25th Anniversary of the IISW Reflections on Directions

Eric R. Fossum
President and Director, ImageSensors, Inc.
A California Non-Profit Public-Benefit Corp.

2011 International Image Sensor Workshop, June 8-11 2011, Hokkaido, Japan

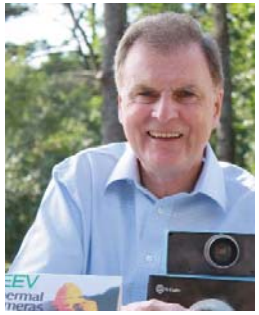
Perspective

We are like dwarfs on the shoulders of giants, so that we can see more than they, and things at a greater distance, not by virtue of any sharpness of sight on our part, or any physical distinction, but because we are carried high and raised up by their giant size..

Bernard of Chartres, c. 1115 AD

Early Giants in Solid-State Image Sensors

Gene Weckler



Peter Noble

Mike Tompsett

Willard Boyle

LJM Esser

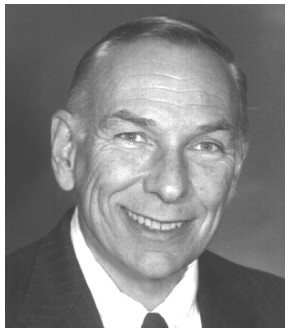
Carlos Sequin

Gil Amelio

George Smith

Rudy Dyck

Walter Kosonocky



Marvin White

Dennis Buss

Jerome Tiemann

Savvas Chamberlain

Ken Hoagland

Jim Carnes

And others…

My apologies to those accidentally omitted

CCD Meetings Prior to 1986

- 1973 CCD Applications Conference
  - San Diego, CA USA
- 1974 Technology and Applications of CCDs
  - Edinburgh, Scotland
- 1975 International Conference on the Application of CCDs
  - San Diego, CA USA
- 1976 3rd International Conference on Technology and Applications of CCDs
  - Edinburgh, Scotland
- 1976 Conference on CCD Technology and Applications
  - Washington, DC, USA
- 1978 International Conference on the Application of CCDs
  - San Diego, CA
- 1979 Technology and Applications of CCDs
  - Edinburgh, Scotland

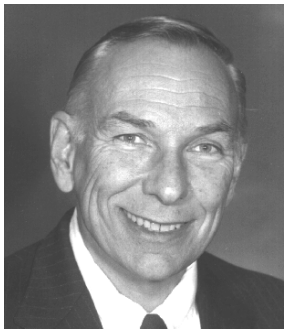
1986 Workshop on CCDs

Columbia University's Arden House
Harriman, New York

-70 participants
-17 invited papers

With help from these guys

McGrath



White

Clips from 1986 Program

Friday, October 24, 1986

p.m. 3:00- 5:30 Check-in and Registration. Main entrance/library
5:30- 7:00 Reception. East room.
7:00 -8:30 Dinner served. Dining room.

8:30-10:00 CCD "MEMORIES"
Michael Tompsett, AT&T Bell Laboratories

10:00-11:30 Bar is open. East Room

HIGH SPEED GaAs CCD'S
Raj Sahai, Rockwell International
VERY LOW DARK CURRENT
Dan McGrath, Texas Instruments
HIGH RESOLUTION COLOR
Bruce Burkey, Kodak
WAFER-SCALE IMAGING
Morley Blouke, Tektronix

IR IMAGING
Walter Kosonocky, RCA
UV IMAGING
Jim Janesick, JPL
UV IMAGING
Nelson Saks, NRL
X-RAY IMAGING
George Ricker, MIT

