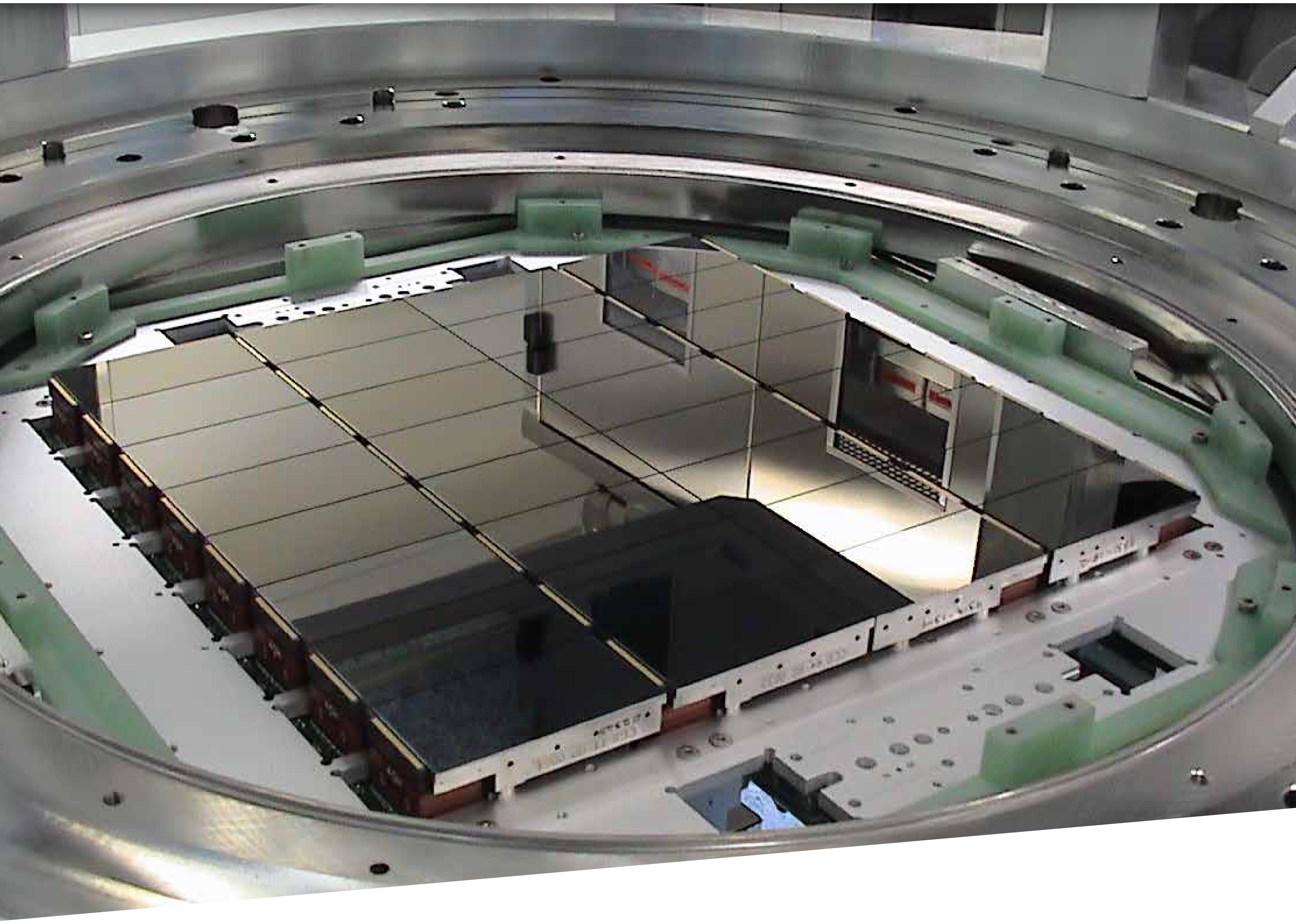


50 YEARS of the
Charge Coupled Device (CCD)

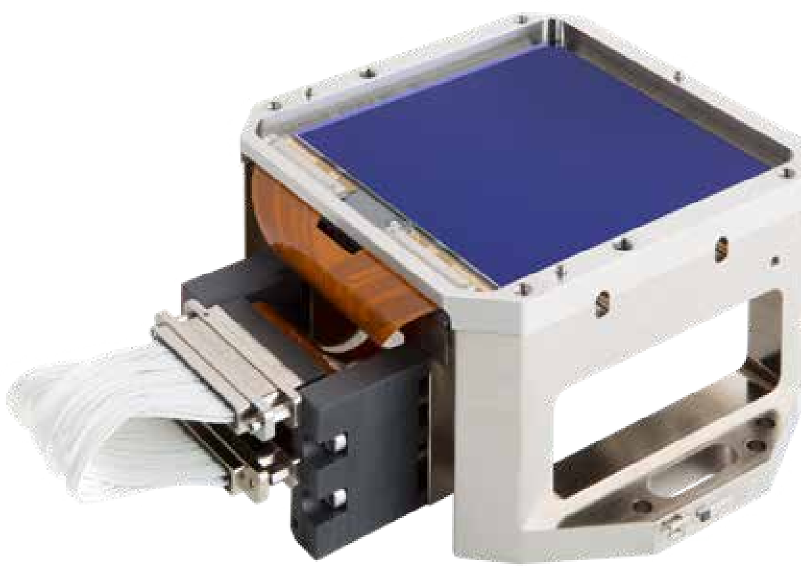
50th Anniversary of the Invention of the CCD

October 2019 through to January 2020 marks the 50th anniversary of the CCD, a device that has transformed the understanding of physics, life sciences, the Earth, our solar system and beyond, and enriched our lives through digital photography.

Willard Boyle and George E. Smith invented the charge-coupled device (CCD) in 1969 in the United States at AT&T Bell Labs. In 1970, Boyle and Smith submitted a paper on their invention of the CCD to the Bell System Technical Journal. Their original ideas for the CCD was to create a memory device. However, with the publication of Boyle and Smith's research in 1970, other scientists began experimenting with the technology on a range of applications. Astronomers discovered that they could produce high-resolution images of distant objects, because CCDs offered a photosensitivity one hundred times greater than film.

"The major thing is the quantum efficiency. You can get close to 80 percent quantum efficiency in a CCD,"
George E. Smith would later explain.

Since then applications have included cameras, ground and space telescopes, as well as spectroscopy and microscopy instruments to name a few.



Teledyne e2v CCD Bruyères CCD image sensor to be used in the PLATO exoplanet hunting spacecraft.

