A High-Performance, Full-Bandwidth HDTV Camera Applying the First 2.2 Million Pixel Frame Transfer CCD Sensor

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A newly developed HDTV CCD camera system, to meet various HDTV standards, is presented. The design aspects and design goals are discussed, as well as the application of a new 1-in. HDTV FT CCD sensor. The main challenges to the development of this sensor were the reduction of RC values of the CCD gates by means of a new interconnection scheme, the design of a very effective image cell, and the low noise-output stages. The optomechanical design aspects of the camera are also described. The focusing problem, caused by the smaller depth of field in HDTV cameras, is successfully tackled by the introduction of two new focus-assist tools: an electronic magnifier and "crawler" circuitry. The low-power, wide-band video processing and full-bandwidth, two-dimensional contour processing are discussed. Signal transmission between camera and camera processing unit is possible in multicore mode with a maximum cable length of 300 m and in fiber-optic mode with maximum 2000 m of cable, including camera power. The system concept, together with the possible different modes of operation, is explained. User experiences, gained during the 1992 Olympic Winter and Summer Games and several other field tests, are also presented.

LDK 9000 in 1920 X 1080 Mode

The camera system, as presented in this article, was introduced in 1992 to meet the European HDTV standard. At this moment the LDK 9000 camera system is also available in other proposed HDTV standards. Recently the LDK 9000 was introduced at the NAB '94 exhibition in Las Vegas according to the new American 1920 X 1080 production standard. This standard is described in SMPTE document S17.394-721B, "1920 X 1080 Scanning and Interface." A request has been made by the Advanced Television Test Centre for possible use of this CCD camera during the production of HDTV test material in the near future.

When the charge-coupled device (CCD) image sensor was introduced in broadcast cameras around 1986, it appeared to be a real breakthrough in the broadcast industry. Five years later, a CCD sensor was introduced in full-bandwidth, high-quality HDTV broadcast cameras, pushing aside the newly developed HDTV pickup tubes before the real inauguration of HDTV in the broadcast world.

In 1992 the first HDTV CCD camera system to meet the proposed (European) Eureka HDTV standard was presented. This LDK 9000 camera system was designed by BTS in Breda, The Netherlands.

Design Objectives

The main design objectives of this newly developed HDTV camera system were:

- Lightweight camera head
- High-performance broadcast camera
- Use of the internationally agreed 1-in. CCD HDTV lens interface
- Film-style applications

Operational flexibility and ease of use were key targets in the development of this system. Operational flexibility starts with small dimensions, light weight, and low power. These are minimum requirements in responding to different modes of operational practice. Users will be found not only in the broadcast community, but it is expected that the world of cinematography will also be interested in the possibilities offered by a high-resolution, full-bandwidth electronic (HDTV) camera. Therefore valuable film-style features have been included without any compromises to broadcast performance, resulting in the following:

- High performance
- Robust design
- Minimum maintenance
- Operational in accordance with established broadcast practices
- A flexible system
- A wide range of accessories possible
- Meeting the extensive environmental conditions

Several factors explain why the heart of such a camera ought to be a CCD sensor: small dimensions, stability, no aging, uniform registration and resolution, and good highlight-handling capability are the major reasons. Experience with standard broadcast products has shown that with the frame-transfer principle and the use of an optical shutter, absolutely no smear is visible under any conditions, even with short exposure times. In cooperation with Philips Imaging Technology (PIT), a totally new 1-in. frame transfer sensor has been developed that features no less than 2.2 million pixels.

CCD Sensor

This section describes the pixel structure and output stage of the first HDTV imager that fits the European HDTV standard and is based on the frame-transfer principle. The device has an optical format of 1 in. The HDTV image sensor has full HDTV

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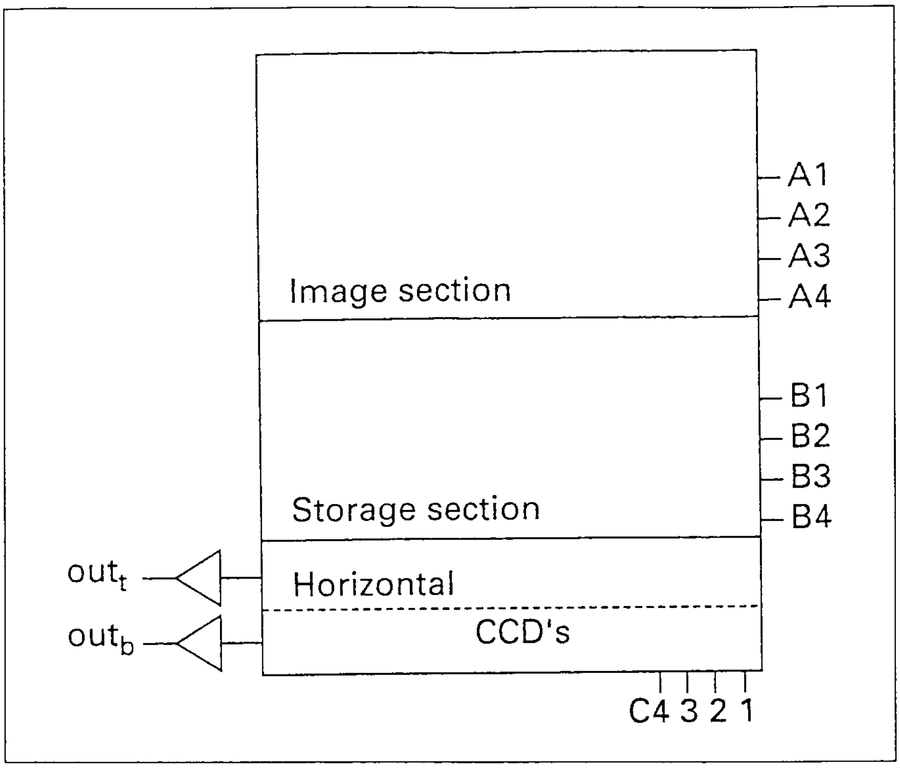

Figure 1. Architecture of the HDTV FT image sensor.

resolution and, as will be shown later, charge resetting can be done very simply. The video performance of the frame-transfer CCD is fully lag-free.

The TV standard the image sensor fits can be summarized as follows: 1250 lines complete a frame of 2 subfields, each subfield has 576 active lines, and each line has 1920 pixels in an active line time of 26.67 µsec. Horizontal and vertical blankings are 5.33 µsec and 0.785 msec, respectively. The repetition rate of the different subfields is 50 Hz and their aspect ratio is 16:9.

The architecture of the imager reported here is shown in Fig. 1. The frame-transfer CCD has a four-phase image area, a four-phase storage area, and a four-phase, dual horizontal output register. The two output stages, out$_b$ and out$_t$, feed the video information to the outside world.

Image Cell Construction

Although a frame-transfer CCD is characterized by a very simple image cell construction, the unit cell has to fulfill several completely different functions. First, the image cell has to convert the incoming photons into a charge packet, which has to be transported (through the same image cells) with a very high transport efficiency. Highlight handling has to take place inside the image cell by means of a proper anti-blooming construction. This construction can also be used to make the charge-reset action effective. The image cell that has the capabilities to fulfill all these functions is illustrated in Fig. 2. A top view of a unit cell is shown in Fig. 2 (left); in Fig. 2 (right), two cross-sections illustrate the effects of the different implants in the silicon bulk.

As depicted in Fig. 2 (left), the image cell is constructed by means of four gates, etched in two different poly-silicon layers. This "4 out of 2" choice makes the unit cell fully flicker-free from one field to the other. Every pixel is defined by a barrier gate made from poly 1, and the integration takes place under the remaining gate from poly 1 and the two gates from poly 2. This setup holds for both fields and eliminates field flicker. The cross-sections show the way the p-well out-diffuses into the n-type substrate. The sinusoidal diffusion profile is created by means of a lateral out-diffusion of two implants on both sides of the cell. The p± regions act as channel stoppers. Note that this channel stopper is extended to the poly-silicon gates by means of a self-aligned implant.

