Increasing Dynamic Range For Digital Cinematography

Michael Bergeron, Panasonic Broadcast January 2004 (*August 2004)*[1]

Introduction:

Much has been made of achieving a "film look" with digital motion picture camera technologies. While discussion has centered on providing a 24 frame per second progressive image at sufficient resolution, there are other differences between what is thought of as video and what viewers expect from film. Among these differences is the limited dynamic range (contrast ratio or latitude) of most video recording. Eastman Kodak has published experimental results showing high definition video delivering a dynamic highlight range relative to an 18% gray of no more than 3 to 4 stops; compared to the 15.9 stops of some color negative stocks[2]. Video camera manufacturers have made progress improving this dynamic range, including the introduction of knee and black stretch (black gamma). Panasonic's *cine gamma* and other methods have further increased the effective dynamic range of CCD image capture, by changing the entire characteristic response of the CCD imager. Digital image capture finally begins to approach the performance of some film negative stocks, mimicking the desired film like contrast behavior.

The effect of applying *cine gamma* has been illustrated in Panasonic marketing literature by comparing a video frame containing a white-clipped window, to the same shot using *cine gamma* where details of the scenery can be seen in the highlights of the same bright window. How is this accomplished, and why didn't anyone do this before?

Cine Gamma Note the bridge! *TU 709 Gamma* sky

[1] This paper was modified in August of 2004. The table on page was found to have errors and was replaced with a corrected table.

[2] February/March 2002 SMPTE Journal - *Assessing the Quality of Motion-Picture Systems from Scene-to-Digital Data*: Roger R. A. Morton, Michelle A. Maurer, and Christopher L. DuMont, Volume 111, pages 85-96.

Notes on Terminology:

For the purpose of the following discussion I will use the following terms as indicated below:

Transfer Characteristic: will refer to the response of an image capture medium to varying light intensities (also known as transfer response).

- For a film print for projection this refers to the density; denoted as a base 10 logarithm (LOG) of the ratio of light that the processed film passes. The film characteristic curve plots the density versus the LOG of the exposure.
- The video response is video level, which is a simply voltage (converted to a digital level in digital video). The standard range is from 0 mV to 700mV (or 0 to 100 IRE) although the peak video level of most systems is 770 mV (110% of this).

Gamma Correction: will refer to the application of a power law to the video level generated by the CCD. The output level is raised to a power of less than one (typically 0.45). This is done to compensate for the non-linear response (transfer characteristic) of a CRT (cathode ray tube) monitor, which applies a power law higher than one (typically ~2.2). When the gamma corrected video signal is displayed on the monitor the two exponents cancel each other out (0.45 x 2.22 = 1) and a linear response is delivered. All display technologies require some kind of gamma correction. A gamma correction for a typical film print projection might be 0.9.

In the video industry the video transfer characteristic curve is often referred to as the *Gamma Curve,* this is where the term *Cine Gamma* comes from. The MASTER GAMMA setting in the VariCam refers to the value of the exponent used for gamma correction (default is 0.45).
Further complicating matters; the slope of the film density curve has traditionally been referred to as the "gamma". In order to adjust this property on the VariCam one might adjust the knee slope and knee point (in VIDEO REC) or the dynamic range (in FILM REC) rather than the MASTER GAMMA.

To avoid confusion in this paper I will use the term *Gamma* to refer to Gamma correction. Other than where Panasonic has used *Gamma* for a feature name or menu item such as, *Cine Gamma, Gamma Mode, or Gamma Box*, I will try to use generic terms such as transfer characteristic or response, instead of *Gamma curve*.

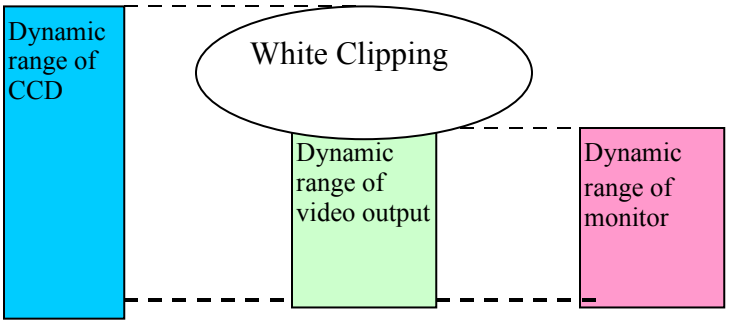
Contrast Ratio: will refer to the ratio of the brightest level possible to the darkest level possible, in either the image capture or display technology.

"Stops": will refer to the number of F-stops or T-stops that an image capture system or display technology can capture or display. The stops are roughly equal to the amount of times the numerator of the contrast ratio must be divided by 2 to get to 1. For example a 32:1 contrast ratio is 5 stops of latitude (32/2 = 16, 61/2 = 8, 8/2 = 4, 4/2 = 2, 2/2 = 1)

Historic Differences Between Film & Video:

A colloquial statement made comparing film to video is that video can only display a 32:1 contrast ratio (about 5 stops) while film can achieve anywhere from 400:1 (almost 9

stops) to 50,000:1 (almost 16 stops). These kinds of statements are misleading at best, however, it is true that film acquisition has always had an advantage over digital acquisition when it comes to latitude. Part of the reason for this is that video standards had been developed (and in some cases mandated) assuming they would be shown on a CRT monitor in a lighted room, rather than projected in a darkened theater. Broadcast equipment tends to sacrifice contrast ratio for brightness in the display, so even when image capture technologies might have allowed for more dynamic range there was little interest in doing so.