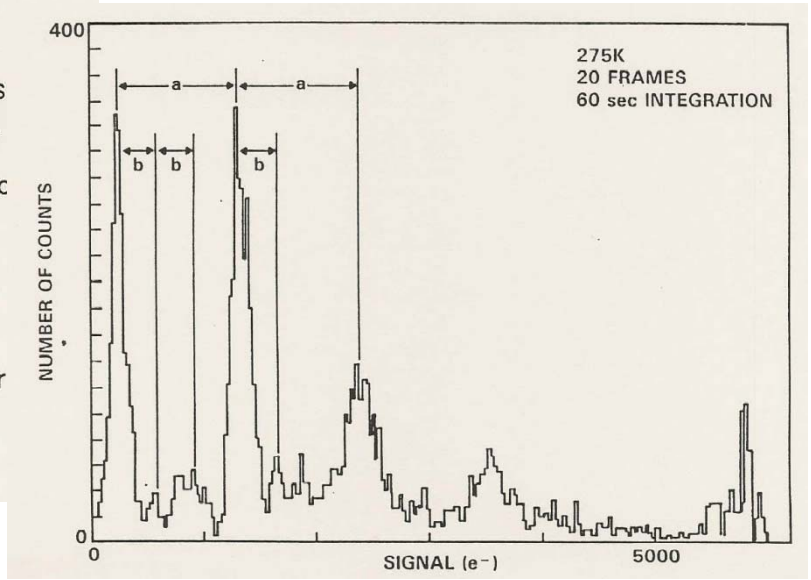
DISCUSSION - THE FUTURE OF CCDs:
MORE THAN A PRETTY PICTURE?

Clips from 1986 Papers

The first is a 360,000 pixel color-image sensor for imaging photographic negatives. This charge-coupled image sensor consists of a 740 (H) X 242 (V) X 2 image area and dual horizontal output registers. The architecture, spectral respons charge capacity, noise, and image quality of the sensor are discussed. The sensor achieves a charge capacity of 10^6 electrons per pixel and a noise of 200 rms electrc per pixel, for a dynamic range of 70 db. Color capability is obtained by an integral organic color filter array fabricated on the sensor.

The second is an advanced full frame CCD sensor for camera applications. This sensor has 1.4 million picture elements, nearly 6 times as many pixels as other sensors used in today's most advanced video cameras. The individual picture elements in this sensor are 6.8 µm square. This small pixel format provides much

Bruce Burkey, Kodak



For scientific images, the important criteria are low readout voice, large well capacity, high CTE, MTF, and CCE, low dark current, high quantum efficiency, and wide spectral response. Using a three phase technology, Tektronix has designed two CCD sensors specifically for scientific imaging. These devices have 512 X 512 and 2048 X 2038 pixel formats; the latter device occupies an entire 100 mm wafer. This paper will concentrate on a description of these devices and their performance. Of interest are recent measurements of quantum efficiencies (> 40 percent at 350 nm and > 70 percent at 700 nm) and very low dark current (<~ 60 pA/cm^2 at room temperature).

Dan McGrath, Texas Instruments

Morley Blouke, Tektronix

1990 Meeting

Organizer and Chairs
Prof. Eric R. Fossum, Columbia University
Prof. Walter Kosonocky, NJIT

CCD-IMAGERS for HDTV

Albert J.P. Theuwissen,
Phillips Research
Eindhoven, The Netherlands.

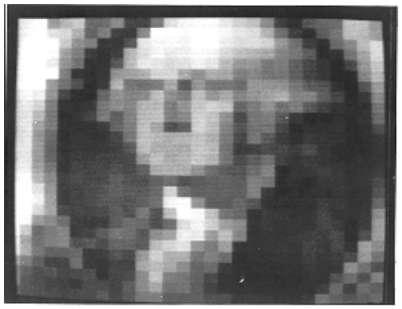
CCD IMAGERS FOR HDTV APPLICATION

H. Tanigawa
NEC Corporation
1120, Shimokuzawa
Sagamihara, Kanagawa 229, JAPAN

In the past decade, CCD technologies were successfully implemented in studio/industrial-use cameras, as well as in home-use video cameras. CCD imagers, with up to 380,000 integrated pixels, are commercially available, and higher density imagers are requested for electronic still camera systems. On the other hand, for future TV systems or HDTV systems, CCD imagers integrated with more than 2-Million pixels will be installed in an image pick-up system. Four CCDs, with from 1.3 to 2-Million pixels, have been reported by Japanese manufacturers. However, no CCD has sufficiently good characteristics for use as a studio HDTV camera. For example, higher sensitivity and lower smear level should be realized. Many basic technologies have been proposed to achieve better characteristics. Higher sensitivity, for a dark level imaging, will be accomplished by overlaying a monolithic micro lens array, and by an overlaid photoconversion layer. Smear level will be decreased by

