Brief History of Imaging Technology

April 2013, v28 Tim Vitale © 2000-2013

Brief Overview: Imaging began when a picture was formed through a tiny pinhole air lens in a Camera Obscura and then traced onto a surface in 1021 Iraq and 1550s Italy. This first phase of the technology was mechanical imaging. Eventually, mechanical imaging gave way to chemical based imaging when the first sun-picture was made in 1816 France. The first stable chemical image was also made by Niépce using bitumen coated on a polished pewter plate, between 1822 and 1826, through a Camera Obscura; which fits one of the popular definitions of a photograph.

Chemical imaging technology uses photons of light, focused through a glass lens, to chemically reduce silver ions to silver metal to create an image; silver chemistry [$2Ag^-$ to Ag_2] is the most common form of this technology. Through a series of baths, the silver image would be made permanent after it was fixed using Hershel's Hypo bath formulated in 1839.

One-of-a-kind photographic images such as Daguerreotype, Ambrotype and ferrotype [tintype] ultimately gave way to multiple prints from the same negative during the 1840-50s era. Printing-out-paper (POP) was developed using light in a sun-frame, albumen print technology became wide-spread latter half of the 19^{th} C.

Film was first manufactured about 1889. However, glass plate negatives remained dominant because of their sensitivity and dimensional stability for an additional 30+ years. Gelatin became the dominate silver emulsion material around 1890.

Half-a-century-later (1947-58) as technology matured from analog election valves to digital switches, moving away from energy-wasting hot vacuum tubes (1904) to small cool transistors (1925-1947) that decreased circuit size about 1000-fold and increased speed. Circuits became more complex and less expensive as many consumer devices were downsized. The transistor radio was the iPod of the late 1950s. By 1971 Intel (Mt. View, CA) was producing the first chips for digital watches and the [brand new] digital calculator that would wiped-out the ubiquitous slide rule used to create the revolution.

Boyle & Smith of Bell Labs (NJ) used photons of light to create an image using their tiny 8-pixel charged-coupled device (CCD) in 1969; followed by Ochj's 8 by 8 pixel CCD in 1972. This technology physically counts the number of light photons falling onto a silicon chip to produce an image directly from light with no intervening chemical or mechanical steps.

Steve Sasson of Kodak created the prototype digital camera in 1975 consisting of a Kodak movie camera lens, a Fairchild Semiconductor 100 x 100 pixels (0.01 MP) 8-bit CCD, using a Motorola A-D converter. The first commercial digital camera was Sony's Mavica B&W camera (1981) with its 0.79 MP sensor. The Canon RC-701 was the prototype color video still system with an integrated transmitter for use at the 1984 Olympic Games and released in 1986.

News photographers were the first to adopt the emerging digital technology because their images have low resolution and a file size that could be transmitted economically over telephone lines, such as during the 1984 Olympics, where color images were transmitted and printed in Japan within hours of the events. USA Today and AP went digital in 1987-8.

Digital imaging matured in 1994 with the development of the scanback by Mike Collette using a Kodak tri-liner CCD array. The scanback camera created superior images at greater resolution than film, by a single operator, who can now print the image within minutes using light-stable inks and paper that are viable for hundreds of years. This was a vast improvement over color photographic technology, which must go through several operators because its chemical processing is so complex, to create prints that often have noticeable fading in 15-25 years and can be almost lost 50+ years. While film's familiar noise (grain) and translucent gelatin emulsion image layer are prized by some, digital images offer the control only dreamt of by some of the greats of photography, e.g., Ansel Adams, Minor White (Zone System), and noise reductions of ten-fold and more.

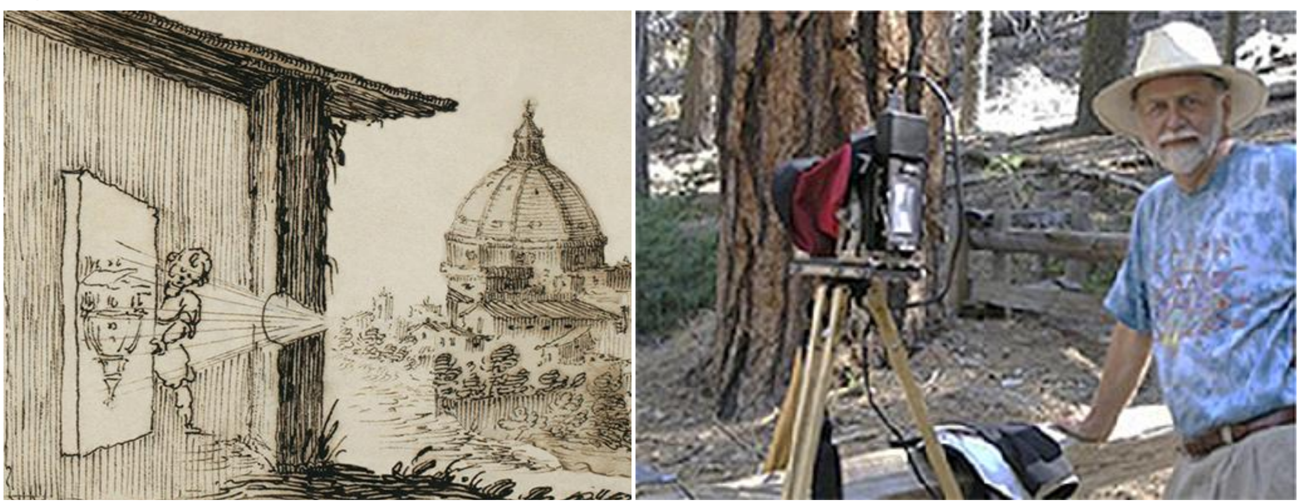


Figure 1- Left: shows the use of a 16^{th} C Camera Obsura; **Right**: BetterLight scanback in a view camera being used deep within Yosemite National Park where images are previewed on a laptop by Mike Collette, scanback inventor.

Hyperlinked Index

Timeline of Imaging Events

Pre-Photography; Lens History; Film Camera; B&W Photography; Color Photography; Digital Photography; Solid-Sate Electronics; FAX Technology; Magnetic Media; Video Technology; Digital Printing Technology

3000 BC/BCE (5000 BP)

- **Polished stones** were used to magnify (early visual aid) and condense light, about 3000 BC, or earlier
- **Glass** was invented in the Bronze Age, and then perfected by the Egyptians 3000- 2500BC
- **Palm Leaf Manuscript first bound** (string through common hole) sometime about 1400-1499 BC
- **Isidore de Seville** publishes the relationship between codex, book & scroll in his Etymologiae between 499-400 BC
- Greek and Chinese scholars describe the basic principles of optics and camera, circa 300-400 BC
- **Aristotle writes of darkened room with small hole** in one wall, inverted image on opposite wall, 330-300 BC
- **Paper fragments are found in China** in materials dated to 179-41 BC

0 AD/CE (2012 BP)

- **Greeks** discover rubbing fur on Amber cause attraction between the two (electron & static electricity) about year 1
- **Paper invented in China in Han Dynasty** court by **Cai Lun** sometime around 105
- **Woodblock/woodcut** printing technology developed about 200
- **Paper technology** adopted in the Islamic world [Samarkand] after the Chinese defeated at Battle of Talas in 751

1000

- **Reading Stone**, a glass sphere use to read by magnified letters was in recorded use around 1000

- **Lens** is first described in the Book of Optics by Ibn el-Haitam an Iraqi Physicist published in 1021
- **Camera Obscura first** published in Book of Optics by Iraqi scientist, Ibn al-Haytham, used a pinhole [air] in 1021
- **Paper technology** migrates to Portugal and Spain in about 1071
- **Paper technology** migrates into Italy sometime between 1300-1400
- **Paper technology** migrates into Germany about 1400
- **Guttenberg Press** [**Johannes Gutenberg**] [also called letterpress] first used in Germany about 1439-1440

1500

- **Movable-type press** is in-use throughout all of Western Europe by 1500
- **Etching plate** and printing technology developed about 1500
- **Camera Obscura with a lens**, Girolamo Cardano replaced pinhole [air lens] with biconvex lens in the 1550s
- **Giovanni Battista della Porta** (1538-1615) published first account of Camera Obscura to aid drawing in 1558

1600

- **William Gilbert** coined *electric* from the Greek *electron* to identify force between materials rubbed together 1600
- **Telescope** - first written mention in Zeeland (Dutch) document, **Hans Lipperhey** claims a new device in 1608
- **Galileo** made his astrophysical studies using a early **telescope** in 1610
- **Antoine van Leeuwenhoek** Dutch amateur microscopist invented the water drop lens latter part of 17^{th} C
- **Newton** discovers that **white light** is composed of colors of light (**spectrum**) between 1664-66
- **Reflex-mirror** design in a camera obscura was first published in 1676

1700

- **Johann Heinrich Schulze** mixes chalk (for white base color), nitric acid and silver and notices **darkening on the side of flask** exposed to sunlight; first photo-sensitive compound discovered, silver nitrate ($AgNO_3$) in 1724-27
- **Hall Achromat** curved-field lens, uses two glass types (crown & flint) to focus red and blue light in the same place, but because green-light focus point was shifted, the resolution was still somewhat soft, developed about 1770-75
- **Benjamin Franklin's** kite flight in 1752 led to discovery of the concept of **electricity**; article was published 1756
- **Elizabeth Fulhame** published *Essay on Combustion*; silver salts to stain designs on cloth in 1794
- **Lithography technology** developed about 1796
- **Thomas Wedgwood** created **Sun Pictures**, cameraless shadowgrams 1790-1802-5; paper or leather with silver chloride-nitrate; un-fixed; darken with more than a candle; 1802 Royal Society pub by Sir Humphry Davy

1800

- **Volta [Alessandro]** constructed the voltaic pile (**battery**) first device to produce a constant electric current 1800
- **Wollaston Landscape lens** first properly designed lens, but still suffers curved-field & chromatic aberrations, 1812
- **Lithography on stone** and metal plate (more modern) began in France about 1813
- **Camera for photography,** used by **Niépce**, was a sliding wooden box type, by Charles & Vincent Chevalier, in 1812
- **Nicéphore Niépce** combines Camera Obscura with photosensitive silver paper; not fixed, thus not permanent 1816
- **Nicéphore Niépce** may have made an foggy image of a table setting in 1822
- **Nicéphore Niépce** creates heliograph print, from a 17thC engraving, lithographically printed from metal plate 1825

1825

- **Nicéphore Niépce** creates first stable image by coating a pewter plate with bitumen, hardened w/ light over 8-hours in a Camera Obscura and washed off the under exposed material using oil of lavender to reveal a stable image 1826
- **Joseph Jackson Lister** develops lenses with **reduced chromatic aberrations** by introducing concept of several different lens elements, each with a portion of the full magnification formerly required from one lens element, in 1830
- **Michael Faraday** created the **electric dynamo** used to generate electricity in 1831
- **Chevalier Achromatic lens**, 2 glass elements cemented together, still found in modern point-n-shoot cameras,1835
- **Chromolithography** color printing using lithography (planograph) technology developed around 1837
- **Daguerreotype,** Louis Daguerre, Ag-I negative on polished copper sheet, developed with mercury vapor, 1835-39
- **Herschel**, John, FW., publishes work on a successful fixing agent, hyposulphites (Hypo) in 1939
- **Daguerre** licensed **Chevalier lens** for a wood-body camera designed for quarter-plate under his name in 1839-40
- **William Fox Talbot** publishes how to make **Photogenic Drawings**, $AgCl/-NO_3$ crystals in paper, fixed, 1839
- **Paper negatives** (waxed after processing) shown to scientists and hobbyist, see Fox Talbot above, in 1839
- **Talbotype (Calotype)** by William Fox Talbot**;** $AgCl/-N0_3$ fixed paper neg. w/contact printing, a pos print 1841
- **Salted Paper prints** (generic name for the Talbot's process) silver salts in paper fibers, fixed, 1841
- **Petzval Achromatic Portrait lens**, first "mathematically designed photographic lens" created in 1841
- **Carl Zeiss** opens his workshop in Jana, Germany to make eyeglasses and microscopes for University 1846
- **Niépce de St Victor** and **Louis-Désiré Blanquart-Evrard** experiment with albumen on glass plates 1847

1850

- **Color Daguerreotypes**, first Hillotype (1851) and then Heilochrome (1853), had a short lifetime beginning in 1850s

- Albumen Print was invented by **Louis-Désiré Blanquart-Evrard** where sensitized egg albumen coated on paper, using Printing-Out-Paper (POP) technology where a print is developed by exposure in a sun-frame, then fixed and dried, or it could be further chemically enhanced by Pyro development for darker image in 1850
- **Crayon Portraits** by itinerate artists, thin POP image under chalk or charcoal design layer, 1850's thru 1900's
- **Collodion Wet Plates**, Frederick Scott Archer, silver-collodion (-Br, -Cl & -I) in ether solvent on glass, 1851
- **Telegraph Fax** - Alexander Bain is credited with inventing the technology (dots & dashes), patented in 1853
- **Ambrotype** invented by James Ambrose Cutting: an underexposed collodion glass plate negative with a black (cloth) background, combined to produce a visual interpretation that appears as a positive image, 1854
- **Tintype** (Ferrotype) by Hamilton Smith, underexposed neg. on black metal plate, makes positive image 1857

