9.3 Ultra-High Resolution Image Capturing and Processing for Digital Cinematography

Albert Theuwissen[1], John Coghill, Lucian Ion, Felicia Shu, Harald Siefken, Charles Smith

DALSA, Waterloo, Canada
[1] DALSA, Eindhoven, The Netherlands and Delft University of Technology, Delft, The Netherlands

The last bastion of analog celluloid film left after the transition of still photography into the digital domain is the art of cinematography. Based on the rapid pace of technical developments in the field of image capturing, computing, data manipulation, mass storage and image projection, it is concluded that the digital cinema is approaching its introduction to a larger audience.

The first element of the complete "scene to screen" digital cinema chain is the image capture. To meet the ultra high performance of cinematography, a frame transfer CCD with an ultra-high resolution in combination with a high frame rate is developed first. Typical pixel count is 8 Mpixels at a pixel size is 8.4 x 8.4μm^2, resulting in an active area of about 600mm^2, just slightly larger than a 35mm motion picture film frame. The optical format of the CCD makes it compatible with existing camera lenses.

To achieve the required high resolution, the high-speed operation, the device is designed with :

- 16 outputs in parallel where each output is a triple source-follower with all loads on-chip, operating at a standard pixel rate of 20 MHz and with matched output structures.
- a dedicated proprietary strapping technology, to lower the ohmic resistances of the various poly-silicon CCD gates and thus reduce RC delays and driver circuit loading.

The sensor's architecture is depicted in Fig. 9.3.1. In the standard mode the imager operates at a frame rate of 24 frames/s, however to achieve slow motion effects (high speed capture, low speed display) the camera may be operated to a maximum speed of 60frames/s and 40MHz per output. An overall (non-linear) dynamic range of 78dB is the design goal; a linear dynamic range of 72dB is measured at 14b digitization. The camera is made fully smear-free by means of a mechanical shutter similar in design to 35mm motion picture cameras.

Figure 9.3.2 gives a complete overview of the sensor design parameters and characteristics measured. The quantum efficiency is shown in Fig. 9.3.3. Figure 9.3.4 shows a photograph of the image sensor dedicated for digital cinema.

The 16 parallel analog signals delivered by the sensor are converted to digital signals by 16 parallel 14b A/D converters. This conversion is done non-linearly to give the sensor-camera combination a photopic response curve similar to film. The change-over from linear to a non-linear response is displayed in Fig. 9.3.5: the linear input-output relation comes from the inherent sensor linearity. The "S"-curve (known as DlogE curve) is generated through A/D converters via a bit allocation scheme that takes advantage of the early saturation region of the CCD itself and the photopic response of the human visual system.

After this digitization step, the data is serialized and transmitted to the digital processing portion of the camera for further processing. The processing algorithms developed include :

- correction of pixel non-uniformities,
- color interpolation,
- color correction,
- white balancing,
- linearity correction,
- lossless compression.

All of these digital processing functions are performed in real-time. The camera hardware contains 3M gates, 1152 BGA FPGAs, fabricated in 0.13μm technology in combination with 4 parallel DSPs. Even more aggressive low power, low voltage CMOS technologies will help to further integrate more functionality on-chip.

Early test results (non-corrected) from the camera are depicted in Fig. 9.3.6 that contains an example image of a test-chart. Clearly visible is the resolution capability of the system reaching 2000 TV lines horizontally as well as vertically.

A complete movie of 90 min is equivalent to about 4 TB of uncompressed digital data (equivalent to 4.10^7 mm^2 silicon). This huge amount of data needs to be stored at a speed of 790 MB/s. The solution proposed is to transmit the serialized data via a fiber optic cable and store the data (which is coming from the camera in bursts because of how movies are shot) in a kind of cache memory [1]. During the periods that the camera is not delivering data, the cache memory is transferring its data via a lower speed output to a more conventional digital recorder.

