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Evaluation of subsampling in a 2/3" 2-M pixel FT-CCD.

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Introduction

A 2/3" 2-M pixel FT-CCD imager for consumer digital still cameras was developed. An overview of the device architecture, operation and performance can be found in [1]. A block diagram of this sensor is shown in Fig.1. The pixel is illustrated in Fig.2. A performance summary is given in Table 1.
This paper presents detailed evaluation results on the vertical subsampling performance.

CCDs for digital still cameras

This CCD, designed for use in a digital still camera (DSC), offers two distinct modes of operation. In the snapshot mode, the sensor generates a full-resolution image of 1600×1280 pixels. The camera mechanical shutter is closed during readout, and the small storage section is not really required. In preview mode, used e.g. for the camera LCD viewfinder, images of a reduced vertical resolution can be generated continuously: the previous image, after subsampling, is read out from the storage section, while a new image is being integrated in the image section. The mechanical shutter remains open.

Subsampling principle

In this imager, the subsampling is performed at the image-storage (Im-St) transition. This on-chip reduction of vertical resolution is achieved by dumping charge from unwanted lines to the n-substrate by using the same mechanism as the electronic shutter in any CCD with a vertical anti-blooming structure (n-p-n).
During integration, two image clocks (A3, A4) are 'high' (typ. 12V), and two image clocks (A1, A2) are low (0V). For the conventional electronic shutter action, all four clocks are set 'low', and a small pulse (typ. 3.3 to 5V) is applied to the n-substrate. Fig. 3 shows the corresponding potential profiles. When the electronic shutter pulse is applied, no local potential minimum is present in the p-well and all electrons flow from the n-channel to the n-substrate.
A similar situation can be created at the Im-St transition during frame-shift, as shown in Fig.4, where a simple 1:2 subsampling is demonstrated. Normally, the image (A clocks) and storage (B clocks) run synchronised, but for subsampling, the storage clocks can be stopped periodically with B1 and B2 low. Then, with consecutive gates A3, A4, B1 and B2 'low' (dotted rectangle in Fig.4), and a pulse on Nsub, charge can be dumped to the substrate. However, here the electronic shutter action must be active very locally, in the area indicated with a circle, and no charge is allowed to spill back into the image section or forward to the storage section. Some precautions were taken in the design and clock waveforms to assure this.

Subsampling performance

To evaluate the subsampling accuracy, the design and the vertical driving pulses, the following measurements were performed: (see Fig. 5 for the pulse waveforms)

- the sensor is set to operate in full-resolution mode
- the substrate voltage Vns is adjusted for anti-blooming (VNS)
- the pulse height on Vns is adjusted for electronic shutter (VNSPS)
- the sensor is then switched to subsampled mode
- the substrate voltage for anti-blooming (VNS) need not to be changed, as the integration conditions are identical
- the pulse height on Vns is adjusted not for electronic shutter but for efficient subsampling (VNSSS)
- the value of VNSSS is determined

Now, for subsampling we require a pulse on the substrate during the vertical frame shift when subsampling is performed, that is not higher than the pulse on Nsub for electronic shutter. The resulting voltages are shown in Table 2.
To ensure that the charge packets that are to be dumped during subsampling are completely drained to the substrate during subsampling, and are not mixed with other charge packets, the following experiment was carried out: for a given illumination with e.g. 'blue-green' light (492nm) and green light (550nm) the average response of each of the R-G-G-B pixel planes was measured both in full-resolution and in subsampled mode. If subsampling would mix charges, different ratios of G/B and G/R would be found, since the 'large' green packets would be mixed with the 'small' red and blue charge packets. As can be seen from Table 3, this is not the case; clearly no charge mixing occurs.
Finally, the best proof of efficient subsampling can be obtained by evaluating processed images after e.g. color matrixing and white-balancing. Identical processing results in exactly the same colors in the full resolution and subsampled images; as will be illustrated at the Workshop with color slides from the same scene, taken in both modes of operation.

Conclusions

With proper design of the image-to-storage transition and the correct vertical driving pulses, the subsampling at the image-to-storage transition of a 2-M pixel 2/3" FT-CCD only reduces the vertical resolution, and does not compromise the image quality w.r.t. color rendition, and there is no additional system cost.

References

[1] J. Bosiers et al., *"A 2/3 2-M pixel progressive scan FT-CCD for digital still camera applications"*, Proc. IEDM'98, San Francisco, CA, 1998.