Gate Interconnect

A fast and optimal CCD transport needs CCD gates with a sufficient low RC value. A classical interconnect scheme for the CCD gates of a 2-dimensional imager is shown in Fig. 3a. The vertically running n-CCD channels are covered by means of horizontally running poly-silicon CCD gates, which normally are connected to a four-phase bus-bar system defined around the image area and made from the metallization level. Every gate is two-sided connected. If this interconnect scheme is applied to the 1-in. frame-transfer imager, with the much higher gate capacitance, the maximum frame-shift speed will be limited to about 30 kHz. On the other hand, to fulfill the frame shift within the verti-

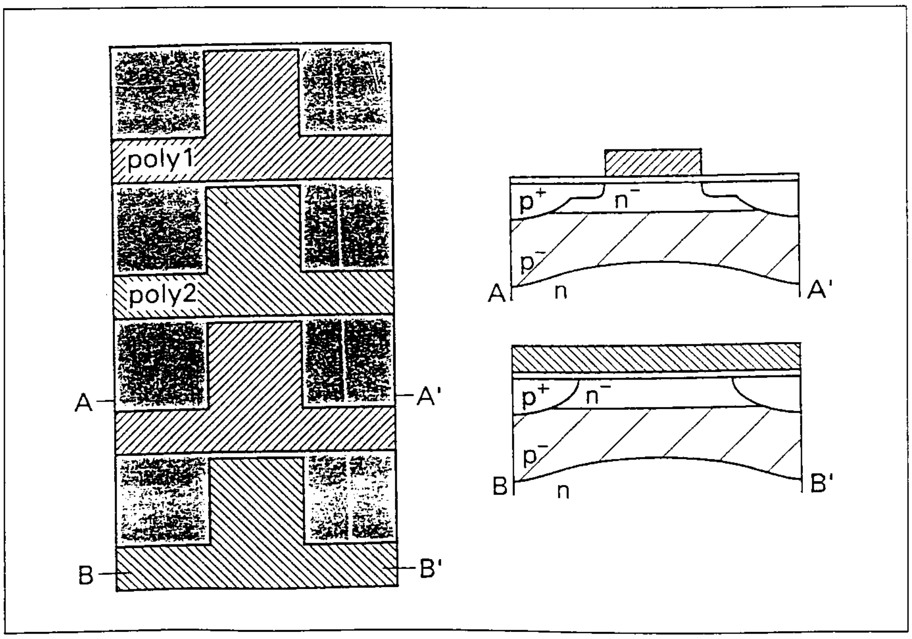

Figure 2. Basic setup of the image cell: (right) top view of the unit cell; (left) cross sections AA' and BB', corresponding to (left).

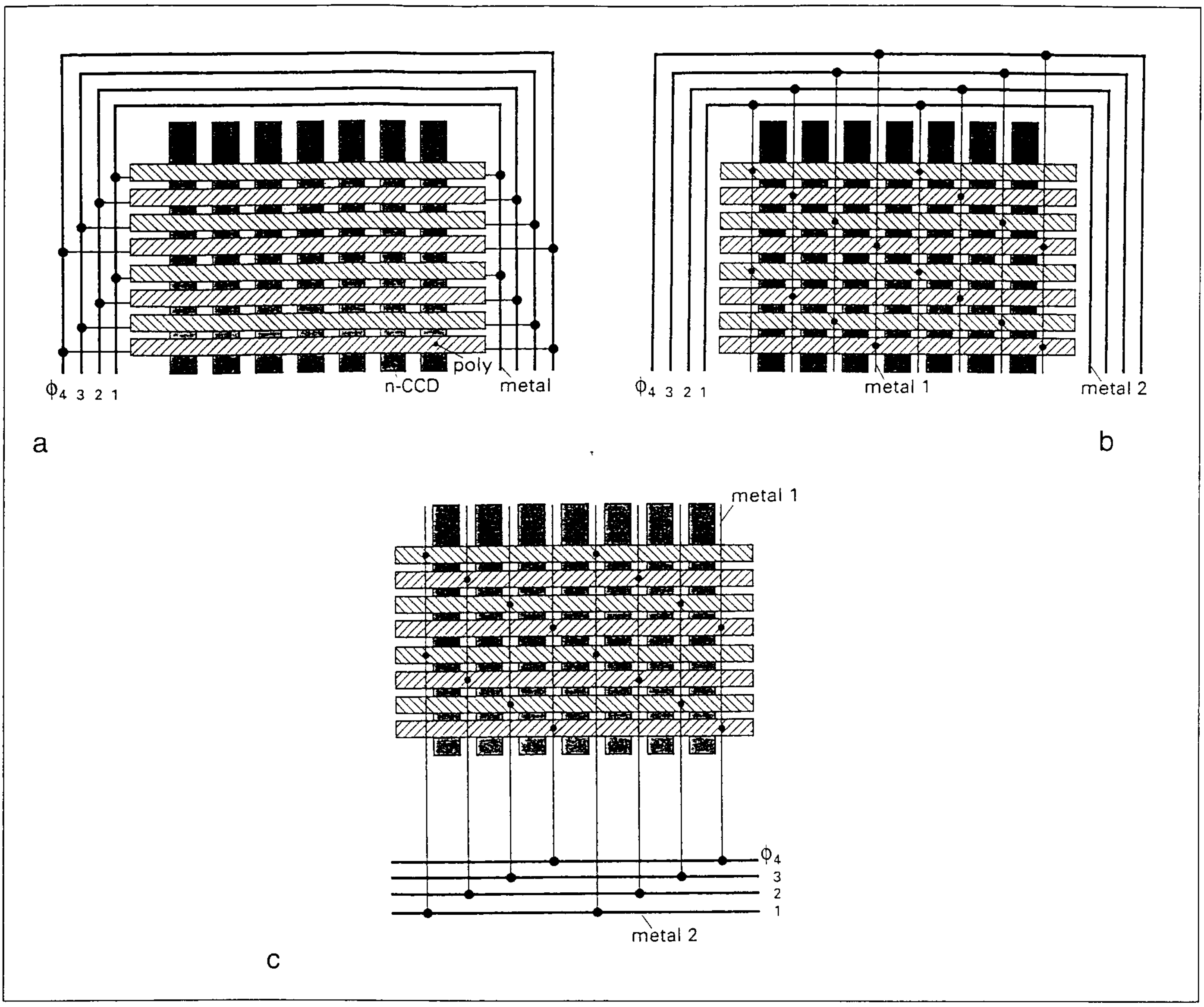

Figure 3. (a) Conventional interconnect scheme for the image section of a 2-D image sensor; (b) lowering the RC-values of the CCD gates by means of an additional metal layer; and (c) interconnect architecture used in the imager.

cal field blanking period, a minimum vertical transport speed of 700 kHz is required.To overcome this problem, the HDTV image sensor has to be built in new technological metallization concept to decrease the RC values of the CCD gates. This new concept is found in a new interconnect scheme, which is depicted in Fig. 3b. In the new concept, an additional (defined as metal 1) interconnect layer is used to bridge the large resistive values of the CCD gates. This metal 1 is defined in very small straps on top of the (light-insensitive) channel stopper implants.

This idea can be explored even further. The metal-1 straps are no longer connected to the bus bars on top of the image section, but are fed into the storage area and are locally connected to the aluminum bus bars. This ultimate construction is shown in Fig. 3c. The net result is an imager with bus bars, very short in length and far away from the image area. In this way, unwanted reflections on the aluminum "mirrors," in the case of Figs. 3a and 3b, can be easily avoided.

Output Register and Output Stage

The requirements put on the output stage are quite severe: high bandwidth, low noise, and high-conversion factor. This is all needed to provide the outside world with video information at 72-MHz pixel rate. To bring this operating frequency to a lower value, the horizontal output register of the imager is designed as a dual horizontal structure. This technique is well known for HDTV imagers, but special attention has to be paid to the layout of the dual register and their "mutual interconnect" to avoid transport inefficiency between the two horizontal registers.

The two horizontal output registers are each provided with a high-sensitivity, low-noise and high-bandwidth output amplifier, built around a triple source-follower stage. Such an output construction is shown in Fig. 4.

Opto-Mechanical Design

The optical system of the new 1-in. CCD HDTV camera is designed to use lenses with a maximum aperture of *f*/1.2. The system consists of: sealglass, IR filter, retardation plate, two 4-position filterwheels (for effect and ND-filters), beamsplitter, optical lowpass filters, and sensors. Some main topics are discussed in this section.

