CCD Imagers for Broadcast Applications

(Invited Paper)

H. Stoldt, A.J.P. Theuwissen, F.F. Vledder, P.G.M. Centen*, A. Mierop*,
A.C.M. Kleimann, H.L. Peek, D.W.E. Verbugt, P.B. Hartog, R.H.S. de Gruyter

Philips Imaging Technology, M.S. WAG-11 - Prof. Holstlaan 4, 5656 AA Eindhoven, The Netherlands
*Philips Broadcast Television Systems, Kapittelweg 10, 4827 HG Breda, The Netherlands

ABSTRACT

A 2/3" FrameTransfer-CCD with 600k pixels for the NTSC standard is reported. Layout of the light sensitive part is based on a single-gate repetition structure. By this the image format is switchable in the **vertical** direction between standard (4:3) and widescreen (16:9) aspect ratios, while maintaining full vertical and horizontal resolution at a constant pixel rate. With the flexible clocking possibility inherent in FT-CCDs, a tunable vertical anti-aliasing filter is built on-chip.

INTRODUCTION

The market for broadcast cameras can be characterized as a professional high-performance market. Image sensors used in these systems require a combination of high sensitivity, high resolution, outstanding overexposure handling capability, low noise, etc. At the same time TV standards, together with the optical format of existing lenses, put strong restrictions on the design of such imagers. Recently, there is an increasing demand to add more functionality directly to the CCD imagers, such as variable aspect ratio. To incorporate standard (4:3) and widescreen (16:9) television aspect ratios into one imager makes broadcast camera systems capable of bridging the transition from traditional 4:3 to the growing world of 16:9. Several approaches for dual aspect ratios in one imager have been reported [1,2]. These approaches suffered from differences in resolution for the two image formats and from the need of multiple pixel frequencies.

NEW SENSOR CONCEPT

This paper presents a 2/3" FrameTransfer-CCD with 600k pixels according to the NTSC standard. The image format of this new sensor is switchable in the **vertical** direction between standard aspect ratio of 4:3 and widescreen aspect ratio of 16:9 while maintaining in both aspect ratios the full horizontal (1000 pixels/line) and vertical (486 lines for NTSC) resolution. Only one horizontal frequency of 18 MHz is required in both modes. Furthermore, it incorporates the possibility of on-chip optical low-pass filtering by adapting the pulse scheme of the CCD clocks. Careful design of the doping profile and gate structure led to a dynamic range as high as 84 dB without compromizing other performance parameters. Layout of the CCD is based on a new design approach. The light sensitive part is composed by repeating a single gate electrode structure, as shown in Fig. 1. It uses membrane poly-Si [3] for high sensitivity (especially for blue light), and a profiled p-well for both antiblooming protection to 10,000 times overexposure and excellent saturation charge capacity of more than 160,000 e^-/pixel.

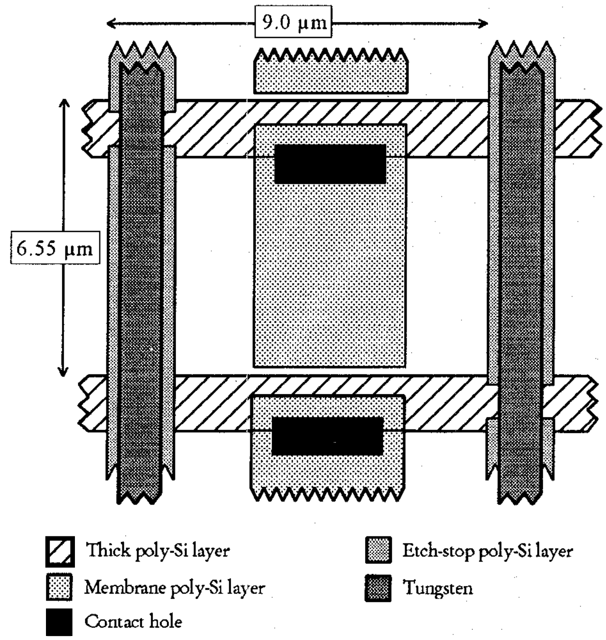


Fig.1. Layout of new gate electrode structure

A total of 1020 gates vertically is provided to supply the required number of lines for the NTSC standard and for contour correcting lines and optical black information. The CCD gates are connected as a 12-phase repetition structure.

