater portion of its pass-band -- but it does definitively determine the ultimate bandwidth limitation.

MTF SYSTEM – FOR 35MM MOTION PICTURE FILM

The MTF curves published by the film manufacturers require close study (see Figure 10). In manufacturers' brochures, film MTF is traditionally depicted on a logarithmic scale and is specified in cycles/mm, thus making an immediate comparison with 24P somewhat difficult.

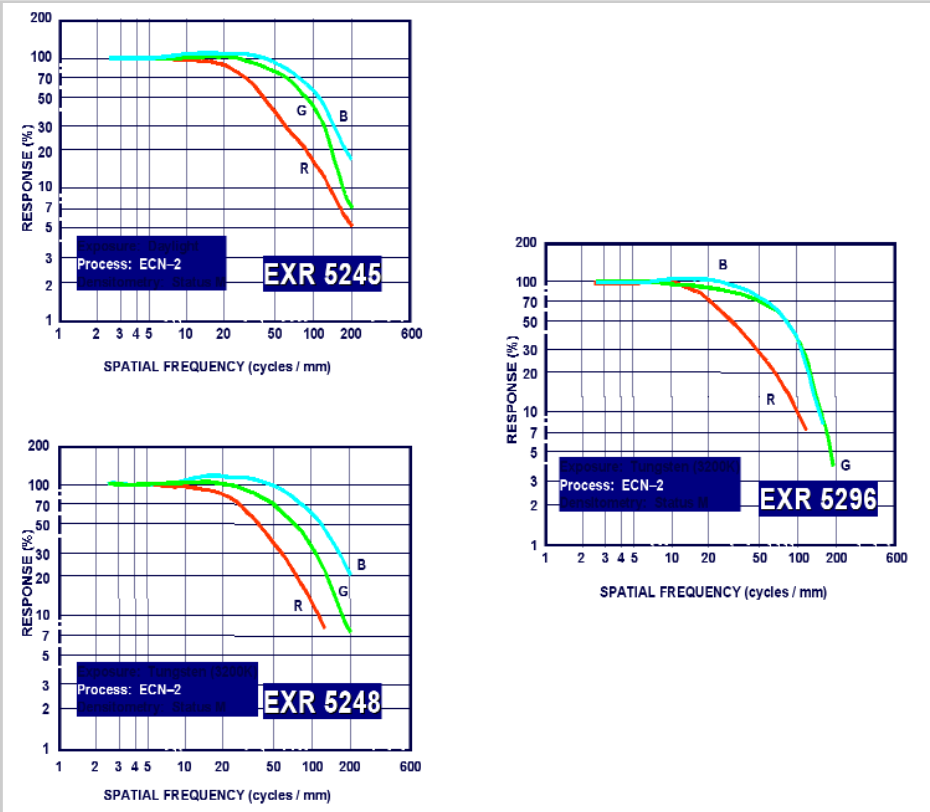


FIGURE 10 Shows the modulation transfer function (MTF) curves for different speed 35mm motion picture films – as typically published by the film manufacturers

Motion picture film is a capture medium that is inherently isotropic, and accordingly, these MTF curves apply to the film plane -- that is, they apply equally to both the horizontal and the vertical domain. Translating them to the domain of video resolution specifications -- the linear TVL/ph -- facilitates a direct comparison with 24P digital. To do this, the film plane MTF is first multiplied by the image height in millimeters to convert to cycles/picture height (c/ph), and then multiplied by two, because two TV lines are equivalent to one cycle. The resulting conversions are shown in Figures 11 and 12.

It will be noted that the emulsions themselves have a very high MTF compared to that of the 24P camera. One striking aspect of motion picture film, however, is that there are quite distinct resolution characteristics between the three emulsions on the film negative.

