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Gamma and Dynamic Range Needs for an HDTV Electronic Cinematography System

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Gamma and Dynamic Range Needs for an HDTV Electronic Cinematography System

By Harry Mathias

A cinematographer's perspective regarding gamma and contrast manipulation in video and film is given. In film, a selective exposure can be used; the negative characteristic is the cinematographer's creative tool. The use of film as a video medium is considered, both negative and positive transfer. Contrast reproduction in the video medium is explained, and film and video gammas are compared. Also compared with the film gamma is the gamma obtained with an HDTV camera. Future trends are sketched, and current HDTV specifications are compared with the characteristics of film. Predictability and consistency of results, that is, the final image on the screen, are the cinematographer's foremost concern.

If high-definition television (HDTV) is to be taken seriously as a future option for dramatic production, we must consider designing into it the creative scene-rendering flexibility that is now available only in motion-picture film. When specifying the system parameters of tone reproduction and luminance transfer function of an HDTV camera, we must remember that it will also be used for purposes other than news broadcasts, game shows, and football games.

This article is a progress report on continuing work on film gamma,* video dynamic range, and contrast reproduction characteristics. These subjects must be investigated if we are to gain a full understanding of what the requirements will be for a high-definition video system that can be used in the production of dramatic films, especially for large-screen display.

Gamma and Contrast Manipulation in Video and Film

It became apparent when this investigation was begun that the subject of gamma and the requirements for gamma manipulation of an image are understood differently by those working in film and those working in television production. In traditional, broadcast-oriented video production, gamma is thought of primarily as "gamma correction," the nonlinear processing of a linear video signal to compensate for the viewing conditions and reproduction characteristics of the video display tube. To a certain extent, gamma in film can also be considered a correction to adapt the photographic image to the viewing conditions of a large projection screen in a dark room. Those working with gamma, namely cinematographers and those specifying gamma characteristics for emulsions, view the contrast reproduction problem as most complex.

Motion-picture film gammas can be divided into three general types: negative emulsion gammas, intermediate stocks, and release print gammas. Negative emulsion gammas (Fig. 1) have as their primary function the reduction of the extreme contrasts found in nature (known as scene brightness range) to the level that can be comfortably recorded on the negative's latitude. Gamma in a negative can be thought of as a contrast reducer and manipulation tool.

In the minds of cinematographers and emulsion makers, however, the gamma and tone reproduction characteristics of motion-picture print film have entirely different requirements. When projected on a large screen in a darkened room, motion-picture print film (Fig. 2) should display black blacks and white highlights, with a gray scale in between (assuming they are present in the original scene and the cinematographer desires to reproduce them in that way).

The key issue here is the matter of choice. By selective exposure of the negative and selective printing of that negative, the cinematographer can create virtually hundreds of "correctly" exposed renderings of a scene, each with a totally different dramatic look. It is a two-step process.

First the negative is over- or underexposed to manipulate its tonal rendering; the exposure selected places the scene on that portion of the negative's characteristic curve most suited to the mood intended. Then the printing process corrects the print's scene brightness for the deliberate distortions of the original photography. Gamma considered in this way is not just a photographic tool; it is primarily a creative tool. Similar tone-rendering options do not yet exist in video, nor will they in the future if the current rush toward adoption of existing video gamma specifications for HDTV continues.

Cinematographers are more preoccupied with predictable photographic response of contrasty subjects than with the more mundane problems of photomechanical reproduction on the motion-picture screen, which can be considered the end product of the filmmaking process. After photographic rendering flexibility, the next most important requirement of a film-stock system is downstream predictability. When a cinematographer is lighting a set and manipulating exposure to control the rendering of a scene, he must be able to predict the rendition of the final scene on the screen or TV monitor as he works.

Even with the complexity of the motion-picture processing system and occasionally great time delays from scene to screen, predictability has never presented a problem. In video, where instant viewing is a primary, salient feature, predictability should certainly never present difficulties. However, the adoption of an automat-

* The word *gamma* has fallen into disfavor as a video term but still enjoys popularity in the motion-picture and photographic communities. Here *gamma* will be used in discussing the historical use of gamma in video and in discussing film applications; *luminance transfer function* will be used to discuss the equivalent parameter in video and HDTV.