Recent breakthroughs in data recording techniques will push data densities to 100x the current state of the art, making 2 TB on a single disc possible [5]. However the write speed still presents a significant challenge needing a solution before a single disc drive mounted in the camera negates the need for the multiple drive high speed disc recorder.

Post production of the digital data takes place at the studio's production facility. Here the data is not handled in real time and remains compressed. The computational work is done on image data originating on either scanned film or digital cameras [2]. However, Moore's Law continues to push the technology and it is expected that in the near future the post processing will emerge and enable real-time interactive processing of 4k pixels of uncompressed data.

Distribution is possible in three ways : Distributing the data on a physical media, e.g. laser disks, or by transmitting the data by means of a satellite or through fibers. Improvements in integrated circuits for telecommunication helps to make the distribution process efficient relative to bandwidth utilization.

After decryption and decompression the data is displayed on a screen via a digital projector. For a comparable resolution as film, a minimum of 4K pixels/line is needed. It is expected that 4K technology may become commercially available based on micro-mirror [3] and liquid crystal technology [4]. Modern semiconductor technology makes this breakthrough possible on a short notice.

The complete chain from scene to screen in future digital cinema is described. Capturing, processing, storing and displaying of ultra-high quality images digitally pushes the limits of even the most advanced electronic parts used in the camera. More advanced semiconductor and circuit technologies are needed to further increase the performance as well as the utility of digital cinema. Particularly in the image capture area size, weight and power consumption are most critical. This paper has highlighted the key areas where improved silicon ICs are needed!

References

[1] see www.ionindustries.com
[2] EFILM : PR Newswire, Aug 14, 2002.
[3] Texas Instruments DLP technology : www.dlp.com/dlp_technology.htm
[4] JVC D-ILA technology : www.jvcdig.cim/technology.hym
[5] see www.seagate.com

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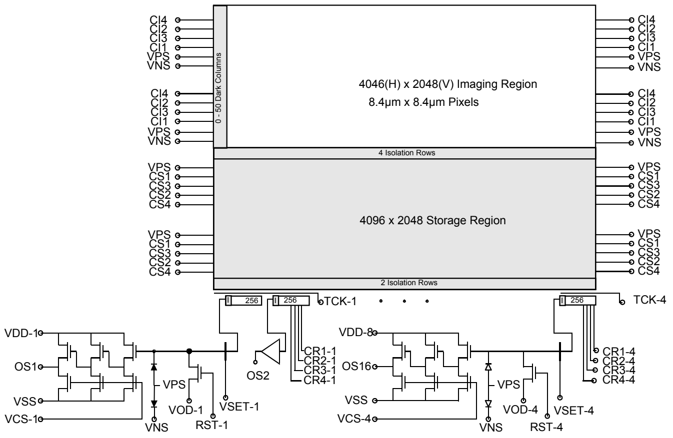


Figure 9.3.1: A schematic presentation of the architecture of the sensor.

Architecture	Frame Transfer CCD
Number Imaging Pixels	4096 H x 2048 V
Dark Reference Columns	50
Pixel Size	8.4 µm x 8.4 µm
Number of Outputs	16 parallel, 3 stage source-followers
Frame Rate	max. 60 fr/s, standard 24 fr/s
Date Rate/Output	max. 40 MHz, standard 20 MHz
Parallel-to-Serial Transfer Time	< 1.0 µs
Frame Transfer Time	2.8 ms
Anti Blooming	Vertical
Pixel Fill Factor	89 %
Exposure Control	Yes, by means of VAB
Color Filter	RGB, Bayer Pattern
Smear	none (due to mechanical shutter in the camera)
Read Noise	20 e^- rms
Saturation level (linear)	80 ke^-
Dynamic Range (linear)	72 dB

Figure 9.3.2: Overview of design parameters and measured characteristics of the sensor.

