ADVANTAGES OF DSP CAMERA PROCESSING

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Abstract: *The implementation of DSP (Digital Signal Processing) to the television, CCTV, medical, industrial and other cameras caused the numerous benefits to the camera picture processing. Even though the camera CCD (Charge Coupled Device) block is basically an analog device and a part of video signal processing is still performed in the analog domain the A/D converter at the CCD output transforms video signal into the digital domain that is offering numerous advantages. Most of these advantages can be seen in the television studio and field shooting applications of the cameras. Easy set-up, high reliability, precise adjustment, flexible signal processing and parameter setting are bringing the TV production possibilities to the another level. Many of the camera parameters like colorimetry, gamma, knee, highlight control and power consumption are significantly improved and many others processing features are invented by using DSP.*

Key words: *DSP, ADSP, camera, CCD*

1. INTRODUCTION

DSP (Digital Signal Processing) and related further developments like ADSP (Advanced Digital Signal Processing) are becoming standard on high-end video cameras. Cameras used for different applications like medical, CCTV (Closed Circuit Television) and specially TV broadcasting are using the benefits of such a way of signal processing. Because of the fact that the final output signal quality is the result of the whole chain of camera subassemblies it is important to discuss how other camera components like imager assembly contribute and relate to DSP [1].

Advantages and disadvantages of DSP compared to ASP (Analog Signal Processing) should be considered. Besides the picture quality many other features like stable performance, reliability, low power consumption, switchable aspect ratio, easy multiple camera matching, powerful, flexible and automated control capabilities, enhanced creative performance and simple maintenance might be beneficial to the user.

2. IMAGER ASSEMBLY DEVELOPMENTS

Total picture performance is a complex function of many attributes in imagery. Improvements in overall picture quality are the result of continuing developments of the CCD (Charge Coupled Device) imager, the CCD support circuitry and video processing. As the CCD imager itself remains central to the direction of recent camera development, enhancements to the total performance of CCDs for broadcasting camera are of critical importance.

Current high-end three CCDs are related to the studio and field TV cameras. Today technology is offering CCD blocks and related support electronics to be easily interchangeable. These so-called imager assemblies are being produced in IT or FIT technology and might be 4:3 standard screen size or 4:3/16:9 switchable. The picture quality is incomparable to the previous generation of CCDs.

Today CCD sensors used in broadcasting cameras have more than 1000 horizontal elements which for PAL represents more than 600.000 total picture elements. Such outstanding horizontal resolution is provided by using submicron manufacturing techniques (which archive a precise pixel spatial offset between the G and R/B imagers) and optimised optical pre-filter.

The horizontal resolution is more than 900 lines with a high depth of modulation and minimum aliasing.

The smear level, despite large number of picture elements, is very low. With the inherent level of picture quality provided by such an imager, the precise picture adjustment capability of the cameras using digital signal processing becomes even more important.

There is a great importance of matching that front-end camera device and further digital signal processing existing. When developing a CCD for digital cameras, the relationships between CCD drive clock frequency, digital signal processing sampling rate and digital VTR sampling rate have to be considered. Simple relationships between these three parameters result in easy signal conversion from CCD output to digital video signal, in turn reducing the complexity of the digital LSIs and reducing camera power consumption. For example, if 18 MHz is being chosen as a CCD clock frequency it has a direct relationship to 18 and 36 MHz sampling rates in camera digital signal processing and 4/3 relationship to the 13.5 MHz sampling rate of widely used Digital Betacam and Betacam SX VTR formats.

By such a high clocking rate, in combination with precision CCD spatial offset and the design of the optical low-pass pre-filter, aliasing is reduced to very low level.

The today's high packing density of CCD elements achieves an excellent depth of modulation performance of 80% at 5 MHz which is almost twice than the Plumbicon™ tube of the same size. The following Figure 1 compares the depth of modulation characteristics of current high-grade CCD sensors (like SONY Power HAD) to previous generation of tube sensors.