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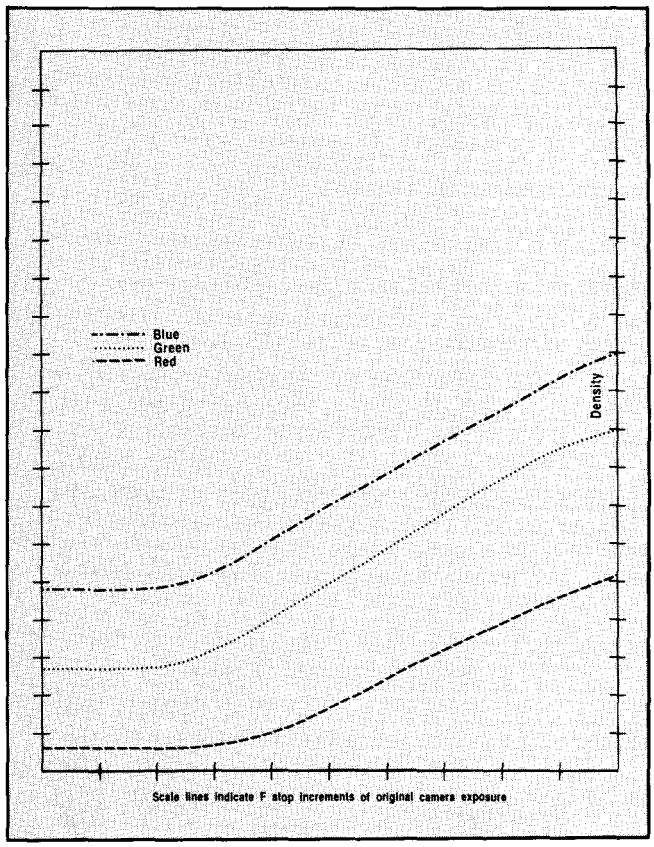

Figure 1. A 16mm standard negative.

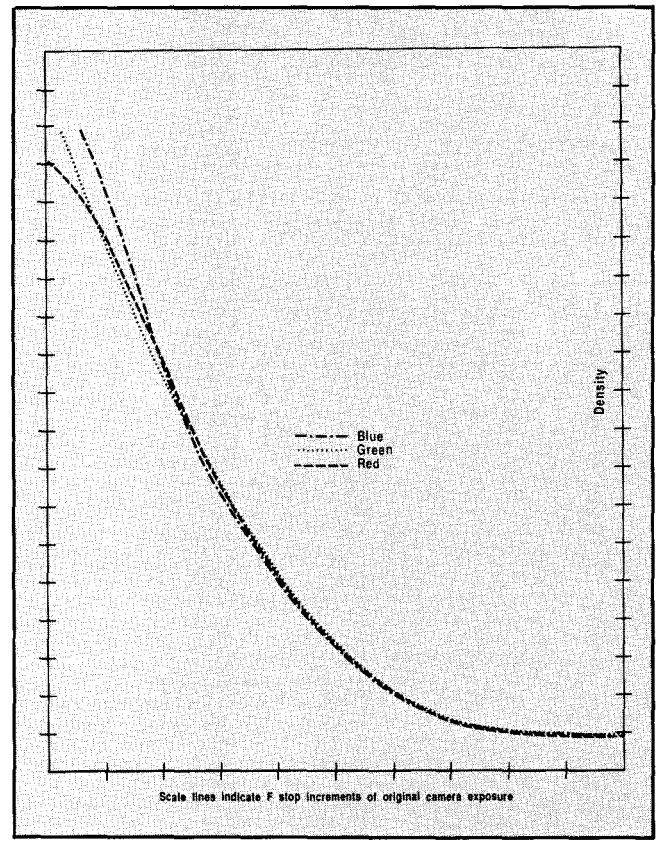

Figure 2. A 35mm positive print.

ic gamma-correction altering device, such as the one designed by Thomson CSF (which varies the luminance transfer function of the video system when the scene's contrast varies from a preprogrammed value), or the acceptance of a specification for HDTV that involves downstream gamma alteration that can't be viewed on the set could create a major crisis in image control.

The Negative Characteristic as the Cinematographer's Creative Tool

Motion-picture negative stock (Fig. 3) has a fairly low-contrast linear response portion, as well as compressed toe and shoulder portions, which affords the cinematographer greater creative latitude when intentional compression of gray scales is desired. The so-called toe and shoulder of the film negative characteristic curve are ordinarily thought of, by those not primarily involved in cinematography, as limitations in the reproduction characteristics of photographic film. It is assumed that a more desirable photographic film, if it could be created, would be one with absolutely linear response, from the darkest blacks to the brightest highlights.

In fact, this is not desirable, and most professional cinematographers consider the shoulder and toe portions of the curve to be valuable tools, allowing them flexibility in determining the photoreproduction of a given scene or the creation of a given mood or style. For example, Fig. 4 shows what Eastman 5294 film stock looks like when exposed at an exposure index (EI) of 200. Notice the linear black reproduction and the absence of a toe.