1860

- **Telegraphic Fax sent,** Giovanni Caselli used the Pantelegraph to send first fax between Paris & Lyon in 1860
- **First additive color process**: 3 exposures thru 3 filters, combined into color image, by James Clerk Maxwell 1861
- **Electro-magnetic radiation** is described by James Clerk Maxwell, radio waves discovered in 1864
- **Silver-collodion paper**, POP by photographer, Ag- or U-NO_3 in collodion on sized paper introduced about 1864
- **Ernst Abbe** joins Carl Zeiss (Jena) as the main lens designer, known for microscope's Abbe Condenser, in 1866
- **Lord Kelvin patents** continuous-stream-ink drop (CJI) inkjet technology in 1867

1870

- **Silver-gelatin process** by RL Maddox: AgCl or AgI crystals in gelatin media (water solvent) on glass 1871
- **Ernst Abbe** at Carl Zeiss (Jena) develops **Abbe sine condition optics** improving optics significantly in 1873
- **Offset Lithography printing press technology developed** about 1875
- **First color print:** layers of subtractive cyan, magenta & yellow gel by Louis Arthur Ducos du Hauron in 1877
- **Rodenstock,** Munich Germany, considered superior LF lensmaker with their 'more corrected" lenses in 1887
- **Dry Gelatin Plates,** over-the-counter glass plate negatives, thru 1930s, by pro-Photogs & press, in 1878
- **Lord Rayleigh** discovered the mechanism by which a stream of liquid breaks into droplets in 1878
- **Edison [Thomas Alva]** in NJ invented the electric light bulb, mother to the electron-valve vacuum tube in 1879

1880

- **Silver-gelatin papers** (Ag-Br) for photographic prints first created about 1880
- **Eastman** began sensitizing photographic paper using uncoated German and French papers in 1880
- **Eastman Permanent Bromide Paper** fast DOP paper, limited success because it was too fast for amateurs,1880
- **Platinum Print** (still salted paper print) was discovered by William Wills in 1873, reached market in 1881
- **Film** first created as silver-gelatin coated on cellulose nitrate base in about 1884
- **Baryta layer** introduced to B&W prints, increases reflectiveness (Dmin) and expands tonal range, about 1885
- **Kodak** releases paper negatives on a roll (paper), processed by Kodak (1888) in 1885
- **Otto Schott** joins Abbe and Zeiss at Carl Zeiss, produces glass equal to Abbe's work, **Apochromatic** lens developed, corrected for all colors focusing in same plane and coma (all points focusing in same place) in 1886
- **POP** 1st **Printed-Out-Paper** which develops using light, matte gelatin emulsion on paper 1885; glossy in 1890
- **Kodak** (product name) for Eastman Kodak's factory-loaded camera w/ paper film consumers (thru 1889) in 1888
- **Film** released by Kodak as silver halide in gelatin on cellulose nitrate plastic film in 1889

1890

- **Silver-gelatin prints** supplant albumen prints, common in 1850, sold pre-sensitized dry in a box around 1890
- **Paul Rudolph,** Carl Zeiss (Jens) develops **Anastigmat** lens w/2 asymmetrical groups, either side of iris, 1890
- **DOP, Developing-Out-Paper[s]** introduced, silver-gelatin (Ag-Br) papers developed in chemical bath, ca 1890-95
- **Aristo**, American Aristotype Co., is a Baryta coated, collodion emulsion Ag-Br POP that was very successful,1896
- **Velox**, one of the most popular printing papers by the Napara Chemical Co., introduced a slower DOP paper for use outside the darkroom, still 500x quicker than albumen (POP) but slower than the early DOP papers in 1897-8
- **Paul Rudolph** of Carl Zeiss (Jena) develops the very fast (f/3.5) **Planar** design, 6-element in 6-groups in 1896
- **Gabriel Lippmann** developed an indirect color process based on Bragg diffraction, **Lippmann Process**, 1891
- **CRT** demonstrated by Karl Ferdinand Braun; cathode-ray tube w/fluorescent screen & electron beam in 1897
- **Wire Recorder** for sound was developed by Valdemar Poulsen**,** the Telegraphone, in 1898
- **Kodak No1 Folding Pocket Camera** used 105 roll film (2¼ x 3¼) on nitrate base (thru 1915) for $10 in 1899
- **Kodak** buys Velox from Baklin for $750K because it's a 5-12 second (slower) gaslight DOP amateur paper in 1899
- **Self-Toning Matte** Baryta-coated gelatin emulsion Ag-Br DPOP papers [no commercial success, too fast] in 1899

1900

- **Kodak No 3 Folding Camera** used 118 roll film (3¼ x 4¼) on nitrate base (thru 1915) for $68 in 1900
- **The Brownie Camera** (thru 1924; No 3 to 1934) used 117 roll film (2¼ x 2¼) on nitrate base, for $1, in 1900
- **Carl Zeiss** (Jena) renames Anastigmat Series I thru V, **Protar**, no astigmatism or field curvature in 1900
- **No 2 Brownie Camera** (thru 1924) child 's box (**cultural icon**) used 120 nitrate roll film (2¼ x 2¼) for $2 in 1901
- **Otto Schott** of Zeiss Jena, develop rare earth glass (aka Jena glass) in 1901

- **Paul Rudolph** of Carl Zeiss develops **Tessar** high resolution & contrast lens; 4 elements in 3 groups in 1902
- **Carl Paul Goerz** (1886, Berlin) developed 1-group, 3-element compact Dagor Anastigmatic flat field lens, 1904
- **Ozobrome,** Thomas Manley invents Raydex proportional color pigments in gelatin layers on paper in 1905
- **Kodak No 4A Folding** w/Goerz Dagor lens ($110) 126 roll film (3¼ x 5½) nitrate base (thru 1916) in 1906
- **Kodak** begins to study in-house papermaking and encouraged others such as American Playing Card Co. in 1906
- **Crystal Detector invented** a wire-end resting on a semiconductor (galena or silicon) forms **point-contact rectifier** 1906
- **Vacuum Tube** was patented as continuously variable **electron valve** (called **triode**) by Lee De Forest in 1907
- **Graflex No1A,** Folmer & Schwing, USA, first MF (116 roll film) SLR w/ waist-level & focal-plane shutter in 1907
- **Kodak No 4 Pocket Folding**, very large body w/20 lens opt' ($83) 123 roll film (4x5) nitrate (thru 1915) 1907
- **Autochrome,** tri-colored starch grains coated on glass was invented by Lumiere brothers, France 1907
- **Dufaycolor** invented by Louis Dufay, mesh of RGB lines on glass, later on motion picture film, in 1908
- **Finlay Colour Process** developed by Clare L Finlay, mosaic of RGB squares on glass plate in 1908
- **Kinemacolor** first color MP process by GA Smith (1906 in UK), alternating R, G & B images, released 1908
- **Cellulose Acetate factory** is opened by Kodak (used for film base) in Australia about 1908
- **Safety Base film** announced by Kodak, cellulose acetate safety film in various formulations beginning in 1909

1910

- **Aristo is reintroduced**, faster DOP papers become popular for enlargement in the [professional] darkroom in 1910s
- **Dye Imbibition** technology created by Fredric **I**ves (dye absorbing) Trichromatic Plate Pack (3 neg; 1 exp) 1911
- **Schneider** Kreuznach optics (German) opens, will make lenses for 35-mm format to large format, in 1912
- **Enlarger** [$95 or $2-3000 today] with electrical-based lighting system become common for professionals in 1913
- **Kodak Park Papermaking machine** is built in 1914, first used at Kodak Park for photo paper in 1915
- **Kodachrome (1) still** film 2-col additive, bleach & dye sub process, John Capstaff at Eastman, between 1914-16
- **Technicolor, Process 1**, 2-color (R & G) additive motion picture with 2 simultaneous images thru filters in 1916
- **Ansco's Cyko DOP** fast Baryta coated fast enlarging paper, "8x-faster than Soft Cyko," introduced in 1917
- **Tri-Color Carbro** subtractive color (CMY) pigmented gelatin layer print, Autotype, H.F. Farmer in 1919

1920

- **Kodachrome (1) MP** film (2-color additive, dbl-sided film) tested by Paragon Studios (Fort Lee, NJ) in 1922
- **Technicolor, Process 2**, 2- color additive, R & G positive images cemented together in exhibition positive, 1922
- **Radiofax - Richard Ranger** at RCA invents wireless fax, first transatlantic photo NYC to London in 1924
- **Leica I,** developed 1913, first 35-mm rangefinder camera with either 5-elm Elmax or 4-elm Elmar lens in 1925
- **Mechanical Television** is demonstrated by JL Baird (technological dead-end) in 1926
- **Philo Farnsworth,** has "hayfield revelation" on electron beam scanning in 1921
- **Field-Effect Transistor** (FET): physicist Julius Edgar Lilienfield filed Canadian patent for **solid-state triode** in 1925
- **Farnsworth** transmits first television moving image and patents invention in 1927
- **Kodacolor (1) MP film,** Eastman lenticular additive color, 16 mm amateur gauge in 1928
- **Technicolor, Process 3**, 2- color additive (R & G) using dye-imbibition process (not cement film) in 1928
- **Magnetic Tape**, iron oxide powder on paper tape was invented by Fritz Pfleumer in 1928
- **Graflex Speed Graphic** f/4.5 B&L Tessar or Kodak Anastigmat , wire loop focus (thru 1939) 4x5 & 5x7sht, 1928
- **Rolleiflex** releases its double lens reflex (DTL) medium format (2¼ x 2¼) camera in 1929
- **Technicolor, Process 4**, full color using 3-strip camera, subtractive (CMY) dye-transfer final print, in 1924/29

1930

- **DOP surface texture variables** (Defender and Kodak brand ranges are wide) released between 1930-40
- **Dufaycolor motion picture film,** 3-color additive using mesh of RGB lines in 1931
- **Contax I** released by Zeiss Icon (east German) 35-mm SLR rangefinder camera with Zeiss f1.5 lens 1932
- **RCA demonstrates television system**, based on electron beam scanning (Farnsworth) technology in 1932
- **Xerographic image first made** in 1932
- **Ihagee Exakta,** (Kine-Exakta) 1st production 35-mm SLR, 127 roll film (1⅝x2½) w/changeable bayonet lens 1933
- **135-mm film** (35-mm format) acetate base film in familiar pre-loaded daylight-loading cassette by Kodak in 1934
- **Retina I** by Kodak (German-built) using their new daylight-load 35mm cartridge w/ integral Schneider Xenar 1934
- **Solid State Triode,** field effect transistor also patented in Germany (see Lilienfield 1925) by Oskar Heil in 1934
- **Magnetic Tape Recorder** was first built by Joseph Begun (Germany) in 1934-35
- **Gevaluxe Velours by Gevaert** a very high-texture matte surface considered height of B&W matte papers in 1935
- **Kodachrome** (final - K14) 3-layered subtractive (CMY) reversal positive MP & still film (yel. fugitive til '37), 1935
- **Nikkor 50 mm** f/3.5 lens (50/3.5) was releases by Nikon, mounted on **Hanza Canon** (Canon rangefinder) in 1935
- **Vacuum deposition of lenses coating** - Zeiss, designated "T or T*" reducing internal reflections & flare, increases contrast & resolution, not available until 1940, then only in Sweden & Switzerland, til after WWII 1935
- **Shockley (Wm) graduates MIT** with PhD in Physics and joins **Bell Labs** (Clinton Div in NJ) in 1936
- **Agfacolor**, tripack subtractive (CMY) color reversal process in 1936

- **Argus A** 35-mm daylight-load cassette camera made for mass consumption ($12.95 - 500,000 sold) in 1936
- **Kodachrome dye stability increased** with the substitution of a 185-year stable yellow dye in 1937
- **Xerography** patented by Chester Carson in 1937

1940

- **Ilford Multigrade** DOP is released, variables facilitated by colored filters for hard & soft negs on same paper, 1940
- **HK7 Hasselblad** (Sweden) reconnaissance camera w/coated lenses, updating German design for Allies in 1941
- **Azochrome** silver dye bleach print created by Kodak from Eastman's Wash-Off process in 1940
- **First multi-layer color negative film**(s) developed in 1941
- **Kodacolor** (final - C22) first color print from a color negative film, red-tone emphasis, thru 1963, began in 1942
- **Kodak releases Kodacolor chromogenic print paper in 1942**
- **Kodak Dye-Transfer**, dye imbibition process, gelatin receiver layer accepts 1 of 3 (CMY) dyes, on paper 1945
- **Bell Labs' Solid-State Physics Group** created w/ Shockley, Bardeen & Morgan to find replacement for vacuum tubes 1945
- **Carl Zeiss (Jena)** assisted by US Army to move into West Germany (Stuttgart) was renamed Carl Zeiss 1946/7
- **Carl Zeiss (Jena) in** East Germany renamed Kombinat VEB Zeiss Jena, labeled Zeiss Jena in west, about 1946
- **Ektachrome** supplants Kodachrome color reversal film, easier processing, blue-tone emphasis in 1946
- **Ektachrome E1, E2 & E3** released, had poor cyan and yellow dye stability (E3 through 1976), E1 & E2 in 1946
- **Shockley awarded Pentagon's Medal of Merit** for radar, anti-sub warfare and radar-controlled bombsite in 1946
- **Graflex Pacemaker Speed Graphic** w/Kodak coated Ektar 101/4.5 (Crown Graphic -1pb) all Press used in 1947
- **First working transistor** by Shockley, Bardeen & Brattain at Bell Labs (NJ) called **bipolar point-contact transistor** is a digital switch, digital amplifier & go-no-go electron gate on germanium replacing (hot) triode electron tube in 1947
- **Edwin Land** develop Polaroid **Model 95**, first instant image camera system, B&W only, in 1948
- **Bob Herr** (3M) proposed **idea of recording pictures & sound**, tape at 15 ips past rapidly-rotating head,1948
- **Haloid Co trademarks Xerox** for Carlson's xerographic technology, (founded 1906 high speed DOP papers),1948
- **Transistor** independently invented by German physicists Mataré & Welker at division of Westinghouse (Paris) 1948
- **Vidicon** the analog electronic **image acquisition tube** used in all television cameras was introduced 1949
- **Contax S** Carl Zeiss Dresden (east German) first pentaprism 35-mm SLR (prototyped before WWII) in 1948-9
- **Hasselblad 1600**, MF SLR, with focal plane shutter used a Kodak Ektar 80/2.8 lens in 1948/9-53