1993 Meeting Univ. Waterloo

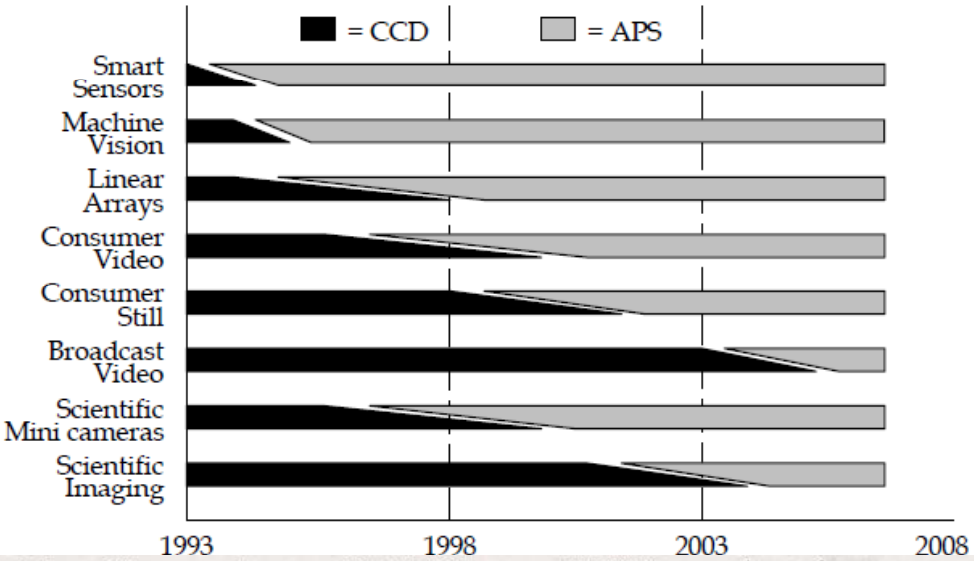
General Chair:
Prof. Savvas Chamberlain
Technical Program Chair:
Prof. Eric R. Fossum
Local Arrangements Chair:
Prof. Arokia Nathan



SPECULATION

Active Pixel Sensors vs. CCDs

Eric R. Fossum
Jet Propulsion Laboratory, California Institute of Technology



It is expected that this paper will lead to a wide discussion of APS vs. CCD technology and further illuminate the topic during the course of the workshop.

April 1995 Meeting Dana Point

1/4 Inch NTSC Format Hyper-D Range IL-CCD

Hiroyoshi KOMOBUCHI, Akira FUKUMOTO, Takahiro YAMADA, Yuji MATSUDA*, Takao KURODA*.

Central Research Laboratory MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
*Kyoto Research Laboratory MATSUSHITA ELECTRONICS CORPORATION

A CMD Image Sensor
-An Approach to High-Resolution Imaging-

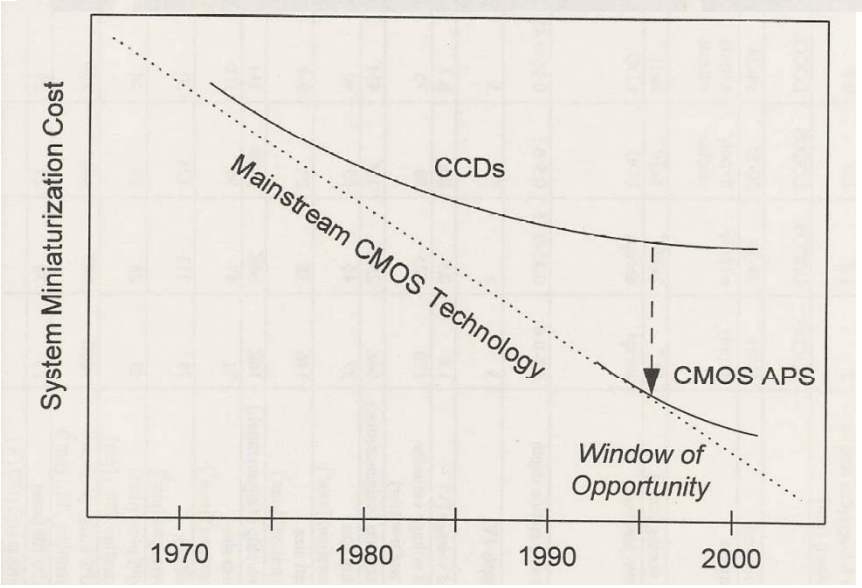
Tsutomu Nakamura, Kazuya Matsumoto, and Tetsuo Nomoto