One need only examine the work of cinematographers like Jordan Cronenwith, who filmed *Altered States* and *Blade Runner*, or Bill Fraker, who photographed *Heaven Can Wait*, or look at Vittorio Storaro's use of film emulsions in *One from the Heart*, *Apocalypse Now*, or *Ladyhawke* to see how these cinematographers routinely work within the photographic extremes of the shoulder and toe of the photographic negative characteristic curve.

Use of Film as a Video Medium

Because of this two-step gamma compression process, we have creative flexibility in motion-picture photography that does not exist in videotape production today. Motion-picture film, essentially, already provides what is being discussed as a possible option for high-definition gamma characteristics based on the intended use of the final image. For example, if a cinematographer photographs the original scene on that portion of the negative's characteristic curve which most suits his intended stylistic reproduction, he then has several options available to him.

If he is going to transfer to video, he can transfer directly from the negative, which is a popular option because it provides the most usable dynamic range and the most complete transfer of the film's latitude characteristics to the video image. When film is used in this way as an origination medium that will result in the ultimate video image, it is important to realize that the low-contrast, linear reproduction characteristics of the film are being used as a contrast-lowering device for the video system. For this reason, motion-picture films shot for theatrical or motion-picture exhibition can be under- or overexposed rather freely. But most cinematographers have found, when shooting negative motion-picture film for transfer to video, that they are well advised to stay within standard exposure practices in order not to exceed the dynamic range tolerances of the Rank

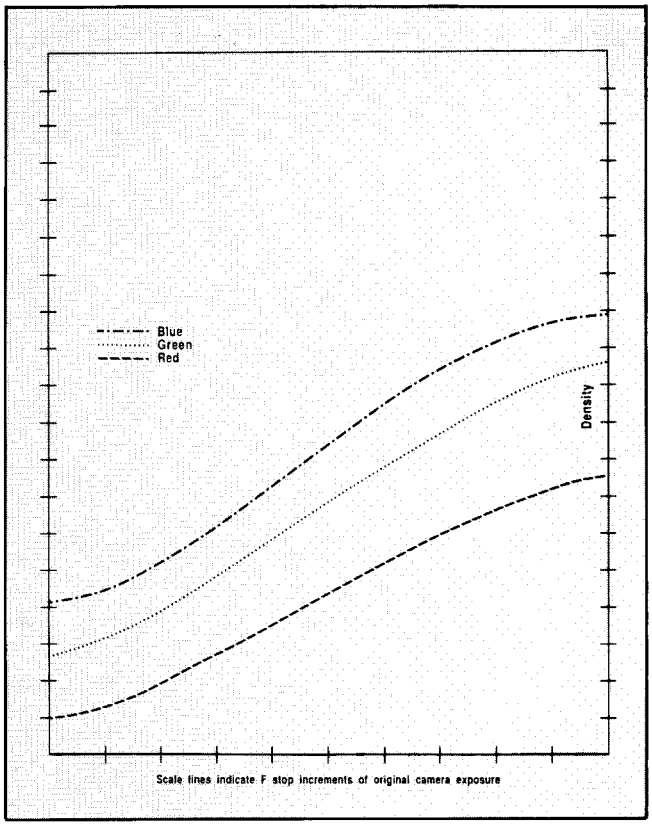

Figure 3. A 35mm negative.

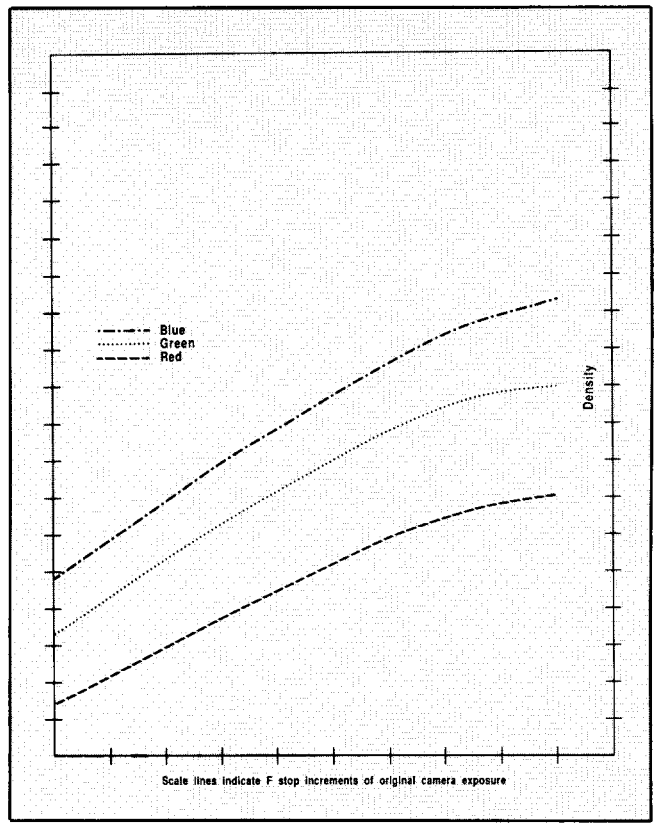

Figure 4. Eastman 5294 high-speed negative exposed at an EI of 200.