PIXEL DEFINITION

In a FrameTransfer-CCD the pixels are defined in the vertical direction by the voltages applied to the gates. This principle allows for extremely flexible definition of the size of the pixels by simply adapting the clocking scheme.
For the 4:3 aspect ratio (Fig. 2) the 12-gate repetition structure (g1...g12) is addressed by a 4-phase clocking scheme (A1...A4) via the vertical shunt wiring. Four gates represent a pixel; for normal operation three gates are biased to a high voltage (+) and one gate is biased to a low voltage (-). The dashed line indicates one of the resulting image pixels as an example. According to the NTSC standard 243 active lines per field are created by this.

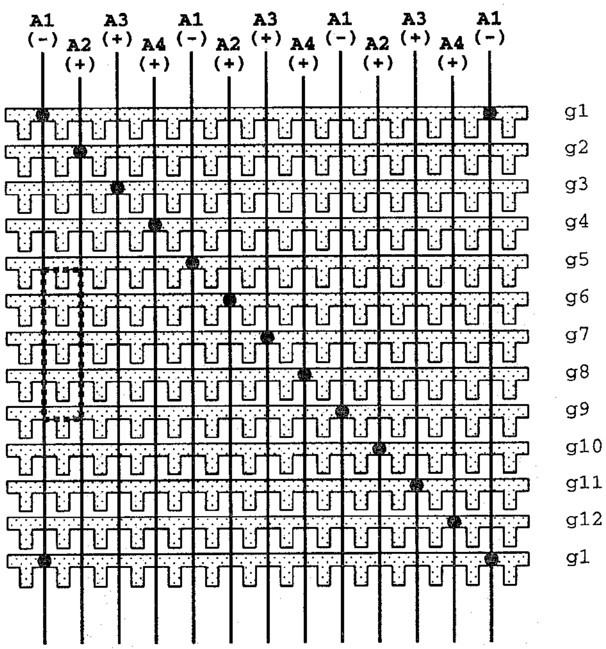


Fig.2. Addressing a pixel for 4:3 aspect ratio

A 16:9 aspect ratio is similarly achieved (Fig. 3) by simply switching to a 3-phase clocking scheme (A1...A3) for the 12-gate repetition structure (g1...g12). Now three gates represent a pixel. In normal operation two gates are biased to the high voltage (+) and one gate to the low voltage (-); the dashed line again indicates one of the resulting image pixels. As a result the total number of available image lines is increased by $^4/_3$. From these the central 243 lines are selected for one field. Due to the constant height of the repeated gate structure the correct aspect ratio of 16:9 is generated automatically.

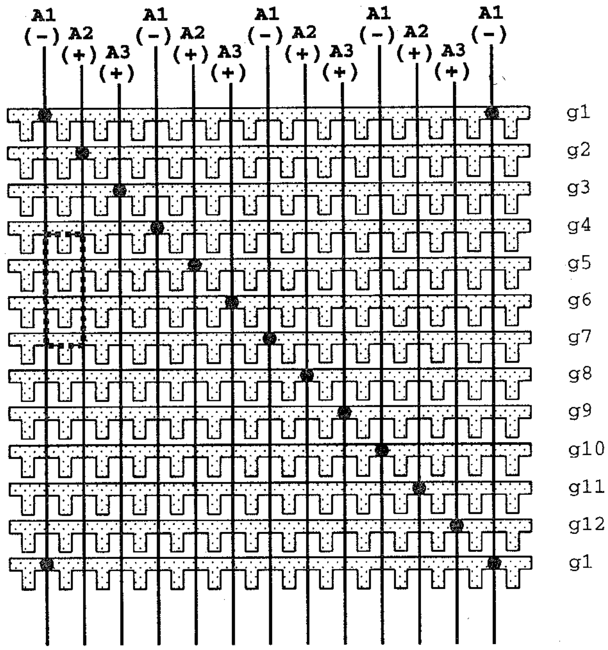


Fig.3. Addressing a pixel for 16:9 aspect ratio

An overview of the device architecture is given in Fig. 4. The 16:9 aspect ratio is derived from the full image area in 4:3 aspect ratio without changing the optical center of the image area. The hatched parts are eliminated in widescreen mode by 'dump' readout.