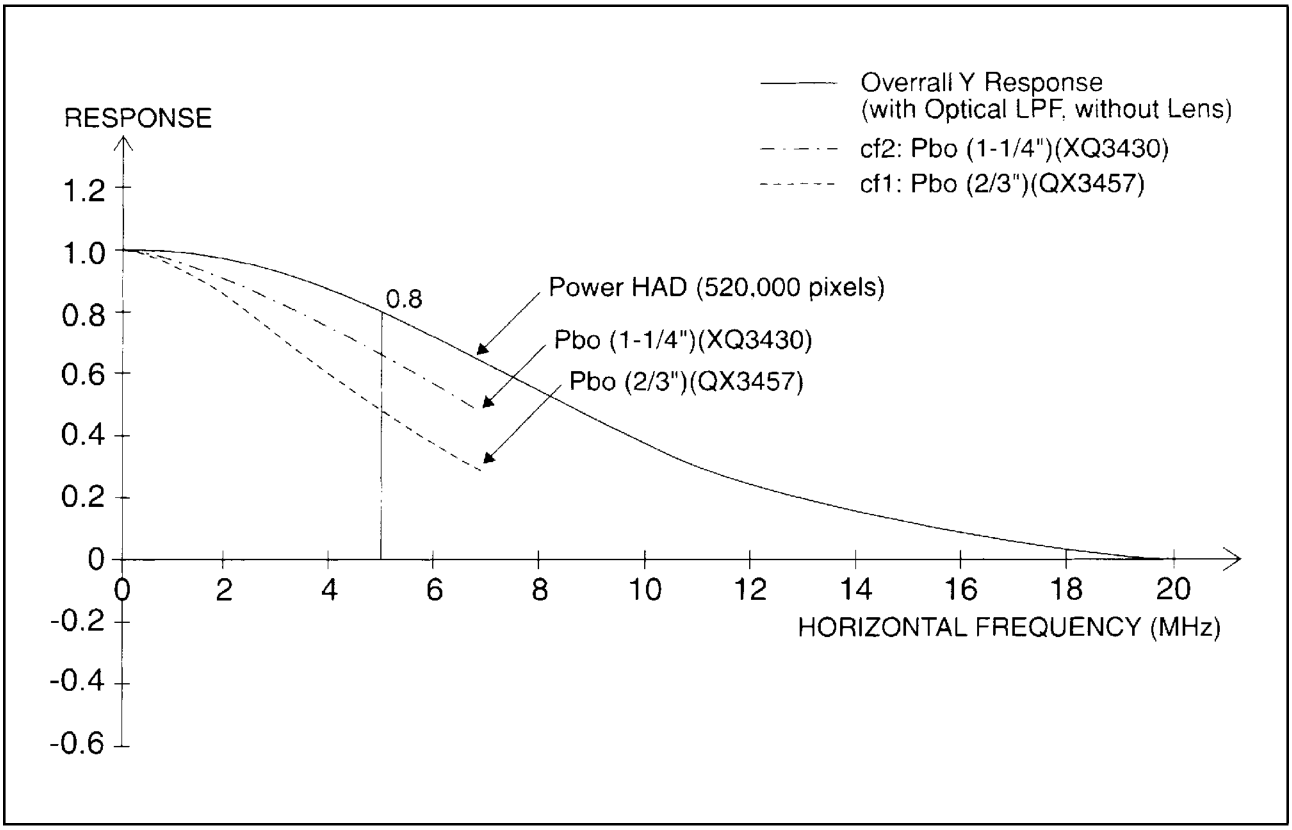

Figure 1. Depth of modulation comparison

The sensitivity of the CCD imager is further enhanced by using different technologies like OCL (on-chip microlens). Such a layer effectively concentrates the incident light on the photo sensor area achieving the double sensitivity compared to the CCD imager without such a microlens over each pixel (up to F10.0 at 2000 lx can be reached). The following Figure 2 shows how the OCL enhances sensitivity.

