Many Pixels Make Light Work

A Brief Early History of Imaging Devices, and a Brief Self-Indulgent History of My Career

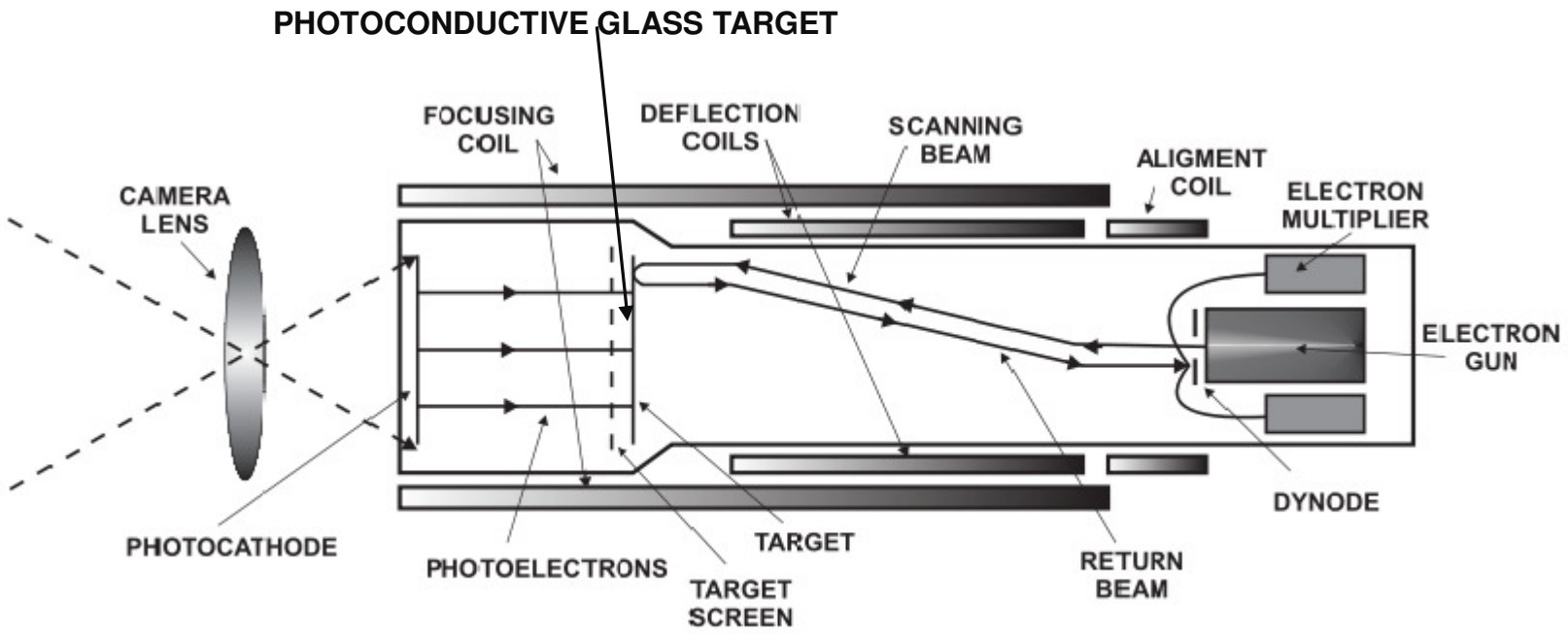
My Career 1 - Materials Science

- 1957-59 Internship with EEV Ltd, a tube manufacturer in UK
- Physics Degree at Cambridge University
- Built a Reflection High Energy Electron Diffraction (RHEED) system. (Engineering Ph.D at Cambridge)
- Built an uhv system to study the structures of thin-films of lead oxide, used for Plumbicon targets, as they were being deposited at EEV Ltd.
- Consulted with VG Systems Ltd to make a commercial system. Similar systems continue to be used today to monitor the growth of MBE Films for LEDs etc.