(Opposite page) Dated lab book entry signed by Willard S. Boyle and George E. Smith, October 19, 1969

Front cover credit:
ESO – 16Kx16K OmegaCAM CCD mosaic (built by ESO's Optical Detector Team, utilizing eev/Marconi/e2v/Teledyne 44-82 CCDs), for the VST (VLT-Survey-Telescope) on ESO's Paranal Observatory. Photograph taken by O. Iwert

DATE 19 Oct. 1969 93

CASE No. 39161-17

Charge "Bubble" Devices:

In colaboration with W. S. Boyle, a scheme for moving pockets of charge (or the absence of charge) along the surface of a semiconductor was devised. This resulted from discussions between W.S. Boyle and G.E. Smith held on Sept. 8, 1969 and the basic scheme was disclosed to F. H. Smits later that day. The principle is demonstrated by the following specific structure.

A negative voltage applied to the electrodes of the above structure causes a depletion region to form under the electrode. The band bending across section A-A when the voltage is first applied is shown below. As a result of generation-recombination centers in the depletion region and at

W. S. Boyle 10/18/69   G. E. Smith 10/18/69

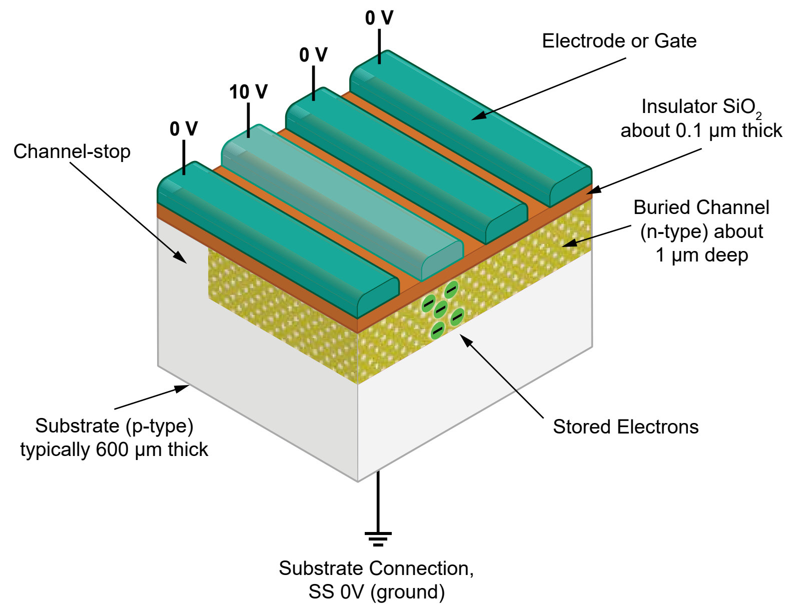
WHAT IS A CCD?

A charge-coupled device (CCD) is a solid-state circuit for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, such as conversion into a digital value. This is achieved by “shifting” the signals between captive bins within the device one at a time.