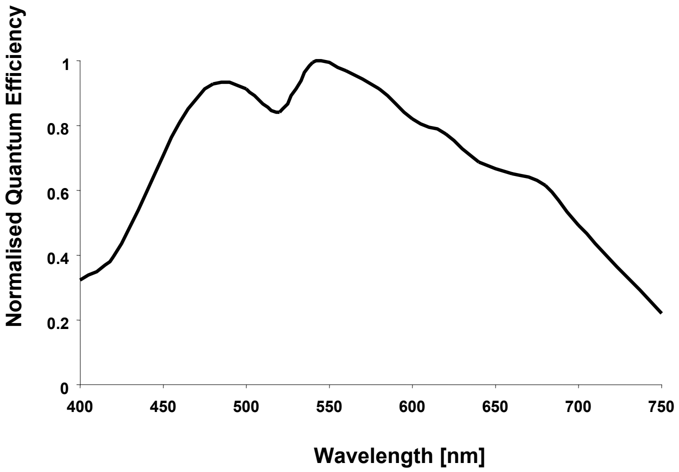


Figure 9.3.3: Normalised quantum efficiency.

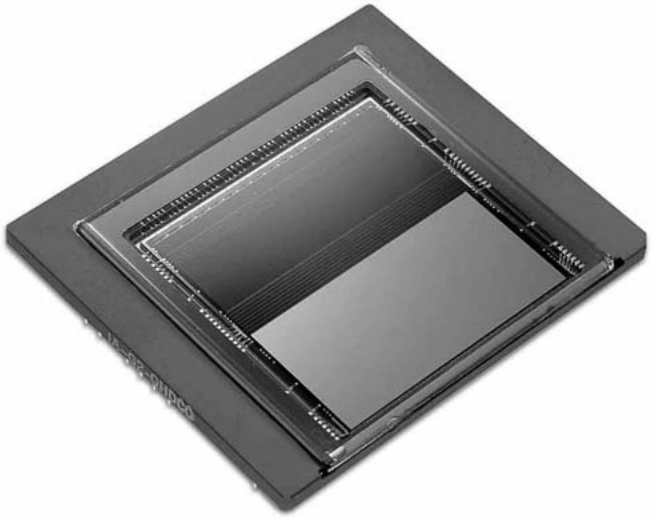


Figure 9.3.4: Photograph of the sensor.

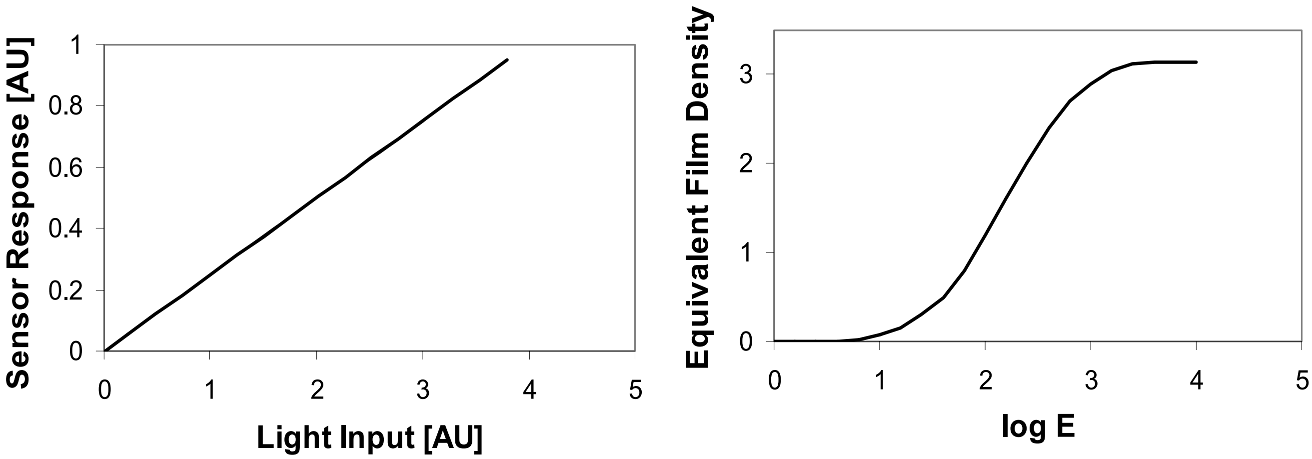


Figure 9.3.5: The linear response of an image sensor (input of the A-to-D converter) versus the non-linear “S”-curve of a film (output of the A-to-D conversion).