Electron Beam Imaging Tubes

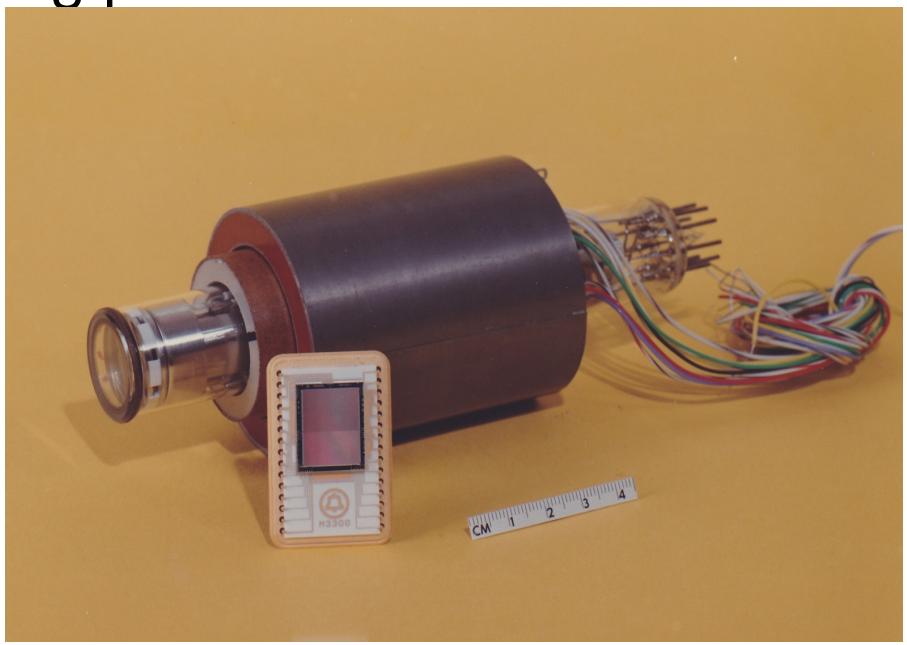
- 1908 Swinton Rubidium Mosaic
- 1915 Minchin Selenium plate
- 1924 Zworykin Iconoscope Photosensitive granules
- 1927 Farnsworth Image Dissector electron multiplier
- Essig RCA silver globules
- 1936 Tedham & Mcgee EMI silver +caesium
- 1943 Rose, Weimer & Law Image Orthicon
- Weimer Historical Review IEEE Trans ED-23, 1976

Image Orthicon Camera Tube 1943-70



Vidicon Camera Tubes

- 1950 Weimer et al Selenium Vidicon
- 1960's Hitachi Saticon SeAsTe Saticon
- 1965 Philips Lead Oxide Plumbicon
- 1968 Bell Labs Silicon Diode Array
- 1970-2000+ 3 tubes were used in tv studio cameras with color splitting prisms.



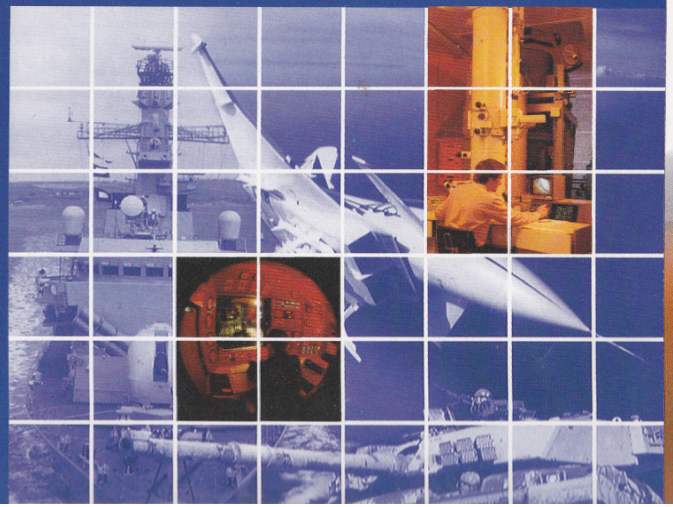
Magnetically scanned Vidicon with the first tv resolution CCD

My Career 2 - Uncooled Thermal Imaging at EEV

- 1962 Cooper defined performance of pyro-electric materials.
- 1965 Hadni et al proposed application of pyro-electrics to IR imaging using Curie temperature transition.
- 1968 Pel'ta et al Metal plug target with external pyro-electric.
- 1968 Invented the pyro-electric vidicon
- Invented a pyro-electric silicon imaging array for uncooled thermal imaging.
- C. Hanson Silicon Array work at Texas Instruments
- Wood and Kruse Vanadium Oxide detectors Honeywell.
- 1997 Wrote book chapters on Uncooled IR Imaging Arrays