Cintel flying spot scanner or the Bosch FDL.

Another option for shooting motion-picture film for transfer to video is the use of low-contrast print film, such as Eastman 5380 LC. This print film is not designed for direct projection, but rather for maintaining the low contrast of the negative, as far as possible, through the process of direct transfer to video. Although low-contrast print film gives higher contrast than direct negative transfer, it does afford the advantages of protecting the negative from the possible abuses of the transfer system. A further advantage is that any dirt picked up by the film during the transfer will appear black on the positive low-contrast print film rather than white, as it would appear on the negative, and black dirt is less visible in the video picture.

A cinematographer has yet another choice of gray-scale reproduction options: the use of interpositive stock (such as Eastman 5243 Intermediate II), which is a low-contrast intermediate film, used principally in making duplicate negatives but also increasingly favored as a preferred medium to transfer motion-picture film to videotape.

It is not sufficiently understood in the video industry that all of these options available in motion-picture film provide gray-scale transfer characteristics that are desirable for their intended use. There really is no typical motion-picture gamma; there is, rather, a range of gammas and exposure options available within the capabilities of each type of motion-picture stock. Now let's contrast this with what currently exists in video.

Contrast Reproduction in Video

The video pickup tube typically has a linear gray-scale response with a sharp toe and a steep shoulder, compared to its film equivalent (Fig. 5). Any attempt to lift or round the toe or to improve black reproduction through the use of bias lights or gamma adjustment techniques frequently results in an increase in black or dark current levels, which results in increased noise. The reproduction of overexposed highlights is the most obvious shortcoming of the video look. Video overexposure artifacts, such as beam-pooling or comet-tailing, are generally considered undesirable in a video image when subjects of extreme contrast are to be reproduced.

To emulate a film look in video, the Ikegami EC35, the Panacam, and other cameras have tried to reproduce, through gamma-compression techniques, a soft knee or soft white clip. These circuits simulate a gamma response curve more perfectly approaching the shoulder of the negative motion-picture characteristic curve. Although these gamma modifications go a long way toward approximating the film look in a picture generated by a video pickup tube, they nevertheless cannot supply in video the dynamic range that is present in a motion-picture negative.

Traditionally, in video production, the requirements of gamma correction have been so specified as to most accurately reproduce the original scene on a kine tube. At the time these specifications were determined, no thought was given to direct video projection or video transfer to film. Furthermore, no thought was given to specifying gamma correction in video as a tool of photographic control or creative gray-scale reproduction. Now that high definition is becoming a reality in video, some thought must be given to the selection of a gamma specification that provides for more photographic versatility than current video gamma designs provide.

Direct Comparison of Film and Video Gammas

Our investigation of this problem began with a direct comparison of film to current video gamma. To can-

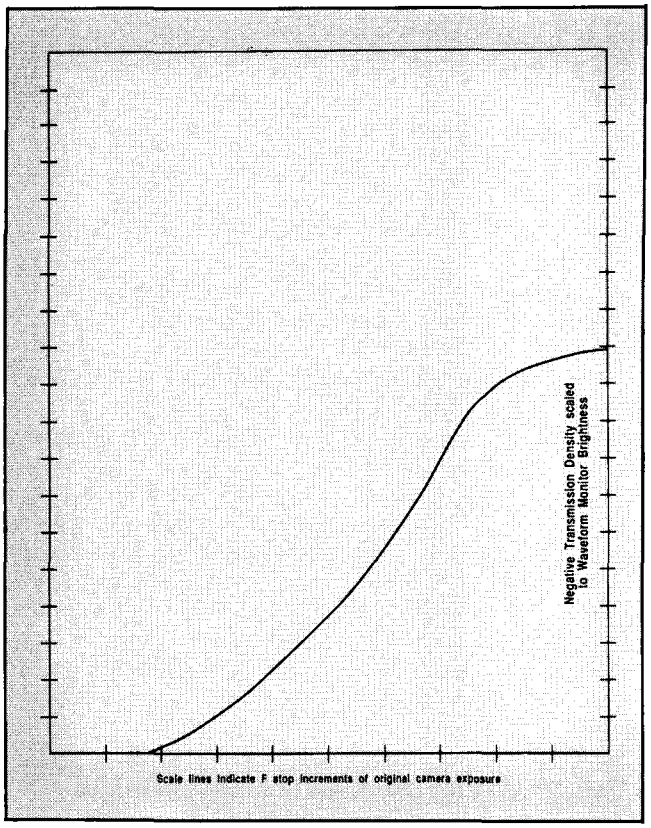

Figure 5. Waveform monitor.