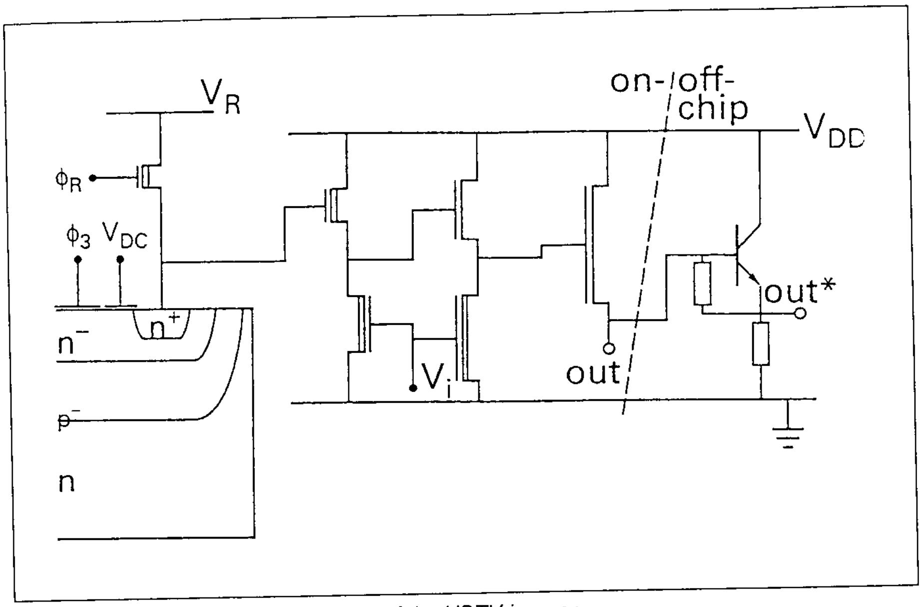

Figure 4. Concept of the output stage of the HDTV imager.

Anti-Reflection Precautions

Special attention has been given to anti-reflection precautions. No bonding wires are located near the image part of the sensor. All nonsensitive parts of the sensor are blackened. Multilayer AR coatings are used on all glass (to air) surfaces. A special treatment has been developed to blacken the metal masks that are inserted in several positions in the optical path. As a result, in the camera even very intensive highlights, in and outside the image, cause no reflections.

Tolerances in Back Focus

All optical components have thickness tolerances and some residual power. The resulting, however small, focus errors, would decrease the MTF seriously, due to the large maximum aperture and the high spatial frequencies. In optical system design 20% decrease of MTF in the most critical conditions is common tolerance practice. For the BTS LDK9000 at full aperture this corresponds to a defocusing tolerance of maximum 10 μ. Because of lens vignetting a defocusing of 13 μ can be accepted in the corners of the image.

Even if the optical and mechanical components are specified tight, the sum of the back-focus errors could be as much as 400 μ. By using all optical and optomechanical components in the sensor alignment process when placing the sensors in the best focus position, these back-focus errors are compensated. The only remaining errors come from differences between filters in each filter wheel and from the cylindrical power of all optical components.

Differences in thermal expansion of large glass-and-quartz plates, cemented together as in optical low-pass filters, can easily give rise to power with cylindrical components. The back-focus change caused by a power is a square function of the distance to the image. Therefore the combination of large aperture, high spatial frequencies, and cylindrical power would cause a serious reduction of the image quality if the optical low-pass filter is placed in front of the beamsplitter. By glueing small optical low-pass filters directly on the sensors, this decrease of image quality has been completely eliminated.

In contrast with a film camera the image planes of R, G, and B of a video camera can have offsets to compensate in first order the longitudinal chromatic aberration of lenses. In the LDK 9000 the sensors are aligned with an offset R-G and B-G, according to the 1-in. CCD HDTV lens interface standard.

Tolerances in Lateral Direction

To avoid shifting of the image center during zoom, the axis error of the camera, including necessary clearance of the lens bayonet, is limited to less than 0.5% of the image diagonal. Registration errors give rise to a decrease of the MTF and colored edges. In Fig. 5 the MTF of the 30-MHz luminance signal is given as a function of the registration errors R-G and B-G. Due to the high frequencies in HDTV, the registration has to be better than 5 nsec, which corresponds to 2.5 μm. Larger errors can be accepted for B-G than for R-G.

Sensor Alignment

To achieve the required accuracies for back focus, offsets in back focus, axis, and registration, a new sensor-alignment machine has been developed. In this machine sensors, held by accurate manipulators, are fixed in the image plane of a so-called master pro-

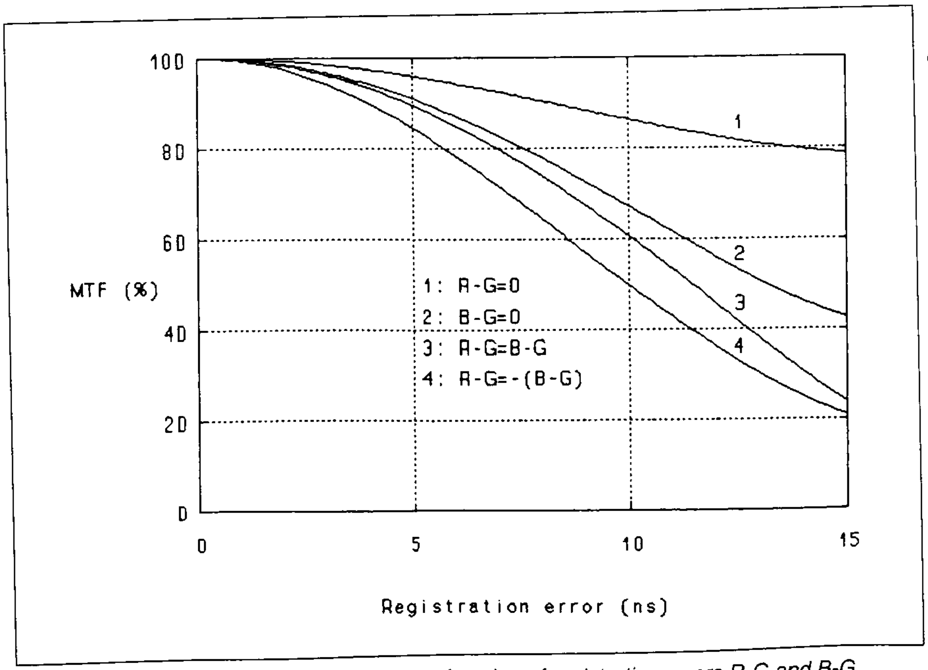

Figure 5. MTF of the luminance signal as a function of registration errors R-G and B-G.

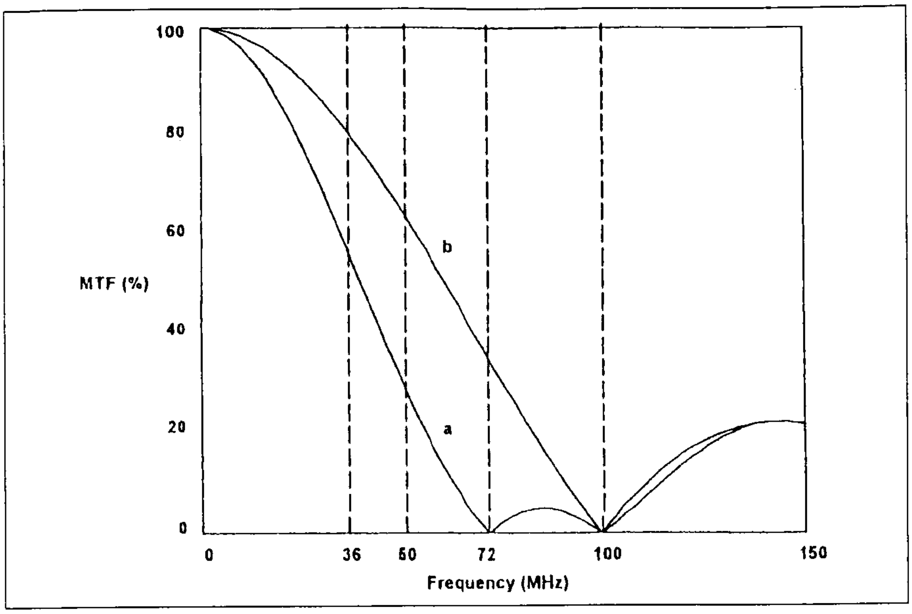

Figure 6. MTF of sampling by 1-in., HDTV sensor: (a) with the optical low-pass filter; (b) without the optical low-pass filter. The lens is not included.

jector. The position of the sensors, with respect to the image from the projector and each other, is judged via the resulting video signal.

Optical Low-Pass Filters

The discrete sampling of the optical image gives rise to moiré patterns for frequencies over 36 MHz. In tests it was shown that, although the amplitude is small, the low-frequency moiré resulting from spatial frequencies near 72 MHz is most visible. Moiré from frequencies near 144 MHz is sufficiently suppressed by the low modulation transfer function (MTF) of the lens. For this FT sensor an optical low-pass filter with a dip at 72 MHz combines an optimal suppression of these moiré patterns with a minimal loss of MTF at 30 MHz (Fig. 6).