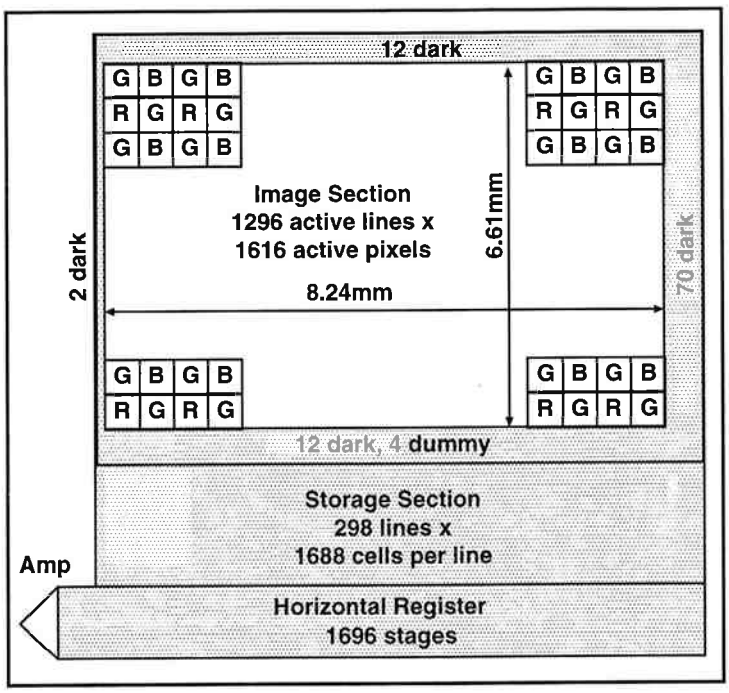

Figure 1: Block diagram of the 2-M pixel 2/3" FT-CCD

CCD type	Frame Transfer with reduced storage
Optical format	2/3"
Operation modes	full resolution typ. 6 im/s monitor preview 8... 40 im/s LCD preview 5... 15 im/s
Number of active lines	1280
Number of active pixels per line	1600
Pixel size	5.1μm × 5.1μm
Minimum features	0.5 μm
Chip size	90 mm^2
H clock frequency & swing	25 MHz @3.3V
Maximum charge capacity	40 000 electrons
Sensitivity (green)	390 mV/lux.s
Color filters	Bayer RGB
Outamp type	triple source-follower
Outamp responsivity	23 μV/electron
Saturation output voltage	900 mV typ.
Outamp noise (5 MHz BW)	10 electrons RMS

Table 1: Summary of 2-M pixel 2/3" FT-CCD

Mode	Pulse type	Pulse amplitude
full-resolution	VNSPS	5V
subsampled	VNSSS	3.3V

Table 2: Amplitude of Nsub pulse for electronic shutter and for subsampling

Mode	G/R ratio	G/B ratio
492 nm		
full-resolution	5.3	0.82
subsampled	5.2	0.82
550 nm		
full-resolution	3.8	4.7
subsampled	3.8	4.7

Table 3: Ratios of G/R and G/B response in full-resolution and in subsampled mode

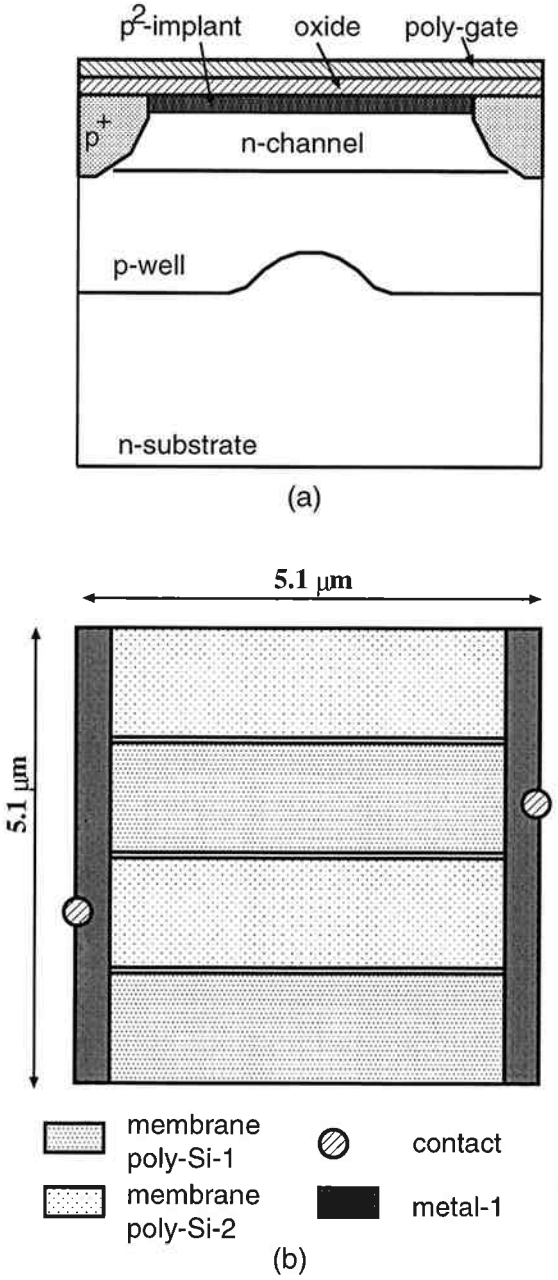

Figure 2: Pixel structure: (a) cross-section; (b) top view of electrode structure