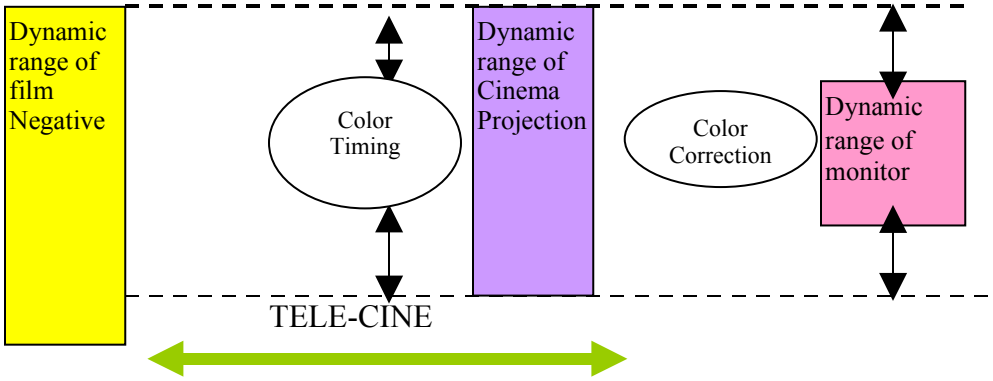
The SMPTE standards specify that a cinema projector should be capable of displaying a contrast ratio of from 400:1 to 600:1 (9 stops more or less)[3]. It is highly unlikely that any theater display technologies will significantly exceed this, as human eyeballs can only perceive 10,000:1 (a little over 13 stops) at a given instant in time, and without a few stops for the ambient theater light, people won't be able to see their popcorn or find their seats. Film stocks have been created where the negative can capture a 50,000:1 contrast ratio, and this allows for a great deal of leeway for setting exposure since only a fraction of the latitude is needed to create a good release print. This makes film a forgiving medium, but it does not change the capabilities of projectors or of the human eye.

Film to video transfer (tele-cine) has been around about as long video-tape itself. Part of the artistic process for modern tele-cine has been choosing what ranges of tonality in the film original to carry through to video, with its more limited dynamic range. Just as "pan and scan" techniques must be applied to get a 1.85:1 aspect ratio image on to a 4:3 screen, choices must be made when a 600:1 release print or a 50,000:1 negative is transferred to be seen on a 32:1[4] TV monitor. Choices are made regarding when to bring out more shadow detail, highlight detail or mid-range color saturation, depending on the needs of the story. The deliberate adjustment of tonal range in the color correction process is an important part of achieving a high-end film look.

[3] ANSI/SMPTE 196M – 1995 – *Standard for Motion-Picture Film- Indoor Theater and Review Room Projection – Screen Luminance and Viewing Conditions* Section 10.2

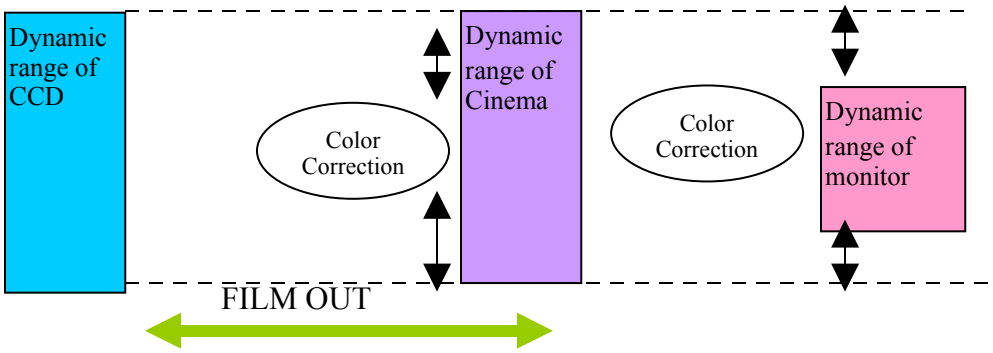
[4] Modern CRT displays have been shown to display far more latitude (even in consumer models) but here we will assume a worse case scenario.

Film Negative Image Acquisition for Film Print Projection and Television



I recent years *film out* (the process of transferring video or other digital recording to a film print) has come into play, and in this case the limited dynamic range of traditional video acquisition can be considered detrimental. A video limited contrast ratio can certainly dissuade filmmakers from originating on HD or DV for a theatrical release. Meanwhile new electronic display technologies with improving contrast ratios (DLP projectors, plasma monitors, etc.) continue to be introduced. Clearly, there has been a strong incentive for increasing the effective dynamic ranges of new cameras.