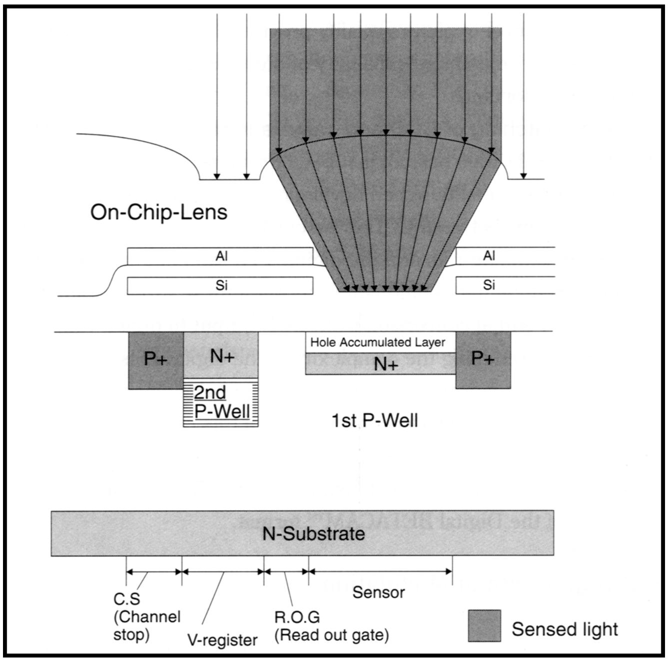

Figure 2. On-chip lens structure

Those microlens effectively concentrate the incoming light on the photo sensor elements so that leakage of light is greatly reduced. The direct result of this is very low smear level. It is further improved by using masking techniques above the sensor area. With the FIT sensors the smear level of -145 dB is achievable. That means smear is improved to the level of not being visible. The masking technique is shown on the following Figure 3.

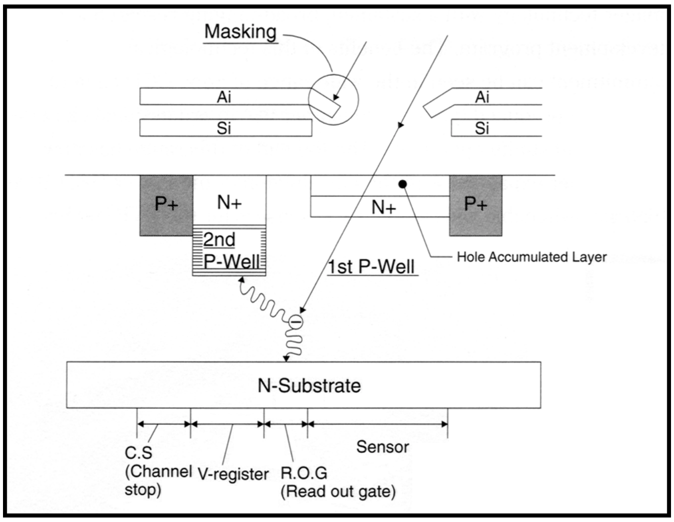

Figure 3. Masking on Power HAD imager

By the new developments of CCDs the dark current noise is reduced by 90% compared to the previous generation of the imagers. This gives a corresponding reduction of the fixed pattern noise, maintaining low noise characteristics in all imaging situations. In combination with an advanced CCD support system the excellent 63 dB signal to noise ratio (for PAL) is achieved.

Further operational advantages like increasing the vertical definition or using shutter operation for shooting computer monitor screen are also improved in the recent generation of the cameras.

Compared to the tubes, CCD imagers typically have a good red spectral response but their blue response is generally inferior. In the new generation of imagers, the response to short wavelength (blue) has been greatly improved and the near-infrared region smoothly attenuated. Thus, an ideal spectral response for a color video camera is obtained by filtering the near-infrared region with a mild infrared cut filter. Thanks to these improvements, the colorimetry of the new generation broadcast cameras is better than that of Plumbicon™ tube cameras. The colorimetry can be normalised to meet the EBU Color Chart or SMPTE C Standard – while also retaining the flexibility for linear matrix adjustment to match another colorimetry norm (another camera type for example).

3. BENEFITS OF DIGITAL SIGNAL PROCESSING

Digital Signal Processing circuit is the heart of the modern broadcast camera and includes a number of capabilities that serve to enhance camera versatility. The use of digital signal processing, with all control values held in digital memories, ensures that operational settings will remain constant, day after day, eliminating the need for skilled set-up alignment. Since all these setting memories are in the camera head, cameras may be quickly changed from one base station to another, even in another studio, without these settings being lost. When first installed, the cameras can be programmed to match any customer's precise preferences for parameters such as gamma, colorimetry and detail.