DEFENCE RESEARCH AGENCY
Malvern

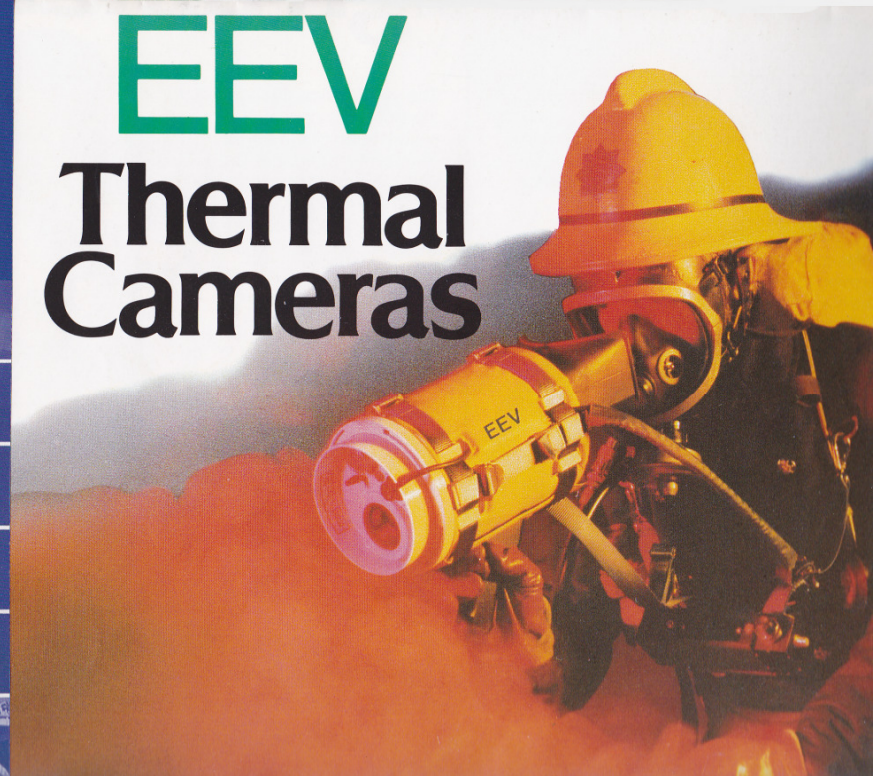
Queens Awards
For Technological Achievement



1987
PYROELECTRIC VIDICON: THERMAL IMAGING CAMERA TUBE

Conferred on the Detector Research Division of the RSRE jointly with the Electronics Division, English Electric Valve Company, Chelmsford for work in the research and development of the pyroelectric vidicon tube with special emphasis on the exploitation of the tube in the Fire Service Camera developed by EEV.

EEV
Thermal Cameras



MOS Imager Pioneers

- 1964 Weimer et al Proc IEEE 52. “Laboratory models of the TFT scan generator are being used to drive the address strips in experimental solid-state image-sensor panels”.
- 1966 Weckler “Both linear and two-dimensional arrays may be fabricated using this structure” IEDM
- 1967 Weimer et al “..experimental television camera incorporating a completely integrated self-scanned solid-state image sensor …..having 32,400 picture elements, …using thin-film CdS...
- 1967 Weckler “Storage Mode Operation of a phototransistor and its adaptation to integrated arrays for image detection”
- 1967 Noble “Light sensitive arrays based on photodiodes combined with MOS device” IEE Conf on IC’s.
- 1968 Dyck & Weckler “Integrated Arrays of silicon photodetectors for Image Sensing” ED-15
- 1968 Noble “Self-Scanned Silicon Image Detector Arrays” ED-15
- 1969 Paul Weimer “..development of ..solid-state Image sensor ..expected .. beyond present-day camera tubes”. IEEE Spectrum

My Career 3 - CCDs

- Self-recruited to Bell Labs, because I wanted to work on solid-state Imagers and AT&T appeared to need a compact imager for their clunky Picturephone.
- On my arrival I wrote letters to Smith proposing work on MOS Imaging arrays, but my letters were ignored. I was assigned to solve a burn-in problem with the Silicon diode-array Vidicon. I realised that the electron beam hit the mesh, and generated soft X-rays, that caused a shift in the oxide Flatband voltage, which caused the stored charge to spread across the array.
- I had told my bosses, Smith and Gordon of this, and Gordon also gave Smith a copy of a description of a Burroughs 3-phase plasma panel, with the suggestion that he investigate a silicon display device. Boyle had been asked by his boss, Morton, to investigate if a silicon “bubble” memory was possible.

Every Idea is a Product of Its Time

- Bucket Brigade Device – Janssen (1952)….
  ……Sangster – Philips.
- Surface Charge Transistor – Engler, Tiemann and Baertsch - GE
- Charge Injection Device - Michon and Burke - GE
- Claim of a two layer Charge Transfer Device using aluminium and overlapping gates – Noble - Plessey
- CCD – Boyle, Gordon, Smith and Tompsett – Bell Labs
- Dynamic MOS Memory – Panousis - Bell Labs
- Minimal Energy Computing – Keyes & Landauer – IBM
- Noble (1967/ 68). CTD with 2 layer metallization device derived from Decatron plasma tube. Unpublished.

The CCD Invention

- 1969 Boyle and Smith invented the basic concept of CCD and cited memory as an application, without any mention in the claims about imaging.
- They had no insight into its application to imaging, and took no part in the invention, or subsequent development of CCDs or CCD imagers.
- I realized immediately that being able to move all the charge to a single small diode would reduce the output capacitance from the 30pF of a Vidicon and dramatically improve the S/N ratio.
- I received the first patent for CCD imagers as sole inventor and made the first CCDs and cameras.