1950

- **Nikkor** lens quality found equal to Zeiss and Leica multi-coated equivalents in the early 1950s
- **Type-C** chromogenic paper is released by in the early 1950s
- **Eastman Color Negative & Positive MP films**, camera negative to positive w/o Technicolor process, in 1950
- **Wetzel** (3M) demonstrates **first B&W video recording**, fixed-head at 7.77 ips for 15 min (7000 ft) in 1950
- **Stefan Kudelski** (Swiss) patents **Nagra 1** first professional tape recorder used in film & recording industry in 1951
- **John Mullin**, Bing Crosby Enterprises**, experimental VTR** blurred,¼" tape, static heads at 360 ips in 1951
- **Siemens** introduced the first continuous inkjet **(CIJ)** commercial printer (strip chart recorder) in 1951
- **BBC VERA** (Vision Electronic Recording Apparatus) first VTR, ½" steel tape, 200 ips past static heads, 1952
- **Asahiflex I** (Asahi - Pentax) first Japanese 35-mm film SLR w/ waist-level finder using M37 lens mount in 1952
- **RCA tests video recording** (B&W & color) experimental ½" magnetic tape, 360 ips, 3/5 static heads in 1953
- **Contaflex** by Carl Zeiss (west Germany) release their SLR (single lens reflex, through lens viewing) in 1953
- **Yashimaflex** (Yashica in Japan) medium format (MF) twin-lens reflex (TLR) in 1953
- **Eduard Schueller** develops **Helical scan** rotating video head, slanted for increase track length, patent 1953
- **Hasselblad 1000F** releases SLR body, used the Zeiss Distagon 60/5.6 or the Tessar 80/2.8 in 1953-57
- **Leica M3** by Leitz (Ur-Leica 1913) advanced 35-mm rangefinder with interchangeable bayonet lenses in 1954
- **Hasselblad 1000F** got rave review from Modern Photography (shot 500 rolls of film & dropped it twice) in 1954
- **Texas Instruments** created the first silicon transistor using lab-grown silicon crystals by Gordon Teal in 1954
- **Ampex Video Tape Recorder,** 2" plastic tape past vertical-rotating Quad head, lead Charles Ginsburg, 1956
- **Fairchild Semiconductor** founded by William Shockley, co-inventor of transistor, with bell lab personnel in San Jose in 1957
- **Hasselblad** releases its flagship 500C body, with modified leaf shutter, using a range of Zeiss lenses in 1957
- **Dye-sublimation** digital printing technology developed in 1957
- **Magnetic Storage** developed by IBM for main frame computers, 305 RAMAC, 50 24" disks holding 5 MB 1950/6
- **Contarex** (Cyclops) by Carl Zeiss (west) releases first SLR with integrated light meter in 1958
- **Integrated circuit** conceived by **Jack Kilby** (Texas Inst), within 6-mos **Robert Noyce** (Fairchild, Palo Alto) perfected in1958
- **Canonflex** by Canon first Japanese reflex SLR w/ prism and focal-plane shutter 1-month before Nikon F 1959
- **Nikon F** is released, a reflex SLR body with interchangeable lens internal metering (compact & affordable) 1959
- **Xerox 914** is released by Haloid/Xerox as the first charged-black-particle-transfer copier on plain paper in 1959

1960

- **MOSFET** (metal-oxide-semiconductor field effect transistor) most common type of transistor by Kahng & Atalla, Bell Labs 1960
- **Phototypesetting** printing technology developed in 1960s

- **Ansco & Agfa** aka IG Farben, last of German "assets" sold to American interests (GAF) after WWII between 1960-7
- **Multiple-coating developed** for lenses, lens development reach penultimate lens performance in the 1960s
- **Estar film** base is introduced by Kodak (polyester, aka Mylar) in Kodalith line, replaced cellulose tri-acetate, 1960
- **Kodachrome II** is introduced by Kodak, transparency film, K-14 processing; very color stable, in 1961
- **Haloid Co** (famous high-end DOP paper maker) changes name to Xerox in 1961
- **Hasselblad 500EL** (electric) started going into space with NASA, went to the moon on Apollo starting in 1962
- **Polacolor** first instant color process, dye diffusion (Dufaycolor) type, by Polaroid in 1963
- **Cibachrome** silver dye bleach process refined, positives prints from transparencies, Ilford, in 1963
- **Xerox 813** releases first desktop plain paper copier in 1963
- **Spotmatic** by **Pentax** a reflex SLR w/ focal-plane shutter, TTL metering and M42 screw lens mount in 1964
- **Bucket Brigade Device (BBD)** the precursor to the CCD developed at Bell Labs (Berkeley Heights, NJ) late 1960s
- **Yashica D** released with Yashinon lens, MF TLR based on the Rollie, $125 D popular w/ prosumer in 1966
- **IVC** (Sunnyvale, CA) introduced **1" tape** helical scan video tape recorder in 1967
- **Porta-Pak** video camera is introduced by Sony, ½" tape (DV-2400 Video Rover) first viable portable video, 1967
- **Robert Noyce & Gordon Moore** left Fairchild Semiconductor to found **Intel** in Mountain View, CA in 1968
- **Sweet, R.G. commercializes continuous inkjet printers** leading to CIJ printers by A.B. Dick, VideoJet & Mead in 1968-9
- **8-pixel linear CCD** first viable light-to-digital chip developed by Willard **Boyle** & George **Smith** at NJ Bell Labs 1969
- **Laser printing** technology developed around 1969
- **Xerox 9700 first Laser Printer** was created by Gary Starkweather from a modified a Xerox copier in 1969

1970

- **High quality [prime] lenses become affordable** and resolution reaches point of diminishing returns in 1970's
- **Digital video camera**, Bell Labs built their CCD technology into the world's first solid-state video camera in 1970
- **Luminos Bromide RD** rapid-dry resin-coated paper (polyethylene fails early do to TiO_2 attack) released in 1970
- **8" Floppy Disk** by IBM to improve the distribution of code patches & diag's in IBM System/370 Model 145, 1971
- **Intel 4004** by Faggin, Hoff, & Mazor, first commercial integrated circuit (IC) with 2250 transistors on one chip in 1971
- **SX-70** is released by Polaroid, color instant camera, opaque screen clears (1 min) after dyes develop, in 1972 **SX-70** is released by Polaroid, color instant camera, opaque screen clears (1 min) after dyes develop, in 1972
- **Kodacolor II**, Kodak begins C-41 color negative process, started with Kodacolor-X (1963-74), begin in 1972
- **Technicolor closes US plant** as dye-transfer process becomes too expensive for commercial films in 1972
- **8 x 8 pixel CCD** by **Shigeyuki Ochi** at SONY Research Lab after Bell Labs gave-up commercialization in 1972
- **Thermal printing** technology developed about 1972
- **100 x 100 pixel CCD (0.01 MP)** by Fairchild Semiconductors (CA) called the CCD201ADC first area array 1973
- **500 pixel linear array** also created at Fairchild Semiconductors in 1974
- **Portable HD,** IBM releases dual-spindle **30/30 Winchester**, sealed portable 60 MB, forerunner to all HDD 1973
- **Xerox 6500** the first color copier developed in 1973
- **Kodak Polycontrast Rapid RC** paper, resin (TiO_2-doped polyethylene) coated multigrade DOP paper in 1974

1975

- **Steve Sasson at Kodak prototypes the first digital camera** 8.5 lbs, made from a Kodak movie camera lens, a Fairchild Semiconductor 0.01 MP 8-bit gray CCD and a Motorola A-D converter, output to a cassette tape, viewed on a TV set in 1975
- **Altair 8800**, Mits Corporation introduced the first popular home computer, w/o operating system, in 1975
- **Flatbed scanner** invented by Ray Kurzweil for OCR (becomes Xerox Textbridge 1980) 1975
- **IBM** (possibly Steven Sears) invents the first (CIJ) inkjet printer, oversprays badly, drop size 15-400 microns, in 1976
- **IBM 3800** released their first laser printer on the market in 1976
- **CASI Photo System** still video TV camera, designed for commercial portraits with computer & printer in 1977
- **Canon (Ichiro Endo)** discovers the **thermal DOD** inkjet printer technology capable of drop sizes around 1 micron in 1977
- **Apple I** by Steve Wozniak & Steve Jobs based on MOStek 6502 chip, Homebrew Computer Club, $666, in 1977
- **Apple II** in full case w/color monitor (Apple I had wood case) by Apple Computer, sold for $1298 in June 1977
- **Ektachrome E4** with better color dye stability supersedes others in 1977
- **Schneider** begins selling multi-coated (flare suppression) lenses, 1977, completes upgrade of full line 1978
- **Fujinon** begins multi-coated (Electron Beam Coating) lenses, prior they were all single coated, 1977-80
- **Intel develops the 8086 then the 8088 8-bit IC-processor**, later found in the IBM PC in 1978
- **Electronic image first published** by National Geographic; Emory Kristof used electronic camera in minisub, 1979
- **HP** develops its thermal DOD inkjet technology [brings to market in 1984] developed in 1979

1980

- **ST 506 Harddrive** released by Seagate Technologies first **5-¼" HDD** for desktops, 5 MB, $1000 in 1980
- **Sony Mavica** B&W 0.79 MP, first viable digital imaging chip based on video still technology (570x490) in 1981
- **IBM PC** was conceived in Boca Raton, FL in early 1980; IBM introduced PC Model 5150 using Intel's 80286 in1981
- **T-grain technology** created by Kodak introduce in silver particles for Kodacolor films (before processing) in 1982

- **Pentax Nexa** a B&W analog video still camera prototype, images stored on floppy disk, in 1983
- **HDTV standard** developed by International Telecommunication Union's (ITU-R) working party (IWP11/6) in 1983
- **Versatec ECP-42** [Xerox] first electrostatic color printer (200 ppi, 24-wide) seeds of graphic arts industry, in 1983
- **MegaVision** introduces a 1000-line digital still camera, uses analog Vidicon to create 1000x1024 still in 1984
- **Canon RC-701 0.4 MP prototype** ($27K) color video still camera w/ analog transmitter for LA Olympics in July 1984
- **Macintosh 128K** Apple-PC 9"-B&W screen w/ 8 MHz Motorola 68000 processor, 16-bit bus, 128K RAM $2.5K 1984
- **JVC GR-C1** first camcorder (camera & VTR) 1/3-size mini-VHS cassette, plays in VCR with adapter in 1984
- **Pentacam VSC-3000 color camera** used Sony's 3-CCD video camera in Nikon's F4S SLR-body (768x494) in 1984
- **HP Thinkjet CMYK ink-set** released first thermal drop-on-demand (DOD) inkjet printers in1984

1985

- **Canon BubbleJet BJ-80 with** CMYK ink-set early thermal drop-on-demand (DOD) inkjet printers in1985
- **Amiga 1000** first mini-computer by Commodore w/superior graphics/sound for video, 12-bit color, 32-bit, 1985
- **Canon RC-701 0.4 MP** was released to public as a color video still system for news gathers, base price of $3K in 1986
- **Polaroid** defeats Kodak in the instant camera patent claims while digital is being developed in 1986
- **Newtek Digi-view**, Amiga platform, first computer capture device, 0.6 MP 12-bit, B&W w/RGB wheel in 1986
- **Kodak develops a 1.4 MP CCD area array** sensor in 1986
- **Videk MegaPlus camera is the first** megapixel camera using the Kodak 1320x1335,1.4 MP in 1987
- **IRIS Model 3024** inkjet printer (IRIS Graphics), using 1-micrometer glass jets, was develop &introduced 1987
- **HP releases PaintJet** a color inkjet technology in 1987
- **Digital Image first published** by USA Today, first video-still image (digital color) on front page in 1987
- **Associated Press** starts 5-yr-conversion program from film to digital photo transmission saves 90% time, 1987
- **Canon RC-760** hi-band video still, news photographers, USA Today, 0.6 MP SLR $5.5K 2" video floppy in 1987
- **HP DeskJet** [first mass-market inkjet] was debuted in 1988
- **Kodak's peak payroll** of 145,300 employees in 1988
- **Electro-Optical Camera** by Kodak, US Gov covert, w/Exabyte tape storage tethered to a Canon F1 body in 1988
- **Canon RC-250 XAPSHOT**, 0.20 MP video still consumer level ($499 1/10th cost of above) hook to Mac, 1988
- **Nikon QV-1000C** B&W video still camera, first DSLR, F-mount (news photographers) 0.38 MP, $20K, 1988
- **JPEG & MPEG file formats** developed, using DCT compression technology, 1988
- **MegaVision Tessera 4MP** first commercial digital camera using 2000-line vidicon tube for commercial photography 1989
- **Sony ProMavica MVC-5000** 2-chip video still, first transmit instant color images over phone (news), 1989
- **Color Studio 1.0** released by Letraset for Mac platform, first professional image manipulation software in 1989
- **Kodak D-5000** a CCD-prototype for all digital SLRs, use KAF-1300, 1.3 MP w/PCMCIA K-mount lenses in 1989