Electronic Device Lab., Applied Research Dept.,
Corporate Research Div., Olympus Optical Co., Ltd.

Future Prospects for CMOS Active Pixel Image Sensors

Eric R. Fossum
Jet Propulsion Laboratory
California Institute of Technology

Philip H.S. Wong
IBM Research Center
Yorktown Heights, NY



1997 Bruges Belgium

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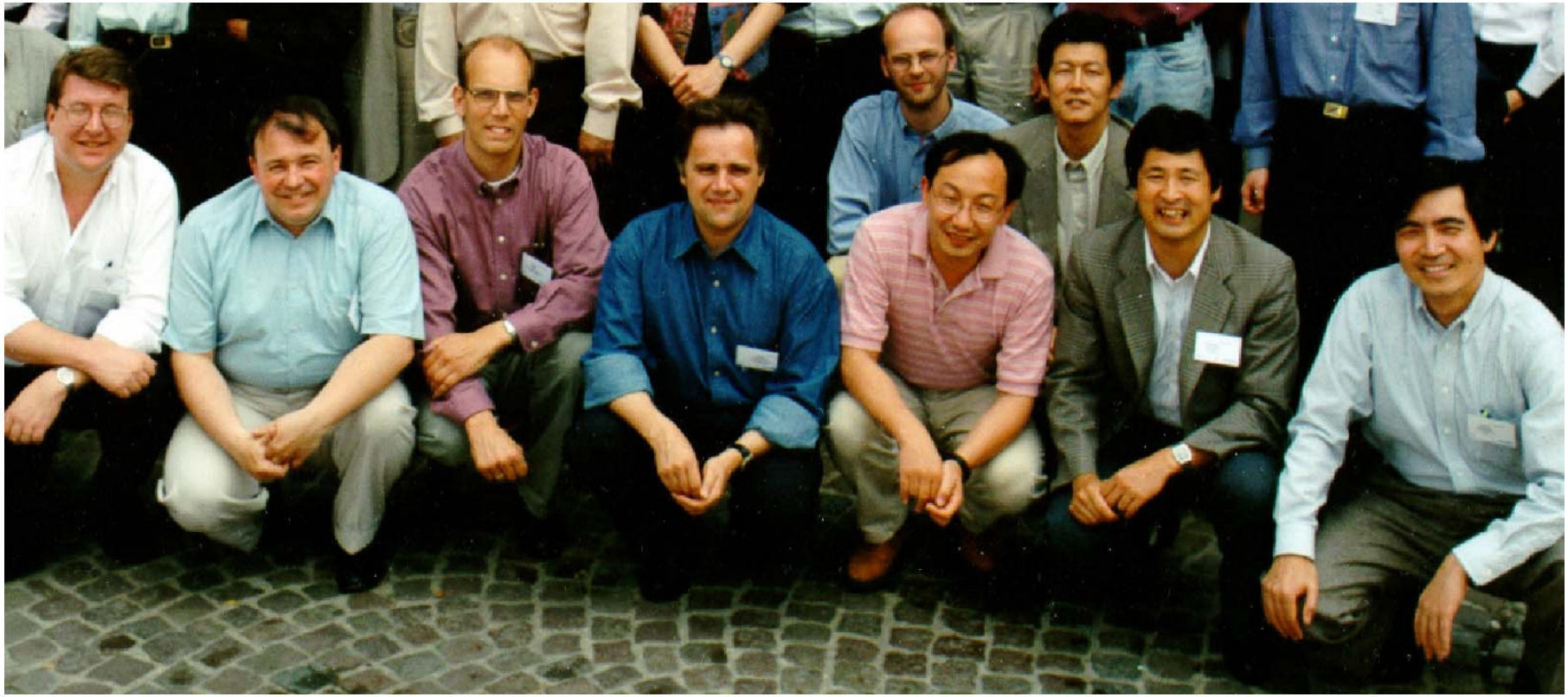

We head around the globe!