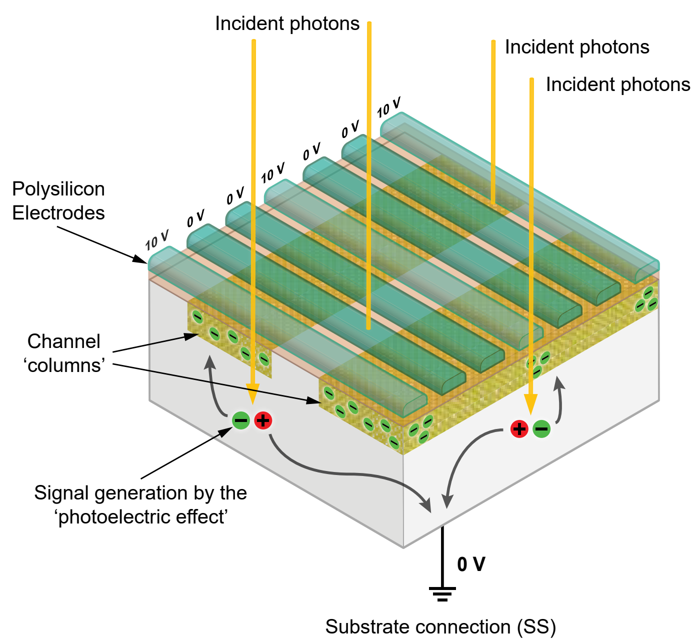
The CCD is a major technology for digital imaging. In a CCD image sensor, pixels are represented by p-doped metal–oxide–semiconductor (MOS) capacitors. These MOS capacitors, the basic building blocks of a CCD, are biased above the threshold for inversion when image acquisition begins, allowing the conversion of incoming photons into electron charges at the semiconductor-oxide interface. The CCD is used to read out these charges. Although CCDs are not the only technology to allow for light detection, CCD image sensors are widely used in professional, medical, and scientific and in the majority of past, current and future space astronomy, science and Earth observation applications.

> **Please see our Charge Coupled Devices Operation information pamphlet for a more detailed explanation.**

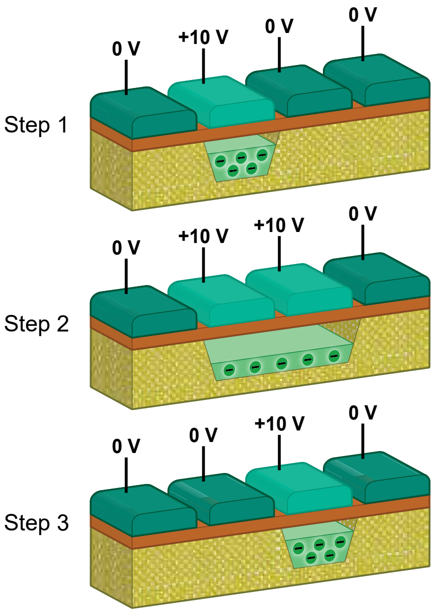
Section of a CCD Array



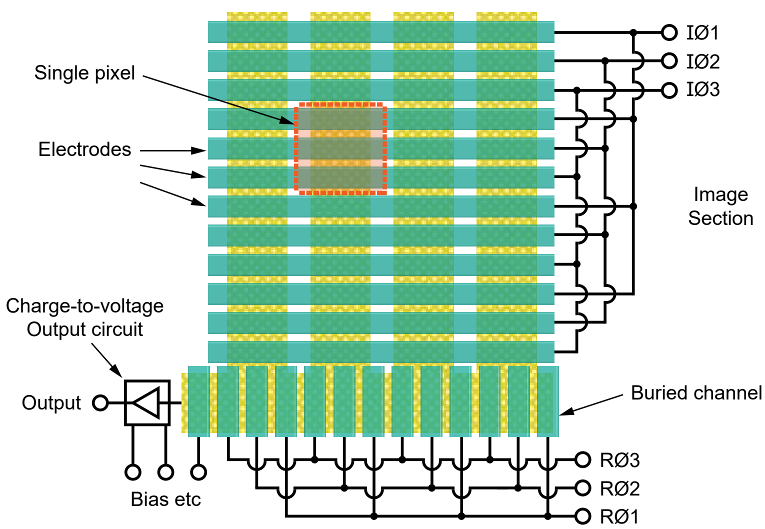
Section of a CCD Array with Electrodes and Channel ‘Columns’



Principle of Charge Transfer



Readout Register



Credit: NASA Earth Observatory images by Lauren Dauphin, using Landsat data from the U.S. Geological Survey.