FIGURE 11 Showing the MTF for a typical slow speed 35mm film

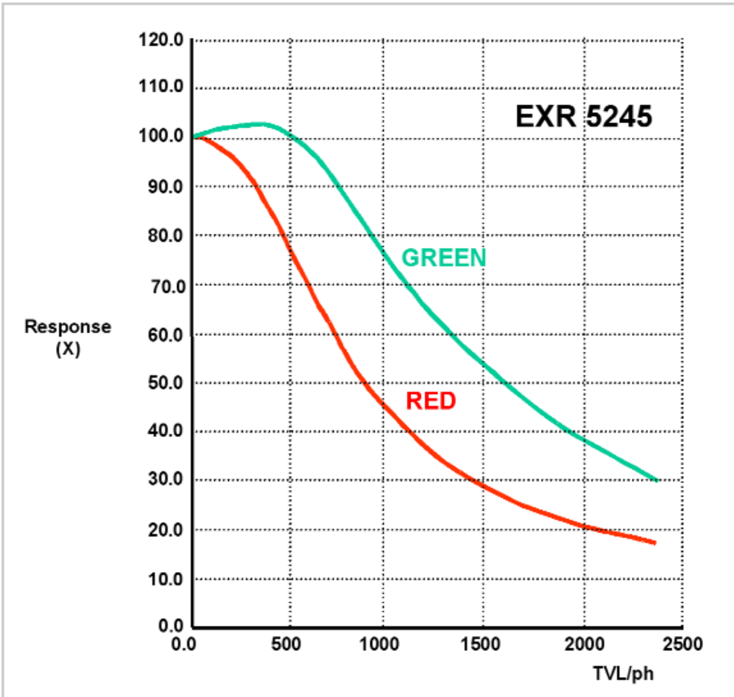
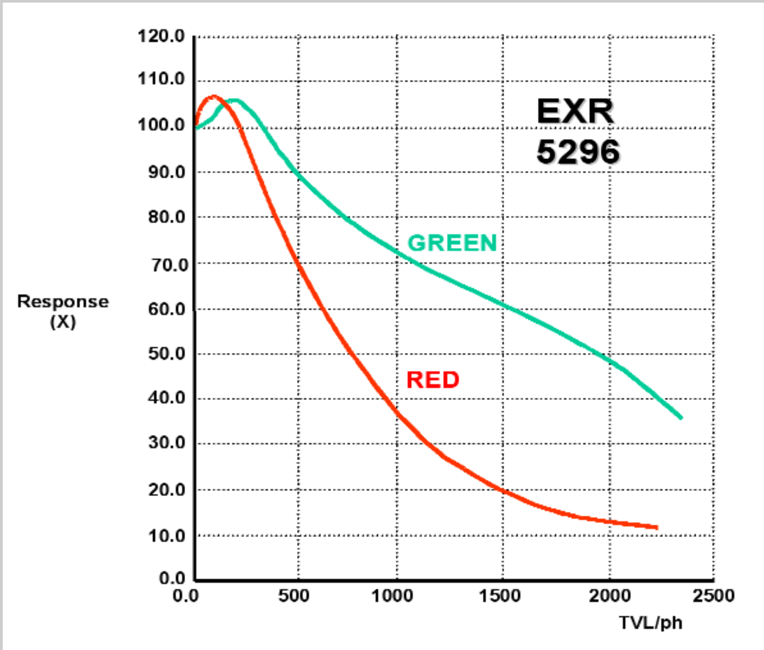


FIGURE 11 shows this for a slow-speed 35mm film stock, and Figure 12 for a high-speed film stock. In both cases we have, for simplicity, removed the Blue emulsion -- which typically has a higher MTF than the Green -- in order to highlight the more dramatic difference between the Green and Red emulsions. Clearly, the effective luminance MTF will be a matrix of the two (along with blue), which will lower its effective MTF. However, the MTF of negative film still remains very high.