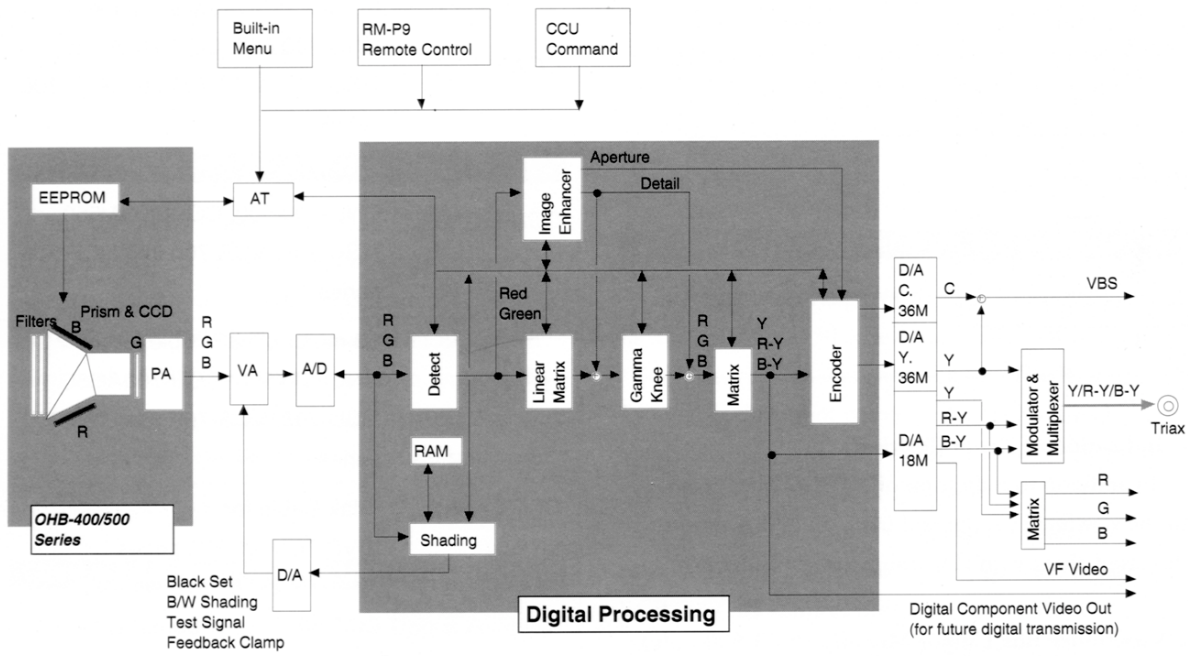

Figure 4. Camera signal processing

3.1 Analog signal processing domain

As described in previous text, CCD sensors are very important part of digital signal processing in cameras, because good S/N ratio and other improved benefits of modern CCD sensors are determining the quality of the camera in general. The Red, Green and Blue CCD sensors are fixed to the prism block using Spatial Offset Technology to provide high resolution. The image captured on the photosensors of each CCD is read out at a clock frequency of 18 MHz. The signal is still in analog domain and it is also during gain boost process that is performed by a Video Amplifier circuit. Most of the broadcast cameras till today were using 10-bit A/D conversion, which was at the practical limit of technology. But nowadays, more and more camera manufacturers are implementing 12-bit A/D conversion. However, cameras in general have some critical characteristics that make it very difficult to implement digital processing. Before digital processing, some processing in analog domain should be done in order to archive best possible signal characteristics.

Camera characteristics such as 600% dynamic range, non-linear gamma processing and white balance adjustment would require an A/D conversion resolution of approximately 13.5 bits to achieve camera performance which is superior to conventional cameras. In order to achieve their target performance with 10 to 14-bit resolution, digital camera manufacturers are using few techniques in analog domain before A/D conversion is done: gain boost, white balance and pre-knee.

Gain boost process is performed in the analog domain by a Video Amplifier circuit. After that white balance and pre-knee are processed with an AD board. The most important is pre-knee processing. In most analog broadcast camera, video matrixing and detail correction are performed in a linear environment (before the gamma/knee process) to obtain the best possible color reproduction and effective detail correction. But in digital cameras manufacturers adopted one or two point pre-knee processing which compresses the 600% dynamic range from the CCD imager to about 200-350%, depending on camera model. After that, video signals are converted to a 10 (or 12) bit digital signal at an 18MHz sampling rate, the same sampling frequency as that of the CCD imager.