NOBEL PRIZE 2009

Such as the significance of the invention, the two physicists who co-invented the CCD image sensor were rewarded with a share of the 2009 Nobel Prize for Physics. Cited from The Royal Swedish Academy of Sciences (Press release. NobelPrize.org. Nobel Media AB 2019. Sun. 10 Nov 2019):

"The CCD technology makes use of the photoelectric effect, as theorized by Albert Einstein and for which he was awarded the 1921 year's Nobel Prize. By this effect, light is transformed into electric signals. The challenge when designing an image sensor was to gather and read out the signals in a large number of image points, pixels, in a short time.

"The CCD is the digital camera's electronic eye. It revolutionized photography, as light could now be captured electronically instead of on film. The digital form facilitates the processing and distribution of these images.

"Digital photography has become an irreplaceable tool in many fields of research. The CCD has provided new possibilities to visualize the previously unseen. It has given us crystal clear images of distant places in our universe as well as the depths of the oceans."

KEY CCD DATES

February 4, 2020 – SC504 Class at SPIE Photonics West — Introduction to CCD and CMOS Imaging Sensors and Applications — Richard Crisp.

February 1, 2017 – Queen Elizabeth Prize for Engineering awarded to Eric Fossum (USA), George Smith (USA), Nobukazu Teranishi (Japan) and Michael Tompsett (UK) for their work on digital imaging sensors. Smith and Tompsett did their work while at Bell Labs.

1980 – DALSA Corporation (now Teldyne DALSA) established and focused on the production of CCD.

January 29, 2020 – 50th Anniversary of the invention of the CCD.

October 6, 2009 – Two physicists who co-invented the CCD image sensor are rewarded with a share of the Nobel Prize for Physics. Willard S. Boyle and George E. Smith developed the charge-coupled device in 1969 while working at Bell Laboratories, producing the world's first solid-state video camera just a year later.

1972 – e2v (formerly EEV and now Teledyne e2v) establishes a CCD wafer fab and processing facility in Chelmsford, Essex, UK that became world's major supplier for the majority of space imaging missions and large ground-based astronomy telescopes.

January 29, 1970 – Willard S. Boyle and George E. Smith, of Bell Labs, submitted a paper on their invention of the CCD to the Bell System Technical Journal.

1970-1971 – Michael Francis Tompsett filed first patent (U.S. Patent 4,085,456) on the application of CCDs to imaging. Savvas Chamberlain also started his research in 1970 into what would become DALSA image sensors.

1970 **1960**

October 19, 1969 – Dated lab book entry signed by Willard S. Boyle and George E. Smith (see page 3).

CCD DISCOVERIES

Just some of the discoveries the CCD has given us so far and some still to come

- Mass low cost DNA sequencing
- Single molecule detection for life science imaging
- Digital cameras giving way to cultural change and access to post-processing techniques outside of the darkroom
- CCD gives way to next generation CMOS digital cameras and an estimated 400 billion digital photos taken globally in 2011 (expected to rise to 1.2 trillion photos in 2017)
- First discovery of an exoplanet orbiting a sun-like star—51 Peg b
- The Kepler Mission space telescope after nine years collecting data that revealed our night sky to be filled with more planets even than stars
- The Cheops mission space telescope to characterize exoplanets known to be orbiting around nearby bright stars
- The PLATO mission space camera instruments objectives are to find and study a large number of extrasolar planetary systems, with emphasis on the properties of terrestrial planets in the habitable zone around solar-like stars

Credits: NASA, L. Hustak and J. Olmsted (STScI)

This artist's impression shows a rocky exoplanet with a wispy, cloudy atmosphere orbiting a red dwarf star. Astronomers have identified a new method that could allow NASA's James Webb Space Telescope to detect an exoplanet's atmosphere in just a few hours of observing time.

THE FUTURE OF THE CCD

Today, the quantum efficiency for some of the most advanced CCDs is in the high 90 percents through innovations such as backthinning, back-illumination, anti-reflective coatings and high resistivity silicon on formats as large as over 9000 x 9000 pixels (81 Mpixels) with large pixels sizes.

Despite their maturity, CCDs have not reached the end of their development, and several aspects have been identified which could be of benefit for future science applications and space missions. Identified improvement areas include enhancements to the signal handling and noise performance, increasing the tolerance to non-ionising radiation, and changes to further increase the ultraviolet and near-infrared quantum efficiency and stability.

Teledyne e2v, in the UK, continues to develop a vertically integrated dedicated CCD fab, make technology developments to the design and production of CCDs, and is committed to the provision of high performance and customized CCD detectors and packages and at the same time are investing significantly in the development of high-performance CMOS image sensors.

Teledyne e2v's CCD fabrication facility is critical to the success and quality of future space science missions and remains committed to being the long-term supplier of high specification and quality devices for the world's major space agencies and scientific instruments producers.

For further information on CCDs please visit www.teledyneimaging.com.