A HIGH SPEED SPORTS ACTION CAMERA SYSTEM

A. Moelands, P. Centen, R. Voet

Philips Digital Video Systems Breda, The Netherlands

ABSTRACT

This paper describes the development and realisation of a high-speed camera system.

This high-speed broadcast camera system operates at a three times faster scan rate w.r.t. present Broadcast cameras and is intended to be used with a Slow Motion disk recorder to produce artefact free slow motion images with improved temporal resolution at e.g. fast moving sports events.

In this paper following topics will be discussed : CCD Sensor, analog signal processing, triax transmission and the digital signal conversion. Also the auto lighting option is explained. Finally the system configuration is summarised together with the system specifications.

Thirty camera systems are being used during the World Championship Football Games in France this summer. The camera system will also be demonstrated at the 1998 IBC Exhibition in Amsterdam.

INTRODUCTION

In to-days broadcast programs repeating of video image sequences at lower speed is common practise. This technique is frequently used at sports events e.g. the finishing at cycling, scores at soccer games, tennis etc.

Acquisition is mainly done at the normal camera speed (50 or 60 fields /sec.). This will however give an unacceptable motion blur at fast moving and relatively small objects in the picture (fig. 1a). Application of the electronic shutter option with decreased exposure time will solve the motion blur problem, however a considerable part of the moving object will disappear and the result will be a so-called shuttered picture (fig. 1b).

To overcome all these problems acquisition at a three times higher field rate will generate the necessary amount of pictures to guarantee a slow motion replay with an improved temporal resolution and without the mentioned artefacts (fig. 1c).

SYSTEM DESIGN

The high-speed camera system is based on the state of the art Philips LDK10P Broadcast Camera System and LDK 4053 Base Station.

The FT17 Frame Transfer CCD sensor is operated at a three times higher field rate and for this reason also three times higher line- and pixel-frequency. Switching from 4:3 to 16:9 aspect ratio, with full horizontal viewing angle in both formats, is standard for all Philips broadcast cameras.

The analog video processing in the camera head has been partly upgraded w.r.t. bandwidth and partly replaced by a dedicated digital signal processing in the Camera Processing Unit (CPU).

The triax transmission system uses standard triax cables and is updated for transmission of wide band component video signals between camera and CPU.

The camera system meets following standards :

* 625/150/2:1 for the European PAL market.
* 525/179.82/2:1 for the USA NTSC market.

The CPU delivers three SDI CCIR 656 signals in parallel for interfacing to an external slow motion system. Also one combined SDI output, with adjustable weighting of the three original high-speed fields, will be available. This feature allows dual operation with standard and high-speed outputs from one camera system.

To avoid fast flicker artefacts at artificial lighting conditions an auto lighting option has been implemented.

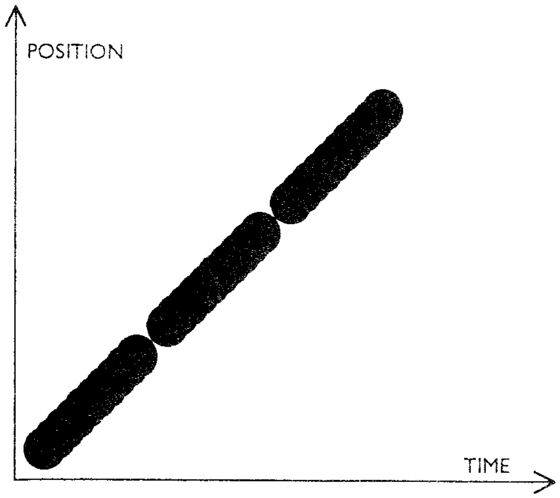

Figure 1a : Aquisition at normal speed.