1990

- **Ektachrome E6** claims 250-year dark fading stability for CMY dyes in 1990
- **IRIS Model 3047** is introduced, on thick paper using fugitive inks is used by Nash Editions for artworks in 1990
- **IRIS Graphics** acquired by Scitex (Israel) in 1990
- **Polymer Plate** technology [water washed relief plate] for Letterpress printing developed in the 1990s
- **Photoshop 1.0** Mac only, John & Thomas Knoll wrote and licensed to Adobe (1988); v1 in 1990
- **HP DeskJet & DeskWriter,** CMYK ink-set inkjet printers are released by HP in 1991
- **Mike Collette** invents **digital scanback** (6000x7520, 135 MP) using Kodak's 6K trilinear CCD, 12-bit ADC, in 1991
- **Leaf DCB-1** "The Brick" first MF mono back, 4.2 MP (Fairchild 2048 x 2048 chip), uses 3-color wheel, in 1991
- **Kodak DSC DC3** prototype for DCS 100, uses F3 body, SCSI, NTSC, 8-bit B&W/color, 600 files,$20-25k, 1991
- **Kodak DSC 100** first Pro DSLR, F3 body w/ very large external HDD, 1024x1280, 1.3 MP, $30K, 987 sold, 1991
- **Giclée coined by Jack Duganne** at Nash Editions for inkjet prints intended as artworks made on IRIS printer, 1991
- **Kodak DCS 200** uses Nikon N8808 film body, has internal HDD, 1012x1524, 1.53 MP, $30K, 3240 sold, in 1992
- **PhotoCD** introduces by Kodak, optical storage media; heavy compression and YCbCr color space, in 1992
- **MegaVision T2** released, a 3-shot (R,G &B) back using color filter wheel for Sinar 4x5, 4MP (2048x2048) in 1992
- **Leaf Volare** (MF) introduced by Scitex (Israel) 3-shot back ($25K), Phillips 24x36 mm, 2048 x 3096, 6 MP, 1992
- **Sound Vision CMOS-PRO** produces first CMOS image (960x800, 1.8 MP) by Bob Caspe (Leaf) in 1992
- **Epson develops the MJ-500 (Stylus 800)** micro piezoelectric inkjet printer in 1993
- **Canon EOS prototype** DSLR, unlike final EOS design but SLR, 1.3 MP in 1993
- **Nikon D1 prototype** F (looks like later model E) uses unique body design but SLR (480x1088) 0.56M in 1993
- **ICC [International Color Consortium]** co-founded, Apple & Linotype-Hell AG, cross-platform color profiles 1993
- **ColorSync 1.0** by **Apple** developed color management integrated into OS by Robin Myers & others in 1993
- **Dicomed creates functional scanback** w/ improved HDD, using Mike Collette's design in mid-1993, released 1994
- **Dye Transfer** (still) process is discontinued by Kodak (sole supplier), some materials found afterwards, in 1994
- **Epson releases Stylus Color P869A** the first high-resolution (720-ppi) color printer in 1994
- **Apple QUICKTAKE 100** 1st consumer digital camera below $1000 VGA-based (480x640) with help of Kodak in 1994

- **DC40** 1st Kodak fixed lens versions of VGA-based (DC50 = 504 x 756 pixels, 24-bit) consumer (≈$1000) in 1994
- **DC50** 1st Kodak zoom-lens versions of VGA-based (DC50 = 504 x 756 pixels, 24-bit) consumer (≈$1000) in 1994
- **AP NC2000** by **Kodak & AP** specifically for news photographers, 700 exposures on disk ($15K) 550 sold, 1994
- **CompactFlash** (CF) (transfer chip in card) and **SmartMedia** image memory cards introduced in 1994
- **Steve Johnson** tests 6000 x 7520 scanback; licensed to **Dicomed** by Mike Collette; "the day film died" 1/15/94
- **KODAK DCS 420** Nikon N90X body, aka Nikon D3 first w/storage cards, SCSI port, 1524 x 1012, $11K, 1994
- **Epson MJ-700V2C**, first photo-quality 720 dpi desktop color inkjet printer in 1994
- **Photoshop 3.0** for Mac, Win, IRIX & Solaris, added Layers, yet no support for 16-bit in 1994
- **Durst Lambda 130** is released by Durst, 3-color laser printer onto chromogenic papers in 1994
- **MegaVision created its first CCD-base system** (no details given) under the Tessera badge in 1994

1995

- **LightJet 2000** 3-color laser-to-chromogenic technology developed by Cymbolic Sciences (sold to Océ) at PMA,1995
- **HDTV standard**, worldwide agreement, ITU-R BT.709-2, 16:9, 1080i/p (maximum) & sRGB color space in 1995
- **Canon/Kodak EOS DCS 3**, Canon EOS-1N body, 1.3 MP CCD (1012x1268) in 1995
- **Canon/Kodak EOS DCS 1**, Canon EOS-1N body, 6 MP CCD (2036x3060) 12-bit ADC in 1995
- **Kodak DCS 460,** Nikon N90S body, 6 MP (2036 x 3060), 18MB file size, 12 bit ADC, $28K, 1995
- **Dicomed Bigshot 4000** first one-shot larger than 35mm (4096x4096 Fairchild CCD) 17 MP $35-55K, 1996
- **Kodak DC-120** first 1 MP (960x1280) digital SLR to break the $1000 barrier in 1996
- **Thinker.org** released by FAMSF with in-depth online accessibility to collection, 83,000 entries now, in 1996
- **Nikon Coolpix 100** stored 19 images (480x512) on a PCMCIA card ($1000) slipped into laptop for download in 1996
- **Nikon E2N** first Nikon DSLR, F4 innards, purpose-built body w/interchangeable lens, PCMCIA, 1.3 MP in 1996/7
- **QuickTake 200** Apple's VGA-based digital camera with video feed ($600) built by Fuji (**FujiFilm DS-7**) in 1997
- **Sony Mavica MVC-FD5** w/47mm/f2 lens used 3.5" floppy disk for 55 - 480x560 VGA ($600) real-estate agents 1997
- **Sony Mavica MVC-FD7** w/40-400/f1.8 zoom lens, 3.5" floppy disk for 55 - 480x560 ($800) real-estate agents 1997
- **Technicolor reintroduce dye-transfer process**, used in film restoration such as Wizard of Oz (etc.) in 1997
- **BetterLight** releases **Model 6000** Mike Collette develops second-generation scanback (6000x8000) in 1997
- **BetterLight** releases **Model 8000** scanback (8000x10660) 256 MP, 14-bit ADC, SCSI interface in 1997
- **Phillips** develops a huge, 63 MP B&W full-array CCD (7000x9000) for use in IR space telescopes in 1997
- **HDTV on air** CBS went on air in NYC with WCBS-HD (4/6/97) top of Empire State Building, 16:9, 1080i, in 1998
- **HDTV sets** (digital) went on sale the USA, 16:9 aspect ratio, 720 (H) x 1280 (W), 720p (<1 MP) in 1998
- **Kodak DCS-560** (Canon EOS D6000) EOS 1N body, 6MP (2008x3040) 12-bit ADC, $30K, 1998
- **Foveon** CCD chip with "depth-based color sensitivity" (no Bayer Pattern on pixels) RGB digital sensor, 1998
- **Photoshop 5.0 [major improvement]** Color Management, basic 16-bit operations & History Pallet added1998
- **Chromira developed by ZBE,** 3-color laser light to chromogenic is released at 300-ppi resolution & 36-bits in 1998
- **Multispectral ink technology** (CcMmYyKkR[O]GB sets & variations) was published by Tzeng & Burns in 1999

2000

- **SpectraShop 1.0** color measurement & analysis software created by **Robin Myers** (co-inventor ColorSync) 2000
- **IRIS printer**, owned by Scitex, is acquired by Creo Products in 2000
- **ICM** [Image Color Management] added to Windows 2000 and XP with Adobe porting to ColorSync 2.0 in 2000
- **Estar base news,** Kodak moves to Estar (polyester/Mylar) for all sheet film (roll film still on acetate) in 2000-1
- **Kodak KLI-10200** tri-linear color CCD array released w/ 10,200 7um-pixels over 3"- beyond lens resolution 2001
- **Polaroid** enters Bankruptcy 2001; sold to BankOne 2002; as of 2006, surviving entity only distributing asset
- **Technicolor ends dye-transfer process** when it was sold to Thompson in 2002
- **RA-4 color print processing technology invented by Kodak,** R, G & B imaging technology is released in 2002
- **Canon 1Ds** (2704 x 4064, 11 MP) first dSLR recognized with resolution superior to 35 mm film in 2003
- **Kodak KLI-14403** tri-linear color CCD array released w/ 14,404 5um-pixels over 3"- beyond lens resolution 2003
- **Kodak announces discontinuation** of **slide projectors**, parts available thru by 2008, in 2004
- **Kodak discontinues Eastman Ektachrome Color Reversal** motion picture film thru-out 2004
- **Kodak discontinues** producing B&W photographic paper, after 125 years of production in June 2005

2005

- **IRIS printers**, manufacturer owned by Creo, is bought by Kodak in 2005
- **Nash Editions donated IRIS 3047** to SI NMAH, begins using Epson 9600 and Pigmented K3 inks in 2005
- **Epson Stylus R2400 inkjet,** optimized for B&W printing using 3-gray inks CcMmYKkM[atte]K in 2005
- **Fujifilm Crystal Archive Type II** paper released for digital chromomeric RA-4 printers in 2005
- **Kodak** announce discontinuation of B&W printing papers in 2006
- **HP Color LaserJet 1018** was introduced in 2006
- **Multispectral ink technology,** CcMmYyKkR[O]GB & variations, was introduced by Epson HP and Canon, 2006-7
- **31 & 39 MP in H3D-body by Hasselblad** medium format using 27x49 MP sensor at 16-bits, $18K & $25K in 2006-7

- **BetterLight** releases **10K scanback** (10200 x 13600) 416 MP, USB, 14-bit ADC, beyond lens capability, 2007
- **39 MP full array CCD**, Kodak creates 37x49mm; 5412x7216 area array w/ Bayer pattern using 6.8-um pixel, 2007
- **Biogon 25/2.8 lens** w/mount for Leica M mount, Zeiss claims 400lp/mm in center at f/4, diffraction limit, in 2007
- **Kodak discontinues** 6K, 10K and 14K tri-linear CCD arrays used in scanbacks and hi-end flatbeds in 2007-8
- **Epson Stylus R1900 inkjet** uses CMYyKkR[ed]&O[range] w/ gloss optimizer to create a wider color gamut in 2008
- **Sony 24.81 MP CMOS** 12-bit A-D on chip 6104x4064 active 5.95-um pixels (24x36 mm) 43.3 mm diagonal, 2008
- **Polaroid** (not original Corp) announces discontinuance of instant films (production will end by 2009) in 2008
- **Instant B&W photography has ended:** was the agreed judgment by photographers worldwide [on listservs] 2008
- **Sony Alpha A900** DSLR, 24.6 MP (6048 x 4032) full frame CMOS for less than $3000, Sept. 2008
- **Canon EOS 5D MKII** lowers price of their 21 MP (5616 x 3744) full frame CMOS,5D MKII, $2700 late-2008
- **ColorSage** is releases by BetterLight**,** first spectral based (380-780nm, 4 nm steps) color workflow tool in 2008
- **Nikon DX3** dSLR full-sized (24 x 36 mm; 6048 x 4032;) 24.5 M at $7100 in late 2008
- **DALSA 33 MP CMOS** (36 x 48 mm; 4992H x 6668V) Bayer pattern in 2008
- **DALSA 48 MP CMOS sensor** (36x48 mm) in late 2008
- **Kodak discontinues** producing Kodachrome after 74 years of production in June 2009, stock gone Fall 2009
- **Kodak Discontinues** EverSmart & Select (5600 ppi) scanners; now: iQSmart, 7.2 -10K ppi, XY-stitch 2009
- **Polaroid** process is being revived by a Dutch-Austrian team in a closed Dutch Polaroid plant, in 2009
- **Sony Alpha A850** DSLR, 24.6 MP (6048 x 4032) full frame CMOS for less than $2000, in late 2009
- **22 to 24.6 MP DSLRs by Nikon, Canon & Sony** w/ full-sized (36x24) CMOS become affordable ($2-3K) in 2009
- **50 & 60 MP in H4D-body by Hasselblad** medium format using 27x49 MP sensor at 16-bits, $27K & $42K in 2009
- **64 GB memory card** ($700) allows the storage of 4-5000 RAW image files in late 2009