- 1999 Karuizawa, Japan
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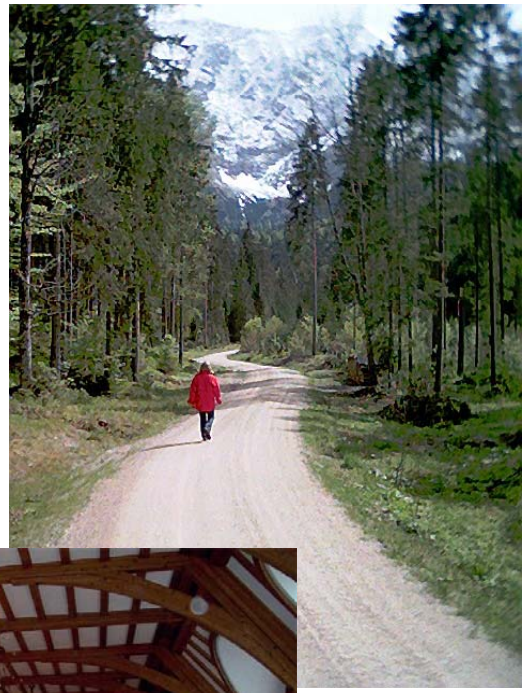

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- 2009 Bergen, Norway
- 2011 Hokkaido, Japan

New Directions

- 1970 Charge-coupled device
- 1993 CMOS active pixel image sensor

What comes next?

- “Black silicon”
- “Quantum Film stacked structure”
- “Organic stacked structures”
- “Plenoptic-like sensors”
- “RGBZ”

New Directions

- 1970 Charge-coupled device
- 1993 CMOS active pixel image sensor
- 2016 Digital Integration Sensor (DIS)