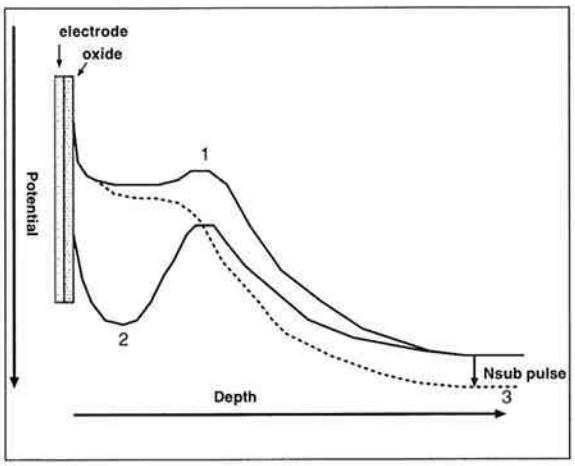

Figure 3: Potential profile in CCD pixel: (1) under 'off' gates; (2) under 'on' gates; (3) all four gates off, Nsub pulse applied

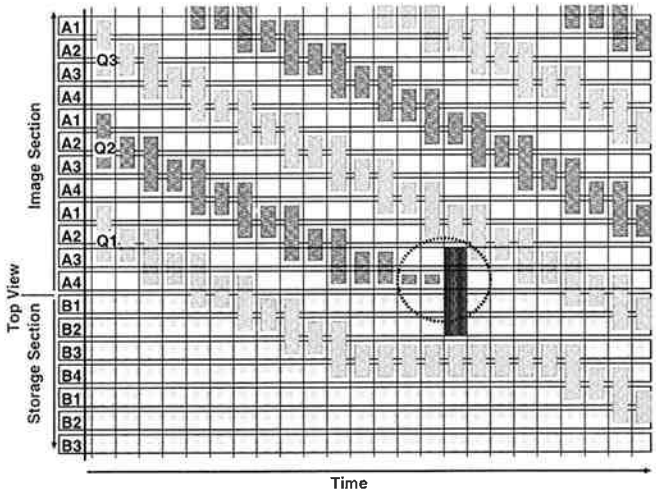

Figure 4: Example of a simple 1:2 subsampling at the Im-St transition during frame shift. A top view of only one column of the imager is shown, at the Im-St transition. The horizontal axis is a time scale. A first charge packet is transported into the storage section, storage clocks are stopped, the second charge packet is dumped by subsampling, storage clocks resume, and the third charge packet again is transported into the storage section

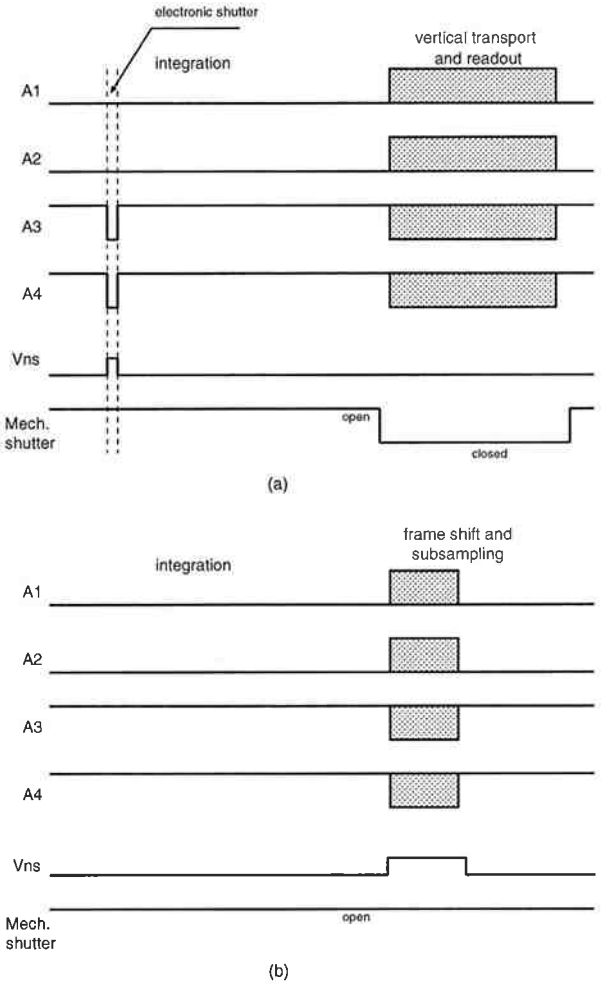

Figure 5: Pulse patterns (a) for full-resolution readout; (b) for subsampled readout. The pulses of the storage clocks are similar to the image clocks