The Nobel Controversy

- The citation for the award of one half of the Nobel Prize in physics given to Boyle and Smith in 2009 reading

  "For the invention of an imaging semiconductor circuit—the CCD sensor"

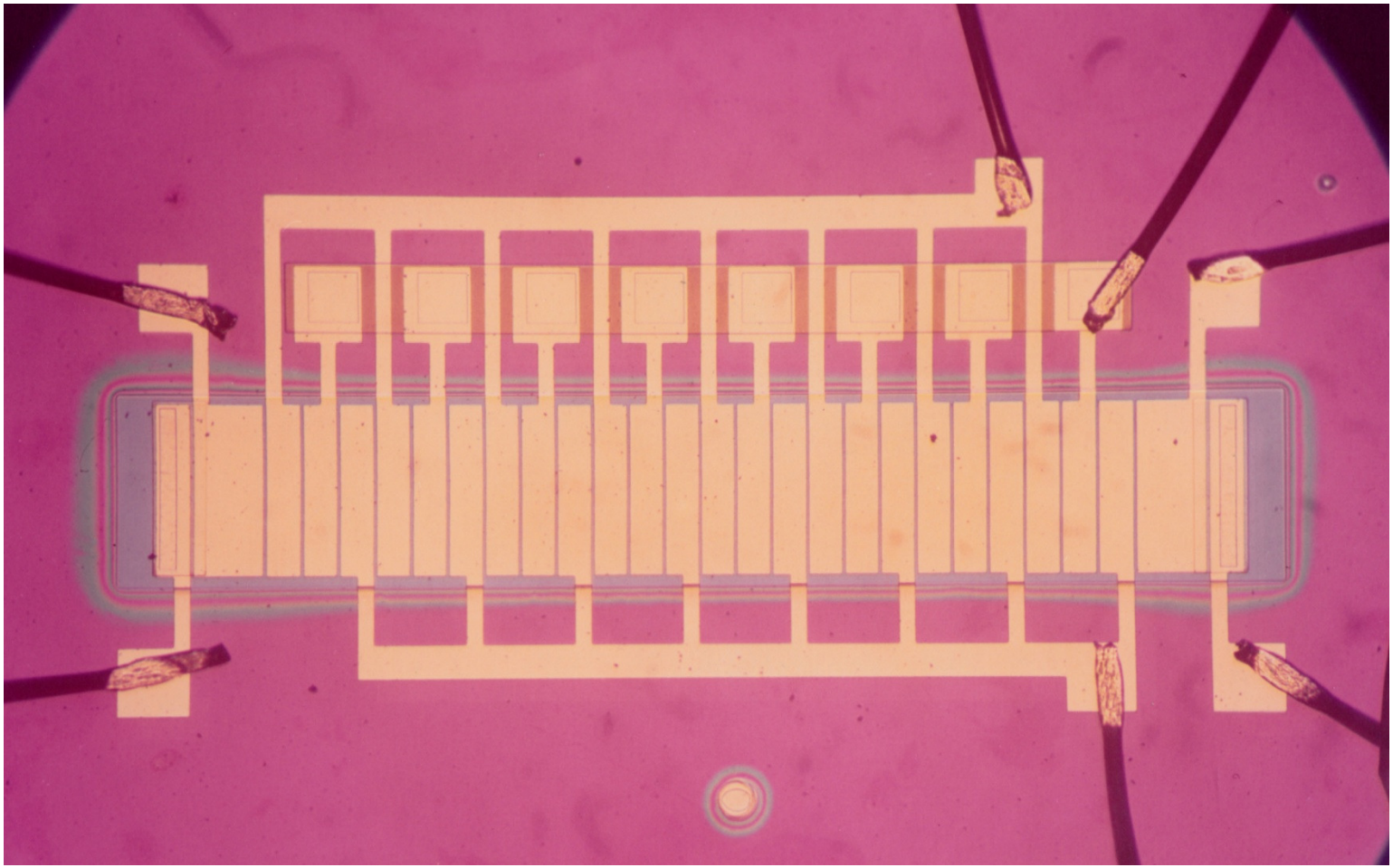
  was grossly incorrect and 'dissed' me, Noble and Weckler.