Enhanced Dynamic Range Digital Image Capture for Film Print Projection and Television

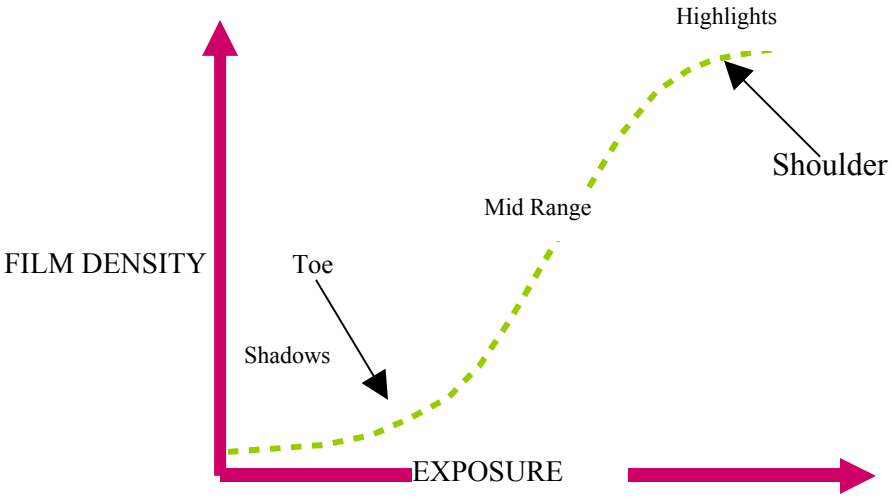


Recent advances in digital video:

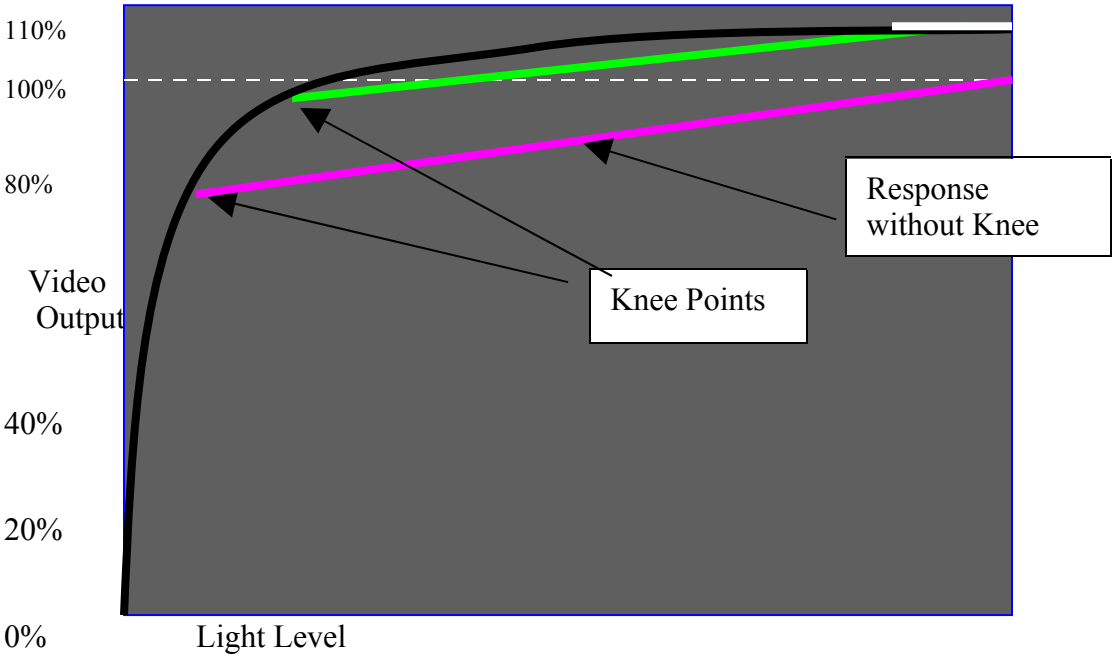
With digital signal processing it is easier to manipulate the cameras response over the full range of the CCD. It turns out that a significant proportion of the full dynamic range of a CCD imager is dedicated to highlight handling, in fact the highlight handling in most CCD cameras represents a greater contrast ratio than the active range. This comes from the fact that extreme highlights could damage earlier (tube) video cameras, and the point stated earlier that contrast ratios much greater than 32:1 are not observable on most CRT monitors. This overhead region of the CCD response is normally clipped white.

Film Density

Film negative handles a wide tonal range in part because it responds more linearly to tones in its mid range and more gradually in the highlights and shadows (the lazy S curve). In other words, there are fewer tonal gradations in highlights and shadows but only very extreme bright and dark areas are clipped white or crushed black. In this way, film negative may capture 5 or 6 stops in the linear mid range and then deal with perhaps 2 to 3 additional stops each in both the highlights and shadows.



Alternately video systems provide extra color saturation within its 5 or 6 stop range for a bright TV image.
Video cameras have, more recently, developed technologies to get some detail out of highlights and shadows. Naturally when viewed on CRT monitors, these methods must use up portions of the full dynamic range of the display.
Black stretch: takes a little bit of the lower mid range to use in the shadows so blacks are not entirely crushed. This shadow detail comes at a cost however, and many blacks end up looking dark gray as black stretch effects are increased.