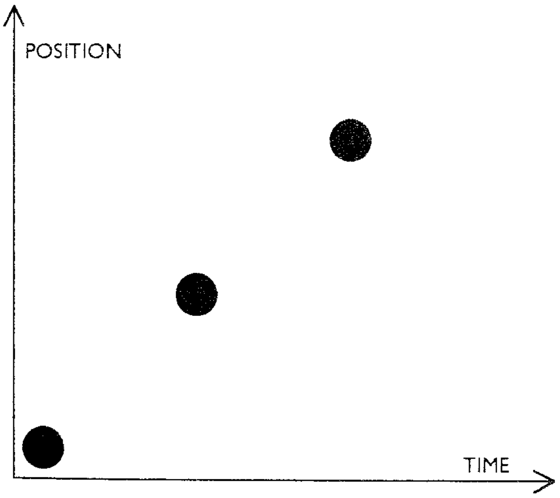

Figure 1b : Aquisition at normal speed with 30% exposure time.

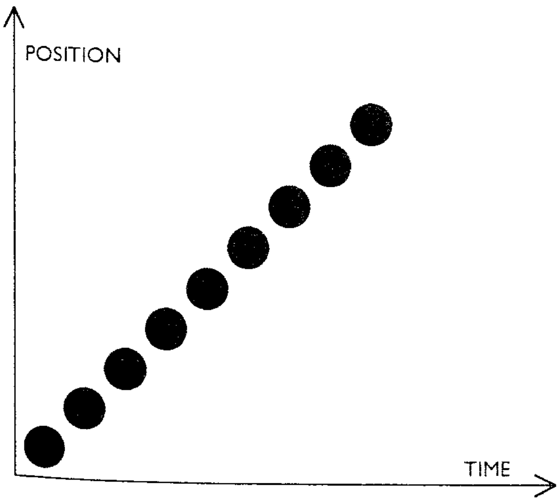

Figure 1 c : Aquisition at triple speed.

All system interfaces and interconnections are identical to a standard broadcast camera system. Apart from the serial digital high speed and standard outputs also analog CVBS, RGB and YPrPb component outputs are available.

The standard Philips Series 9000 Control System can be used.

THE CCD IMAGE SENSOR

Aspect ratio switching from 4:3 to 16:9, with full horizontal viewing angle and resolution in both modes, has been maintained in this high-speed camera using the FT CCD imager.

Second generation aspect ratio switching

The high-speed camera utilises the DPM-Imager [1,2] which is a second generation aspect ratio switching imager. This means true 4:3 and true 16:9 image formats. Due to the unique DPM feature the number of pixels in 4:3 and in 16:9 is the same. The horizontal angle of view is the same. The uniqueness of the Frame Transfer technology with DPM [3] lays in the flexible definition of an image cell. Instead of using 'hardware' photo-diodes as used in IL or FIT the image cell in an DPM-imager is 'software' defined through the voltages applied to the gates. So changing the software changes the image cell dimensions, hence the Dynamic Pixel Management DPM is exploited in full in the Philips series of cameras.

With Dynamic Pixel Management 575-lines are generated in 4:3 aspect ratio. In the 16:9 mode the imager is driven in such a fashion that 767 lines are generated in 4:3 aspect ratio. Of the latter, 575 lines are within 16:9 aspect ratio. It is the Frame Transfer technology that enables this flexible use of an imager. It offers the same high horizontal pixel count in 4:3 as in 16:9.

A second aspect of the DPM-principle is the physical filter which is embedded in the imaging area of the FT-DPM-imager itself. This is possible since with DPM there is a spatial (vertical) over sampling by a factor of 4 in 4:3. The software adjusted FIR-filter coefficients are determined such that low aliasing [1] is obtained.

True high speed

Originally the DPM-imager was developed for the use in a SDTV camera where the clock frequency is 18MHz. Due to steadily improvements on imager and cameras it was possible to drive the imager and the patented Integrating Clamp and Sample pre-processor at the required clock frequency of 54MHz. The fast vertical transfer of the charge-image from image-area to storage-area is at 3.375MHz.

SIGNAL PROCESSING AND TRANSMISSION

In this area most attention has been given to the bandwidth of the video signals. Three times the amount of fields at the remaining horizontal pixel count will increase the necessary RGB bandwidth with a factor of three to approx. 15 ... 18 Mhz.

Video processing

The video processing is divided in an analog part in the camera head with low power consumption, and a digital part in the CPU (figure 2).