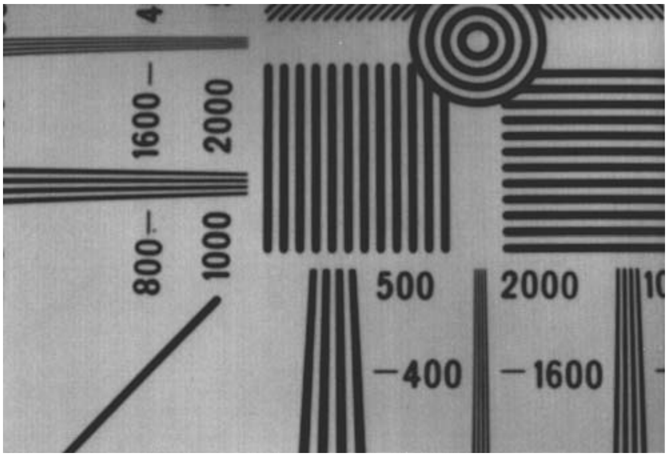
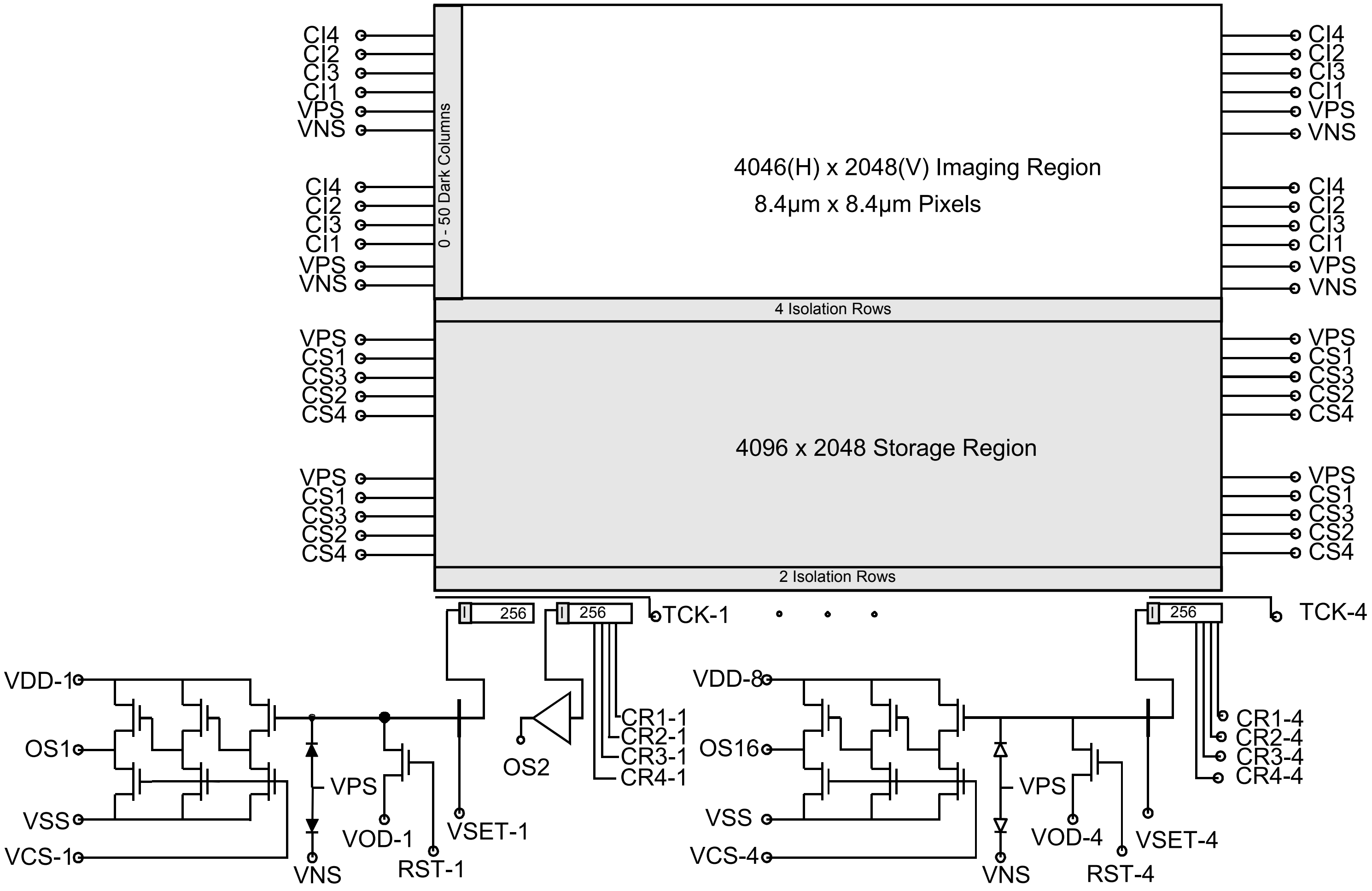