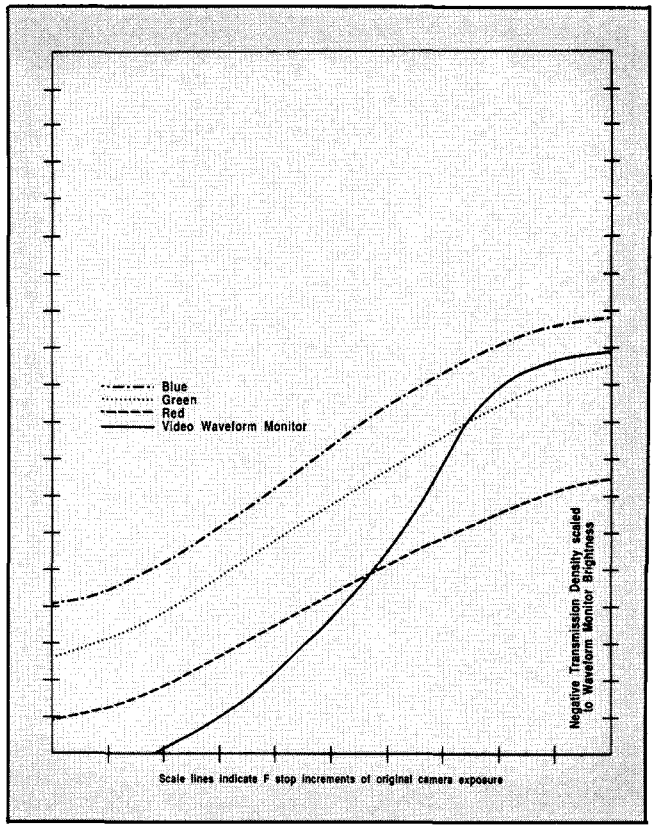

Figure 6. Video waveform monitor compared to 35mm negative.

cel out, as nearly as possible, the obvious errors that would result from direct comparison of two so dissimilar visual media, we used a method that would rely entirely on their commonalities rather than their dissimilarities. In the camera, a stepwedge was produced in both film and video by exposing the camera to an evenly lighted 18% gray card and by increasing and decreasing the exposure in steps of one full stop with the camera lens iris. In film, the resulting negative was printed at the best laboratory printer light; then both the negative and the resulting print were plotted in the standard manner, with density as a function of exposure. The same procedure was followed in video, but the resulting waveform indications of the camera (set at the normal gamma crossover point of 0.45, as is standard in video practice) were plotted as a function of original scene exposure. Figure 6 shows the resulting plot of video overlaid on a typical film negative.

Typical picture monitors were also read with a precision photometer under these test conditions, and a plot was made of the light output on the monitor screen as a function of video camera exposure (Fig. 7). The results of the waveform display were taken more seriously than the monitor brightness plot, since the monitor brightness plot was far from exhaustive. It was simply made as a casual check of whether current video monitors exhibit the same gamma characteristics as the monitors were believed to exhibit when the video gamma specifications were created. Figure 8 shows how the resulting plot matches with a typical film release print. The monitor curve in Figs. 7 and 8 has been inverted as a correction for the fact that picture whites are displayed on a video monitor by its emitting light, while film displays picture whites by failing to inhibit the projection lamp's brightness through an absence of density.

Comparison of HDTV Video Camera Luminance Transfer Functions with NTSC Video and Film Gammas

With the assistance of Sony Corp., these experiments were also conducted with the current Sony HDVS high-definition video camera, in an effort to analyze the similarities and differences in the gamma and dynamic range of a high-definition video camera and present film and video cameras.

Figure 9 shows the luminance transfer function of the Sony HDVS camera with knee and slope functions off. The camera has an adjustable knee circuit that allows the operator to adjust the slope and onset point. It is a conventional straight-line knee circuit, however, and not a gamma-compression circuit as in the EC35 or Panacam. Figure 10 shows the luminance transfer function of the camera with a gain boost of +3 dB.

Figure 11 is a plot of the HDVS camera luminance transfer function, adjusted for sensitivity and overlaid on a standard video camera plot. Figure 12 shows a comparison of the luminance transfer function of the HDVS camera overlaid on a film negative plot.