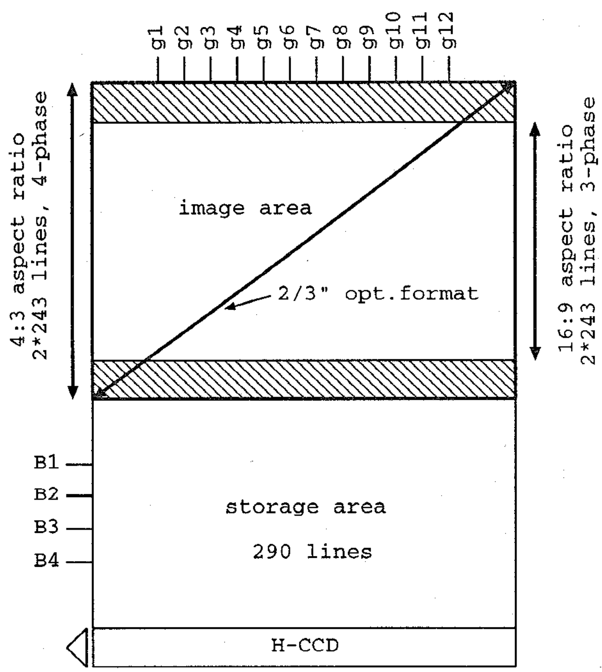


Fig.4. Architecture of vertically switchable FT-CCD

ON-CHIP LOW-PASS OPERATION

The resolution ability of a CCD image sensor can be described by the Modulation Transfer Function or MTF. The sampling nature of the imager together with the MTF behaviour can result in an interference signal known as aliasing. In a camera this aliasing component, due to foldback at the sampling frequency f_{smp} of the imager, can be suppressed by an external optical low-pass filter. Such a filter has to limit the bandwidth of the optical input signal to the Nyquist frequency $f_{Ny}=f_{smp}/2$.

In our new FrameTransfer-CCD we have incorporated the possibility for vertical optical low-pass filtering within the 4-phase (or 3-phase resp.) scheme **on pixel level**. In an FT-CCD the contribution to the video signal of each part of a pixel (on gate level) can be modulated externally. A gate can be made 'optically passive' by means of a very low DC setting. All other settings turn the gate into an 'optically active' state. So a weight factor can be applied to the contribution of each CCD gate by

- chosing appropriate relations in time between active and passive state for each gate, and
- chosing appropriate relations spatially between the different gates of each pixel.

With this we achieve the possibility of a flexible filter function to optimize sensor performance between MTF and aliasing. The adjustment range of the filter characteristics is limited by the situations as depicted in figures 5 and 6 for the 4-phase scheme.

One extreme is to apply an equal weight factor of $^1/_4$ to each gate. Figure 5.a shows a schematic representation of the applied weight factors per gate and the resulting active pixels (thick lines) per field. In interlaced scan this results in vertically overlapping pixels with an active pixel window equal to twice the pixel pitch. Comparatively we achieve the lowest MTF by that, but also the smallest aliasing component (Fig. 5.b). The spatial sampling frequency in interlaced NTSC equals 486 cpph (cycles per picture height). As MTF=0 for f_{Ny} and f_{smp}, in particular there will be no aliasing component present at the spatial field frequency (243 cpph) or frame frequency (486 cpph).

In figure 6 the other extreme is shown with a weight factor of $^1/_1$ for one gate and 0 for the three other gates, resulting in non-contiguous pixels with 50% fill factor in interlaced scan. By that the maximum MTF is realized but also a relatively large aliasing component. In this case MTF=0 for $2 \cdot f_{smp}$. With the right choice of weight factors the MTF vs. aliasing behaviour of this imager can be tuned to any desired shape in between the two limiting situations as shown in Fig. 5 and 6.

CONCLUSIONS

The CCD imager reported here is the first and still the only one that combines a 4:3 and a 16:9 aspect ratio, while maintaining vertical and horizontal resolution and horizontal video frequency. With the flexible clocking possibility inherent in frame-transfer CCDs, a tunable vertical anti-aliasing filter is built on-chip. An overview of the main device characteristics is given is table 1.