Colorimetry

The colorimetry of the LDK 9000 camera is according to the EBU/SMPTE-C specifications.

Lenses

Lens Interface Standard

The lens interface is electrically, mechanically, and optically designed according to the 1-in. CCD HDTV lens interface standard. Because this standard is supported by all lens manufacturers and most camera manufacturers, a full range of lenses is available from the start: lightweight, barrel-type, and box-type zoom lenses with apertures up to *f*/1.5 for TV-style applications; and fast *f*/1.2 fixed focal-length lenses for film-style program origination.

Accessories

The LDK 9000 is designed so that in film-style applications ARRI standard accessories, like bridgeplate, follow focus, support, and matte boxes, are available for use with barrel-type zoom and fixed focal length lenses.

Depth of Field

The depth of field is defined as the distance range in a scene for which the modulation is over 80% of that in the best focus position. Because of the high spatial frequency of the HDTV systems and the absence of large aberration in fixed focal length lenses, the depth of field can be as small as, for example, 6 cm at 25-mm focal length and 2-m object distance. The high sensitivity of the new camera allows stopping down the lens to increase the depth of field for ENG and sports applications. In case of small depth of field it would be difficult for the cameraman to judge the focus from the viewfinder, especially when a 1-in. viewfinder is used. In these cases the focus-assist tools may be used.

Focus-Assist Tools

Even with high-resolution HDTV viewfinders, it is in practice often difficult to find the optimal focus position on a rather small viewfinder. The size of the details in the displayed picture is so small that the eye is not able to discriminate them properly at a normal viewing distance. Part of this problem could be overcome by enlarging the size of the viewfinder screen to approximately 2X the dimensions of traditional broadcast viewfinders, but this would lead to rather bulky and power-unfriendly viewfinders. Peaking in the viewfinder is a usual kind of focusing assistance to improve the visibility of the optimum focus point in traditional broadcast viewfinders but is not always adequate for HDTV.

Another alternative to find the exact focus position is Auto Focus. The authors think Auto Focus might be a help under certain circumstances, but in general the professional cameraperson prefers to decide individually which picture details need to be in focus. Focusing by the operator at an operational control panel is already possible, but may in practice lead to confusion between cameraman and video operator.

Focus-Assist Tools for HDTV

Apart from peaking in the viewfinder, the new HDTV camera system is provided with two extra focus-assist tools. The first of these is the so-called "magnifier." By momentarily activating this function the center part of the viewfinder picture is enlarged, filling the whole viewfinder screen. The magnification is approximately 1.6X, resulting in a viewfinder picture with better visibility of horizontal and vertical details. A drawback is that, due to this overscan, the borders of the HDTV picture are not displayed on the viewfinder. Therefore this assist may only be used for a moment to find the exact focus in the central part of the picture.

The second focus-assist tool is the so-called "crawling information." The small details in the picture are converted to a coarser structure, which for optimal visibility shows up as a crawling pattern at the relevant places of the picture. Optimum focus is obtained at the edges when this crawling serration reaches the maximum intensity. It acts more or less like "peaking" and can be used continuously. The advantage of this assist is that it gives better focus discrimination and makes accurate and quick focusing possible, even with a small viewfinder. Both focus-assist tools are incorporated in the 1-in. as

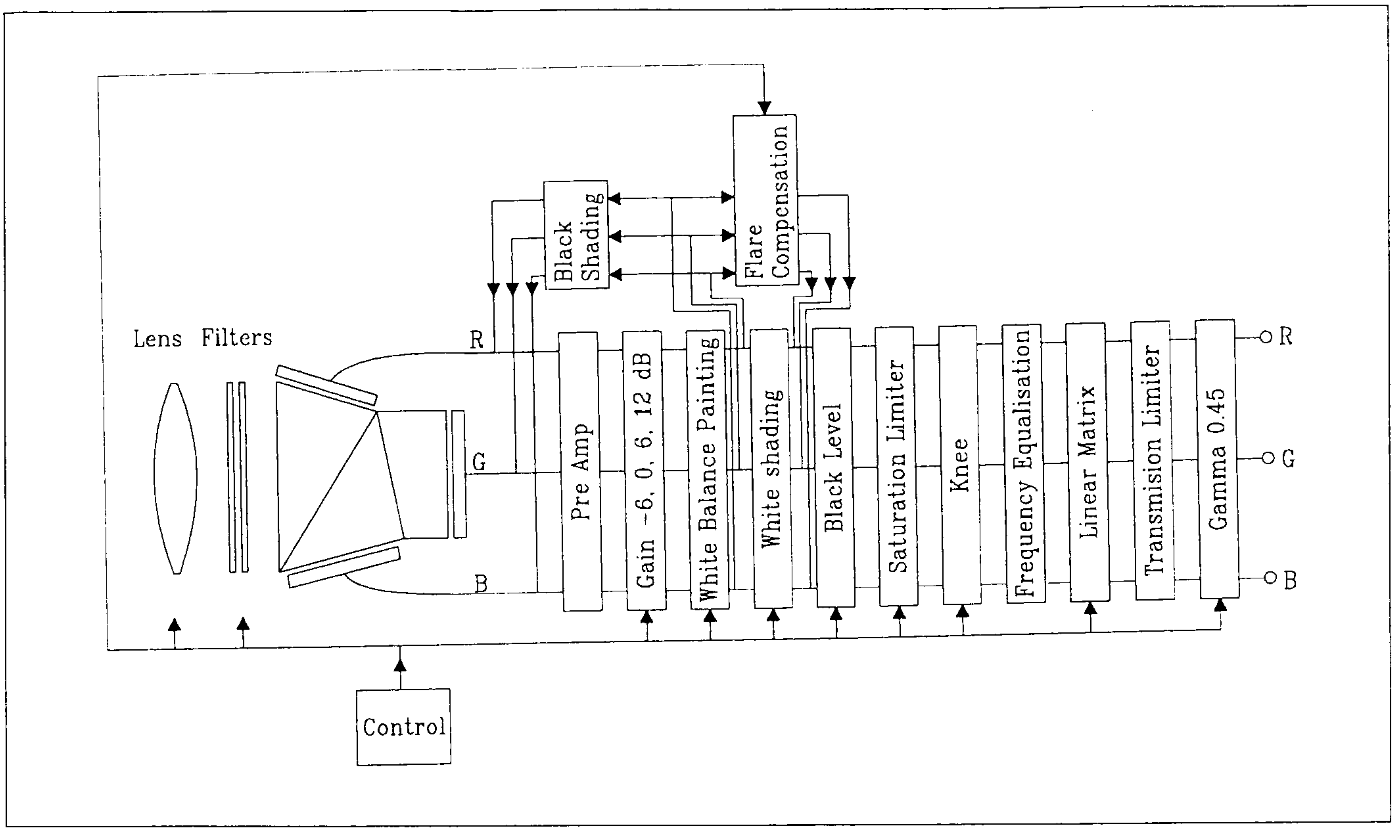

Figure 7. Block diagram of video-processing camera head.

well as in the 7-in. viewfinder and have already proven to be a valuable tool for the cameraman.

Video-Processing System

Important design objectives for the LDK 9000 video-processing system were (Figs. 7 and 8):

- Gain control over full color temperature range
- High dynamic range
- Headroom before highlight compression of more than 14 dB
- Signal-to-noise ratio (SNR) deterioration due to video processing less than 1 dB
- High quality, reliability, and operational flexibility
- Low power consumption (camera head less than 6 W)

Some of the system aspects and video-processing operations concerning these objectives are highlighted.

SNR, Signal Headroom, and Dynamic Range

The combination of SNR, gain control, and signal headroom calls for a very careful design. For the signal multipliers used in painting, white balance, and white shading, a special design has been made, overcoming the classical tradeoff between SNR and control range. Blackstretch and knee give a HDTV CCD camera a dynamic range superior to 35mm film; especially the contrasts in dark scene areas are, even without blackstretch, superior. The blackstretch and knee circuits of the new camera fully exploit the dynamic range of the 1-in. CCD sensor.

Knee

The pivoting knee, used in almost every BTS camera, is also implemented in the LDK 9000. The control system for auto knee is fully digital, offering the additional possibility of a manually operated kind of "momentary knee" action (similar to the common momentary iris function): the value of slope and attack level obtained by the auto knee circuit are frozen.