Ikegami was unable to provide a sample of its HDTV camera at the time because its American cameras had all been shipped to Japan for modifications. The company, however, generously provided information about the gamma characteristics and dynamic range of its current high-definition cameras. With slight differences, these cameras appear to exhibit many characteristics similar to those of present standard-definition cameras. According to Ikegami, its camera is somewhat more limited in dynamic range: above 100 IRE units, two stops of additional (200% more) latitude can be expected, with three stops being a practical maxi-

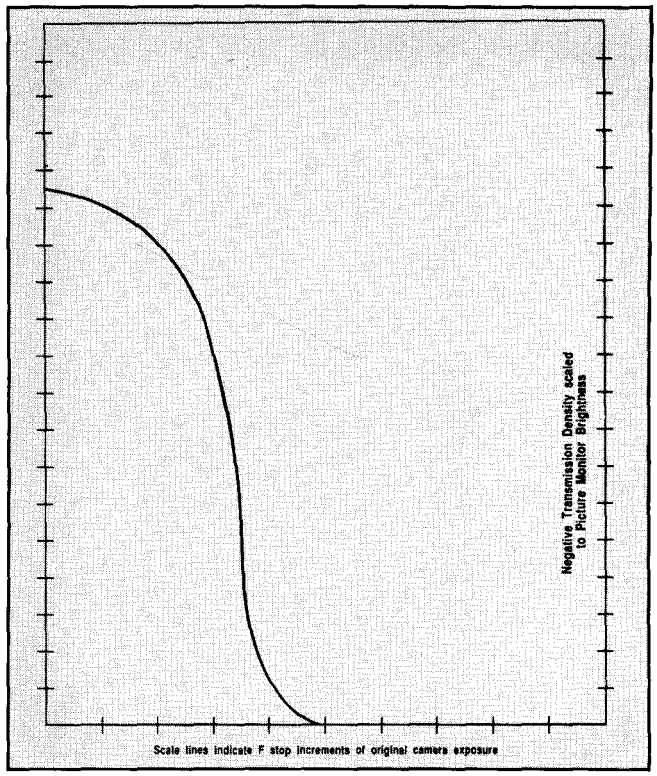

Figure 7. Picture monitor.

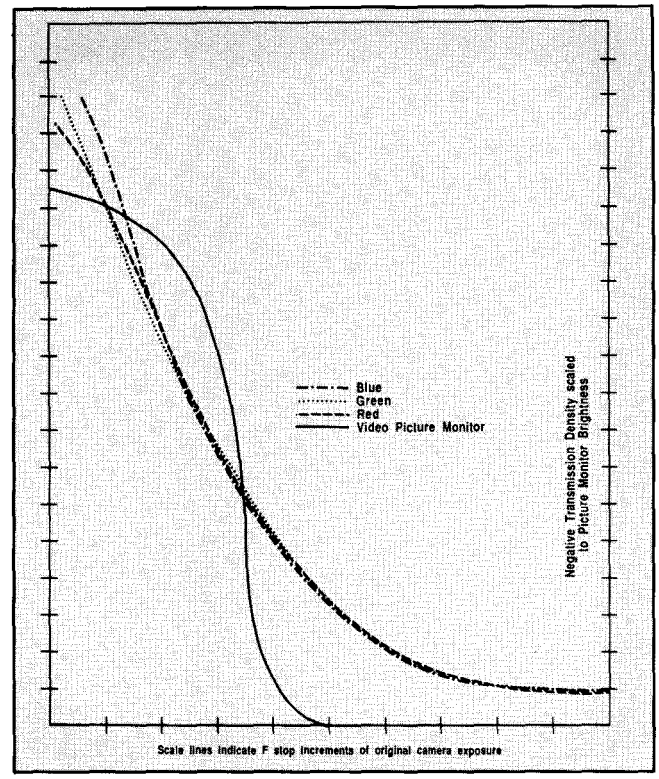

Figure 8. Positive film print compared to video picture monitor.