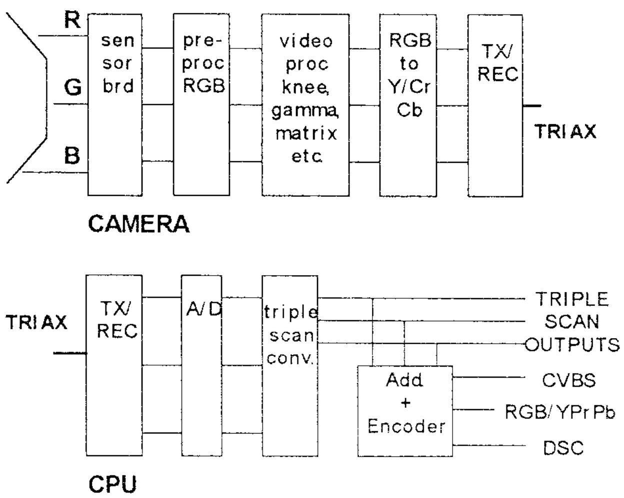

Figure 2 : Video processing block diagram.

The analog functions include: gain switch/multiplier, automatic/manual knee, flare correction, black level control, black- and white-shading, matrix, gamma correction and the auto lighting circuitry.

In the CPU a newly designed digital processing provides the (3x) time expanding by means of field stores. Additional digital processing uses three Asics in parallel as applied in Philips standard broadcast cameras to generate contours, apply leaking pixel correction, if necessary, and provide the VF return signals.

Triax transmission

The transmission between camera and CPU is allmost identical to the present Philips LDK 10P Camera System with respect to power, fm channels (audio, intercom, data, hv lock) and the VF video return channel.

All signals between camera and CPU are multiplexed (apart from the power supply) and transported by a special coaxial cable, provided with an extra screening, a triax cable. This triax cable is a worldwide standard for camera signal transmission.

In the original LDK 10P camera system RGB signals were transmitted from camera to CPU where the Green signal carrier was at 28 MHz and Red and Blue were modulated in quadrature on a 45 MHz carrier.

In the High Speed Camera System video transmission from camera to CPU is done by means of component signals Y, Pr, Pb, mainly because of bandwidth reduction and minimising the visibility of crosstalk artefacts at quadrature modulation. Due to the increased bandwidth (Y = 18 MHz, Pr,Pb = 9 MHz) the carrier frequency for luminance is shifted to 112 MHz. Pr/Pb are on the original 45 MHz carrier modulated in quadrature.

Channel	Carrier freq.	Bandwidth
Viewfinder	11 MHz	5 MHz
Pr/Pb	45 MHz	9 MHz
Y	112 MHz	18 MHz

The maximum triax cable length for full specification of video signals is 600 meters. With a minor decrease of noise performance 1000 meters of triax cable is applicable.

Allthough not implemented a teleprompter channel is still feasible but will be hardly used in this high speed camera application.

DIGITAL SIGNAL CONVERSION

The main tasks of the digital signal processing in the CPU are:

1) Convert a video signal recorded at three times normal speed, into three signals at normal speed called phase1, phase2 and phase3. Each of these signals is converted according to the CCIR656 serial digital interface standard.

2) Perform a number of video processing functions like leaking pixel correction, black stretch/press, contour processing and colour bar generation.

3) Generate a combined output signal that can be either one or a combination of the three signals mentioned above. The mix is optimised for SNR on one hand and vertical resolution on the other hand. This signal is converted according to the CCIR656 serial digital interface standard, as well as converted to the appropriate analog standard (PAL or NTSC). This encoder can be genlocked to the outside world and will deliver CVBS, Y+sync, Pr, Pb, R, G and B.

4) Generate an analogue viewfinder signal with separately adjustable contours, monitoring selector, zebra etc. The signal will be one of the phases mentioned above, *not* the combined signal.

YUV to RGB conversion

The CPU digital video processing receives its component input signals from the triax transmission system. Existing asics developed for digital signal processing require RGB input signals. For power saving reasons, YPrPb to RGB conversion is done in the analogue domain, using a standard high-precision resistor network.