Contour Processing

In today's cameras the contour processing does not only equalize the MTF losses of the opto-electronic conver-

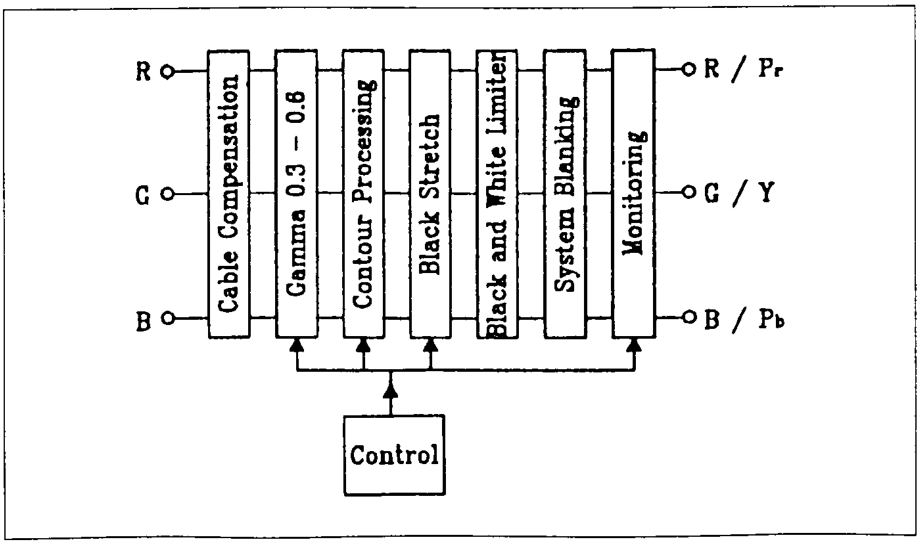

Figure 8. Block diagram of video-processing CPU.

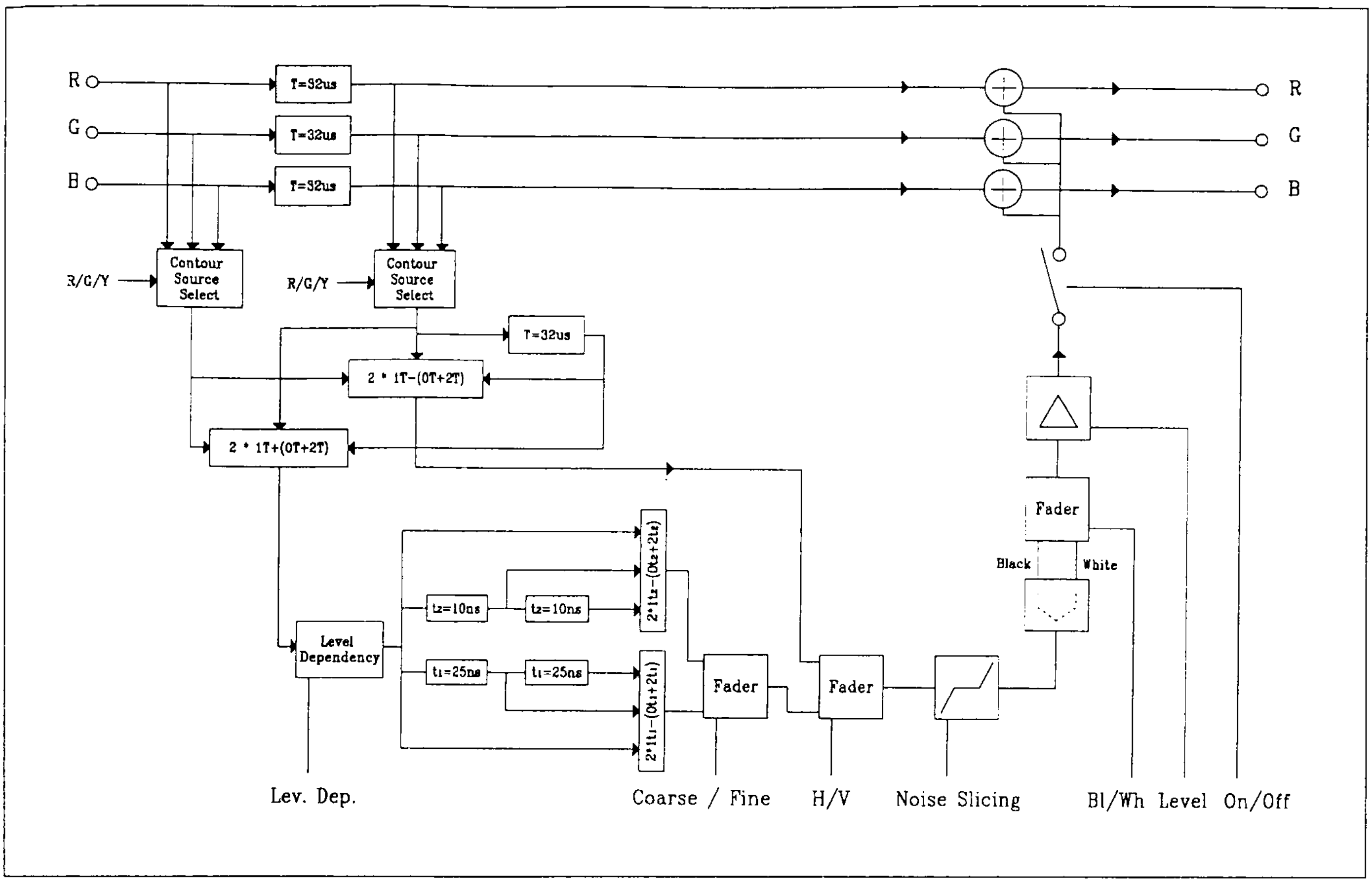

Figure 9. Contour processing.

sion process, but it also functions as a pre-emphasis for losses of MTF in subsequent stages of the video system. Therefore it is common practice to use a much higher contour level setting than is justified by the loss of MTF due to the opto-electronic conversion process alone. Moreover, contour processing has become an instrument for enhancing the subjective sharpness perception (especially in HDTV, where the picture without contour processing is already extremely sharp). So there is a need for sophisticated control of the contour-processing parameters. To fulfill these artistic needs, the operator can adjust the following (Fig. 9):

- The source of the contour signal (R/G/Y)
- The suppression level of horizontal contours near black (LEV DEP)
- The fineness of the horizontal contours (COARSE/FINE)
- The ratio of the horizontal and vertical contours (H/V)
- The ratio of the black and white contours (BL/WH)
- The level of noise slicing of the contour signal (NOISE SLICING)
- The total level of contour to be applied (LEVEL)

Furthermore, the horizontal contour signal has a nonlinear gamma-like transfer characteristic, so that excessive shoots on large transients will be prevented.

All controls can be operated from the master control panel. BL/WH, NOISE SLICING, and LEVEL can be operated from the operational control panel as well. Some controls are made nonlinear, so that in the most frequently used regions of control the greatest accuracy is achieved. All in all, the contour processing in the LDK 9000 camera provides the means to adapt the HDTV picture to a great variety of scenes.

Blackstretch

In certain types of high-contrast scenes, e.g., scenes with direct sunlight and shaded areas, the darker parts of the scenes are lacking in contrast. This contrast can be enhanced by increasing the amplification of the signal near black while keeping the lighter areas unchanged. This contrast enhancement can, of course, be accomplished by increasing the initial gain of the gamma correction, but all standard gamma curves (ARD, SMPTE 240M, CCIR, and BBC) have a limited gain near black because of the visibility of noise and other artifacts.

A better approach is applying the contrast enhancement in the luminance signal only, and this is realized by means of blackstretch. In the conventional way (processing the luminance signal only), blackstretch has no effect on the RGB outputs of the camera system. In the LDK 9000 a different principle is used. From RGB a luminance signal is derived. This signal is processed to obtain a blackstretch signal that is added to R, G, and B. In this case blackstretch effects the RGB outputs of the camera system as well as the luminance output.