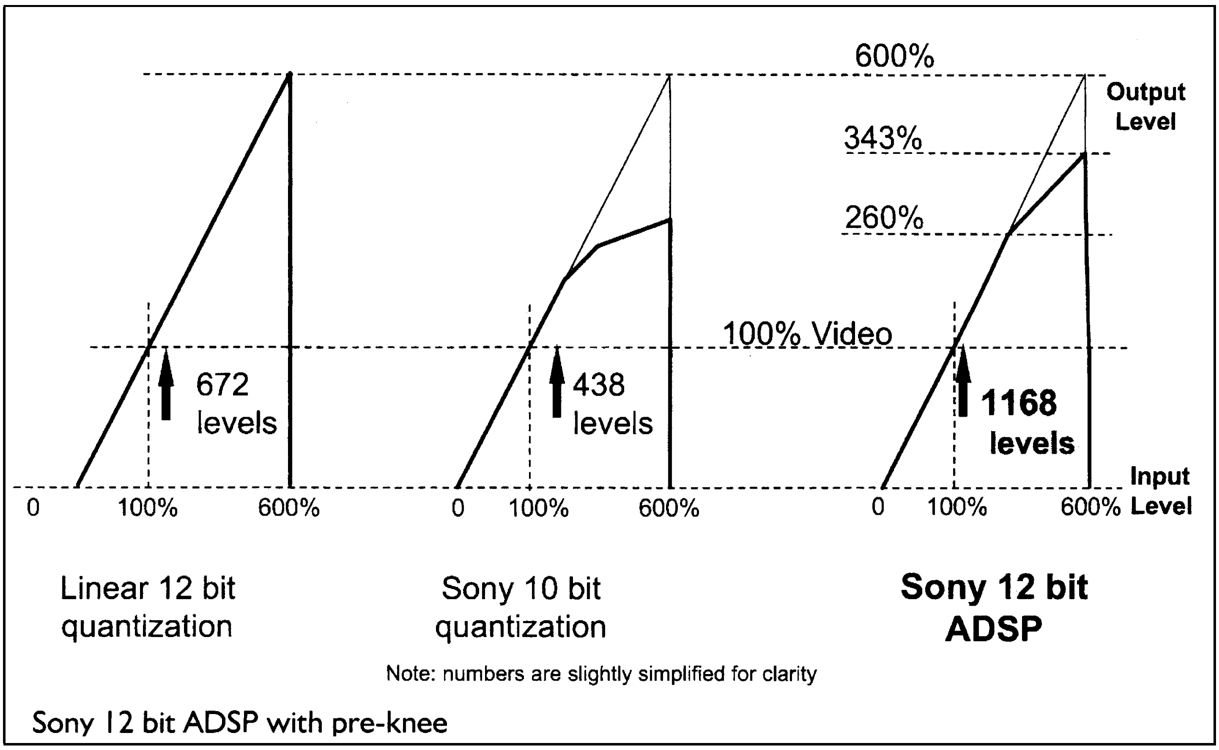

Figure 5. 2-point and 3-point Pre-knee in SONY cameras, with 10 and 12 bit quantisation

3.2 Digital Signal Processing domain

Over 80% of camera signal processing is executed in the digital domain. In certain parts of digital processing, such as in the image enhencer, gamma correction and encoder circuitry, resolutions of greater than nominal (10 or 12 bits) and a sampling frequency of 36MHz are used.

VLSI chips are used for digital signal processing. In first part, Detect (DET) circuits measure the peak level, average level and provide other information about the video signal and these measurement are sent to Auto (AT) circuits as feedback signal for functions such as auto black/white balance, auto iris and Dynamic Contras Control (DCC, Auto Knee). In order to maintain a wide range, flare correction is located in Video Amplifier (VA) circuit.

The shading circuit divides the picture into many zones and generates white/black shading compensation signals for each zone. The black set signals are also generated here and added to the black shading compensation signals. The resultant signals are converted to analog form and sent back to the VA to provide compensation. The white shading compensation data is stored in EEPROM inside the CCD block, being useful in case of CCD block interchange. Furthermore, a digital feedback clamp signal is generated and sent to the VA. This feedback clamp plays an important role in maintaining a stable black level. Black level is now controlled by digital feedback so that extremely precise black is generated.

A detail correction signal is derived from both the Red and Green signals. This process is carried out at the extremely high frequency of 36MHz for accurate correction. The detail correction signal is added to the R/G/B signals both before and after gamma correction. The aperture correction signal, which is also derived from the Red and Green signal, is separately added to the R/G/B signal to improve its resolution. Linear matrix correction is prior to gamma correction so that the accurate colorimetry can be reproduced. Gamma correction is also fully digital. The high quality gamma correction ensures excellent gamma balance between the R/G/B channels.