AD conversion

Memory based digital signal processing and therefore AD conversion is needed to convert the triple scan signals to three normal scan outputs. Conversion is done at the CCD pixel rate (54MHz) to maintain optimum MTF and lowest aliasing. Since highlight compression and gamma correction are already done, 10 bits AD conversion is sufficient. At the time of development, Burr Brown introduced their newest state of the art 10 bit AD converter, which delivers over 9 effective bits for frequencies up to 15MHz, at a power usage of less than 300mW. The ability to operate with single ended inputs made the design simple and straightforward. A partly digital, partly analog clamp circuit takes care of offset differences between AD converters. The blanking level is clamped to digital level 64. The 100% video amplitude (white-black) is 876 (CCIR601).

Min	Black	White	Max
0	64	940	1023

Memory based functions

To convert this triple scan signal into three signals according to normal scan standards, it has to be split up field by field (not line by line or pixel by pixel). So after a frame pulse which is genlocked to an externally applied blackburst or sync, every first (odd) and fourth (even) field is directed to the phase1 output, every second (even) and fifth (odd) field to the phase 2 output, and every third (odd) and sixth (even) field to the phase3 output (see figure 3).

The signals created in this way are still sampled at 54 MHz. One third of the time there is video information, two-thirds there is not. Therefore, after separating the input signal into three signals, the signals have to be stretched out field by field. This means that exactly one field has to be stored at 54MHz (during 1/3 of the time) and read out at 18MHz (permanently). By the time the last pixel of e.g. field 1 is read out at the end of the memory the first pixel of field 4 will be written at the beginning of the memory.

There are now three video signals at normal scan rates. The first pixels of these signals lay one-third field period apart. To be able to combine these signals into one, phase1 is delayed 2/3 field period and phase2 1/3 field period.

There are two ways of adding synchronisation to these signals. The first one is straightforward implementing the CCIR656 standard. This means that the sync of phase2 is delayed 312 lines with respect to the frame syncs of phases 1 and 3.

The other method, used in the EVS Super Live Slow Motion disk recorder, is applying the same sync to all three phases. This implies that in phase2 the even field is coded as odd and vice versa. Since the vertical blanking periods are different the original odd field has to be delayed one line to fit into the CCIR656 format.

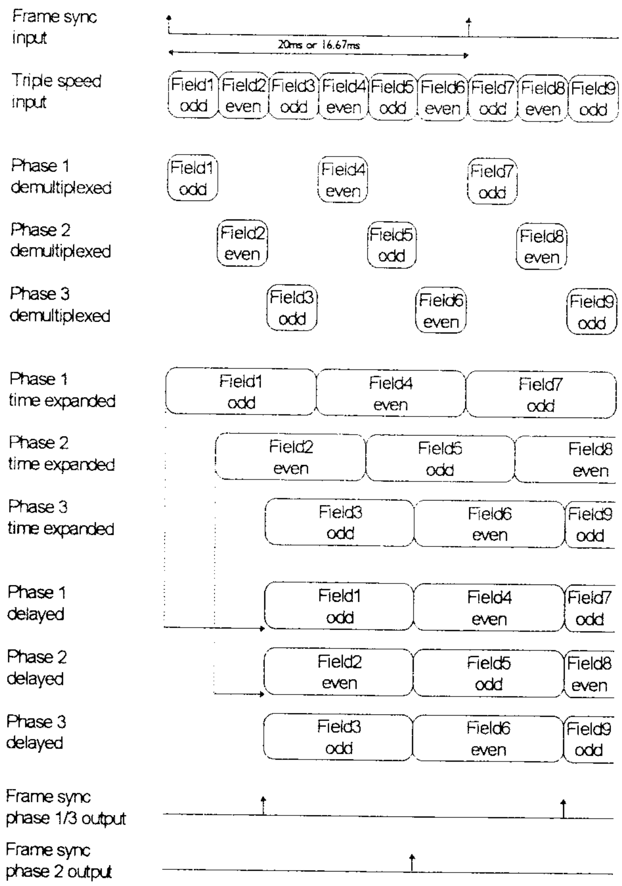

Figure 3 : Triple to normal scan conversion.