It is essential that the blackstretch function increase the amplification of a signal near black while keeping the lighter areas unchanged. Moreover, the overall system transfer characteristic must remain a smooth curve when applying blackstretch; discontinuities in the slope of the curve are highly visible. The transfer characteristic of the LDK 9000 with the application of blackstretch has such a smooth curve. Figures 10 and 11 show clearly that there is only an amplification change

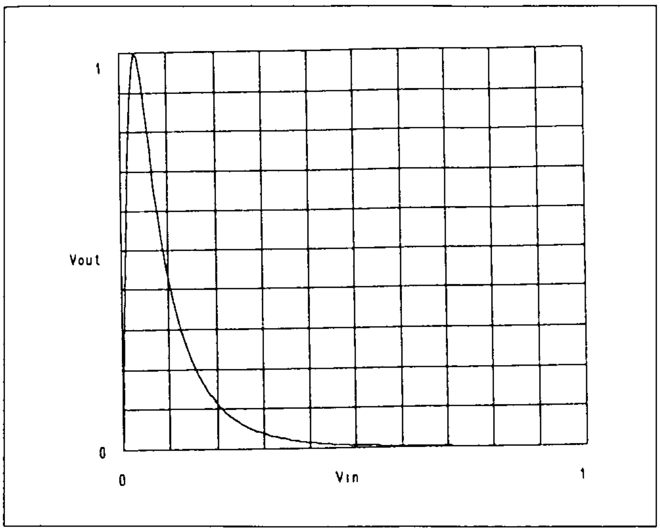

Figure 10. Transfer characteristic of blackstretch.

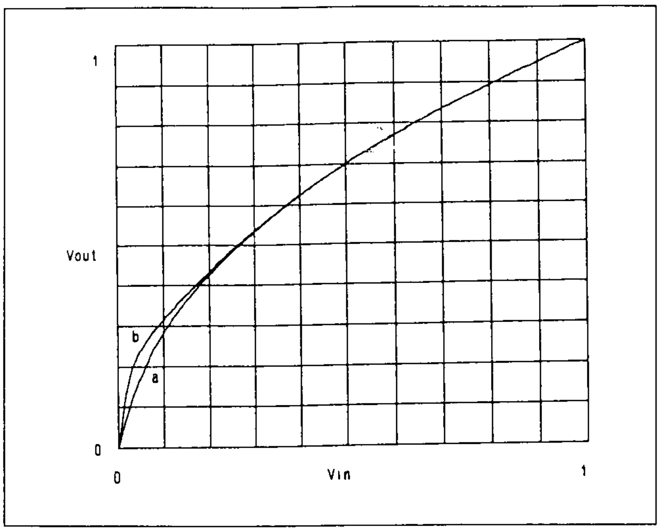

Figure 11. ARD-gamma and ARD-gamma plus blackstretch.

near black. The design of the blackstretch circuit is flexible; the shape of the curve can easily be changed according to user needs. The level of amplification can be controlled from the master control panel as well as from the operational control panel.

Signal Transmission

In an HDTV camera system the bandwidth of the video channels is expanded from 7 to 30 MHz. Therefore the carrier frequencies in a multiplex system have to be at least 45 times as high as in a traditional system. This results in an unacceptable signal attenuation at the standard length of 2 km. Therefore the application of 2-km triax cable for the transmission of full-bandwidth component video is out of the scope for HDTV. To bridge the distance between camera and CPU, a system has been designed that operates at medium cable lengths with multicore cable; at longer cable lengths the multicore cable system can be expanded by a fiber-optic system.

Using four coaxes for the baseband R, G, B, and viewfinder video signals and multiplexing all remaining signals in both directions creates the possibility of a multicore with only five coaxial cables and power cores. By using only coaxes with signals in one direction, six coaxes are necessary (Fig. 12).

In this way a simple interface with an optical fiber system can be created. The construction of the custom-made multicore cabele has circular symmetry. With the applied high-quality coax this results in small delay differences: maximum 1.5 nsec between R, G, and B video signals at 300-m cable length. Above the so-called corner frequency, typically 200 kHz, the coaxial cable's behavior is well defined: the characteristic impedance is 75 Ω. This behavior is gradually diminishing below the corner frequency.

Small imperfections of the cable loss compensation in this frequency range could cause streaking, which would be predominantly visible in the dark scene areas. This problem is solved by placing the contrast-law compensation (the gamma correction) in the camera head, before the cable transmission. This keeps the residual errors invisible.

The coax cores in the multicore cable have a loss of 8 dB/100 m at 30 MHz. A cable length up to 300 m can properly be compensated. One of the goals of the multicore system was to automatically compensate for each length between 0 and 300 m. This is realized by dividing the total compensation into a fixed part and an adaptive part.

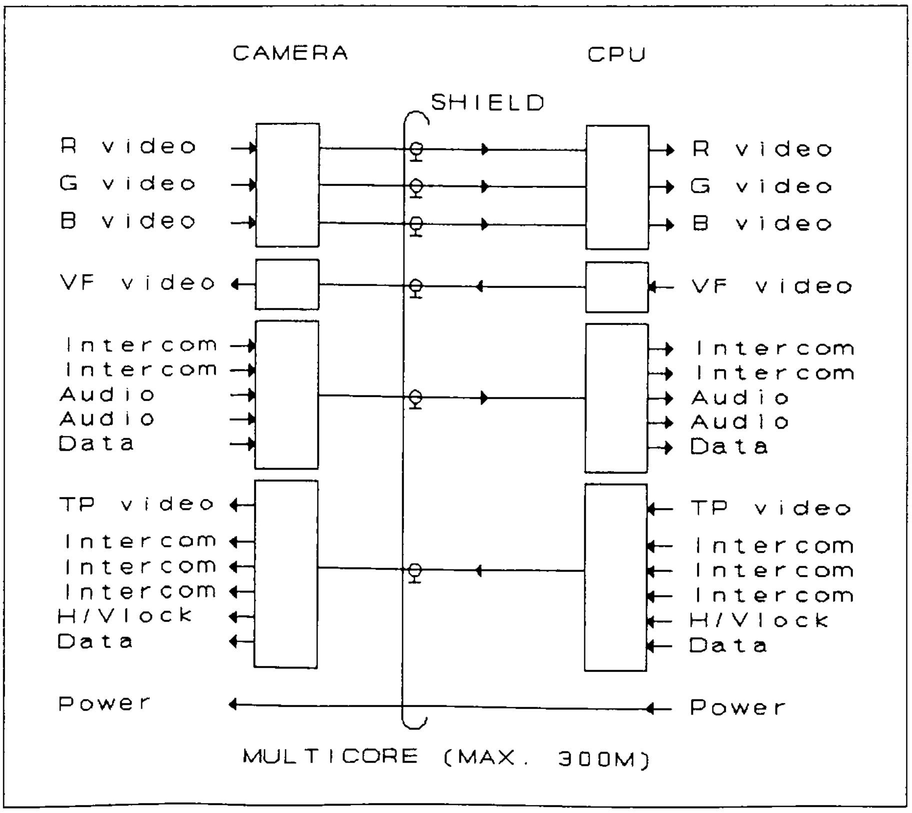

Figure 12. Multicore transmission system camera and CPU.