- Gene Gordon – Former Lab Director Bell Labs wrote

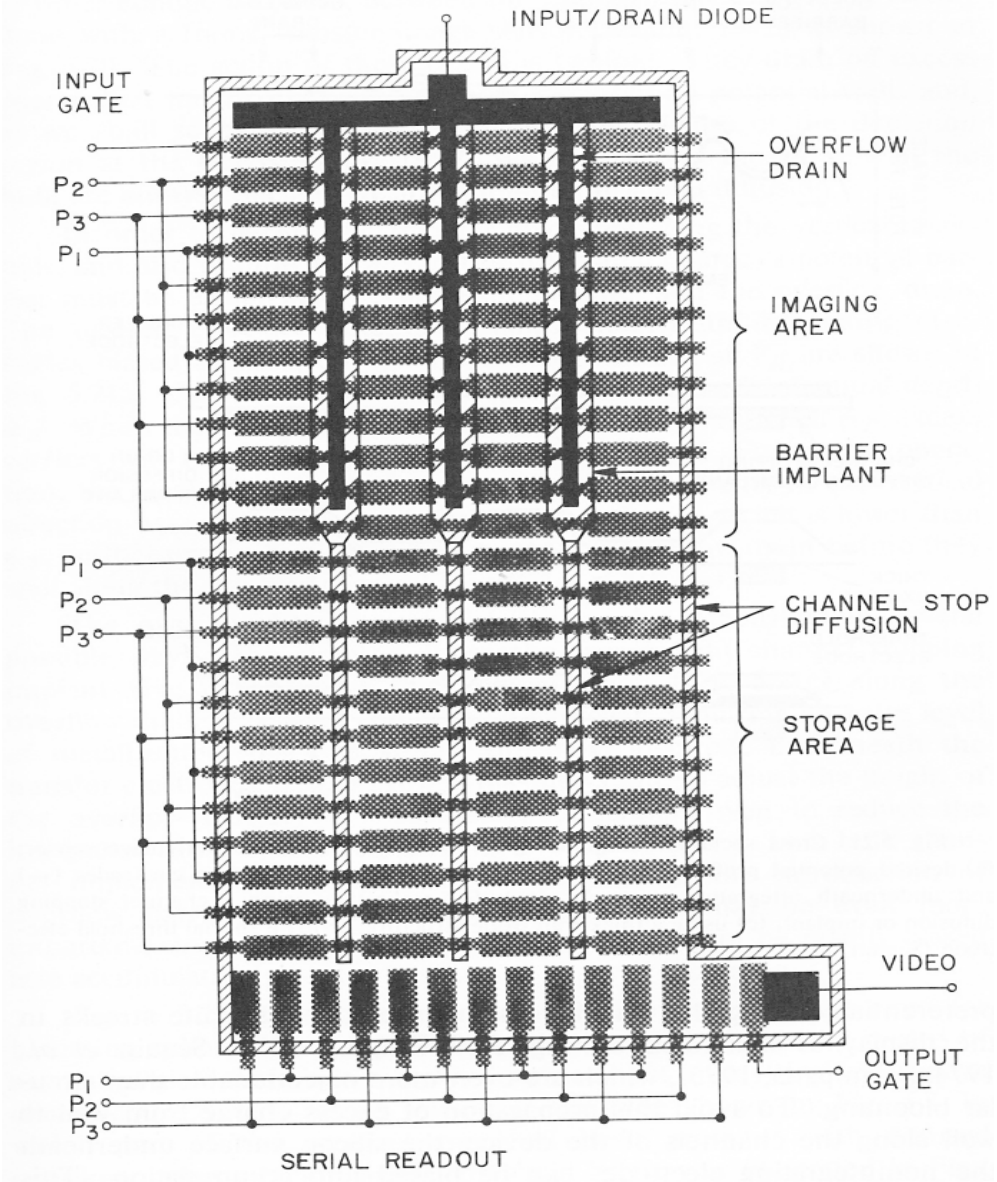
  "*The patent for the area device entitled "Charge Transfer Imaging Device" to which the Nobel award actually applies was in the name of Tompsett, and not Smith and Boyle. Their patent entitled Information Storage Device, had nothing to do with an imaging device. They never built an imaging device or any related device. Tompsett built the device of his patent, a color TV camera, and it worked. Since both Smith and Tompsett worked for me, I can say with great certainty that the award is a terrible injustice. The invention record is clear. How could the Nobel award committee mess up so badly*?"

  "*They [Boyle and Smith] wouldn't know an imaging device if it stared them in the face*."

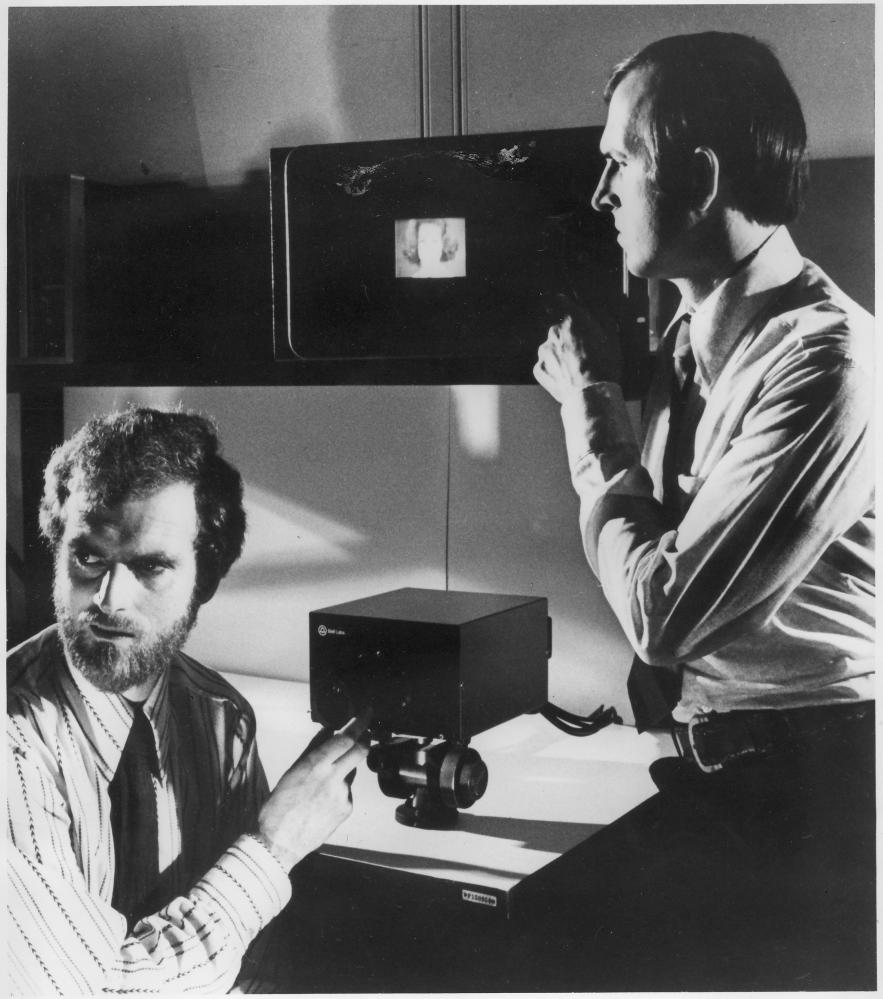
The First CCD with 8 Pixels and Input/Output Diodes