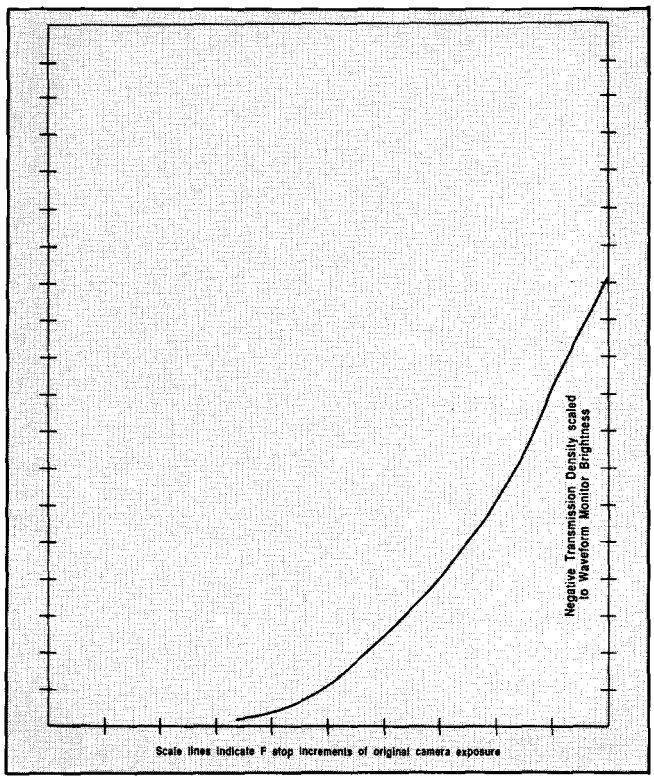

Figure 9. HDVS camera waveform monitor display.

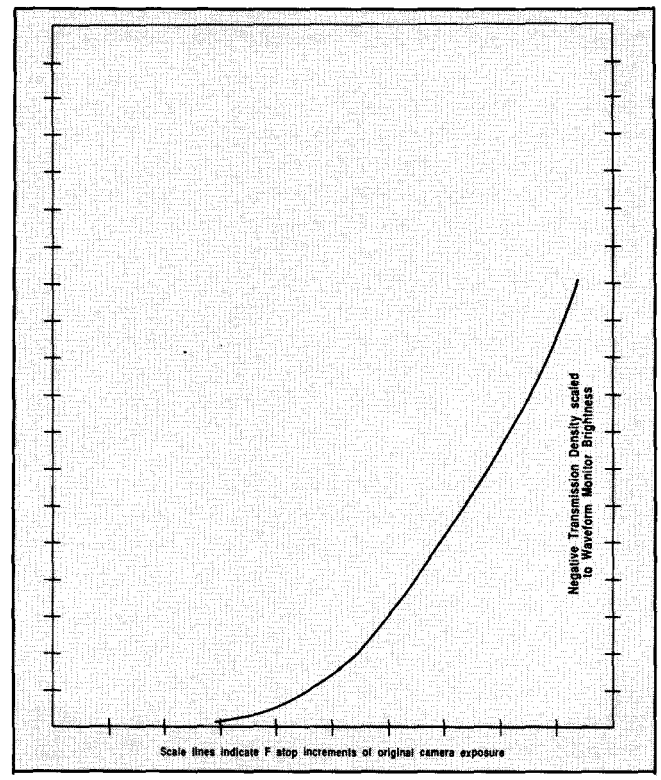

Figure 10. HDVS camera with a gain boost of +3 dB.

mum limit. Current video cameras with dynamic beam optimization have been found to provide, comfortably, a latitude of three stops and, with cameras using gamma-compression circuits, as many as four.

The Ikegami high-definition camera has a gamma crossover of 0.45, similar to existing video practice. Contrasted with current video cameras, there are differences in the toe response, or black levels, the toe of the high-definition video camera being more linear to suppress the noise that would result from the increased amplification of a raised or curved toe.

Conclusion

This is a report of work in progress, and results so far are inconclusive, but a few trends can be observed:

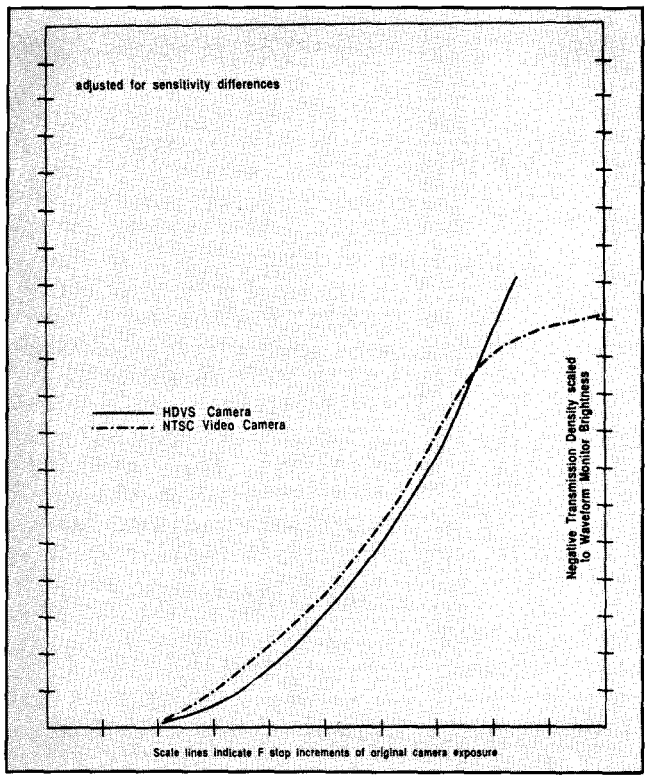

Figure 11. HDVS camera compared to standard NTSC video camera.