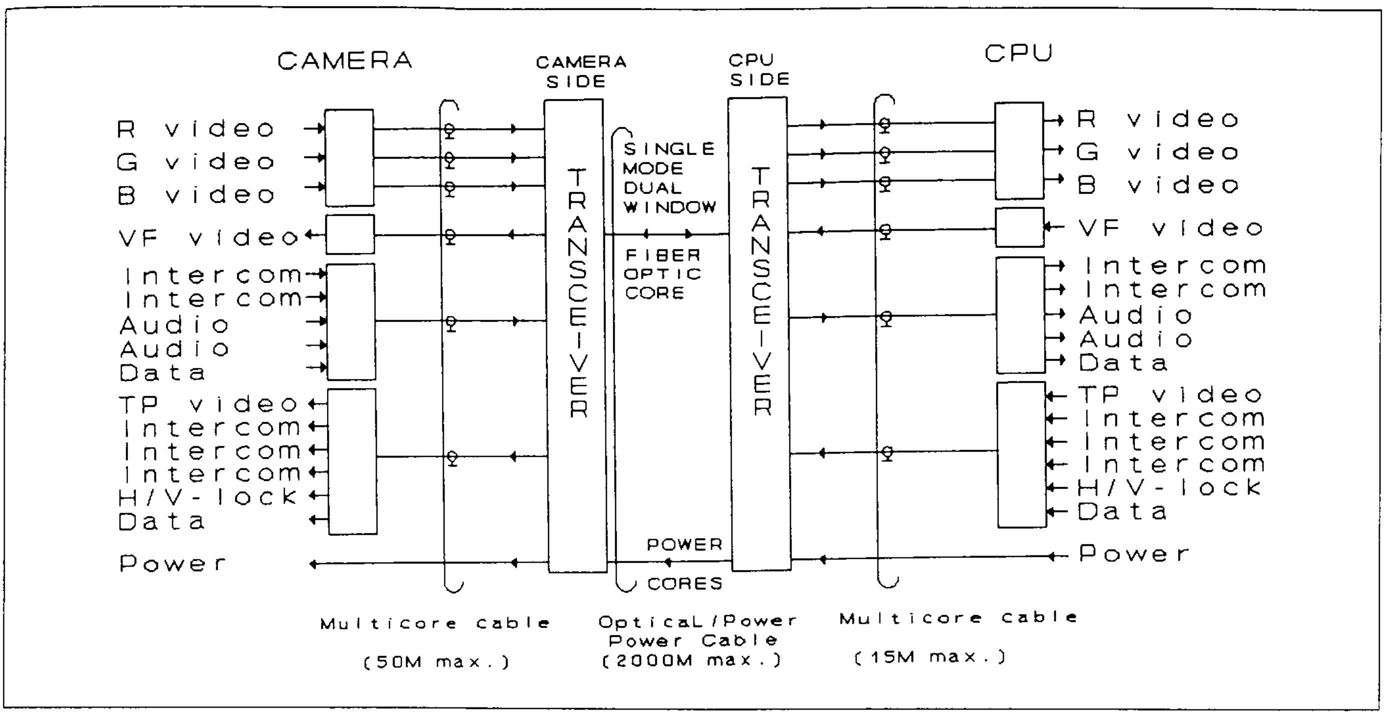

Figure 13. Multicore plus fiber transmission system.

The fixed part can compensate any cable length between 0 and 300 m with a resolution of 12.5 m. This length is determinated at power-up by means of a successive approximation measurement.

The adaptive part, which is independent in each channel and continuously active, has two functions:

• It has to compensate the last few meters of multicore that are within the resolution of the fixed part.

• It has to compensate (the frequency-dependent) loss differences as caused by temperature changes, for example, of the multicore cable and differences between the individual coaxes.

For longer distances the already mentioned fiber-optic link is available. From camera to CPU there are four inputs for R, G, B video and the intercom and data signals. From CPU to camera there are two video inputs for the viewfinder and the multiplexed teleprompter, intercom, HV-lock and data signals. An additional two audio inputs are available on the camera fiber interface unit.

Because optical fiber contacts are much more vulnerable compared to electrical contacts, minimization of the amount of optical contacts in each connector attributes highly to the reliability of a fiber-optic system. Contact exchange on the site is another desirable feature for a fiber-optic connector.

The preferable connector will have only one optical contact analogous to the triax connector. Just as in the triax systems, this can be achieved by frequency multiplexing. Here both electrical and optical multiplexing are possible.

In the transmitters on each side the video signals are frequency modulated on different carriers each and multiplexed together with the already FM-modulated other signals within an electrical spectrum of maximum 1.3 GHz. These broadband multiplexed signals are converted with laser diodes into lightwave signals. Bidirectionality over one single-mode dual window fiber is achieved by optical wavelength division multiplexing at a wavelength of approximately 1300 nm in one direction and 1550 nm in the other direction.

In the receiver sections the desired

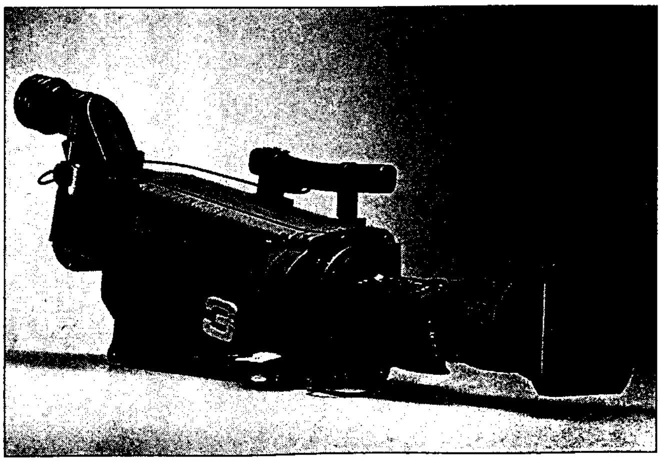

Figure 14. LDK 9000 camera head.

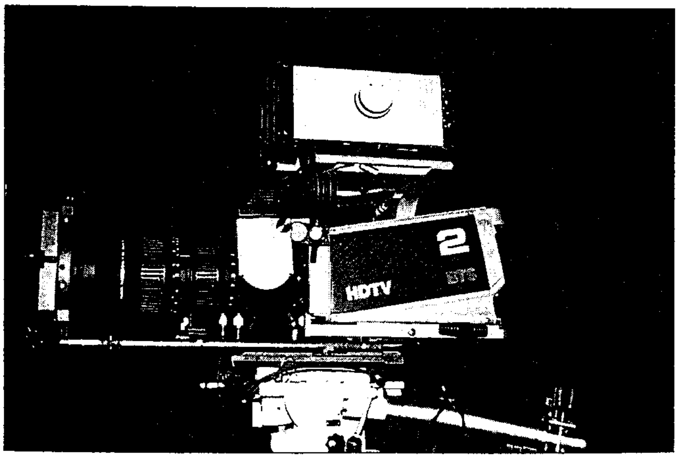

Figure 15. The new camera on 7-in. VF support.

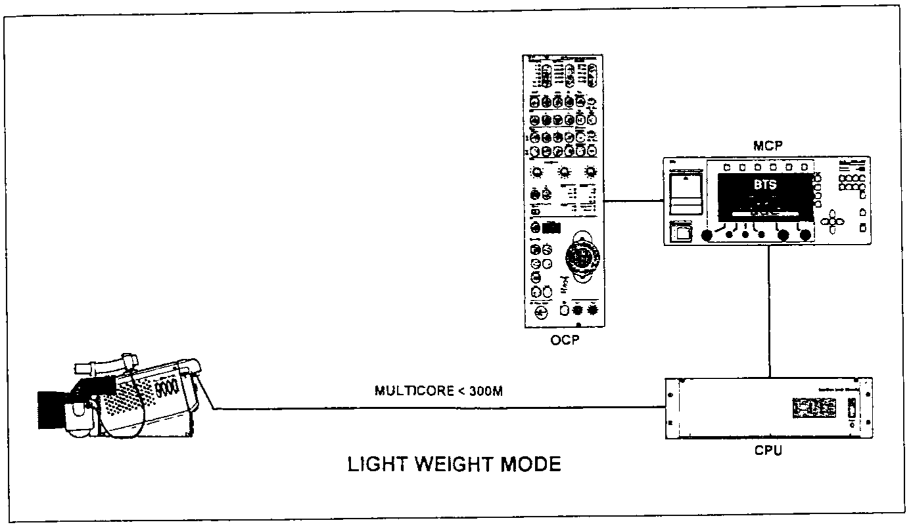

Figure 16. Block diagram of lightweight mode.

optical wavelength is filtered and reconverted into the electrical form with a PIN photodiode. Both electrical broadband signals are demultiplexed and demodulated. The fiber-optic system is virtually transparent for the multicore signal format (Fig. 13).

The single-mode dual window fiber-optic cable has a tremendous low loss compared to copper cables. For light with a wavelength of 1300 nm, which means a frequency over 200 THz (=2•1014 Hz), the attenuation is 0.4 dB/km. At the slightly lower frequency, with a wavelength of 1550 nm, the attenuation is only 0.2 dB/km. The camera cable in use has, besides the single-mode fiber, power cores and a safety shield.

For distances up to 2 km, the electrical power for the camera head can be supplied via the power cores of the specially designed fiber-optic/power cable. In this case the distance will be covered by 4X 500 m cable with five interconnections, meaning an optical attenuation of approximately 7 dB (5 X 1.2 dB in the connectors and less than 1 dB in the optical fiber).

System Concept

The LDK 9000 system is completely new, and all system components have been designed for optimal use with the HDTV CCD camera.

System Component Parts

The major system component parts are listed below:

- Camera head
- Camera processing unit (CPU)
- 1.5-in. and 7-in. viewfinders
- Multicore cable
- Fiber-optic cable, together with fiber-optic interface units
- Control panels
- Large lens adapter (LLA)
- Lenses
- Accessories

The camera head has been designed as a compact, lightweight, modular unit (Fig. 14). The dimensions of the camera head are: length 339 mm, height 218 mm, and width 143 (183) mm. The weight of the camera is approximately 7 kg (including. 1.5-in. VF). The camera contains two four-position filter wheels with 3X ND filters and 2X special-effect filters.

The CPU is a 19-in. rack-mount unit that is 3 units high. It contains standard Eurocard PC-boards and a connector panel with all the interconnection possibilities commonly used in standard broadcast studios.