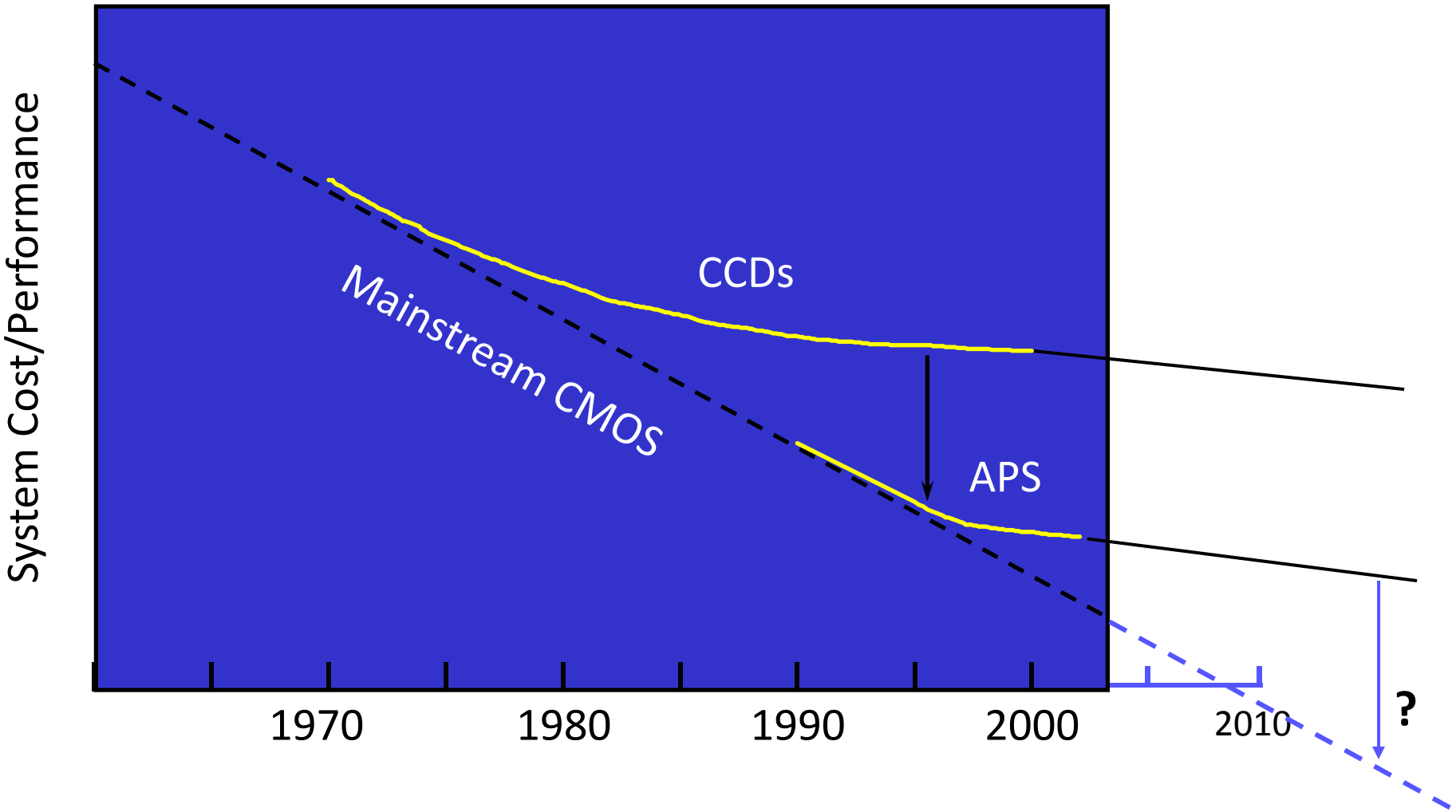
Digital Integration Sensor

- More than evolutionary, less than revolutionary
- Enabled by high speed on chip ADC and digital readout.
- Every image requires multiple subframes (e.g. 8) added in external digital memory.
- Full well capacity and ADC resolution requirements reduced but DR and SNR maintained.
- WDR easy to implement
- Subframes can be shifted for motion correction.

New Directions

- 1970 Charge-coupled device
- 1993 CMOS active pixel image sensor
- 2016 Digital Integration Sensor (DIS)
- 2021 Quanta Image Sensor (QIS)

From 1995 IEEE Workshop on CCDs and AIS



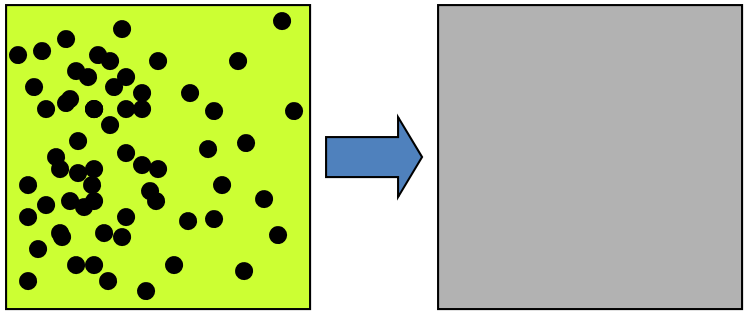
Quanta Image Sensor

- What will we do if we can't absorb light in 3 um of silicon and dynamically store charge with low dark current?
- Advancement of digital logic will probably continue at Moore's Law rate.
- Everybody loves digital and firmware programming.
- Best to go digital ASAP and let the programmers create the image!

Time for a Paradigm Shift?