Video signal processing

ASIC B [4], jointly developed by Philips Digital Video Systems and Thomson Broadcast Systems is applied once for each phase. With sample rate converters and a CCIR656 formatter on board it is well suited to provide the needed SDI signals and do a number of video processing functions like:

- leaking pixel correction
- video noise reducer (optional)
- contour processing
- black stretch
- black and white limiters
- viewfinder contours and zebra processing
- test signal generator

Normal Scan Operation

Additional to the triple scan function of the camera, at the same time normal scan operation is possible. For this purpose a Combine signal is generated. This signal can be either phase3, for optimal vertical resolution, or a combination (27/64 : 10/64 : 27/64) of the three phases, resulting to normal integration times and improved SNR specs. The combine signal is available three times as SDI output with EDH (Error Detection Handling) inserted or as analog signals. The digital encoder provides CVBS, Y+sync, Pr, Pb, R, G and B. Although intended for monitoring purposes, the CVBS and Y signals have (pseudo) 10 bit resolution and can be genlocked to an external reference.

AUTO LIGHTING

The light output of artificial lighting from ac power sources is not constant in time. Especially FL and HMI light sources have a strong ac component. The cycle time of this effect is 1/100 sec. for 50Hz power sources and 1/120 sec. for 60 Hz power.

Modern CCD cameras have a controlled exposure time. To avoid beat frequencies in the exposed picture in artificial light situations the camera exposure time can be chosen to integrate exactly one cycle time of the artificial light source used.

The described high-speed camera however uses a field frequency of 150 Hz in Europe and 180 Hz in the USA version. The maximum exposure time of this camera is less than one period of the artificial light source used. This means that on light with a strong ac component the occurrence of beat-frequencies in the camera signal will be unavoidable. The ac component of the light-source is sampled in three phases resulting in a beat frequency over every 3 fields periods. This fast change from field to field is the most annoying effect. The slow change caused by the difference between field frequency and mains-frequency is a secondary effect.

A way to correct for the fast flicker effects in the high-speed camera is explained in figure 4.

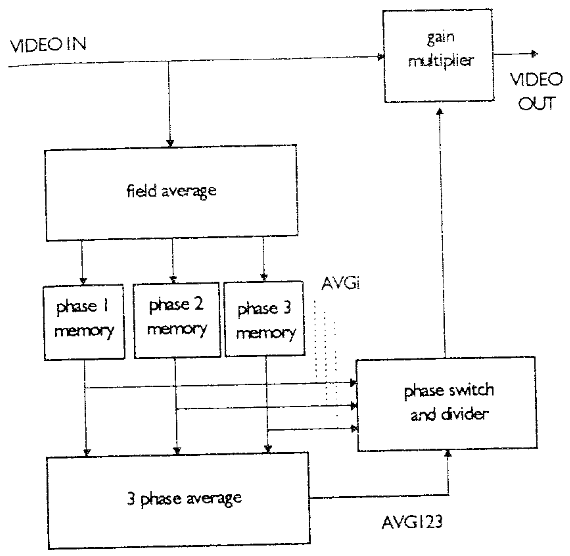

Figure 4 : Block diagram auto lighting option.

Each field of the incoming video signal is averaged and the result is sampled and cyclically stored in three memories (AVGi). The result in these memories is a "snapshot" of the fast repeating flicker effect. The results in these three memories are averaged once again in an additional memory resulting in the average of the video over one cyclic period of three fields (AVG123). The "snapshot" of the cyclic pattern is used to correct the video signal by means of gain modulation with a video multiplier.

For each cyclic period the video signal of that period is multiplied with a factor AVG123/AVGi resulting in an average video level of AVG123 for each cycle.

CAMERA SYSTEM PERFORMANCE

The camera system presented is a complete system configured for broadcast studio and EFP (OB-van) applications. All standard system components and accessories will fit on this system.