2010

- **Océ** while still making wide-format inkjet papers, discontinued the LightJet and its inksets, sells to Canon in 2010
- **Pentax 655D** is released, 40MP 44x22 mm CCD medium format camera (larger pixels w/ less noise) $10K, in 2010
- **The Impossible Project,** organized in the Netherlands, released 2 instant B&W **Polaroid-based** film in March 2010
- **The Impossible Project** at **Polaroid** plant in Enschede, NL, released an improved instant color [for SX-70] film 2011
- **Sigma SD1 Merrill** is released after EQ & Tsunami w/ its Foveon 15x3=46 MP, APS-C at 24x16mm $1800 in 2011
- **Kodak sells Image Sensor Division** to a private equity firm - Platinum Equity, in 2011
- **Sony SLT-A65** is released by Sony for under $1K utilizing its 24.3 MP APS-C (23.5x15.6) CMOS in 2011
- **Kodak discontinues digital cameras,** after early success w/ DCS 4, 5, 6 & 700 series & DCS pro 14n, in 2011
- **Kodak sells Image Sensor Solutions** (Chip Mfg) division to a holding co. becomes Truesense Imaging, Inc in 2011
- **Nikon D800** is releases a dSLR with a 36.3 MP full frame (36x24 mm) CMOS, for $3K, in 2012
- **Kodak files for reorganization under Chapter 11 bankruptcy** in early 2012
- **Kodak discontinues Ektachrome color reversal slide film**, motion picture reversal remains, in March 2012
- **LSST camera, SLAC, NSF & MREFC:** 3200x3=9600MP w/1.5 min cycle, 350-1100nm w/6 filters, announced 2012
- **Nikon releases D800** a full-frame Bayer pattern 36.6 MP system for under $3K, in 2012
- **Sigma released 35mm f/1.8 lens**, next in the series of high-quality prime series :**15**, 20, 28, 50/2.8, **70**, 85, 150, 300 & **500** w/ Sigma, Canon, Sony & Nikon mounts in 2012
- **BetterLight closes/moves** in October 2012, but Collette continues to sell new scanbacks & support via web 2013
- **Kodak continues to divest & discontinue films:** business said to be digital printing inks and paper in early 2013
- **Sigma SD1 Merrill (SD1m)** increases price to $2300 w/ no apparent spec change: 46 MP 24x16mm-APS-C in Jan 2013
- **Fujifilm** navigated the transition from film to digital with its own unique EXR SuperCCD SR II chip in early 2013
- **Fujifilm announces it is discontinuing the manufacture of Motion Picture film** in March 2013
- **Kodak announces an upturn in the sales of Motion Picture film** and overall sales up 372% in March 2013
- **Kodak announce the return of Kodachrome** in March 2013
- **Sigma DP1/2/3 Merrill** released w/1-of-3 prime lenses (19, 50 & 75 mm) on 46 MP sensor under $800 in 2011-12
- **Transistor built from DNA & RNA molecules,** Jerome Bonnet bioengineering created at Stanford University 2013

History of modern imaging technology begins with Joseph Nicéphore Niépce using a Camera Obscura in 1816 to form a black silver chloride (AgCl) image on paper. Similar to Schulze discovery of darkened silver nitrate on the side of a flask exposed to light in 1724/6. Sometime between 1822 and 1826 Niépce made the first permanent photograph [Heliograph] using photo-sensitive bitumen of Judea (tar) dissolved in oil of lavender (solvent evaporated over time). The image was developed using oil of lavender (solvent) to wash off the unexposed or under-exposed bitumen from the shiny pewter metal sheet, this revealed an image from black with the silver shining back, the images is known as "View from the Window at Le Gras". The image was made in a Camera Obscura over 8 hours. See Figure 2 below.

Niépce's photographic plate and Heliograph process were rejected by the French Royal Society. He deposited the image (hardened bitumen on pewter) with his colleague Francis Bauer in England in 1827. By 1829 Niépce was working with Daguerre on the Physautotype process also using oil of lavender on a polished metal plate. Niépce died in 1833, unrecognized for his contributions. Today there are yearly workshops on Niépce's contributions to photography.

The Daguerreotype was invented in 1838/9 France. It was related to Physautotypes because they both use a shiny metal (silver-coated copper plate vs. pewter) as a light-reflective surface. The Daguerreotypes silver surface is sensitized by the photographer using iodine vapor to make silver iodide (AgI) just before exposure. Then the plate is developed using mercury vapor and fixed (unexposed silver removed) using salt (NaCl) to make white sliver chloride particles on the dark slivered plate when held at the appropriate angle.

Figure 2 – **1**: Niépce's first permanent image ***View from the Window at Le Gras*** c. 1826; the copy image was created by Helmut Gemsheim at the Kodak Research Lab in 1952 from the plate in the center. **2**: Actual plate for "***View…***". **3**: One of the two earliest known pieces of very early photographic study, made by Niépce in 1825 using the Heliograph process. This image was printed from a metal plate that was etched following exposure to sunlight; the print is a reproduction of a 17th-century Flemish engraving, of a man leading a horse. Credit to Wikipedia and the Henry Ransom Humanities Research Center.

Herschel published the first viable fixing agent in 1839 – Hypo. The fixer removes silver salts that were not exposed; see the Wood's 2008 article http://www.midley .co.uk/midley_pdfs/herschel_14mar1839_wood.pdf. Later he coined the term Photography to describe Talbot's new invention of light sensitive paper.

William Fox-Talbot worked out the first paper print; he published an article on the "Photogenic Drawing" in 1939. He reported on a stable chemical image formed using silver salts on paper, after fixing. Generically it was called the salted-paper print. A positive image was made from a [paper] negative by exposing a copy-print using the same light-sensitive paper. Talbotype prints, however, were known for their fading; see Weaver, 2009. By the 1850s, Blanquart-Evrard introduced a 2-bath fixing process that solved this problem for his albumen prints. Much alter the excessive elimination of Hypo (the fixing agent) also caused fading, which was solved by toning. Excessive washing (1950 & 60s) after fixing and hypo elimination, also contributed to the fading problem from the opposite end of the chemical continuum, where too little residual fixer (sodium thiosulfate) would later evolve free sulfur ions over time to lightly self-tone the image.

The history of the silver-image-on-paper goes back to Schulze who discovered the first photo-sensitive compound in 1724-7, when he found black silver nitrate ($AgNO_3$ is normally white) on the side of a flask exposed to sunlight. Niépce was making images on paper as early as 1816, but without fixing they were unstable.

Britain became the technological battleground in 1939 for Daguerre and Fox-Talbot who had developed competing imaging technologies. Daguerre's unique shiny silver image battled with Fox-Talbot's bright black and white paper image that could be made in multiples and easily viewable, however soft and prone to fading. Daguerreotypes were gorgeous little sliver gems, while the salted-paper print was a continuous tone picture that can be viewed at any angle, readable as a painting. The drawback in the first decade (1840-50) was the image was soft because the paper negative, or waxed paper negatives.

One-of-a-kind photographic images prevailed for years, then multiple identical images became common using positive print technology from a paper or glass negative. The single unique images from Daguerreotype (1839), Ambrotype (1855) and Ferrotype (1857) remained common through the 1880's. Multiple positive copies from a (paper) negative image could be contact printed using Talbotype (1841) or albumenized paper (1850). The problem was that images were softer than the one-of-a-kind photographs because the negatives were on paper.

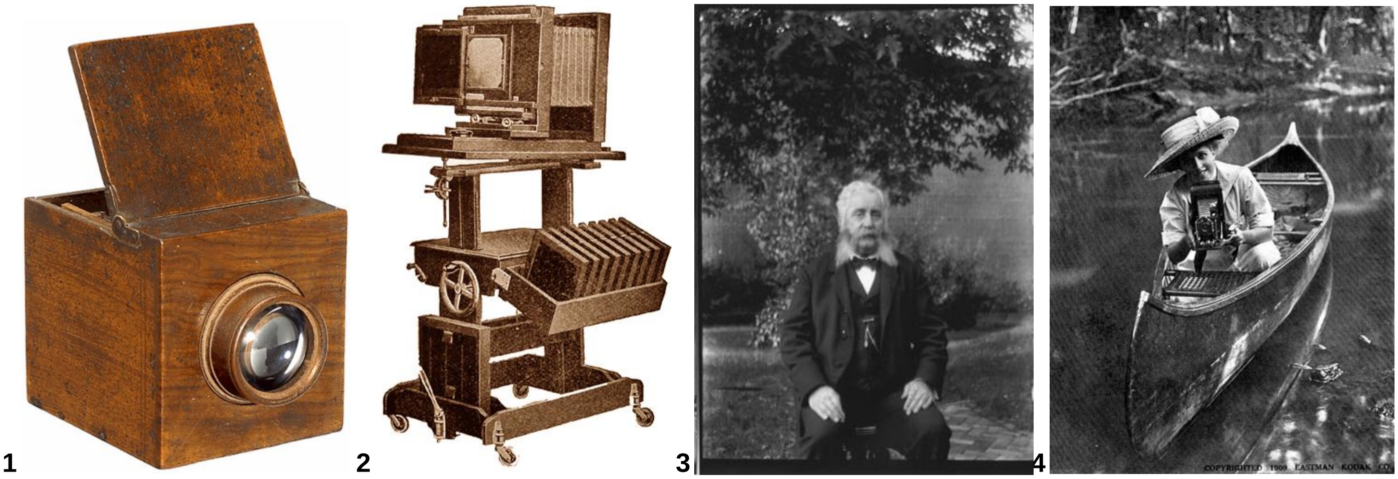
Louis Désiré Blanquart-Evrard created t**he albumen print in 1850**; it became the first commercial photographic process. It allows multiple identical prints from the same negative. Pre-sensitized albumen prints were sold sensitized and dry in a box off the self. The prints were formed and developed in a sun-frame via POP technology. Later the print could be enhanced in a Pyro developer bath, then fixed in a series of baths and washed. Albumenized paper is purchased from the Chicago Albumen Works in eastern Massachusetts.

Sharp multiple prints were made possible with the invention the Collodion Wet Plate process in 1851. It was the first glass plate negative, as opposed to a semi-translucent paper negative. Glass creating a truly transparent negative carrier which made multiple sharp prints common when using albumen paper. By 1878, Kodak brought Gelatin Dry Plates (see Fig 3, No 3) into commercial production; they were sold photosensitive and in a box and were faster (more sensitive) than dry collodion, but not faster than handmade wet collodion plates. Glass plates were considered superior to film through 1920-30s by studio photographers and newspaper-publishing technicians, now called prepress, because of their controllability, planarity and dimensional stability in water and air.

Film became a photographic image carrier around 1889 as amateur roll film was released to the public. A gelatin layer with silver salts was formed on a cellulose nitrate base, a modern plastic of the 19th C (see Fig 3, No 4). However, the earliest amateur roll film cameras (1884/5) used a roll of paper as negatives that were sent in-camera to Kodak for processing.

Sheet film came into wide use around 1913 by WWI news gathers transitioning from glass plates for convenience during war reporting. The last to switch were the newspapers who began replacing glass plates with Kodalith film, which was thicker and more dimensionally-stable film released in 1931.

Film rose to a very high technological state before it was eclipsed by digital technology due to the chemical system noise (film grain)**.** During WWII film and lenses were strategic materials. Later they also played critical rolls in Cold War (1945-91) espionage, such as in the U2 spy plane. Film remained unchallenged technology through the 1990s. Kodak T-grain (1982) flat silver particle with greater surface area and lower overall bulk, was the last major innovation in film. The technological drive was for less silver use during manufacture to lower cost, however, the drawback was image noise – film has a signal-to-noise-ratio (SNR) of 6:1 to 10:1. This doomed the technology.



1 **2** **3** **4**

Figure 3 – 1: small 3"x3"x4" Niépce signed (1826) camera with signed Chevalier lens. **2**: Kodak Century Studio Camera 1890 that uses glass plates. **3**: Gelatin glass plate negative from 1890. **4**: Kodak film 1906-contest winner using a Kodak folding camera.

Film grain is the creation of the human visual-system's need for order, the agglomeration of tens to hundreds of fundamental film elements seen through the thickness of the image layers creates the appearance of grain. Film grain is often assumed to be fundamental film particles but it is hundreds of fundamental particles that create the system noise. Fundamental film particles are either (a) silver particles (0.2 - 1 microns) or (b) color dye clouds (approximately 1 - 3 microns) are an order-of-magnitude smaller than film grain, whose size is roughly 10-20 microns. Note that grain appears even larger as one magnifies an area, in an attempt to define the grain more clearly.

Film grain became perfectly acceptable and was largely ignored until digital imaging became common. When digital imaging evolved into a mature technology, about 1994, its inherently low SNR, ranging from 500:1 to 1000:1, made it a more desirable imaging tool.

Noise in a digital system can be very bad too, when manufacturers use (1) small digital chips as found in (i) phone-based cameras, (ii) P-n-S (point-n-shoot) models and (iii) less expensive dSLRs using smaller chips and (2) digital system operating at high ISO such as above 600-1000. Ironically, noisy digital images still have the advantages of portability and web-usefulness however they appear.

Film is now historic technology some twenty years after its zenith. It was a fantastic technology and will always be human readable, except for those "orange" color negatives. Film is still used by (a) film enthusiast, (b) the motion picture industry and (c) camera users slow to adopt digital for a variety of reasons. Film is now being discontinued.

Kodak still finds the manufacture of motion picture film profitable especially since Fujifilm announced it suspension of MP film manufacture. Kodak filed Chapter 11 bankruptcy in early 2012 and has started to sell off divisions. When movie theaters move to mostly digital display, the end of film will follow shortly. Eventually economics will force film manufactures to discontinue their relatively small runs of "still" film formats, which are produced while manufacturing huge runs of motion picture film. When MP film is discontinued, film will become very rare. However, some small-run film manufactures have sprung up in this country and Europe.