Two VF types are provided, a 1.5-in. VF and a 7-in. VF. The 1.5-in. VF can be located at various positions on the camera, and the 7-in. VF can be mounted on the optional 7-in. VF support (Fig. 15).

Transmission of signals between camera and CPU can be done with multicore cable or with fiber-optic cable. The maximum multicore cable length is 300 m, with available lengths of 10, 30, 50, 100, and 150 m. The maximum fiber-optic cable length, including camera power, is 2000 m. Fiber-optic cable (with power) is available in lengths of 100, 200, and 500 m.

The control panels follow the Series 9000 control philosophy used with BTS standard TV cameras. The master control panel (MCP) is exactly the same with adapted software and is fully compatible; it also gives access to most of the set-up controls via menus.

The operational control panel (OCP) has a minimally adapted control panel to meet the operational control functions of the HDTV camera. The panel is arranged with user-friendly, directly accessible controls for easy operational control. For those users who have a different operational control philosophy the separate mono control and color control panels are available which fit into the same data

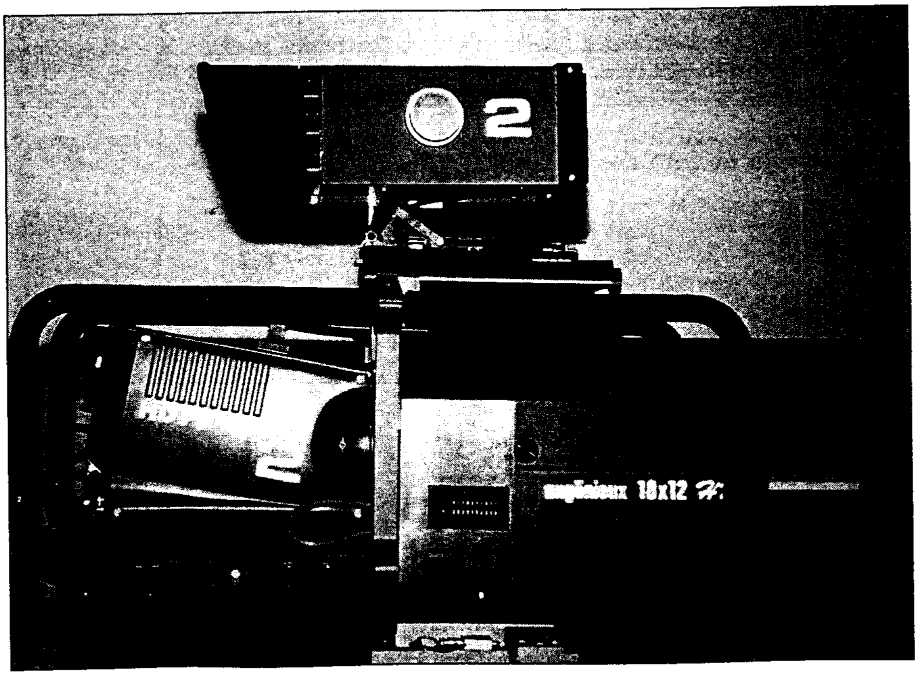

Figure 17. Large lens adapter for camera.

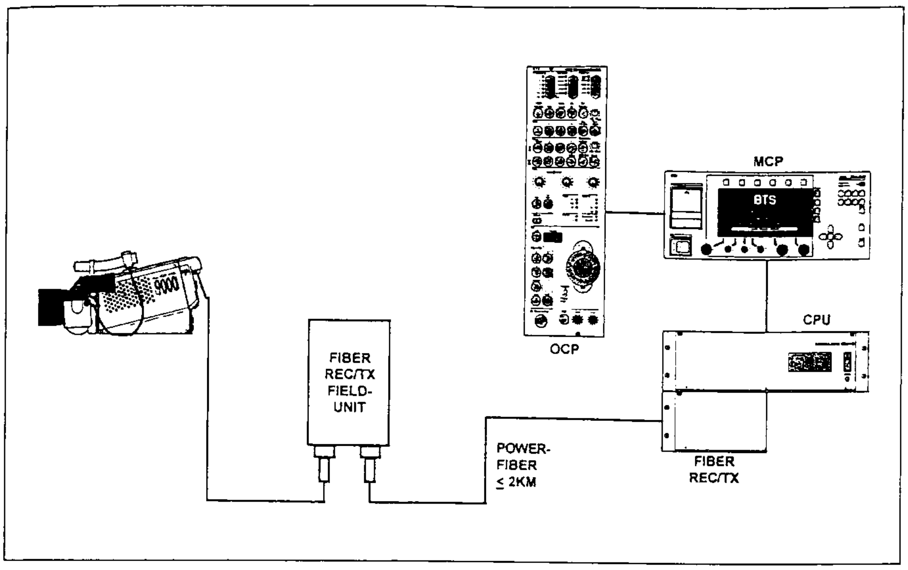

Figure 18. Block diagram of fiber mode.

bus via the remote control interface (RCI).

A wide range of lenses with the internationally agreed standarized interface is available:

- Lightweight barrel-type zoom lenses with iris up to *F*/1.
- *F*/1.2 fixed focal length lenses for film-style program origination
- Box-type lenses with iris up to F/1.5

Among the accessories can be found the 7-in.VF support. For film-style operation matte boxes, filter units, lens supports, focus follow, etc. from ARRI will fit the system.

Different Modes of Operation

The LDK 9000 is a very versatile performer. The lightweight head design and compactness enables use of the camera on lightweight tripods, from the shoulder, from the hip and on Steadicam®. In this lightweight mode the camera head, 1.5-in. VF and a portable 6 X12 zoom lens may be used. The camera is connected with maximum 300 m multicore to the CPU (Fig. 16).

The application of the camera system is not limited to lightweight portable use only but can easily be extended. A 7-in. VF support is designed to accept the lightweight camera combination. The camera, with 1.5-in. VF, can easily be placed upon or taken out of this support, leaving the support and 7-in. VF on tripod.

Heavier barrel-type zoom lenses will be supported by standard film-style accessories: a bridgeplate underneath the camera accepts support rods, lens supports, matte boxes, etc.

A large lens adapter forms the link between camera, box-type lenses, and 7-in.VF. Utility outlet, teleprompter signals, extra audio facilities, etc., transform the lightweight camera system into a full-size outside broadcast (OB) or studio camera (Fig. 17).

The fiber-optic transmission interface completes the system to bridge long distances between camera head and CPU (Fig. 18).

The main camera characteristics and specifications are summarized next.

Camera Characteristics

- An electronic white balance range from 2500K to 15000K.
- Highlight compression (14 dB) in automatic and manual mode.
- Black stretch in Y and R,G,B.
- Colorimetry according to Eureka/EBU standard.
- Two-dimensional contours.
- Electronic shutter with 5 and 2-msec exposure time. Also 50-Hz and 60-Hz lighting positions are available.
- Camera power consumption of approximately 22 W.

Camera Specifications

- Modulation transfer function of over 40% at 800 TVL (27 MHz) without contours.
- Limiting horizontal resolution of 1000 TVL.
- Sensitivity of 1000 lux at F/4.
- SNR of 50 dB at a bandwidth of 30 MHz.
- Weight of camera in the so-called lightweight mode, consisting of camera, 1.5-in. VF and 6 X 12 zoom lens, is less than 10 kg.
- The maximum lens aperture is *F*/1.2.
- Dimensions are approximately 140 X 210 X 350 mm.

Conclusion

Since February 1992, the LDK 9000 camera system has been used at several events:

- During the Olympic Winter Games in Albertville (France), a first trial was held, using four of these cameras together with several fiber interface systems.
- Official press introduction in the beginning of April 1992 in Aintree, England, during the Grand National (horse race).
- Introduction at IBC in Amsterdam in July 1992.
- At the Olympic Summer Games in Barcelona (Spain) eight LDK 9000 cameras were used by Vision 1250, at several events, during the official HDTV introduction in Europe. Also the large lens adapter was used together with Angénieux 18 X 12 box-type lens.
- For an extensive period of time several cameras were used during the world exhibition in Seville, Spain.
- Several other HDTV productions, captured by the LDK 9000, have been made recently in different countries.

Despite the fact that most of the cameras used so far were technically speaking, prototypes, their performance and ease of operation have received high praise from directors, vision engineers, and cameramen. The authors believe this new camera system, which is a revolutionary step forward in broadcast camera technology, meets all of their design goals and more than broadcasters' expectations.

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