Figure 9.3.6: Detail of image taken with the sensor from a test chart to proof the high resolution.



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Frame Transfer Time	2.8 ms
Anti Blooming	Vertical
Pixel Fill Factor	89 %
Exposure Control	Yes, by means of VAB
Color Filter	RGB, Bayer Pattern
Smear	none (due to mechanical shutter in the camera)
Read Noise	20 e^- rms
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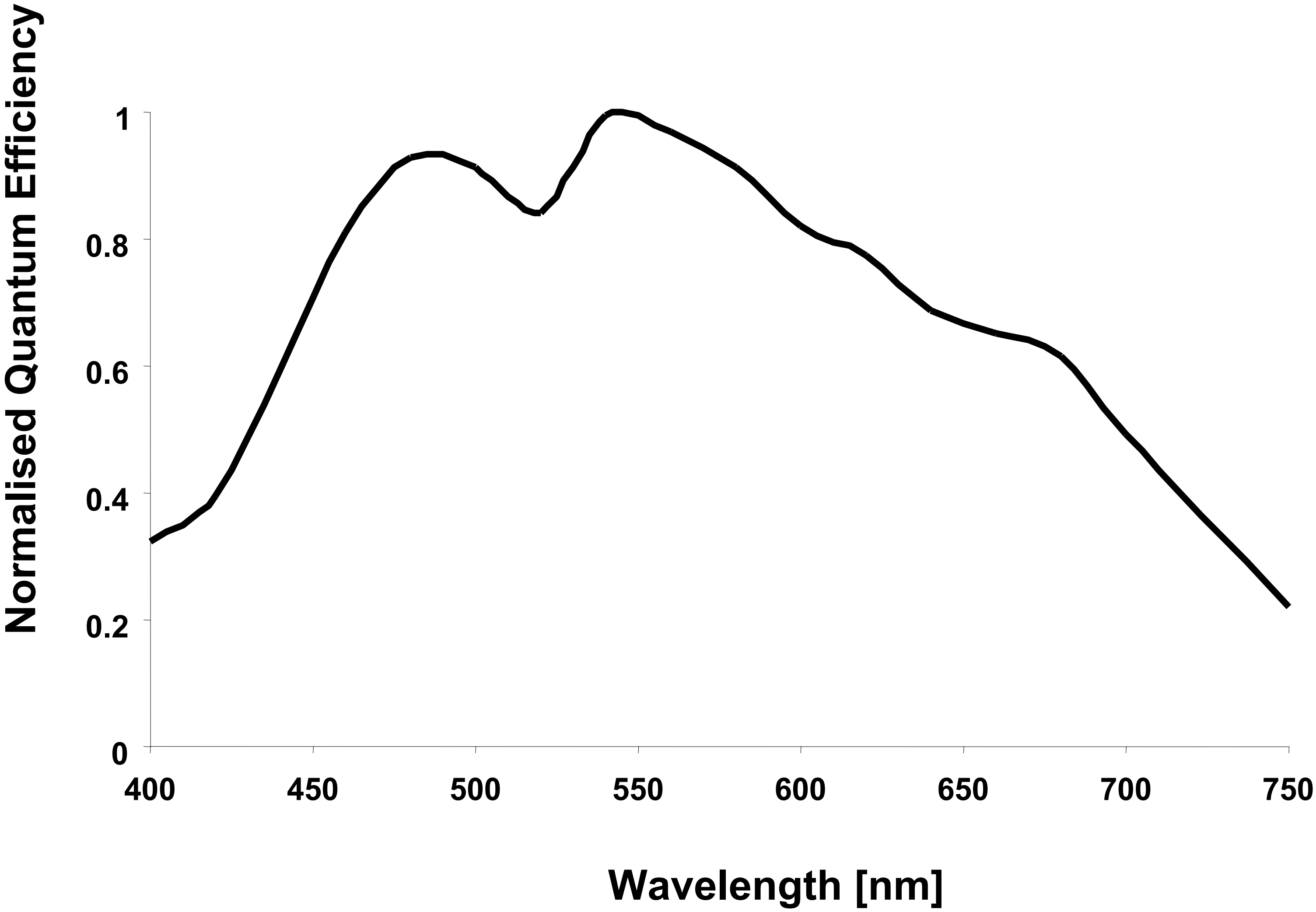