The Frame-Transfer Imager Structure (Tompsett) with Anti-blooming (Sequin)



The First CCD Color Camera



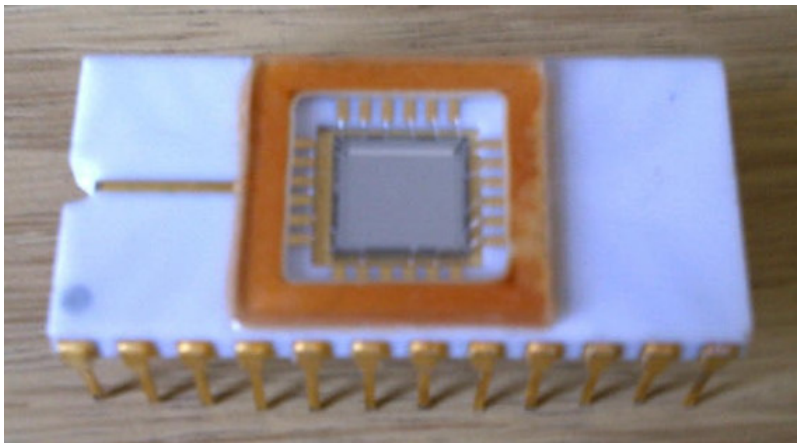
BELL LABS ENGINEERS TEST NEW CAMERA. Mike Tompsett (left) and Ed Zimany, members of the technical staff at Bell Labs, Murray Hill, N.J., test Bell Labs new solid-state color television camera. The first all solid-state color camera uses three tiny charge-coupled devices (CCDs) as image sensors instead of the more cumbersome vacuum-tube and electron-beam-scanning system of existing color cameras. Bell Labs engineers expect it to lead to a new generation of color cameras much smaller, simpler and less expensive than conventional color television cameras.