Knee: can suppress objectionable hot spots. When using knee one may choose a point along the transfer characteristic below the full dynamic range (e.g., 85%) and set the response above this point to a more gradual tonal response farther into the CCD's full dynamic range. When the knee is active, white on a chip chart no longer is 100% white but detail can now be seen between the white chip on the chart and the ultimate clipped white. When a knee is applied to the characteristic response, levels below the knee point are still exposed in the same way. Aggressive knee adjustments attempt to mimic the film "shoulder" (the highlight portion of the film's negative's transfer characteristic). By lowering knee point and tweaking the knee slope the effective dynamic range can be increased. Knee adjustments are possible in most manufacturers latest professional production cameras. And while digital cinematic productions have used the above methods to achieve latitude acceptable for some large theatrical distributions, knee adjustments have the following limitations when used to significantly increase dynamic range:

- Any part of the scene that is illuminated at the knee point may exhibit artifacts
- The knee area is not gamma corrected like the mid range (it is linear)
- The only way to get a contrast ratio approaching a typical film stock would be to set the knee point extremely low;
    - This leaves an extremely small mid range
    - This creates a relatively large knee area that is not gamma corrected
    - This removes some of the levels of tonality from the midrange, and this can cause banding
- Knee adjustments can be difficult to make, because potential artifacts introduced by extreme knee settings are unpredictable and difficult to detect on a field monitor

In summary using knee adjustments is very good for enhanced highlight handling for TV applications, but must be approached with caution when attempting to significantly increase the dynamic range of the camera beyond that of traditional video monitoring. When the final product is to be shown on a CRT display, the highlight handling and increased latitude made possible through knee adjustments should be more than adequate.

Cine Gamma, The Next Step:

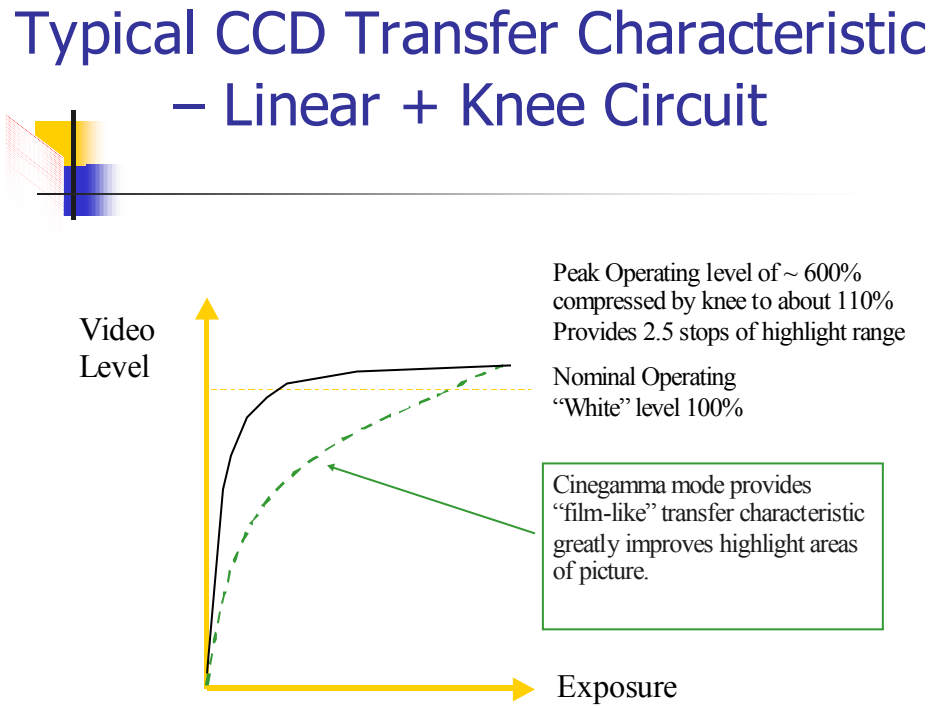
Panasonic's *Cinema Series* cameras all use knee and black stretch when shooting for NTSC, ITU 601 DV or ITU 709 HD standards. Normally these are destined for CRT, DLP or LCD viewing. In addition the *Cinema Series* cameras have one or more *cine gamma* modes, which takes the above techniques a step further and a step closer to the behavior of film.

For the DVX100 *Cine Gamma* operation is activated by setting gamma to CINE-LIKE; for the SDX900 the *Gamma mode* select is set to FILMLIKE1 or FILMLIKE2; for the VariCam VIDEO REC or FILM REC can be chosen as the *Gamma mode* when using the FILM USERS MENU. Further discussion here will center on the VariCam's FILM REC mode. The FILM REC mode is radically different from VariCam's other shooting modes and although many of the basic principles apply to the other *cine gamma* features, the

changes are more subtle and require little change to shooting style when compared to standard video modes.

VariCam's FILM REC mode:

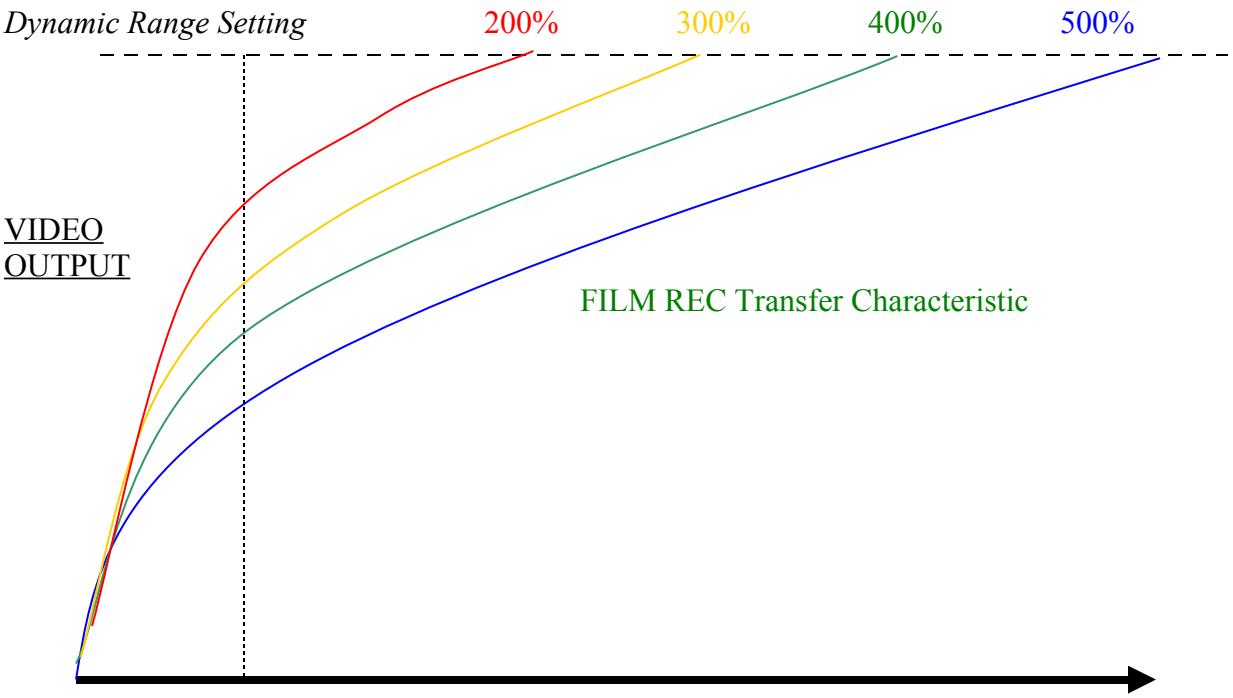
FILM REC provides an alternate approach to using the knee functions for highlights (Black Stretch still works the same way), and addresses the problems encountered as the practical limits of knee adjustments are reached. Because FILM REC pushes the entire characteristic response below where it could be pushed using knee adjustments, there is no knee in FILM REC.



In the mid range of a video transfer characteristic, a power law is applied to the response, giving the line a slight curve, and this cancels the non linearity of the response of a CRT monitor (a non linearity that is shared by most display technologies). This is known as gamma correction and is adjusted using the master gamma setting. Gamma correction has the added benefit of applying a decreasing value to tonal changes as the extreme highlights are approached. Gamma correction is not applied to the knee area when knee is in use.

The cine gamma transfer characteristic applies a series of power law curves joined to form a seamless more gradual function that applies gamma correction throughout the transfer characteristic. The CINE GAMMA transfer characteristic is capable of increasing the contrast ratio to better than 1,000:1 (10 or 11stops). As with the knee, this means that white is not seen as 100IRE on a video display because "white" will contain some details. The dynamic range of FILM REC is comparable to the contrast ratio of a some film prints, and is enough to utilize the full contrast range of a theatrical projection. User adjustment in the FILM REC mode is simplified as well. The somewhat confusing knee adjustments are replaced by one dynamic range adjustment known as DYNAMIC LEVEL, which is set from 200% to 500% of standard video dynamic range. The transfer

characteristic of the VariCam shooting in the FILM REC mode is designed to simulate a film positive in the middle "linear" range.



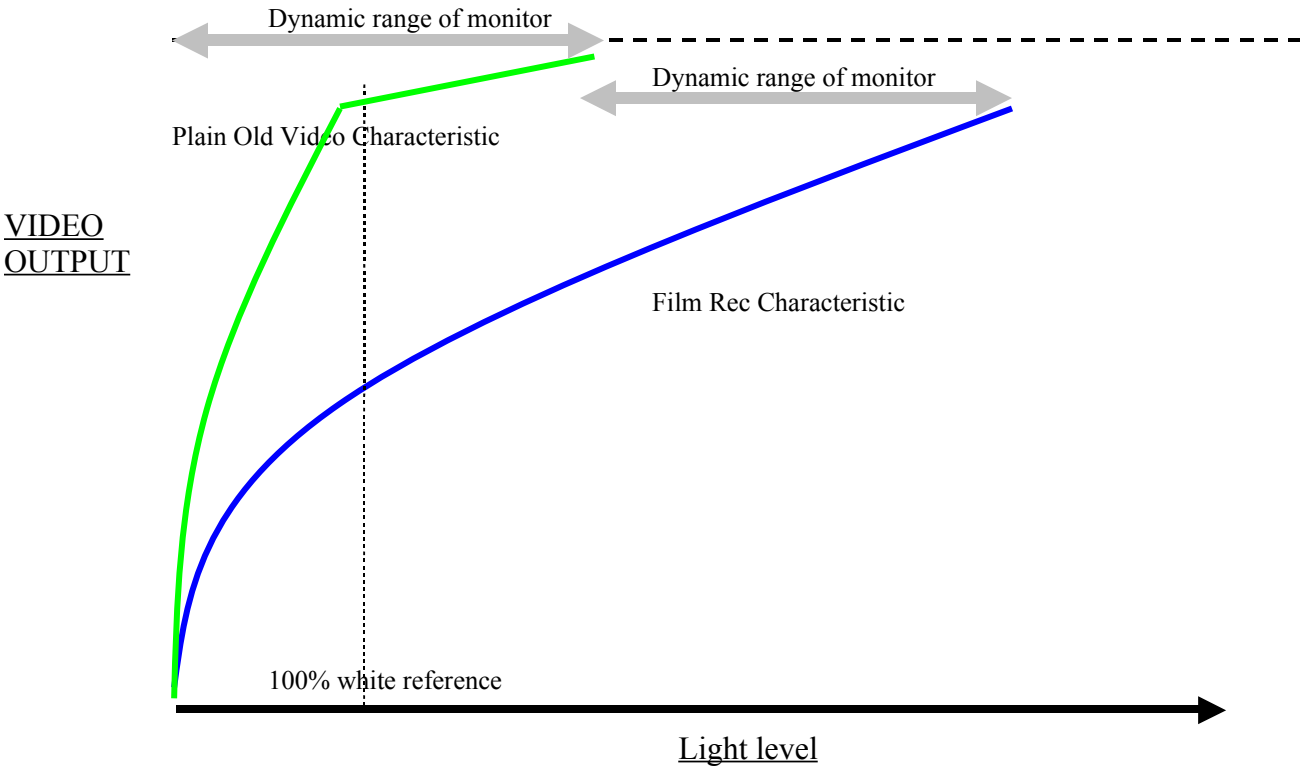
Reducing Dynamic Level increases the image contrast similarly to increasing the master gamma. If the full 500% is not needed for the scene content, more tonal levels can be used by the image if the dynamic level is decreased. This will also yield a more saturated image.