The transition from cellulose nitrate film base to cellulose acetate film base started about 1908, when cellulose acetate was first used in amateur (small gauge) motion picture film because many local laws required safety base for amateur motion picture films. The final transition to acetate base was made between 1935/38 thru 1948/51 depending on format and end user. While cellulose acetate is not flammable, it can degrade faster than its cellulose nitrate precursor. This was not widely understood until recently when it became clear to the preservation community, at the 2007 AIC-PMG bi-annual meeting in Rochester, NY, where researchers announced that they have found acetate base unstable for decades.

Cellulose acetate base is used in 90%+ of all film sold today, even though it is destine to fail in 60+ years. Modern triacetate base (1955 onward) is far superior to earlier acetate formulations, so modern acetate base film is considered more stable than earlier versions such as di-acetate, etc.. Cellulose acetate film base fails by yellowing, curling, shrinking and channeling. Deteriorating acetate base film releases acetic acid that smells just like vinegar, hence the name Vinegar Syndrome. Heavily channeled and warped acetate base film looks very bad and scans poorly, but don't throw out severely damaged acetate film because the image can be reclaimed. The gelatin pellicle (image) can be salvaged by dissolving away the damaged film base using solvent, which does not harm the thin gelatin image layer.

Cellulose nitrate base deterioration was thought to be a more serious problem than acetate deterioration. However, some historic nitrate based film is still in better condition today than acetate base film made at an equivalent time, or older. A local collection of 1906 nitrate roll (still images) film negatives is still in very good condition a hundred years plus, later. The main problem with nitrate film is that it can weld together into small bricks that cannot be salvaged. The strong acid that evolves during deterioration liquefies the gelatin image layer creating a brown-ooze material that sticks the sheets of film together. Once the gelatin is damaged, the image is lost. This is different for acetate base film, where the gelatin layer remains intact because the deterioration by-product is a weak acid, not strong nitric acid.

The acetic acid that evolves from deteriorating cellulose acetate is a weak acid and does not destroy gelatin, while nitric acid is a strong acid that completely destroy the gelatin image layer. Both acids donate hydrogen ion to another substance, however weak acids hold on to some of their protons, while strong acids release them all. Both types of film degrade so they need to be preserved using cold storage. **DO IT NOW.**

Estar base began to be used in the 1960s by Kodak, it was finally a truly permanent base. As of 2001, Kodak uses Estar for all sheet film but it still uses triacetate base for roll film. British chemists Whinfield & Dickson of the Calico Printer's Association patented "polyethylene terephthalate" (called PET or PETE) in 1941. The first polyester fiber was called Terylene in 1941, manufactured by Imperial Chemical Industries or ICI. The first plastic film was Dupont's Mylar. Kodak leases rights from Dupont to make their Estar base.

Color imaging technology was invented by the noted physicist James Clerk Maxwell in 1861. Maxwell used three separate images photographed using separate additive color filters (red, green and blue). The resulting three B&W transparencies were projected using those colors of light, recombining into a full color image on a screen. Significant experimentation by many workers was required for producing the common color print.

Louis Arthur Ducos du Hauron developed a subtractive color (cyan, magenta & yellow) print (1877) using three layers of pigmented gelatin laid on a reflective surface yielding an early color print common today. This technology evolved into the very stable Tri-Color Carbro print technologies; influenced the by the T. Manly (1905) Ozobrome color pigment print; sold in London as the Autotype after 1919; also referred to as a Fresson print (4 layers) after 1951 in France. This technology influenced the 1945 creation of the highly stable Kodak Dye Transfer print process, which was unfortunately discontinued in 1994. Kodak dyes and materials for Dye Transfer can still be found occasionally on eBay and there are still a few practitioners.

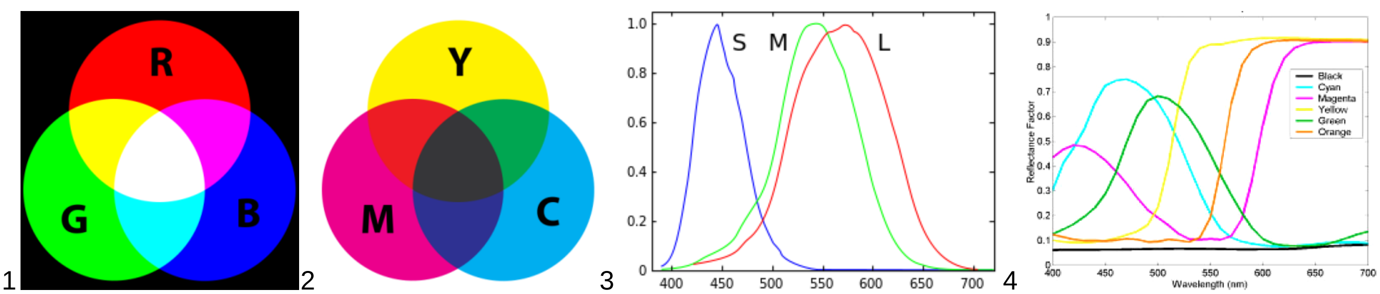


Figure 4 – **1**: additive color. **2**: Subtractive color. **3**: Spectral response of human eye. **4**:Spectral response of some colorants used for inkjet printers, up to 12 colorant are possible.

Early color film technologies used color-separated B&W negatives that were printed onto film that had the image silver bleached-out and replaced with dyes in a multiple-stage process, such as the 2-color Kodachrome (1914/16) process (not the same Kodachrome released in 1935). Early "all-in-one" color image "capture" technologies that included color dyes in the original were (a) Autochrome, colored starch grains on glass, developed by the Lumiere brothers in 1907, (b) Dufaycolor meshed RGB lines on glass in 1908 and later (1934) on motion picture film; and (c) the Finlay Colour Process in 1908 that used a RGB additive checkerboard screen on film. Color image capture took a giant leap forward with the release of the Kodachrome 3-color-subtractive reversal film (positive image) on still and motion picture film in 1935 (discontinued in 2009). Post-1937 Kodachrome transparency film (K-14) has very high dye stability, with 185 years (yellow) in dark storage. Early color dyes (pre-1938) were highly unstable, even dark fading in as little as 6 to 10 years. Ektachrome transparency film (1941) was easier to process, but the early versions E1, E2 & E3 were notoriously unstable. Kodak is now estimating 250 years (Wilhelm & Bower, 1993) of dye stability in dark storage for their post-1990 Ektachrome E6 films. On the other hand, Ektachrome films have a very short life when displayed in a slide projector, only 1-4 hours. Cold storage is the only preservation tool for both dye and base deterioration.

Pigments [not dyes] are being used today in permanent inkjet prints. Dye colorants were found to be less stable in inkjet printers. Pigment colorants are in common use by Epson, HP and Canon inkjet printers (subtractive CcMmYKk inksets) with very high light level display and also in dark storage. Inkjet technologies can range from unstable to very stable.

Fading studies of printing technology are being conducted by both WIR (Henry Wilhelm) **and** AI or Aardenburg Imaging (Mark McCormick-Goodhart). Mark introduced the iStar methodology for fading studies a decade ago. Henry uses both methods, but his 50+ years of fading studies generally use his proprietary technique for rating inkjet and photographic prints. Although proprietary, Wilhelm's shear depth of information makes the data very valuable. WIR has more published results than AI, but Mark is working hard to fade samples and report result in real time using the iStar metric. Henry [a true imaging hero] has a long history of pushing for, and analyzing, print permanence going back to the 1960s when his East Street Gallery was making B&W print washers.

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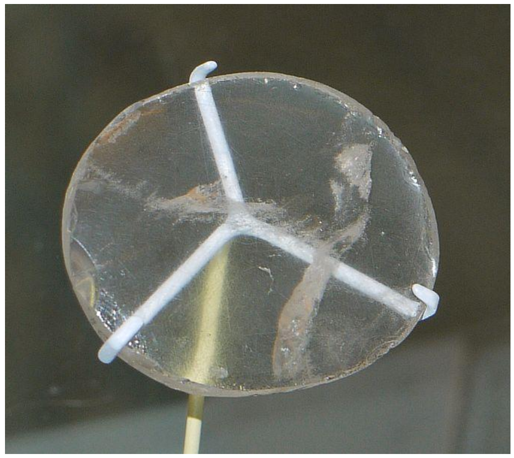


2


Figure 5 – **1**: Nimrod Lens approximately 3000 years old (British Museum) found in an Assyrian palace of Nimrod, artifacts with very small inscriptions were also found, suggesting the lens was used in their creation. **2**: Undoubtedly, lens shaped water on a high surface tension surface (wax coating on leaves) gave rise to the permanent magnifier.

Lens history in photography begins in 1816, but lenses have been use for millennia. Early lenses evolved from magnifier stones. Then eyeglasses and telescopes were created to aid the elderly and scientists. They both tend to have 1 or 2 elements, which are unable to focus all colors of light in the same field, softening the resolution of the lens significantly. They can focused in a curved image-plane (field) on the back of the human eye. Focusing in a curved field was acceptable for film that is always slightly curved in its path or holder, but this is a fault in digital imaging.

Chevalier Achromatic lens (1835) used two cemented glass elements made from different glass formulations to focus blue and red light in the same plane, the green light focused slightly out-of-plane, producing a slightly softly-focused image even in a curved plane-of-focus. Daguerre officially adopted the Chevalier lens in 1839, and, it still gets heavy use in modern [simple] systems due to its compactness and simplicity. In the historic era, the design probably delivered about 15-20-lp/mm (soft focus). See Figure 7, Number 1.

Opticians were the first lens makers, making both eyeglasses and lenses for scientific instruments. Their designs focused light in a curved field replicating the back of the eye. A single element can't do much more that perform minor magnification, as in eyeglasses. Two elements can create more magnification, yet all colors of light are not focused in the same plane, depending on glass formulation and the coating (after about 1950s). Three elements in two groups can be useful when designed with light is bent through a specific glass formulation and/or a cemented interface where light scattering is diminished. Modern [digital] lenses focus light in a flat field.

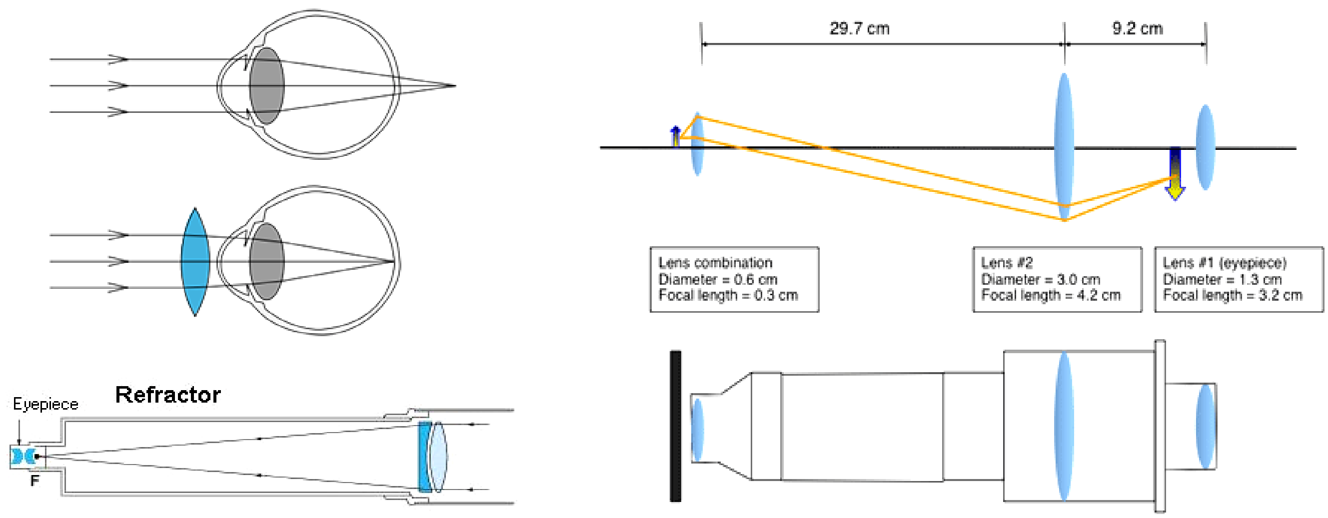


Figure 6 – Upper-left: Depicts the correction of an eye who's lens focus light behind the retina, using 1-element eyeglasses. Lower-left: Diagram of a 4-element refractor telescope, note Chevalier lens at front of telescope. Right: Diagram of 3-element compound microscope, note the magnification between "Lens combination" and Lens #2, and, the small eyepiece lens (Lens #1) the on the right that further enlarges the image, from the #2 lens, making it a compound optical device. Images credited to Wikipedia and The Golub Collection.

Kingslake said: "it is hard to understand why the development of a good camera lens was such a slow process, between 1840 and 1890." Both Chevalier and Petzval lenses have soft focus compared to later designs where more colors of light were focused in the image plane. Kingslake's excellent book "***A History of the Photographic Lens***," can be found on Google Books where sections are available to read. Also view Brief History of Optics and Wikipedia

History of photographic lens designs.

Petzval designed his 4-element in 2-groups achromatic portrait lens in 1841. It became a photographic standard that was used through middle of the 20th C. The **Petzval Portrait** (see Fig 7, No 3) lens had a long shape (several inches) due to a large air gap, and thus couldn't be used in amateur cameras that favored the compact Chevalier and Dagor designs. The Petzval lens pushed the use of different glass formulations further to improve light handling, but still only focused two colors in the same field; it is thought to be capable of 20-30 lp/mm resolution, medium resolution.