No. 19.3–23 August, 1972 Bell Laboratories

The First CCD “Digital”/Pixelated Image 1972

Dr Margaret Tompsett

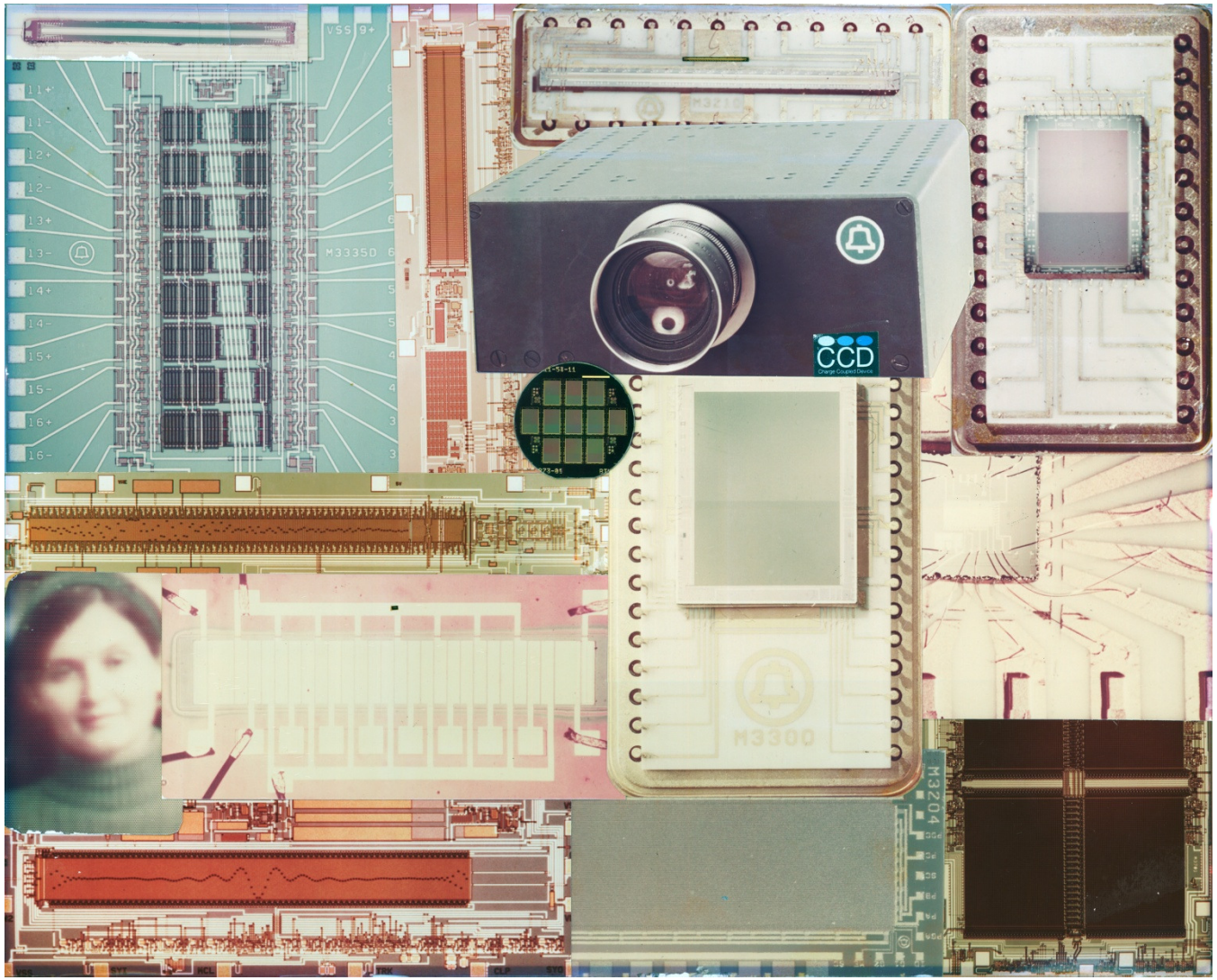
MOS “Digital”/Pixelated Image



64x64 pixel MOS Imager

Noble 1972/1973

We tried everything!
Area & Linear Imagers, Memory, Signal Processing



“How did you do so much so quickly?” Fossum

- I had a great collaborative group, especially Carlo Sequin, Ed Zimany, Dave Sealer.
- We used an easy-to-make 3-phase, 3-level structure instead of moving to 2-phase and buried channel.
- Received great collaboration from good friends in the shops.
- Did a dark-current study with dramatic results (~1000 fold improvement).
- We never let analytical work stand in the way of development.
- It was all ups and no downs.
- Bell Labs research was funded from a 1% levy on phone revenues.
- The first color camera used a commercial tv camera prism splitter.
  I “borrowed” the time of an optical designer for a miniaturized one.
- I wrote the Book on CTDs (with Carlo Sequin) after hours.
- I disobeyed my bosses.

“Why did we not go into production?” Fossum

- AT&T cancelled Picturephone because 1Mbps brute force transmission on copper wire required $2000 of line conditioning.
- Non-communication sales by AT&T/Western Electric were disallowed by the 1956 Consent Decree.