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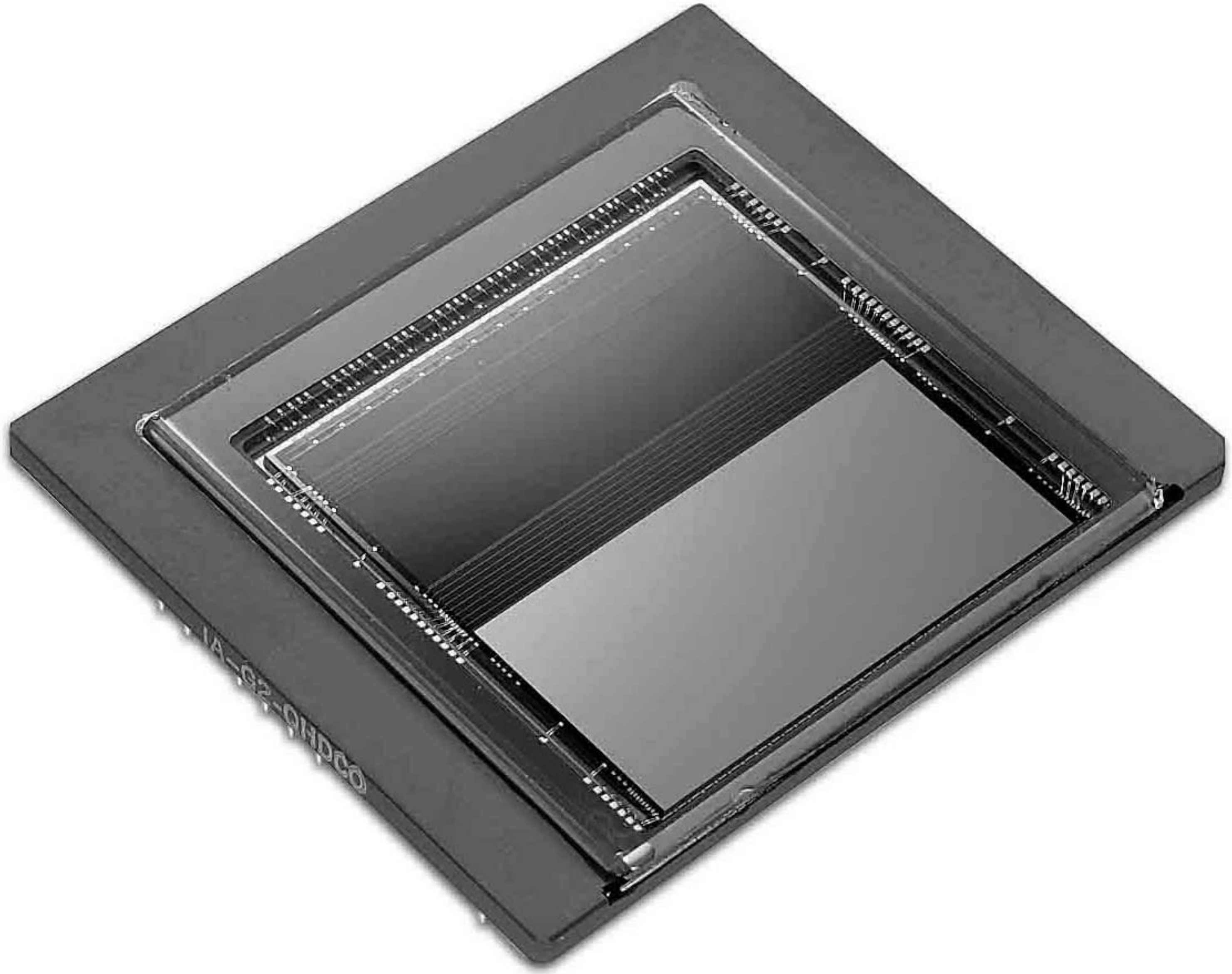