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

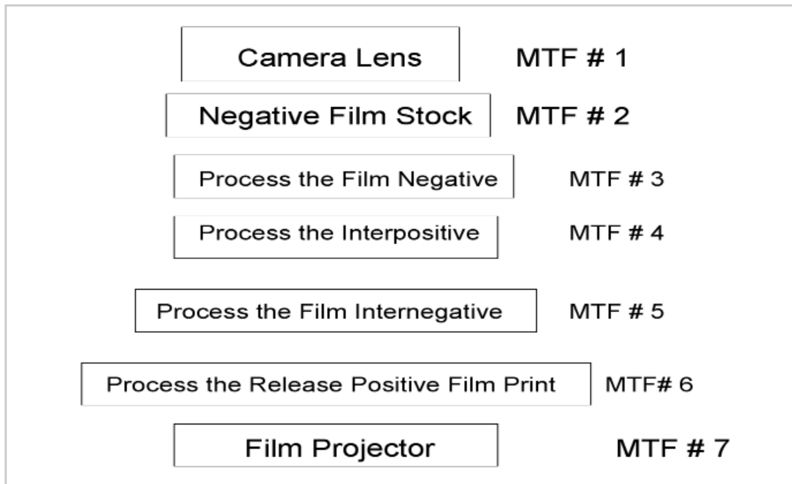
FIGURE 12 Showing the MTF curves for a typical high speed 35mm film



GETTING TO THE POSITIVE RELEASE PRINT

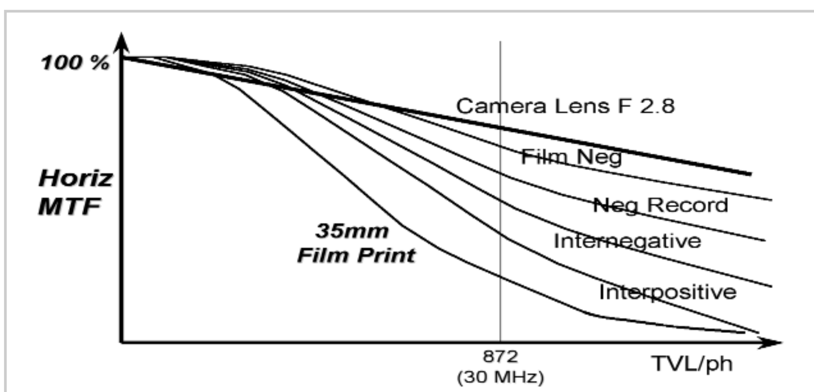
The MTF convolution for the film scenario is more complex than that of the 24P camcorder. This is particularly true in the case of the creation of the first generation 35mm positive print as earlier shown in Figure 7.

FIGURE 13 The sequential processes involved in creating the final positive release print used for theatrical projection of motion picture film.



The final MTF of the 35mm positive release print is indicated in Figure 14. Every step of the serial opto-chemical process takes its inexorable toll on resolution. It should also be noted that each step takes a small, but cumulative, toll on the lower frequency in-band MTF.

FIGURE 14 Summarizing the individual MTF characteristics associated with each stage of the opto-chemical process involved in the creation of a contemporary 35mm positive release print.



TRANSFERRING THE DIGITAL 24P TO A 35MM FILM RELEASE PRINT

To complete the comparison of the 24P and 35mm film in the domain of optical projection, the digital 24P edited master must first pass through its own multifaceted process of transfer to the theatrical film release. There are a number of technologies to do this – Electron Beam Recording (EBR) and Laser Recording being two contemporary techniques employed today.

The EBR [3] has the advantage of being a very high-resolution approach by virtue of the fact that the initial transfer from digital tape to film is done in non real-time via an exceedingly fine electron beam directly exposing a low-grain slow-speed high resolution black and white negative – all within a meticulously controlled vacuum system. Because no optical system is entailed in this process, the MTF of the 24P recording is transferred virtually unimpaired across to the very high MTF of the film negative. The RGB digital frames are transformed to sequential monochrome RGB frames on that film negative. A subsequent optical step-printing process (involving appropriate color filters) then photo-optically creates an internegative 35mm film from which the release print is then printed. The concatenation of that photo-optical MTF and that of the release print are the dominant MTFs that determine the final convolution of the 24P system MTF on the release print. In total, this process takes a lesser toll on MTF than that described for the film system.