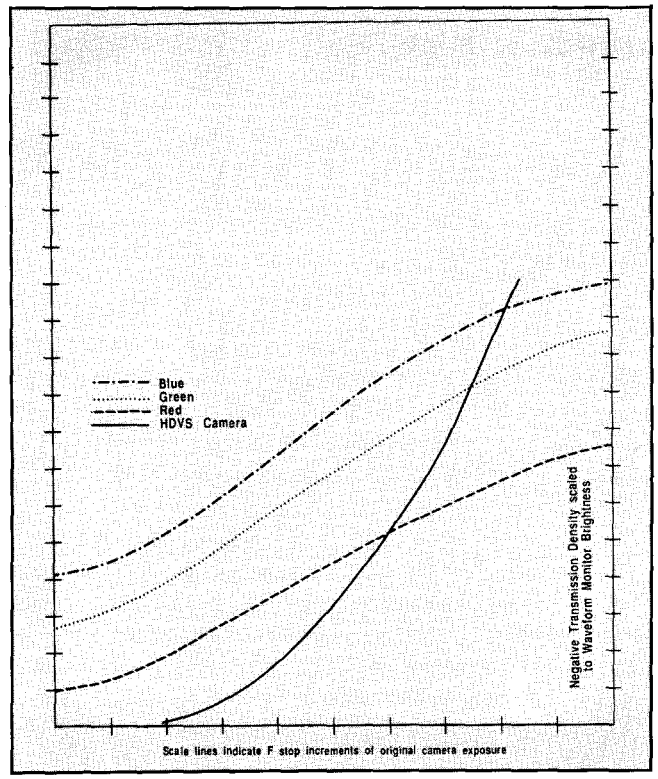

Figure 12. HDVS camera compared to 35mm negative film.

HDTV camera specifications. It appears that current high-definition video cameras have specified video characteristics equivalent to those of current standard-definition video cameras. It also appears that attempts to increase sensitivity and lower noise in high-definition cameras have resulted in a slightly shallower dynamic range and in a trend away from some of the knee-compression circuits that we were beginning to expect in state-of-the-art standard-definition video cameras.

Film characteristics versus video characteristics. Our film tests, also, have resulted in some interesting findings. Results of the investigation and interviews with people in motion-picture laboratories and with other cinematographers have provided information that tends to dispel a widely held but mistaken idea. It has always been assumed that because motion-picture film has a wider latitude than video, as indeed it has, video would simply have to equal this latitude in order to create, on video, the so-called film look.

It turns out, however, that not all motion-picture scenes use simultaneously every part of the extreme exposure latitude available in negative motion-picture stock; cinematographers routinely use the shoulder or toe portion of motion-picture film to compress a greater scene brightness range within the reproduction capabilities of motion-picture film. In other words, the motion-picture negative is an adjustable gamma-contrast-compressing tool, and the cinematographer can select the degree of contrast compression he desires by simply placing his exposure on a given scene, higher or lower on the motion-picture negative's reproduction capability range.

Therefore, when gamma characteristics are specified for a high-definition camera to be used for motion-picture subjects (that is, dramatic or creative subjects as opposed to football, news, or documentary events), it is imperative to select a luminance transfer function that allows the camera operator photographic flexibility. It is not enough to simply specify a gamma "correction" for accurate reproduction of a typical scene on a typical home television receiver, with all the shortcomings to be expected from a specification that involves so many assumptions.

Predictability and consistency. A cinematographer is not as concerned with linearity in gray-scale transfer function as he is with repeatability and predictability. The danger of any variable gamma scheme that allows infinite variation in the way a camera responds to photographic contrasts is that it must be calibrated to permit predictable repetition of a given gamma contrast characteristic for a given photographic situation — in other words, downstream predictability. Without consistency and repeatability, variability and adjustability are useless.

Many circuits and options in current video cameras are advocated as giving the video camera the flexibility of a motion-picture laboratory, but one essential attribute of a motion-picture laboratory that is missing in this analogy is consistency. A film cinematographer does not want his laboratory to provide him with flexibility and variability; he wants it to provide him with absolute image consistency. There is enough variability in photographing nature and attempting to match different weather characteristics and light qualities to provide all the excitement a normal cameraman ever needs, without his being subjected to the vagaries of adjustable gamma and adjustable contrast reproduction characteristics. These circuits, if used at all in a camera, must have a calibration standard, a unity gain position, or at the very least, an off switch.

Acknowledgment

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