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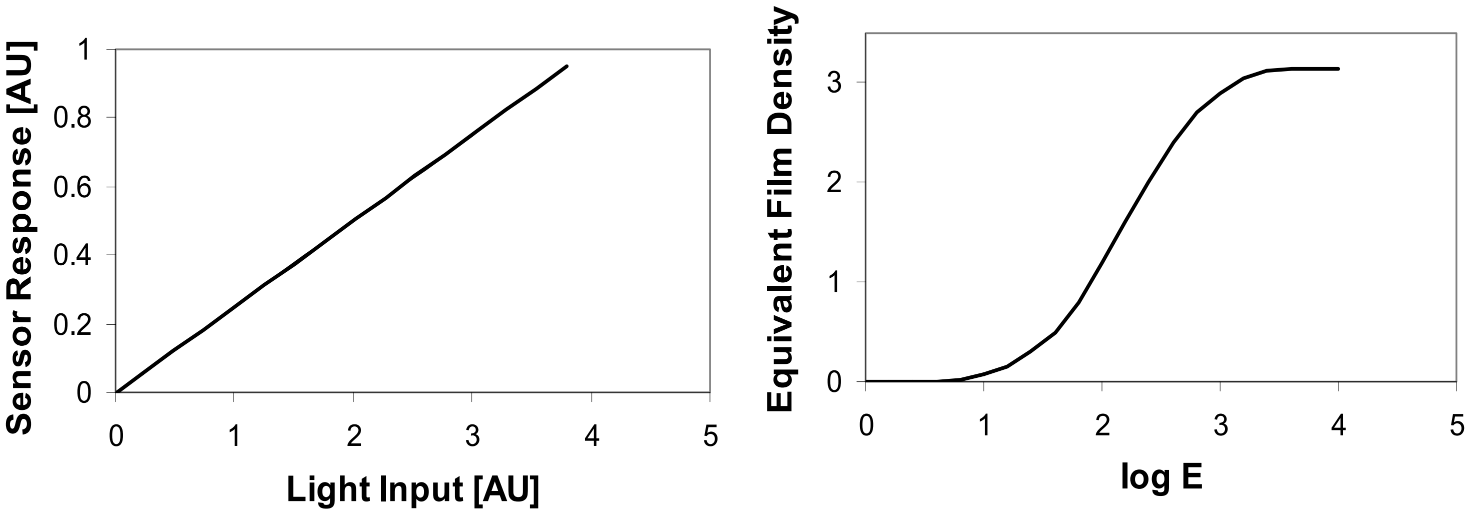