4. CAMERA DSP FEATURES

4.1. Multi Matrix

Commercials and drama work sometimes requires very precise color adjustments to satisfy the client and on many cameras it is possible to switch to the various preset colour matrices to provide different colorimetry. Multi Matrix is a function that electrically adjusts the basic RGB color “taking characteristics” of the camera to archive optimum colorimetry. It makes easy to match the color of camera under multi-camera operations, or to reproduce the characteristics of another type of camera. It can also be used to manipulate color for a particular special effect. A conventional linear matrix function provides only six adjustable parameters, with considerable interaction between their effect on a specific color. Multi Matrix function divides the spectrum into 16 segments, each of 22.5 degrees, for each of which there is an independent hue and saturation parameter. Multi Matrix allows the selection of each of these segments, with separate adjustment of hue and saturation parameters.

4.2. Adaptive highlight control/auto knee

For a many years, camera designers have tried to improve the rendition of strong image contrast by using knee techniques to compress highlight information into the standard “1 Volt” video signal. Conventional cameras only have single knee point/slope characteristics. In contrast, broadcast DSP cameras have multiple knee point/slope characteristics. The principle is that camera intelligently monitors the brightness of all areas of the picture and adopts the knee point/slope for optimum reproduction. A typical example is an interior scene which includes a sunlit exterior seen through a window. This function applies only to video levels in excess of the knee point, the middle and low luminance parts remaining unchanged.