ACKNOWLEDGEMENTS

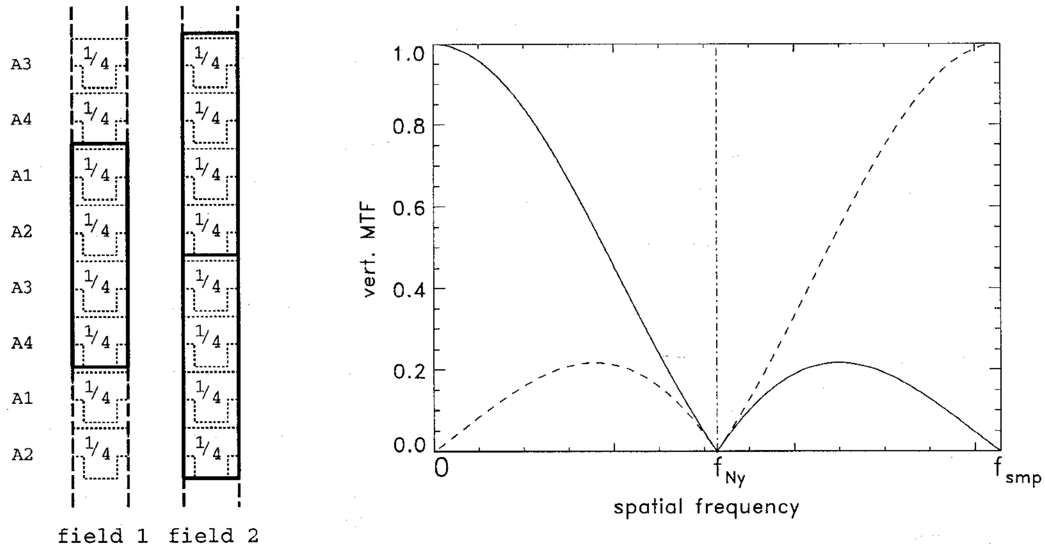
The authors would like to thank their colleagues at Philips Imaging Technology, Philips Broadcast Television Systems and Philips Research Laboratories for their support in design and fabrication of the imagers.

REFERENCES

[1] M.van de Steeg et al., "16:9 aspect ratio for broadcast applications and its consequences for new CCD imagers," in *Charge-Coupled Devices and Solid State Optical Sensors III*, Morley M. Blouke, Editor, Proc. SPIE 1900, pp. 77-84, 1993.

[2] K.Itakura et al., "An aspect ratio switchable 2/3-inch 800k-pixel CCD image sensor," in *ISSCC Digest of Technical Papers*, pp.220-221, 1995.

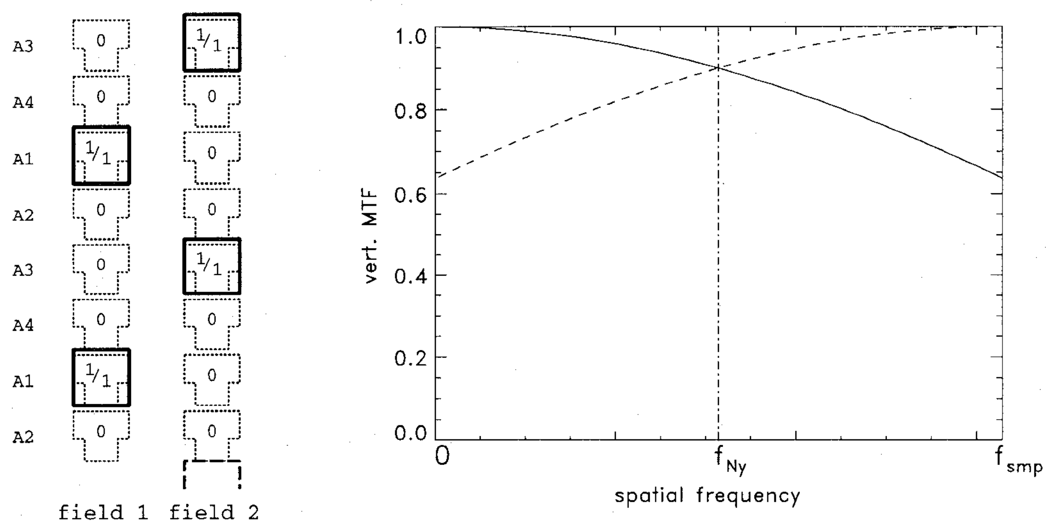
[3] H.Peek, A.Theuwissen, A.Kokshoorn, and E.Daemen, "Groove-fill of tungsten and poly-Si membrane technology for high-performance (HDTV) FT-CCD imagers," in *IEDM Technical Digest*, pp. 567-570, 1993.



5.a: weight factors

5.b: vertical MTF (solid line) and aliasing component (dashed line)

Fig.5. Fully overlapping 4-phase pixels



6.a: weight factors

6.b: vertical MTF (solid line) and aliasing component (dashed line)

Fig.6. Non-contiguous 4-phase pixels

	4:3 aspect ratio	16:9 aspect ratio	
number of pixels	942 (H) x 486 (V)	942 (H) x 486 (V)	
image area	8.48 (H)x 6.36 (V)	8.48 (H) x 4.77 (V)	mm^2
pixel size	9.0 (H) x 13.1 (V)	9.0 (H) x 9.825 (V)	μm^2
clocking scheme	4-phase	3-phase	
saturation charge	> 160,000	> 100,000	e^-
dynamic range	> 84	> 80	dB
S/N ratio	> 63	> 60	dB

Table 1: Device characteristics