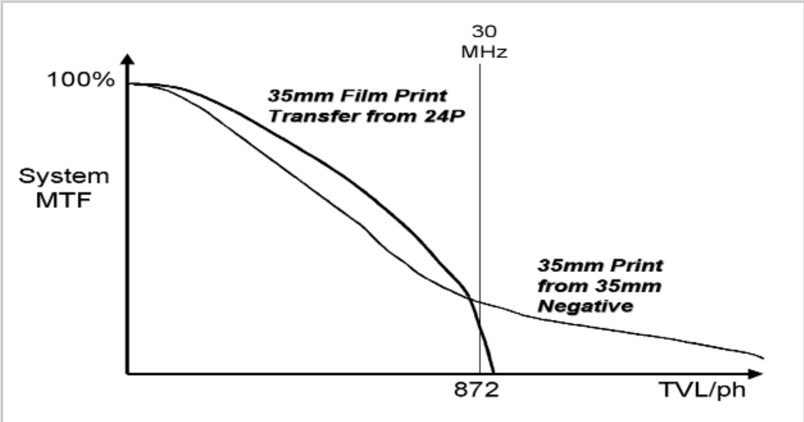
The 24P camera does embody some very sophisticated digital enhancement controls, which can be used to alter the final system MTF. This enhancement does not come for free -- it will raise the noise level proportionally. However, confining this to a modest three dB boost will make a considerable enhancement to both the horizontal and vertical MTF, and the noise increase (at a normal 0 dB camera gain setting) will be almost imperceptible. Optimum deployment of digital image enhancement in the 24P camera should be carefully tailored to counter these transfer-to-film MTF losses to the degree possible – and this does involve a systematic pre-testing of the system.

The alternative Laser recording transfer system utilizes very high resolution RGB laser direct exposure of the three emulsions that constitute a 35mm internegative film. From this film the release 35mm positive is printed. This system is also an inherently high-resolution system that creates an internegative film with high MTF.

COMPARISON OF THE FINAL MTF OF 24P AND 35MM FILM

When the final 35mm film MTF is superimposed on the final recorded MTF of the digital 24P system when transferred to 35mm film by EBR or Laser recording (see Figure 15 below), two distinct differences become apparent. First, the 24P MTF characteristic typically has a higher "belly" in its curve, at the lower end of the passband; contemporary digital tape to film recorders have quite flat response up to high frequencies. Second, in the upper frequency region, the bandwidth-limited 24P system MTF conversely terminates more rapidly than the 35mm all-film system's positive print, which extends to higher spatial frequencies (albeit at a considerably lower MTF than the original 35mm negative recording). The 24P curve is the curve inherent to the camera-recording system, without any image enhancement.

FIGURE 15 Showing the MTF curve for the 24P digital transfer to 35mm film positive and the 35mm positive release print derived from the 35mm film negative.



Shade's technique now allows these disparate curves to be compared based upon the premise of the Ne Sharpness Rating. By squaring the above two curves and then constructing the associated equivalent Area MTF rectangles, a direct comparison of picture sharpness Ne is possible -- as shown in Figure 16.