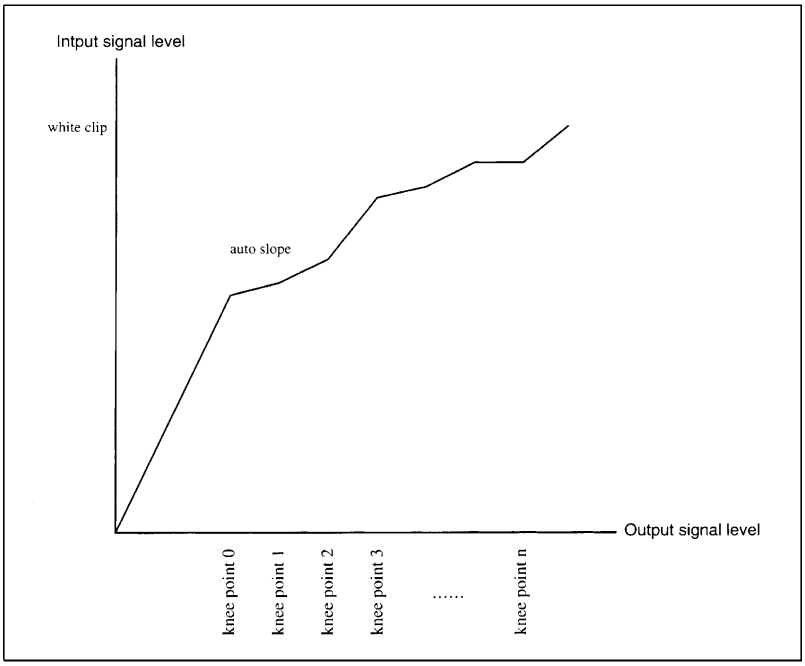

Figure 6. Knee curve image

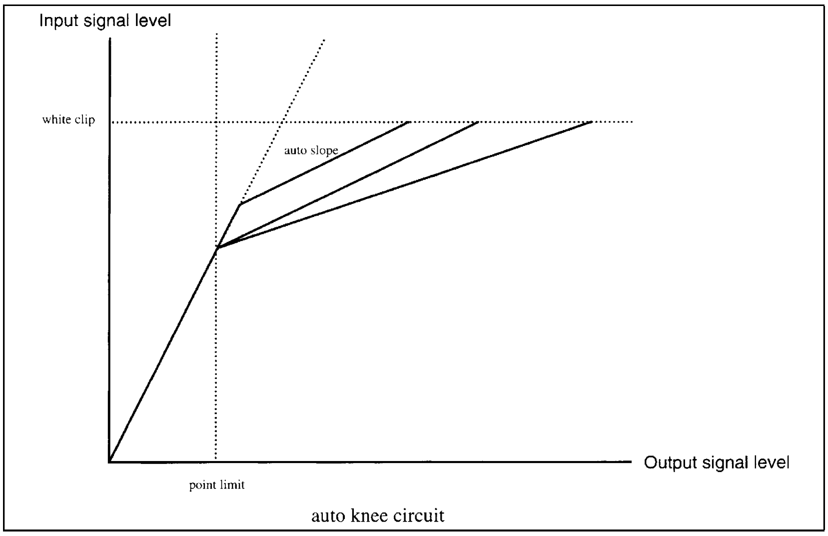

Figure 7. Auto Knee curve image

4.3. Gamma

Television cameras must incorporate appropriate non-linear electronic pre-correction (gamma) to ensure maximum picture contrast portrayal on cathode ray tube displays that have an inherent non-linear electro-optical transfer characteristic. Gamma correction has a powerful influence on color reproduction. The gamma correction curve is a very complex non-linear curve. Therefore, precise gamma correction requires extreme accuracy. Gamma correction curve is achieved by piece-wise linear approximation created from segments. In new generation cameras there are 48 segments. While a typical value of gamma in TV cameras is 0.45, cameras with digital signal processing have few presets and ability of variable control between these values, typically between 0.4 and 0.5. Independent variable gamma controls for Red, Green and Blue permit fine differential adjustment. These gamma controls smoothly control the entire gamma curve.

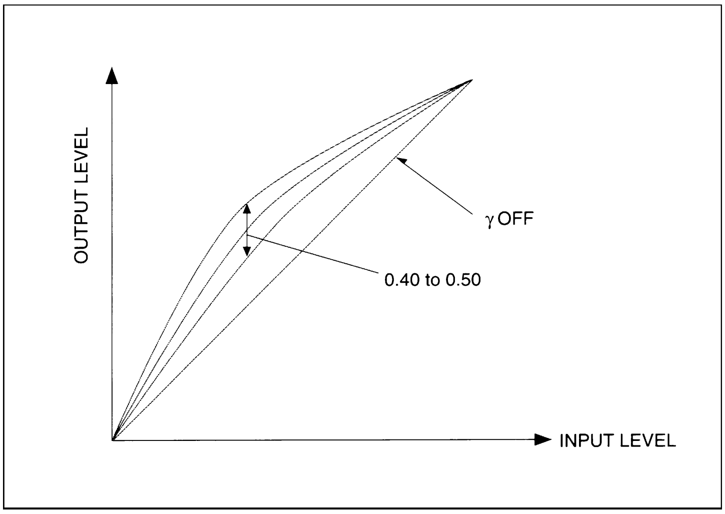

Figure 8. Gamma control

A black gamma control is provided for flexible color reproduction especially in the dark parts of the picture. In a scene that contains deep shadowed areas, this innovative control allows an improved extraction of picture information within those regions. The control allows the slope of the linear part of the Red, Green and Blue transfer characteristics to be simultaneously adjusted over a range of 3.0 to 5.0 without affecting the gamma curve above the cross point.

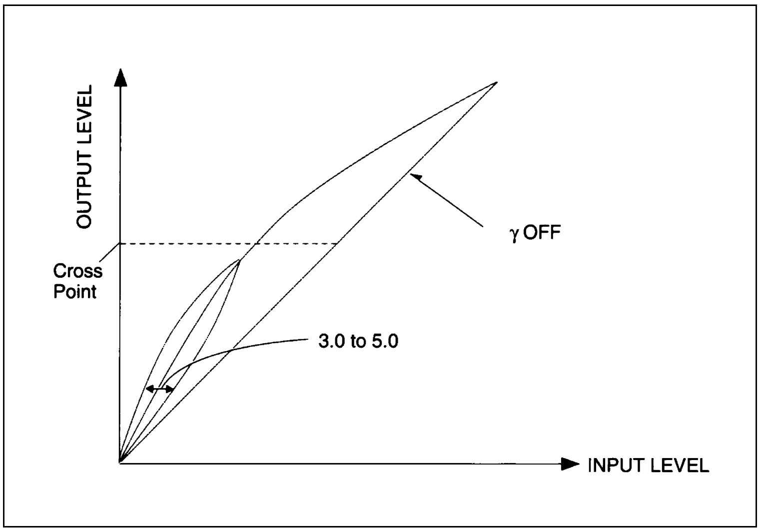

Figure 9. Black Gamma control

4.4. Accurate auto black/white shading compensation

In general, black shading is caused by the thermal characteristics of electronic circuitry, while white shading is due to the uneven sensitivity of the optical devices such as the lens, prism and CCD imager.