Viewing FILM REC:

Because we have not confined our contrast range to something a CRT monitor can display we cannot necessarily set exposure using a field monitor as the only reference. For a DP accustomed to shooting film, this lack of instant feedback should not pose a problem but still bears some explanation.

If we are capturing more than 10 stops of latitude (in the camera imager as well as on tape) we cannot possibly view all of this in a monitor that displays only 5 or 6 stops. For better or for worse the monitor is biased towards the top of the tonal range, not the center. The maximum video signal delivers the maximum brightness level of the monitor, so a properly set monitor is displaying the top 5 or so stops of the full dynamic range of the camera. Panasonic recommends that a scene shot in FILM REC not be exposed much differently than if it were shot in VIDEO REC (perhaps only 1/3 of a stop) but you will observe when switching between the two modes that FILM REC looks underexposed in the monitor by comparison (perhaps by as many as 2 ½ stops). In other words, the image will look dark, dull and the darker areas may not be visible on the monitor when viewing FILM REC. The diagram below Illustrates how the full dynamic range of the monitor is biased to the top portion of the video signal, and it also shows how everything being

recorded can be seen on the monitor in VIDEO REC and how much of the shadow detail cannot be seen.



If you increase the monitor brightness (please don't leave it out of adjustment!), you may find additional detail in the shadows. These details in the shadows should reproduce on a film-out and could likewise be brought out in color correction at the expense of highlights or overall saturation. The monitor is still showing what any other monitor will show if raw footage is played back, so if you will not be going to film-out or color correction, you may want to expose for that image (i.e., overexpose), even though you will not be utilizing the full range of the camera. Anything clipped white on the monitor will be clipped on any reproduction, but areas that look too dark can be recovered in post. Practically speaking, this means that the convention of setting normal (18% gray) exposure to 60IRE or 70IRE must be abandoned since it will put most of your subjects in the highlight area. The following table is an example of compared light meter readings to video levels as camera parameters are adjusted:

24fps T.2.8 EI	5.3	4.4	3.4	3.0	2.4	1.5	0.5	N	-0.7	-0.9	-1.8	-2.6	-3	-3.8	-4.5	-5.4
D500MG0.45	**106**	**105**	**89**	**80**	**68**	**49.5**	**34**	**30.5**	**23**	**21**	**14.5**	**9.5**	**7.5**	**5**	**2.5**	**1.5**
D400 MG0.45	109	109	94.5	85	72.5	52.5	36.5	32.5	24.5	22.5	15.5	10	8	5	2.5	1.5
D300 MG0.45	109	109	106.	95.5	81.5	59	41	36.5	27.5	25	17.5	11.5	9.5	6	3	1.5
D200 MG0.45	109	109	109	109	95.5	69	48	42.5	32.5	29.5	20.5	13.5	11	7	3.5	2
D500 MG0.35	105.	104.	89	79.5	68	50.5	37	33.5	26	24	17.5	11.5	9.5	6	2.5	1.5
D500 MG0.40	105.	104.	88.5	79.5	68	50	35.5	32	24.5	22.5	16	10.5	8.5	5.5	2.5	1.5
D500 MG0.55	105.	104.	89	79.5	68	48	31.5	27.5	20	18	12	7.5	6.5	4.5	2.5	1
D500 MG0.65	105.	104.	89	79.5	68	47	28.5	25	17.5	15.5	10	6	5	3.5	1.5	1
D500 MG075	105.	104.	88.5	79.5	68	45	25.5	21.5	14.5	12.5	7.5	4	3.5	2	0.5	0.5
D500 MG0.45	105.	104	89	80	68.5	50.5	35.5	32	25	23	16.5	11.5	9.5	7	4	2.5
D500□MG0.45	105.	104.	89.5	80.5	69.5	51.5	37.5	33.5	26.5	24.5	18.5	13.5	12	8.5	4.5	2.5
D500 MG0.45	105.	104.	90.5	82	71.5	54.5	40.5	27	30.5	28.5	23	17	14	9	4.5	2.5
D500□MG0.45	105.	104.	90.5	83	73.5	57.5	44.5	41	35	33	25.5	21	13.5	9	4.5	2.5
D500□MG0.45	105.	104	88.5	79.5	68	49.5	34	30.5	23.5	21.5	15.5	10.5	8.5	5.5	2.5	1.5
D500□MG0.45	105	104	88.5	79.5	68	49.5	34	30.5	28	22.5	17.5	12	10	6.5	3	2
D500□MG0.45	105	104	88	79.5	68	49	34	30.5	22.5	20.5	13.5	8.5	7	4	2	1
D500□MG0.45	105	104	88	79.5	68	49	34	30.5	22	19.5	11.5	6	5	2.5	1	0.5