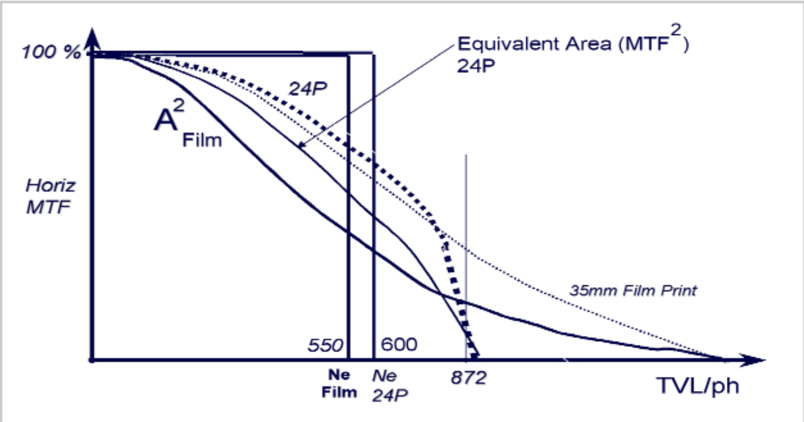


FIGURE 16 The Picture Sharpness Ratings for the 35mm positive release print transferred from the 24P system and the 35mm release print derived from the original negative film

It has been noted, during various tests conducted with the 24P camcorder shooting side by side with 35mm motion picture film, that when a comparison was made at the 35mm film positive release print stage, the 24P image was often judged to be sharper. The technical explanation for this is outlined above: that the more complex MTF concatenation in the case of the 35mm all-film system erodes more of the lower detail frequencies, and, as taught by Schade, this impairs perceived picture sharpness at normal viewing conditions. It should however, be noted that each system involves many elements, any one of which is a variable. For example, just lens variations could reverse the final results, as could different film stocks and film processing behaviors.

PICTURE SHARPNESS – COMPARISON IN THE DIGITAL 24P DOMAIN

A great percentage of prime time television and television commercial production still originates on 35mm motion picture film. A considerable number of side-by-side tests have been conducted over the past year and a half to assess the performance of the 24P system as a possible alternative for such program origination. Figure 17 summarizes the nature of these tests.

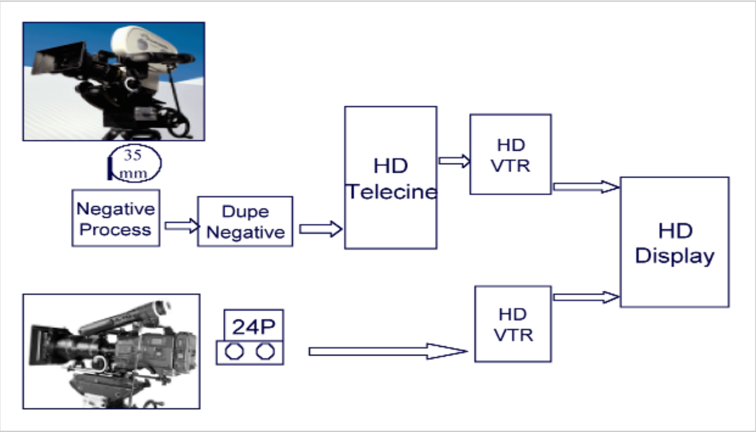


FIGURE 17 Outlines the comparative 24P and 35mm film tests that sought picture quality assessments between the two media (including picture sharpness) in the electronic domain – some on large screens and others on high performance HD studio monitors.

35MM FILM AND THE HD TELECINE

FIGURE 18 shows that the system originating with a 35mm film shoot subsequently transferred to 24P digital HD involves a considerable number of system elements each with their own MTF characteristic.