The system consists of following components:

- Camera Head + Lens
- 1.5-inch / 7 inch Viewfinder
- Large Lens Adapter (optional)
- Camera Processing Unit (CPU)
- Master Control Panel
- Operational Control Panel

The camera is designed as a compact, lightweight modular unit. The camera is equipped with a six-position filterwheel with three neutral density filters and two special effect filters. Together with the 1.5-inch viewfinder the camera can be used on the shoulder as well as on a tripod with an optional 5-inch viewfinder.

The 7 inch viewfinder can be mounted on a Large Lens Adapter or 7 inch viewfinder support. Both adapters will accept box type lenses with large zoom ranges (e.g. Fujinon 66x9.5).

The CPU is a 19 inch rack unit which is 3 standard units high. The CPU uses standard Eurocard PC boards and the rear panel is equipped with all signal interconnection options commonly used in broadcast applications.

The Control Panels follow the Series 9000 control philosophy, as used with all Philips standard TV cameras. The Master Control Panel (MCP) gives access to most of the set-up controls via menus. The Operational Control panel (OCP) provides all the operational control functions of the High Speed Camera System. The OCP is arranged with user-friendly directly accessible controls.

The camera can be used with a wide range of standard 2/3-inch barrel-type and box-type broadcast lenses.

The main camera characteristics are summarised in following table:

- Aspect ratio switching between 4:3 en 16:9.
- An electronic white balance range from 2500K to 15000K.
- A dynamic range of 500% with highlight compression in automatic and manual mode.
- Colourimetry acc. to the EBU standard.
- 2-Dimensional contours incl. soft contours.
- An electronic shutter with three fixed positions (5, 2 and 1 ms) and variable exposure time.
- Dynamic white shading and lensfiles.
- Automatic reduction of flicker artefacts caused by artificial lighting.

- Simultaneously available high-speed and standard video signals for dual operation.
- Adjustable combination of high speed fields into a standard output signal.
- Extra VF contour boost for focus assist.

The main camera system characteristics are summarised below:

- 2/3 inch 600.000 pixel FT-CCD sensors.
- Sensitivity of 2000 Lux. at F/4.0
- MTF: typ. 60% at 400 TVL.
- S/N ratio of typ. 58 dB/60 dB in 150/180 Hz mode, at normal scan output.

CONCLUSION

This paper reports the successful adaptation of the Philips LDK 10P broadcast camera system to a triple speed scan rate intended to be used at slow motion applications.

A prototype camera has been built and demonstrated at the 1998 NAB exhibition.

Thirty cameras have been assembled and used, together with the EVS Super Live Slow Motion disk recorder at the World Championship Soccer Games in France this summer.

This project also represents the successful co-operation between the Philips Camera development department and the EVS Company who supplied the Disk recorders and slow motion interface equipment (remote control panel).

REFERENCES

[1] P.Centen, A.Mierop, H.Stoldt, A.Theuwissen, G.Pine, M. Stekelenburg. *Dynamic Pixel Management for second generation aspect ratio switching.* Montreux International Television Symposium Record, pp 199-211, June 8-13, 1995.

[2] H.Stoldt, A.Theuwissen, F.Vledder, P.Centen, A.Mierop, A.Kleimann, H.Peek, D.Verbugt, P.Hartog, R.de Gruyter. *CCD Imagers for Broadcast Applications.* Technical Digest IEDM96, pp. 899-902, San Francisco, Dec 8-11, 1996.

[3] A.Theuwissen. *Solid-State Imaging with Charge-Coupled Devices.* Kluwer Academic Publishers 1995; ISBN 0-7923-3456-6.

[4] J. van Rooy, H. Voet. *Twelve bit aquisition, the next step in digital broadcast cameras.* SMPTE Journal, pp 698-704, october 1997.

ACKNOWLEDGEMENTS

The authors would like to thank there colleagues at the Philips DVS camera development department for there contributions to this paper, especially Mr. J. van Rooy for his contribution regarding the auto lighting option.

During the development of this camera system and at the World Soccer Games in France the EVS Super Live Slow Motion Disk recorder was used.