Seminal innovation in lens making was to focus the all colors of light in the same field, or the image plane. Otto Schott joined Ernst Abbe and Carl Zeiss in the Zeiss workshop (founded 1846) http://www.smecc.org/ziess.htm to produce glass capable of implementing the workshops **Zeiss Apochromatic** a flat-field lens design that corrected both spherical (all 3 colors) and chromatic aberrations (2 colors) in 1886; resolutions of 40-50-lp/mm are thought possible, which is good resolution.

By 1896, the Zeiss workshop developed the **Protar** and **Planar** lens designs, which only came into wide use after lens coating was developed 40 years later. Light scattering at the many air-to-glass surfaces (6-elements in 4-groups) was the problem with those formulations. The compact **Dagor Anastigmatic** with 3-elements in 1-group (all 3 colors) was a flat-field lens produced by Goerz (Berlin) in 1904 and it is still being used today in modern Point-n-Shoot & mobile (cell phone) cameras. The design was a significant advance, correcting spherical aberration, coma and astigmatism; it is thought to be capable of 40-60-lp/mm, very good resolution for the era. A 1917-version of the Goerz lens was MFT-tested in 2003, it produced a very respectable 55-lp/mm, even without coating.

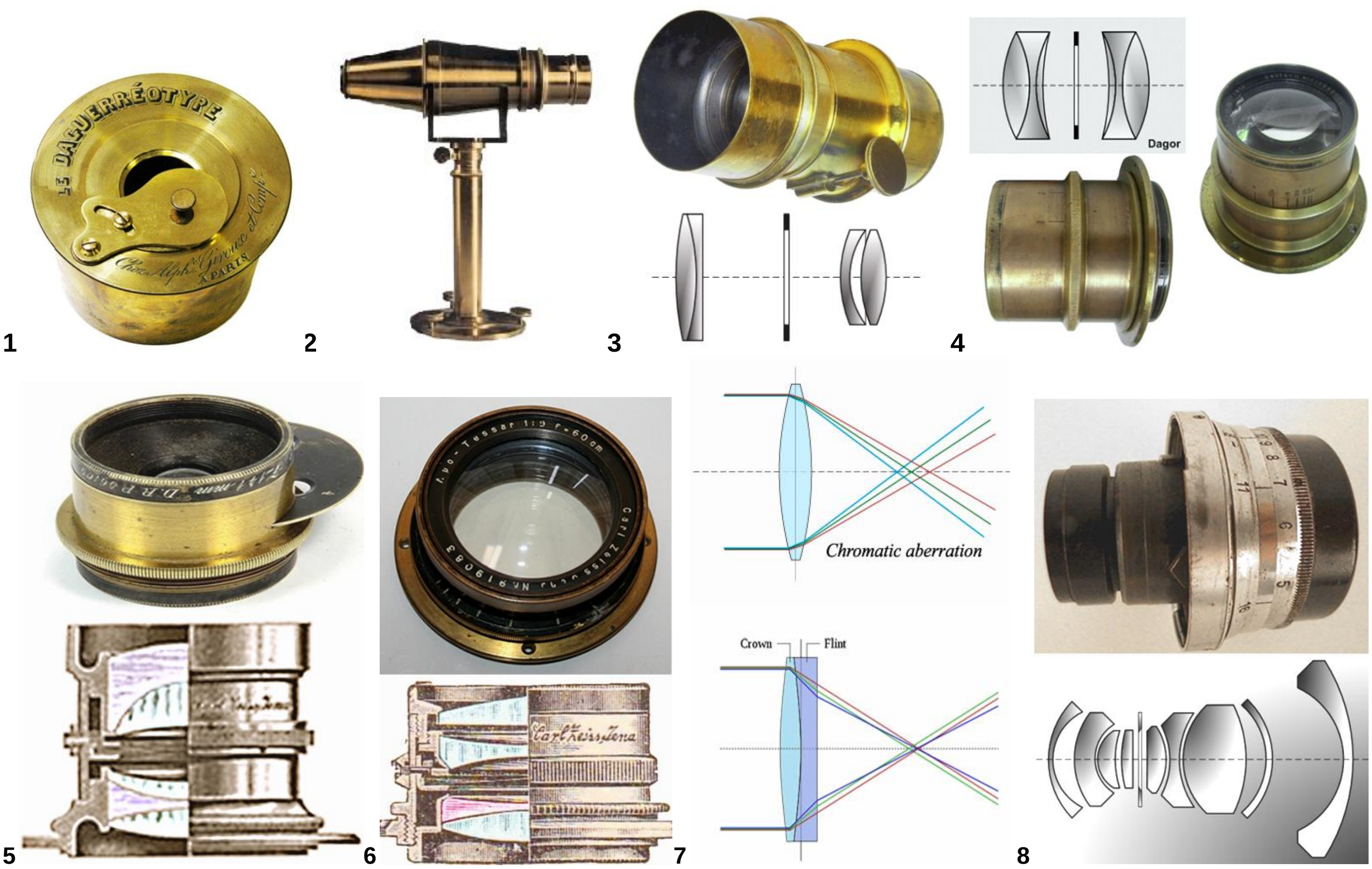


Figure 7 – **1**: Chevalier lens for Daguerreotype camera 1839-40. **2**: Voigtlander circular Daguerreotype camera with lens (right end) circa 1841. **3**: Petzval portrait lens designed in 1840. **4**: Goerz Dagor designed in 1889, was found to be similar to the Protar lens designed by Paul Rudolph in 1890 at Zeiss. **5**: Paul Rudolph made with his Protar lens designed in 1890, bottom is the 1907 version. **6**: Tessar cut-away showing 4-elements in 3-groups, designed 1902 capable of 60-lp/mm without coating. **7**: Diagram showing how chromatic aberration are corrected using Apochromatic lens designs using different glass formulations. **8**: Zeiss Biogon a super wide-angle lens designed in 1935 and made famous with the Schneider Super-Angulon.

Early 20th C lens designs are still being used today because they are simple, effective and compact. The **Tessar** (see Fig 7, No 6) was the next significant advance, it has 4-elements in 3-groups design by Paul Rudolph at Zeiss to be a higher contrast yielding greater resolution; 40-60-lp/mm is thought possible, superior for the era. It is said to be a combination of the front half of the Unar with the rear half of the Protar. Its potential for modification allowed the maximum aperture to increased from f/4.5 in 1902, to f/3.7 in 1917 and f/2.7 in 1930. It is said that most lenses have a little bit of Rudolph's Tessar in them. The Goerz Dagor (Fig 7, No 4) was another classic design, c. 1890, that is a double-Anastigmat which shows up in future designs, on many camera of the era and is still in use today.

German designers continued to refine glass formulations and then introduced anti-reflective coatings altering the optical properties of just the lens surfaces, raising lens quality to a very high level. Alexander Smakula (Zeiss) developed single pass lens coatings in 1935. The 1941 the Hasselblad HK7 reconnaissance camera (made in Sweden which had access to Zeiss coating technology) was commissioned by the Allies http://www.hasselblad.com/about-hasselblad/history/a-man-with-small-hands.aspx. The result was said to have better resolution than the captured German equivalent spy camera.

Lens coatings advancements didn't reach consumers until after WWII. Large-format lenses made prior to 1980 were not even single coated. Smaller format lenses were coated earlier because of cost and early coating equipment geometry. Lenses reached their and penultimate state during 1960s-80s with multiple coatings, consisting of alternating pure-silica and magnesium fluoride http://en.wikipedia.org/wiki/Anti-reflective_coating thin layer deposited on the surface of the glass.

Most prime lens (fixed focal length) designs were developed over 80-110 years ago by the great German designers. The Tessar in 1902. The Symmar designed by Schneider in 1920 as a wide-angle, with a 70° angle of coverage. The Sonnar was designed by Ludwig Bertele (Zeiss) to be a very fast (f/2.0) in 1929. Bertele later worked-out a very wide-angle (90°) Biogon f/2.8 in 1935; it was later metamorphosed into the Schneider Super-Angulon (120°) in 1956.

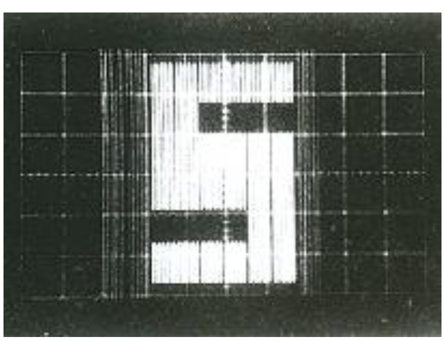
Modern prime lenses have advanced in only small increments over those older designs. The current development cycle emphasizes glass composition (last seen during the late 19thc) and the economical manufacture of exotically-shaped lens elements using modern precision molding and hybrid processes, rather than the more expensive grinding process, an expensive three-centuries-old technology.

Computer-aided-design continues to help improve all lens designs, but zoom lens designs have been helped the most because they are inherently less sharp (15-25% less) than the equivalent prime lenses. Multiple coating have helped immeasurably by reducing internal light scattering with the many elements found in zoom lenses. Major additional improvements include very exotic glass formulations and modern molding technologies of both glass and plastic.

Street price is a rough indicator of lens resolving power. The cost of a specific lens within a group of like devices tends to denote its resolution capabilities, such groups as all the (a) 35-mm lenses, (b) 50-mm lenses, (c) 85-mm and (d) 135 mm prime lenses or the ubiquitous standard 24/28mm-to-70/85mm zoom lens. See http://photodo.com/ & http://www.dpreview.com/lensreviews/ for reviews based on MTF. For details on lens design and history see http://en.wikipedia.org/wiki/List_of_lens_designs.

Camera History: The function of a camera is to hold the lens exactly perpendicular to the film axis. Box cameras do this very well. Folding cameras have the unrecoverable fault of "lens alignment variability" with no way to check alignment when the camera is re-opened. View cameras that are used for large-format and studio photography must also be aligned each time either the lens or film standards are moved or even bumped. This is done using the Zig-Align tool. The BetterLight ViewFinder software also has a focusing tool that makes the problematic ground-glass using a loupe an issue of the past. There is a great deal of camera design and history information online, Google "camera history" or see: http://en.wikipedia.org/wiki/History_of_the_single-lens_reflex_camera, http://www.midley.co.uk/index.htm, http://www.digitaljournalist.org/issue0602/dunleavy.html, http://en.wikipedia.org/wiki/History_of_the_camera, http://www.graflex.org/speed-graphic/graphic-models.html, http://www.boxcameras.com/camcolhome.html#Cameras: 1880-1899 , http://www.digicamhistory.com/1970s.html http://www.nwmangum.com/Kodak/FilmHist.html, http://www.kodak.com/global/en/consumer/products/techInfo/aa13/aa13.shtml, http://www.camerapedia.org/wiki/Kodak ; http://www.ndsu.nodak.edu/instruct/rcollins/242photojournalism/historyofphotography.html, http://www.nikonweb.com/files/DCS_Story.pdf & http://www.digicamhistory.com/Index.html. Also Check Google Books: "cameras."

Digital imaging was born when the CCD was invented by Boyle & Smith at Bell Labs in 1969. See http://www.nobelprize.org/nobel_prizes/physics/laureates/2009/smith_lecture.pdf. The crude 8-pixel linear (eight pixels total) array used a bucket brigade system to empty the photon wells via a shift register with the ability to pass the charge along the surface of the semiconductor to the ADC. An oscilloscope display was the first imager used by Boyle & Smith. Electronic imaging counts the number light photons falling directly onto a chip, focused through a lens, to produce an image directly from light.

1 

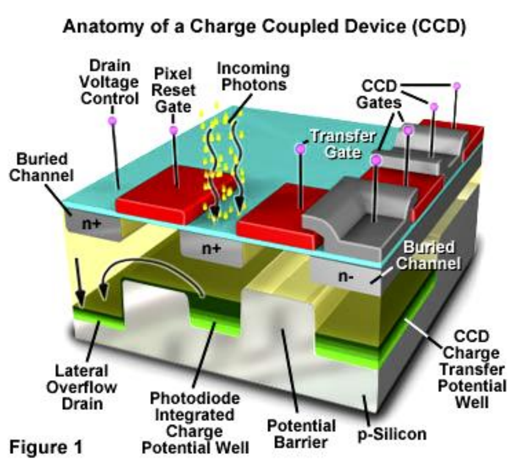
2 

Figure 7 – **1**: Ochi's first 8 x 8, 64-pixel device with the Sony "S" for the research Lab it was developed at in 1971. **2**: Anatomy of a Charged Coupled Device (CCD) credited to Micro-Magnetics at FSU in 2000.

The first commercial digital cameras were introduced between 1981-1984. The Sony Mavica (1981) is a B&W 8-bit 0.79 MP digital TV camera making still images that were recorded on a 2" floppy disk. The Canon RC-701 (1984 & 1986) was a color 0.40 MP device that was also a digital TV camera used mostly by news photographers at the

Olympics because of it built-in transmitter. By 1987-88 the leading edge of news photographers, USA Today and AP, began using images transmitted over telephone lines. Years later in 1998, 85% of all press photographers said that digital imaging technology was indispensable for meeting deadlines.

The **analog video stream was used for some of the earliest electronic imaging** applications between 1977 and 1987, but the technology persisted thru 1993 developments. Video stills were pulled from an analog video stream in the CASI Photo System (1977, TV camera) are an example; see http://www.digicam history.com/1970s.html. Still frame video capture proved unwieldy and was a photographic dead-end.