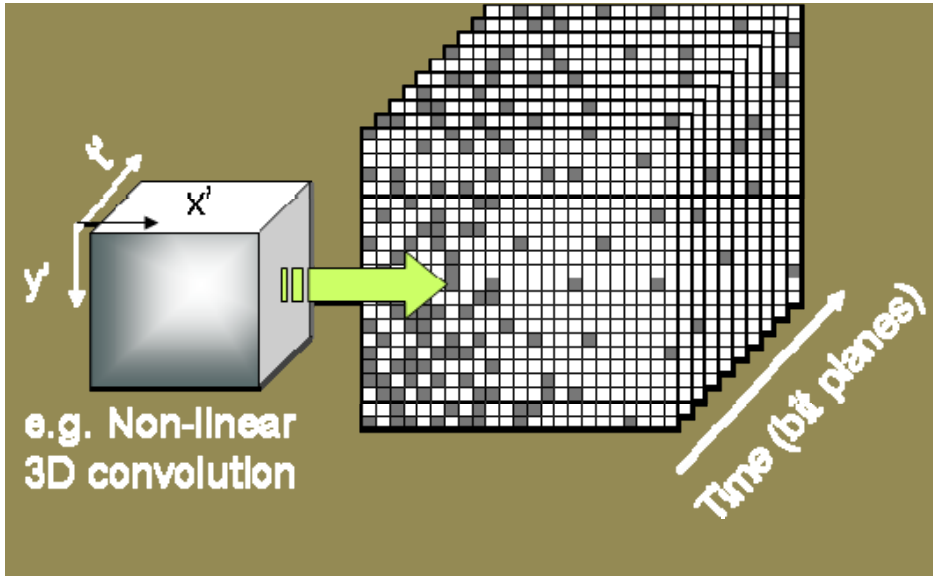
Current paradigm:

- We collect photons for a predetermined amount of time in a silicon “rainbucket” determined by physical size and capacity of silicon pixel.