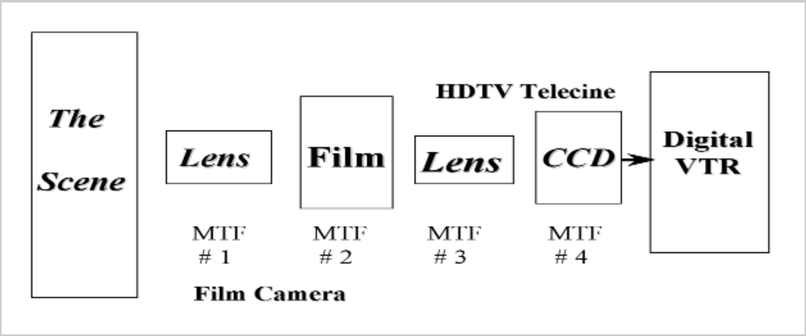


FIGURE 18 Indicates the 35mm Film-Telecine process

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

This process involves multiple factors: the concatenation of the MTF characteristics of two lens systems, the MTF characteristics of the film process (the number of these MTFs is variable depending upon whether a dupe negative or an interpositive transfer is being made), and finally, the complex MTF processes of the Telecine itself. In the case of the Sony Vialta™ Telecine system, the MTF concatenation can be assumed to be identical to that of the 24P camera described earlier (the Vialta system employs 22:22:22 CCD spatial sampling using the same area array imagers as the 24P camera). Other Telecines utilize 22:11:11 CCD spatial sampling, and this fact would need to be accounted for in the system MTF assessment.

As a consequence of the increased number of contributing MTF elements, it is obvious that the film-through-Telecine process will incur a slightly higher loss in overall MTF than the same original scene captured directly by a 24P camcorder. This will be the case when the 24P camcorder and Telecine both do not employ image enhancement, and the resolution assessment is made using the Ne Sharpness Rating. However, it should be pointed out that the situation could very easily be reversed with the application of only a modest degree of image enhancement in the HD Telecine. The same can, of course, be utilized in the 24P camera. So it is safe to conclude that parity in picture sharpness can be realized between 24P and a 35mm film transferred on an HD Telecine.

SUMMARY

The wonderful work done a half-century ago has finally come into its own. Otto Schade, Sr., was comparing an embryonic 1950-vintage television system with an established photographic film system. Even then, however, he was able to demonstrate the potential of electronic imaging (his lab work included a prototype high-resolution television system). More important, he quantified the electronic imaging specifications that needed to be sought in order to achieve image quality parity with 35mm motion picture film.

It is only today, in an era of digital HD video, that the full import of his work can be brought to bear on advances in imaging. Schade's legacy lies in the ability we now have to objectively assess the realities of resolution in contemporary digital HD and film imaging systems. A matter that might appear intuitive -- based upon published specifications and attendant conjecture -- in fact turns out to be far more complex.

A great deal of global discussion is underway today in the broad quest to define the specifications for an all-digital "cinema" system -- from acquisition, through postproduction and distribution, to final display on very large screens. Sharp divisions exist between the aspirations of various parties involved. If Otto Schade Sr. taught us anything, it is that electronic bandwidth is a commodity to be carefully nurtured. Today, this translates into the associated digital data rate -- and in the context of an overall Digital Cinema system, digital data rate is a precious commodity indeed. A proper understanding of Picture Sharpness, as it affects both digital cinematography and digital cinema distribution/display, can enormously aid in the pragmatic disposition of digital data rates.

To date, the news is very good. The first-generation 24P system, with all of its necessary pragmatic design compromises, has proven far better than some had anticipated. Specifically, in terms of perceived picture sharpness, the 24P system has surprised many who have viewed 35mm film transfers from this digital origination on very large screens. Indeed, some recent tests involving transfers of 24P to large-format 16-perf 65mm film have been cause for even greater surprise. This has stirred a new interest in mobilizing the 24P digital system as an adjunct in large-format film productions, using 24P as a more compact and mobile acquisition package for shooting difficult scenes where camera size and weight might be a logistical issue.

SONY HDCAM: PICTURE SHARPNESS - ISSUES OF IMAGE RESOLUTION

by Laurence J. Thorpe

REFERENCES:

1. O.H.Schade, Sr. "Image Quality: A Comparison of Photographic and Television Systems" Reprinted SMPTE J., 100: 567 – 595, June 1987

2. L.Thorpe et al, "The HDTV Camcorder and the March to Marketplace Reality", SMPTE J. 107:164 – 177, March 1998

3. L.Thorpe et al, "HDTV Electron Beam Recording", SMPTE J. 97:833 – 843, October 1988