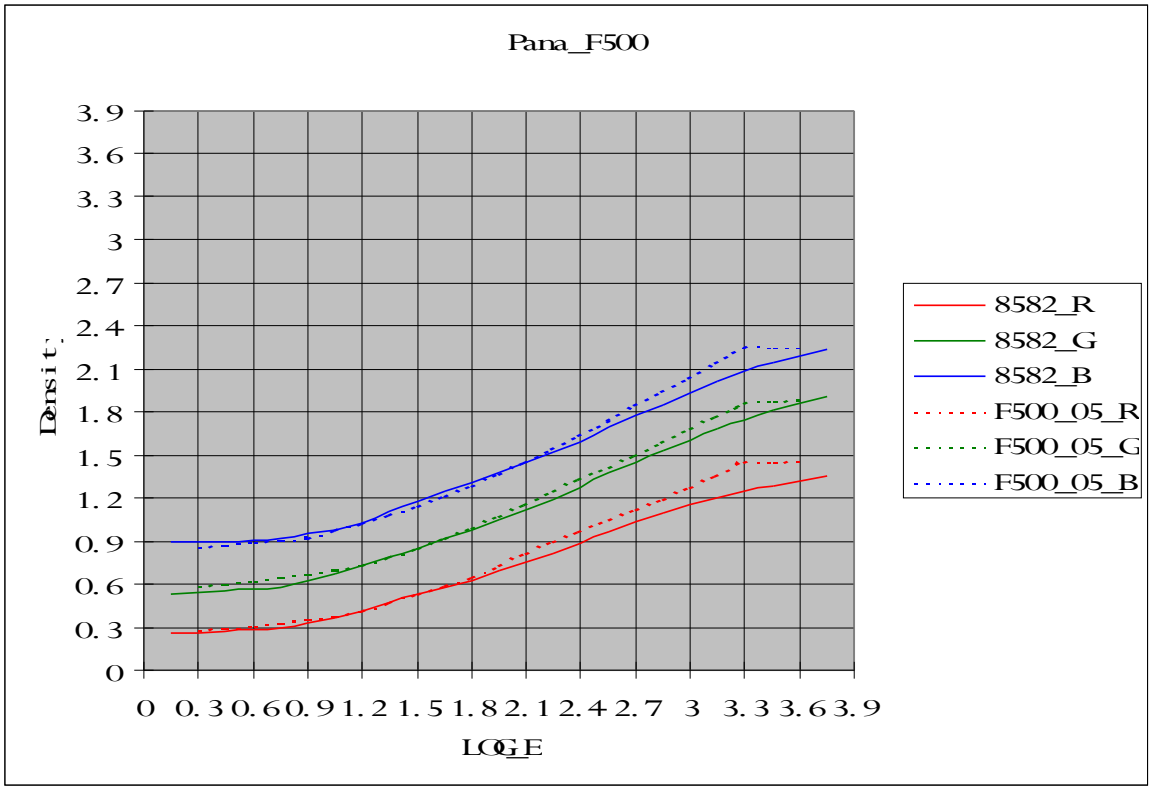
xxx At this light level the VariCam can no longer see tonal changes
xxx Here is where “low light” indication will come up in the default setting (45%)
xxx Here is where “low light” indication will come up at the minimum setting (20%)

Clearly low light level indications and zebra patterns should not be used in the same way.

Post Production:

So what can be done with material recorded using FILM REC? The original intention of the feature was that data might be handled like a film negative (or more precisely, positive). Either it is color corrected to be sent to a film out, or it can be color corrected tape to tape and optimized to be shown on another electronic medium, (just as is done in tele-cine). By delivering superior dynamic range at image capture FILM REC delivers the one-source-many-uses possibility previously unique to film. The following workflows have been used by VariCam productions using the FILM REC mode: The DP sets up each shot adjusting the dynamic range, black stretch and other camera parameters until the light levels (determined by the cameras internal spot meter “Y-GET” function) register where the DP’s experience tells him they should be. From here a special look up table for the Arri Laser is used, such that the scenes are accurately reproduced during a film out without any color correction. This would be a workflow similar to using color reversal, and has been successfully utilized in Japan. A look up table (LUT) created for this purpose can be obtained from Panasonic. Using a custom LUT, a film out was created that very closely approximated the density curves of 35mm print, derived from 35mm negative (see below).