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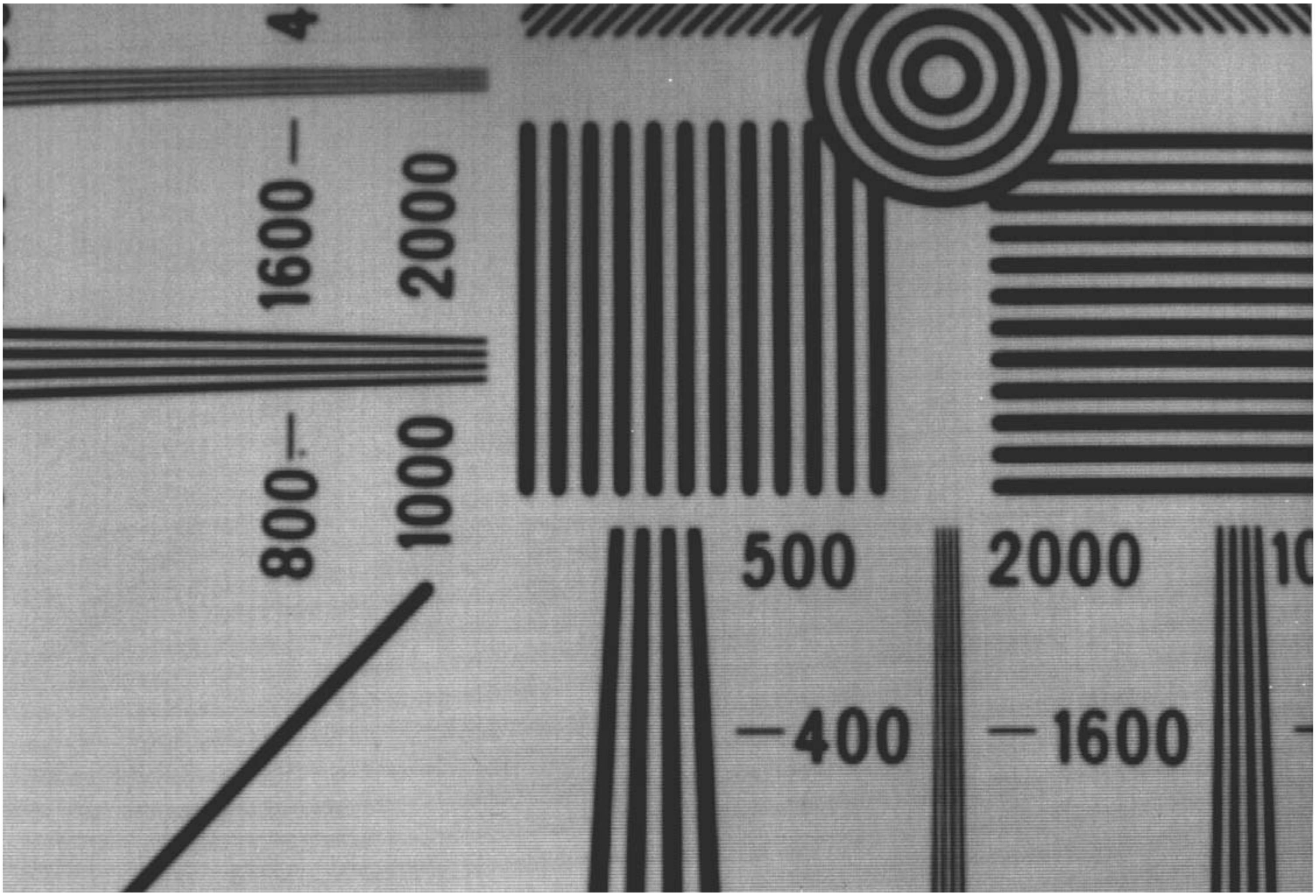

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