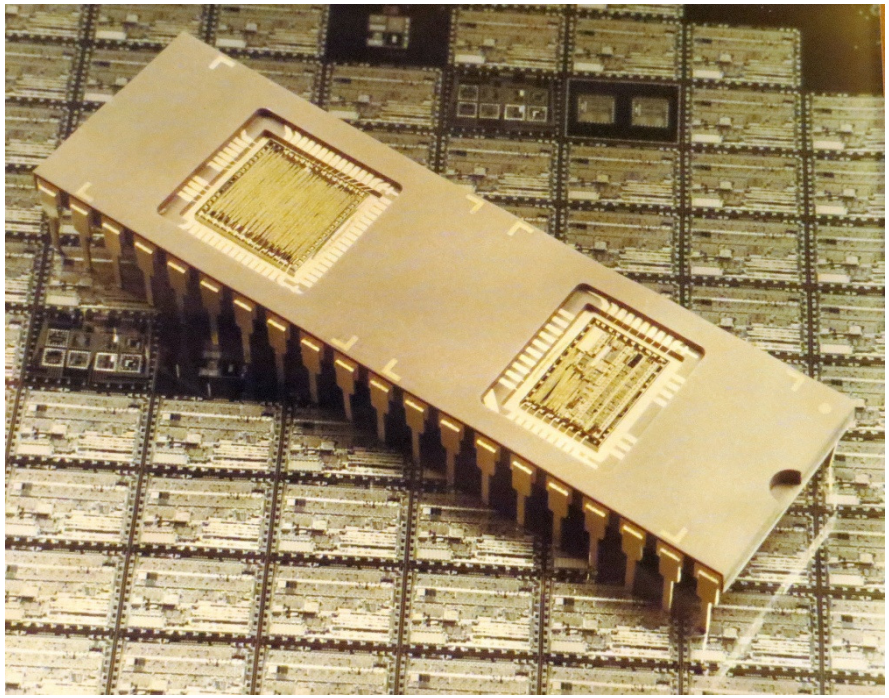
CCDs After Area Imagers

- No product group for linear imagers.
- Serial memories lacked random access.
- Developing voice-band filters using CCDs (also Henaff in France) were unsuccessful.
- Patented and made a pipelined CCD Analog to Digital Converter but no market.
- 2 colleagues wanted me to do a startup with them, but I contended that in the 1970s cost and quality would take too long to solve.

My Career 4 – Integrated Circuits

Developed First Mixed-Analog Digital MOS IC/Integrated System for a 2400/4800bps modem to go into Manufacture

- 1200bps Modems were very bulky.
- I had kept a paper gathering dust on my desk for years describing switched capacitor filters.
- Capacitor D/A invented at UC Berkeley.
- Enlisted help from modem, filter and CAD groups.
- Dynamic range almost killed the project and required inventing an MOS AGC.
- Developed analog testing on a digital wafer test machine.
- A vicious manager could not understand innovation and almost killed me and the project.



My Career 4 contd. Video Analog-to-digital Converter

- After 10years of trying, Imagers and Signal Processors still lacked a low-power integrated video ADC.
- 1987 Finally invented a simple architecture for a recycling two-step ADC in MOS.
- Prototype and production of 10bit 15MHz CMOS chips were designed by BangSup Song and ADI sold $25M in first year.

My Career 4 contd. Product Development

- Took over a $20M product line of MOS CODECs that was in trouble.
- Solved problems and reduced $20 cost/CODEC to $1.
- Worked with a German company to develop a µP controlled single chip telephone.
- Worked with Nokia to develop the analog interface chip for a 5-chip set for their first GSM mobile phone.

My Career 5 – Federal Government

- 1989 Retired from Bell Labs.
- 1990 Stay-at-home Dad - Conceptualized a product giving directions from digitized Geological Survey maps but without knowledge of GPS. A missed opportunity to start a new business.
- 1991-97 Director of Electron Device Research Division for US Army with ~140 people (70Ph.Ds).

My Career 6 – Software Developer & Entrepreneur

- 1998-2012 Founder and President TheraManager LLC. Developed an **E**lectronic **M**edical **R**ecord and Practice Management Software Program for Medical and Mental Health Offices.

2010 Lifetime Achievement
National Medal of Technology & Innovation

2012 IEEE Edison Gold Medal. 2010 NJ Inventors Hall of Fame Pioneer Lifetime Award

"Almost everything that I have done has been on my initiative, and without direction".

Peter Noble – MOS Imager Pioneer

- TI Bedford England - Engineer
- 1966-69 Plessey Research Team Leader for image sensors initially for an OCR application. Successfully made experimental arrays (72x5) arrays, but management did not share Noble's vision (pun intended).
- 1969 Founded Integrated Photomatrix Ltd with fab to make small MOS sensor arrays for many applications. Then developed a 4k (64x64) pixel array, and 256, 512 and 1024 linear arrays. The 4k array and camera was awarded a Queen's Award in 1974. In 1973 started work on a full colour sensor array using digital signal processing to enhance resolution, but the new owner of the company did not share his color vision.
- 1974- present Independent global consultant.. Development of positioning technology for a robotic pcb assembly machine and other products, patents, book writing etc.
- 1988 Founded Team Extreme now UK's top professional extreme sports show team.
- Remains unrecognized for his pioneer work in Britain.

Gene Weckler – MOS Imager Pioneer

- 1951 – 1955 Electronics Technician US Navy
- 1959 – 1963 Shockley Transistor Corporation Testing and application development
- 1963 –1971 Fairchild Semiconductor R&D Labs Developed first practical integrating silicon detector, a photodiode and an MOS Transistor, integrated as a single pixel. Developed both linear and area arrays of integrating pixels in the mid 60's.
- 1971 – 1997 Co-Founder Reticon Corporation Developed and marketed the first solid state imaging devices, the first digital imaging cameras, and the first computer controlled vision systems marketed in the USA. Introduced the first commercially available switched capacitor filters, and a variety of discrete time analog signal processing devices. Under EG&G Optoelectronics Group looked for new markets and new semiconductor based technologies.
- 1997 – 2009 Founder Rad-Icon Imaging Developed high performance cost effective digital x-ray imagers and cameras based on CMOS technology.

Many Pixels Make Light Work

16 Mpixel Frame-Transfer CCD 1980's Astronomical Imager