The dotted lines represent FILM REC originated material



1. Another operational mode, favored by some DPs in the USA (many of whom are unfamiliar with HD or video) is to simply treat FILM REC as a 640 ASA film stock (depending on how parameters are set 400 ASA or 800 ASA might be more appropriate), and light using a light-meter, as if film were being exposed. By shooting tests beforehand the DP can learn the highlight and shadow behavior (these tests would be necessary when approaching any new film stock). Color correction using a high-end, system proceeds as if it were a digital intermediary, having skipped the 2K scanning process. For any video deliverable, color correction would be approached similarly to tele-cine for a DVD or broadcast release.
2. Another approach would be to keep a waveform monitor on set, and light as if shooting for broadcast, getting maximum information within the full camera imager dynamic range and color correcting in post to match lighting scene to scene. The difference for FILM REC would be that normal exposure would be kept closer to the middle of the range.
3. Lastly, it is still possible to simply ignore the fact that the camera is recording a wider dynamic range than the monitor can show and simply use FILM REC to achieve a desired look. By exposing to the highlights the user has a way of shooting that can deliver superior highlight handling without making knee adjustments. This is similar to how Cine Gamma features are used on the standard definition cameras with *Cine Gamma* modes. A helpful item to keep in mind here is that video is like a film positive (not negative) so when in doubt you should close the iris a bit rather than opening it as would be wise when exposing film.

More workflows may develop as the technology gets into the hands of the creative community and complimentary technologies come into the marketplace.

The AJ-GBX27 "Gamma Box":

Until a body of experience recognizing how a FILM REC image on a monitor will look when filmed out and projected, there is a need to provide a means for optimal and intuitive field viewing in real time. Since people of varying experience will always be looking at field monitors, the need to provide an optimum and intuitively satisfying image for video assist will never go away. A correction to the video output image will also open the possibility of lighting to a good quality master field monitor.

The AJ-GBX27 or "Gamma Box" has been created as an accessory VariCam monitoring to address the above issues with FILM REC. Running the HD SDI video out signal through the Gamma Box before connecting to the monitor will return FILM REC mode images to something resembling ITU 709 specifications (in terms of transfer characteristic and dynamic range). In other words, it will put the monitors more limited contrast range in the center of the cameras full dynamic range, rather than at the top, and therefore allow the operator to light more intuitively. The Panasonic BT-LH900 9" LCD monitor has been designed with a built in gamma mode selection that performs the function of the Gamma Box internally. Both adjust the video signal such that a viewed FILM REC image is displayed "brighter" and therefore shows the approximate middle of the contrast range

The Gamma Box is performing a first approximation of the gamma correction done to optimize FILM REC footage for standard CRT viewing, therefore the Gamma Box is also useful to create a quick single step tape to tape gamma/color correction. Tape footage corrected in this way is useful for creating video dailies or burning a quick DVD before time or budget allows for a proper color correction. It should be remarked that this automatic gamma correction is no substitute for a professional color correction system in the hands of a skilled colorist. A high-end color correction system allows for the flexibility of favoring highlights or shadows from scene to scene, not to mention working in a 16 bit RGB space. The Gamma Box will provide a real time approximate correction that can keep everyone, from advertising agency types, to assistant executive producers, to craft services from complaining about underexposure.

VIDEO REC:

VariCam offers a shooting mode optimized for delivery to an ITU 709 HDTV system, and a third mode in between ITU 709 and FILM REC, this mode is referred to as VIDEO REC.
In the VIDEO REC mode the VariCam still exhibits some filmic quality and still shows improved dynamic range over ITU 709, as well as black stretch and knee features. VIDEO REC differs from FILM REC in that it does not seek to exceed the contrast range of the monitor, and instead uses available data to deliver bright colors. In this way VIDEO REC is optimized for electronic display technologies. VIDEO REC can produce a video image that approximates tele-cined film right out of the camera with no color correction. VIDEO REC is also viable for film-out and can be thought of as a high contrast (not to be confused with contrast ratio) stock, as opposed to the wide latitude

stock (FILM REC). VIDEO REC will also deliver a good WYSIWYG image directly to the monitor, so if you need richer colors rather than wide latitude, VIDEO REC may still be your best choice. VIDEO REC behaves similarly to competitive HD and DV cameras, and is also most similar to the CINE GAMMA features in other Panasonic cameras.

The Cine Gamma Look:

As more and more shooters have been exposed to the look of FILM REC on the VariCam, as well as the cine-gamma features of other Panasonic cameras, many have been pleased with the look on its own. The muted highlights and reduced color saturations seem to resemble film acquired material that has been transferred to video. Many users have adjusted exposure and other camera settings to make raw FILM REC recorded material look good, right out of the camera. The FILM REC look has its own properties that may be just what a DP wants to deliver.

Budget Concerns:

Many VariCam users choose HD digital acquisition over 35mm or 16mm film because of a limited budget. When working on a shoestring, the post-production budget may be unknown, or non-existent. Part of the case for digital cinematography, is the ability to quickly and inexpensively create material that can be shown to potential financial partners, in hopes of getting further investment for post production. Independent film crews have been shooting using FILM REC optimized for the field monitor, knowing that the cost of a film out might be covered only after the project has been projected digitally at a film festival. This mode of operation was not anticipated by the manufacturer (as is often the case) but certainly is capable of producing some good images.