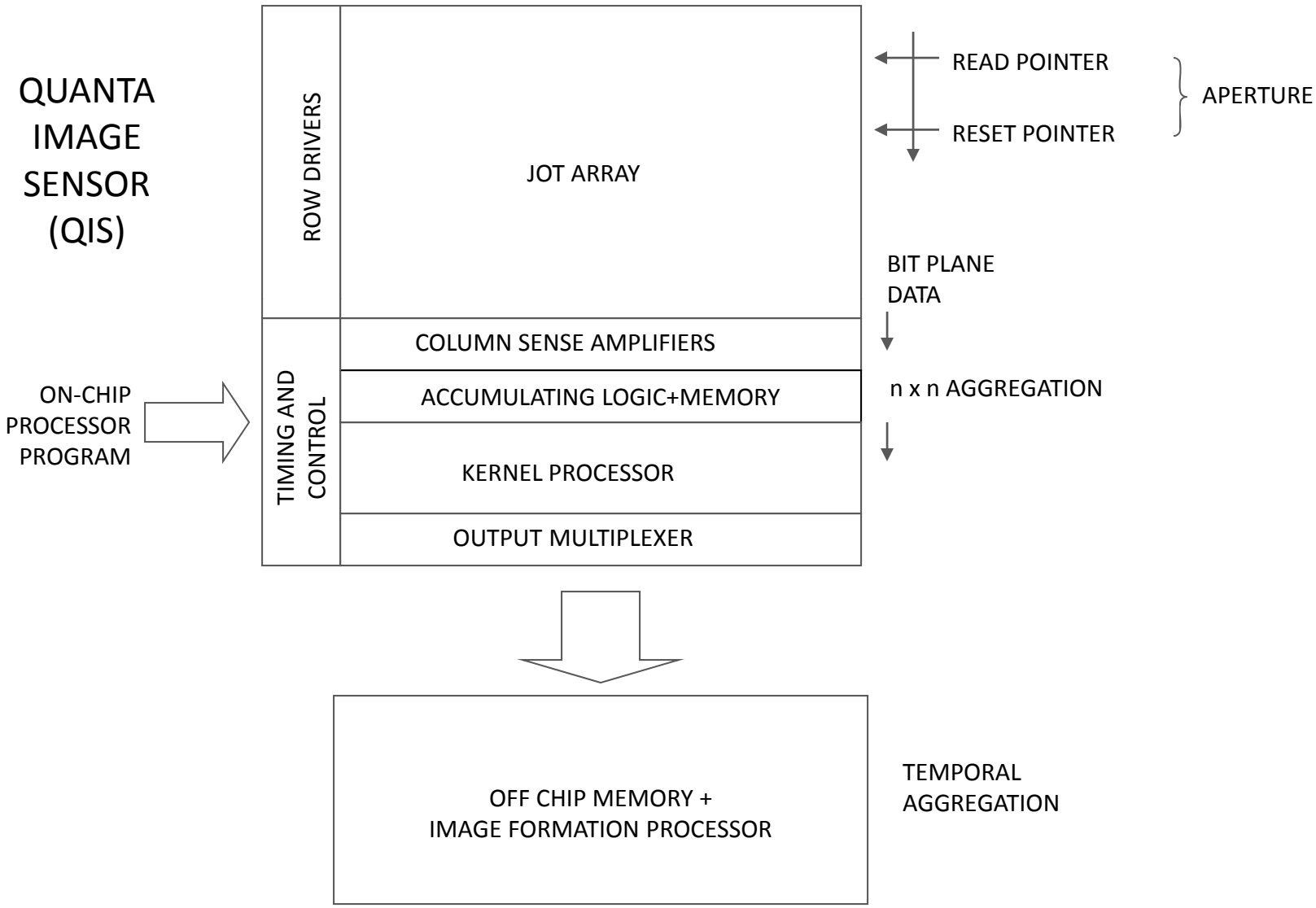


New paradigm:

- Let’s count each photogenerated carrier and record time and location, creating binary bit planes for each time slice, and then digitally form image by digital convolution over X,Y, t.



QIS Planar Architecture



QIS: Is the CMOS APS a future dinosaur?

(of course!)

25 Years and Going Strong!

- Thanks to so many people that made the meetings from 1986 work so well!
- Marvin White, Walter Kosonocky, Savvas Chamberlain, and especially my co-directors of ImageSensors Inc, Nobukazu Teranishi and Albert Theuwissen. The chairs, co-chairs, program committee chairs, and local arrangement chairs over the years. These are Arokia Nathan (’91,’93), Junichi Nakamura (’95, ’99, ’05,’11), Jan Bosiers (’97), Jerry Hynecek (’01), Sayed Eid (’01), Edwin Roks (’03), Bedabrata Pain (’07), Alex Krymski (’07), Johannes Solhusvik (’09) and Shoji Kawahito (’11).
- And of course I thank our image sensor community for strong support and participation!

CMOS APS Technology allows camera size reduction

Nixon circa 1994

CMOS APS Technology allows camera size reduction

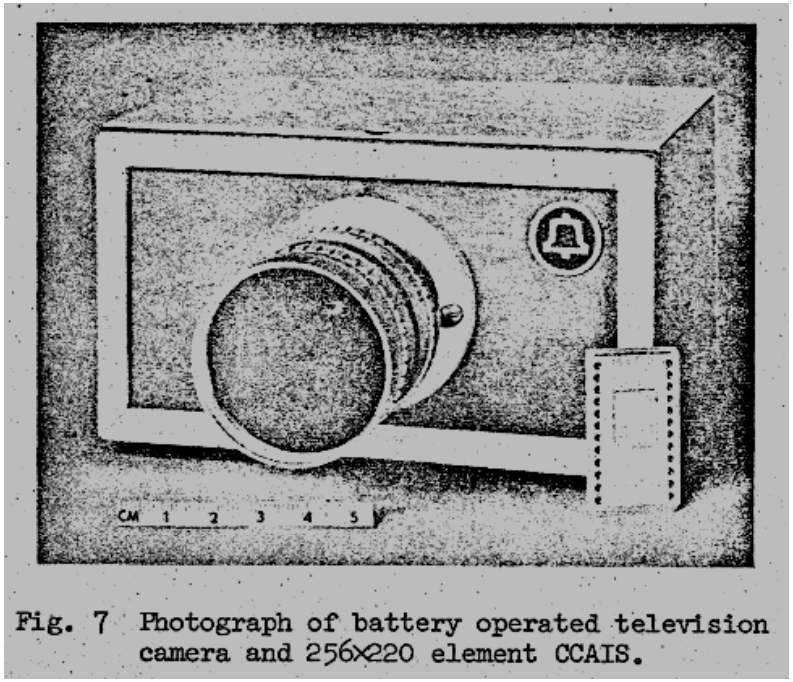


Fig. 7 Photograph of battery operated television camera and 256×220 element CCAIS.

Tompsett 1974

Nixon circa 1994