Compared with tube type cameras, these shading effects are much smaller. One of the benefits of broadcast cameras with digital signal processing is that they achieve complete compensation automatically, accurately and quickly. Shading compensation system is able to provide whatever complex shading corrections are required.

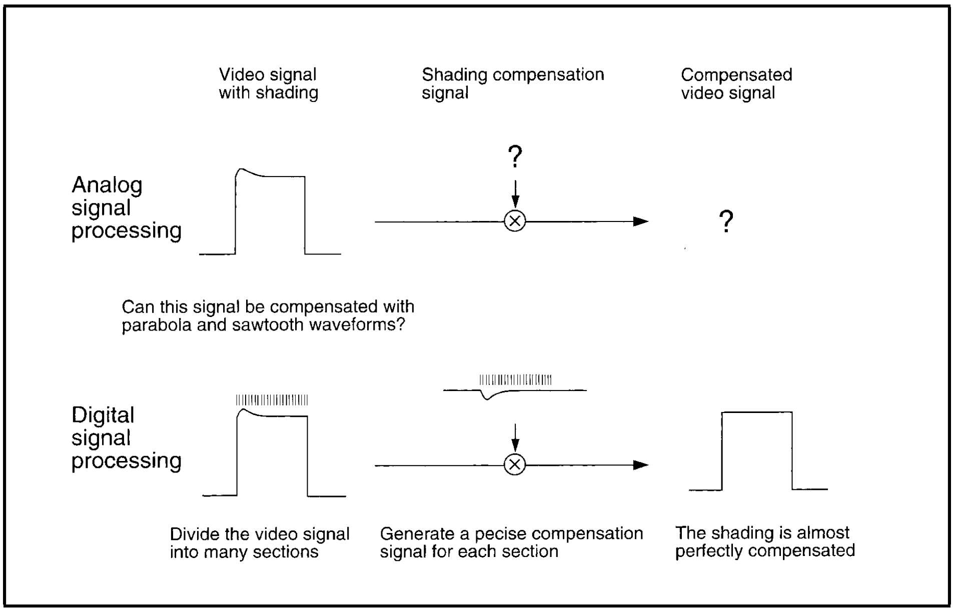

Figure 10. Shading compensation

4.5. Skin tone detail control

Skin Tone Detail Control allows variable image enhancement to be applied to the overall scene while separately controlling the specific degree of enhancement on any facial control within the scene. The skin detail function allows separation of facial skin color from all other colors in a given scene, and its detail level can be enhanced or suppressed, without affecting other areas of the picture. The color range can be adjusted for:
Phase – Sets the color phase for which Skin Tone Detail Control is activated.
Width – Sets the color width for which Skin Tone Detail Control is activated.
Saturation – Sets the saturation for which Skin Tone Detail Control is activated.

4.6. Skin tone auto iris

A problem with conventional auto iris is that movements of bright objects in a scene adversely affects facial exposure. Skin Tone Auto Iris is a function that controls the auto iris system to ensure a constant video level for a defined human skin area within the scene.

4.7. Detail correction

Detail correction is one of the greatest influences on overall picture sharpness and digital camera processing allows the introduction of new techniques in the control of this important function. For horizontal details, it is possible for width of the detail edge to be adjusted without changing the peak level. When peak frequency is moved, the width of the detail correction signal, in other words the effect of the detail correction signal on picture transitions, is changed accordingly. This feature allows more precise and creative picture control for subjects in different shooting conditions, and for different lens settings.

With a high contrast subject, extreme dark-to-light or light-to-dark transitions can create excessive detail correction. This results in “black halo” and “stepping diagonal” effects. The black halo effect is seen as thick black edges surrounding an extremely bright object, while stepping diagonal edge is seen as jagged slanting edge. These unpleasant side effects can be reduced by clipping the excessive detail signal to appropriate level in both H and V directions. Digital signal processing within camera accurately clips the detail signal, resulting in a very effective reduction of the black halo effect.

5. CONCLUSION

Advantages of digital compared to analog signal processing within the video camera are obviously so numerous that it is to be believed that in a short time all types of cameras, from consumer grade and low level surveillance to high level TV broadcasting cameras will employ DSP. It is to be expected that some of the picture performance related features like number of quantisation bits and sampling rates are still to be further improved for high-end applications.

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