Figure 8 – **1**: Prototype of the first Sony Mavica with the 2" floppy disk used to view the images by transferring them to a computer. **2**: The Kodak Electro-Optical Digital Camera with satellite storage box in 1988. **3**: Videk MegaPlus 1.4 MP camera using the Kodak CCD in 1987. **4**: Kodak DCS 100(M) system ($25K) using a 1.3MP CCD in a Nikon F3 body with a 200 MB HDD and batteries (55

pounds) in 1990. **5**: Crosfield 130 that used 3-CCD (with a beam-splitter) with an overall 7.1 MP (non-video still) professional studio system in 1991. **6**: MegaVision T2 3-shot 12MP camera back on a Calumet Cambo view camera body from 1991. **7**: Leaf DBS-1 “the brick” in a medium format camera, note the 3-filter wheel and storage box holding the tripod stable in 1992. **8**: BetterLight scanback developed in 1994 in a view camera (that is more than a decade old technology) on a monopod in a studio at the Wilderness Studio in Solon Iowa in 2013. **9**: Kodak DC-120 a 1.1 MP consumer model that was the first to break the under $1000 barrier. **10**: Kodak DCS 460c color 6MP using Nikon N90 body in 1995. **11**: DCS 460c 6 MP CCD from the open camera back. **12**: Sony Mavica MVC-FD76 MP color with a 10:1 40-400 zoom designed for real estate agents at $800.

MegaVision (1983) made many significant contributions to the transition from analog to digital imaging, although evidence of it is difficult to find outside older photographers. Their first innovation was a video processor (1024 XM) for converting analog video signals from a vidicon TV tube for capture, through a 1000-line 1024-XM ADC into digital images. It was later upgraded to 2000-line Tessera system (1986) designed for professional catalog work. Then in 1992 MegaVision introduced a 6MP CCD 3-shot T2 all-digital system in using a 3-color filter wheel in front of a 2024 x 2024 monochrome CCD from Fairchild Semiconductor made three exposures as a digital back for a view camera; similar to Figure 8, No 7.

Kodak released its Kodak Electro-Optical camera in 1987 (Fig. 8, No 2) that used its new 1.4MP CCD (1987). The CCD replaced the film pressure plate on a Canon F1. The analog stream went through the ribbon cable to the analog to digital converter (ADC) in a satellite storage box including a 100 MB HDD in 1988. This was the beginning of a digital imaging system for the government (spy stuff). Read The DCS Story about Kodak professional digital cameras using Nikon and Canon bodies.

The banner era for digital was 1990-1994 when high-resolution cameras were introduced for (a) gathering with the 1.3 MP Kodak DSC 100 using an Nikon F3 body in 1990; (b) Crosfield 130 was introduced 3-CCD using a beam-splitter for a one shot 7.1 MP studio system in 1991; (c) catalog photography with the Leaf 2K, a 3-shot “Brick” in 1991 or (d) product and architectural photography using a Dicomed 6K scanback (in a view camera) which later became BetterLight Model 6000 in 1997.

BetterLight technology moves a carriage across the back-plane in a view camera creating a very high megapixel image. Each pixel has unique R, G & B color values created at the bit-depth of the ADC (14-bit). The image is as good as any digital image can be made. The problem with the technology is that the scan takes time. It can be as short as a one minute scan, but in operation, even with a reasonable amount of light, the scan times are 8 to 15 minutes. Flash can’t be used, so many shops do use one, even though they may own a BL back. In addition, the photographer must have a moderate level of skill to produce the best quality images. Kodak was the supplier of the 8000-pixels (8K chip) tri-linear array to BetterLight, but the division was sold in 2011. Shortly before that, Kodak discontinued the 6K, 10K and 14K liner arrays. Now only a limited number of new scanback are being produced. Most users buy used equipment on eBay. Mike Collect (now near Sacramento) sill provides technical support and service. In reality, the best digital camera is no long being made on a routine basis. Digital imaging has progressed so far in 20 years that the best is no longer critical to many users.

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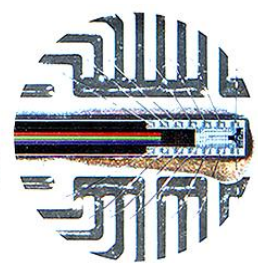
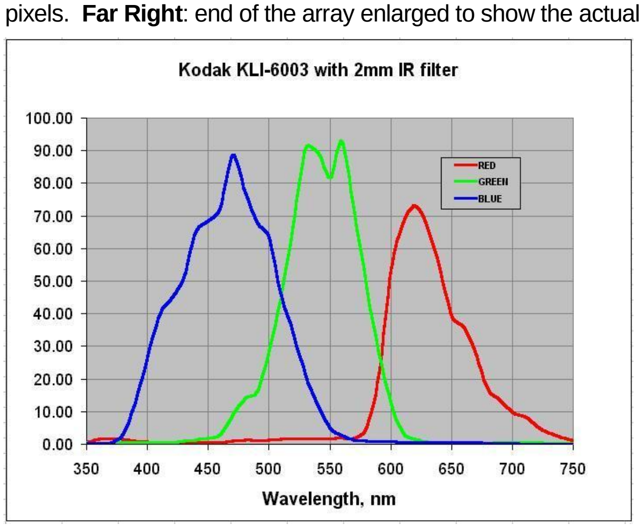


Figure 9 - 1: BetterLight scanback with the sensor parked mid-scan. **2**: enlargement of the trilinear CCD array with individual R, G & B rows of pixels. **Far Right**: end of the array enlarged to show the actual red, green and blue bands of pixels all from BetterLight website.



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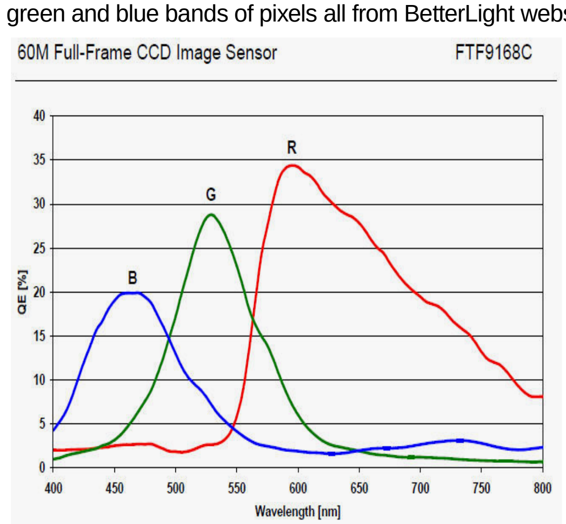

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Figure 10 – **1**: spectral response of the BetterLight scanback in 2006. Compare to the response of the human eye. **2**: Spectra response of the 60 MP (8956 x 6708) Bayer Pattern CCD area array. Graphs are to scale; credit BetterLight and Teledyne Dalsa.

Digital imaging resolution is limited by lens quality. Lenses are the limiting factor in the advancement in digital imaging development. High-end commercial digital sensors are sold (3-4 um pixel size) that have finer detail (pixel pitch) than the capabilities of current lenses. Note that (a) high performance military lenses, (b) spy equipment and (c) astronomical systems are excluded because they not commercial equipment. The best over-the-counter lenses are few and far between. Look to small-format (35-mm format) Canon, Nikon and modern Sigma for the best commercial lenses. In general, the most expensive in the following groups (i) 35-mm, (ii) 50-55-60-mm, (iii) 85-mm, (iv) 135-mm and (v) 200-mm Canon and Nikon prime lenses have the best performance. Mike Collette at BetterLight developed a 10K scanback using a 10K tri-liner array (10000 x 13640 with 2.7um pixels) formerly offered by Kodak (now discontinued) that had greater resolving power than large format lenses with a focal length large enough (150mm) to cover the image. The minimum focal length for the 2.75" x 3.75" format lens is a 135-150mm large format lens. Collette tried to have a lens designed to be superior to the [best] 80-lp/mm lenses available, but it could be done at a price that was reasonable.

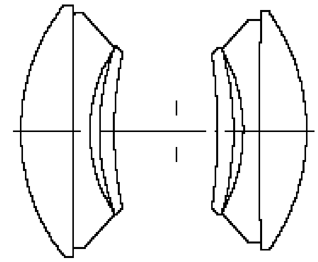


Figure 11 - Schneider Apo Symmar f5.6 150-mm (non-digital) lens c. 1980; capable of 80-lp/mm.

Chris Perez has measured only 1 of 30 medium-format lens that had a center resolution of 120-lp/mm, at f11; the edge resolution was considerably less. Some of Canon's best prime lenses (35-mm format) have been measured by Lars Kjellberg at 90- & 100-lp/mm: (a) 90-lp/mm (center) at f8 for the 200-mm f1.8 EF USM, which is the highest rated lens on the photodo.com website; (b) 96-lp/mm at f8 for the center of a 135-mm EF f2 USM; and (c) 96-lp/mm at f8 for the center of a 50-mm Macro EFf1.4 USM. Thus, some of the best commercially available lenses can only perform at about 100-lp/mm. These lenses will support sensors capable of 5080-ppi (100 x 50.8 = 5080), which would have 5-um (microns) pixels. However the actual active area of the pixels is usual ranges from 50-95% of the pixel pitch, thus 2.5 to 4.5 um actual pixel size.

The Kodak **PhotoCD** (1992) was the way many workers started using digital technology. Film originals were migrated to the digital format by a service bureau using Kodak equipment. This harkened back to the first Kodak cameras (1884) where the slogan was "You press the button - we do the rest." Eventually the PhotoCD was a technological dead end.

Path to digital image technological began with the development of a working transistor in 1947. About a decade later the all important integrated circuit (IC chip) was developed in 1958 where a full circuit contained on one chip. A decade later this lead to Boyle & Smith developing the charged coupled device (CCD is an IC) at Bell Labs in 1969. The CCD quantized light focused directly on an array by counting the actual photons of light that fall on individual picture element (pixel) creating a serial numeric count of light in each pixel, down the line. The first CCD was a linear 8-pixel, later Ochi at Sony produced a 8 x 8-pixel area array in 1972. A chip's exposure time could be varied making it similar to film. The stream of electron counts coming from each pixel in the array is converted into machine code by the analog to digital converter (ADC) also an IC. The first known CCD digital still camera was made by Steve Sasson in 1975, at Kodak. The Sony Mavica (magnetic video camera) was the first (1981) commercial CCD dSLR with interchangeable lenses that also included onboard storage on 2"-floppy-disks.

Digital was found to be the equivalent of film in the mid-1990s to 2003. Between 1973 and 1994 the quality of CCD pixel density and noise (SNR) improved to a point where digital was consider superior to film. **Stephen Johnson** (Pacifica, CA) pronounced film dead in early 1994 after testing the Dicomed (BetterLight Model 6000) scanback prototype developed by Mike Collette. The BetterLight used a Kodak 6K trilinear array with three 6000-pixel long rows of red, green and blue (RGB) pixels. By 2003 the 35-mm format Canon 1Ds 11 MP (2704 x 4064; 12-bit ADC; Bayer pattern) dSLR was acknowledged in **Popular Photography** to be capable of producing digital images equivalent to 35-mm film.

Bayer Pattern enables the area array chip to create color images, yet it had to degrade image quality to achieve the goal. Most dSLR cameras use a **Bayer Pattern** of color dyes (BG-GR) over their full array of pixels, producing image data with diminished resolution because it spreads the RGB-data over 4-pixels. Scanback cameras and flatbed scanners have unique RGB data for each image pixel; this is a superior technology compared to arrays with a color-filter pattern.

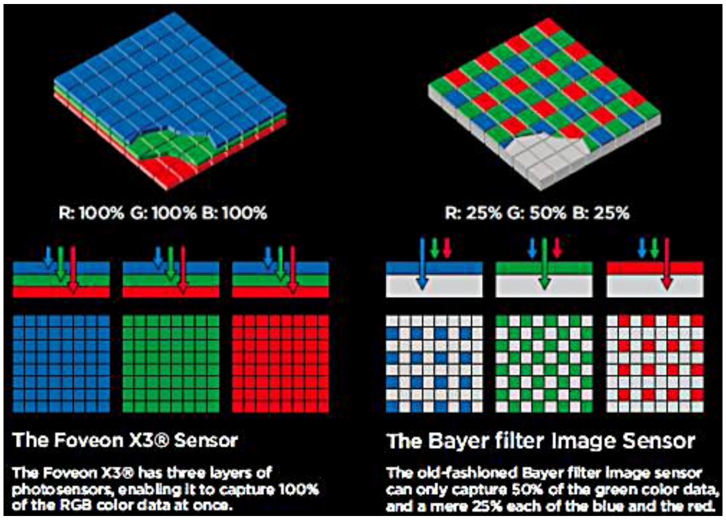
Currently there are huge area array sensors, 60 MP, made by Teledyne Dalsa that use the Bayer Pattern. The Bayer Pattern CCDs generally have resolution that is about a third less than a monochrome equivalent. This is higher than expected because that are two green pixel for the other red and blue pixels.

Figure 12 - Teledyne Dalsa 60MP CCD & ADC, see also Fig 13.

Foveon X3 technology is the closest to the scanback technology creating R, G and B values for each pixel. Sigma, the Japanese camera and lens manufacturer licensed the Foveon technology to produced a 3-layer 4.7 MP-per layer CCD, called 15 MP, in a dSLR known as the SD14 & SD15 for $1000 in 2006. The system produced equivalent image resolution to Canon dSLRs with 15 to 18 MP (the largest of the era) because Canon use Bayer Pattern sensors that degrade image quality for a couple of reasons (a) RGGB 4-pixel sub-array and (b) use of low pass filter. In the past, Sigma made some fairly poor quality third-party lenses, but these cameras clearly outperformed the best of the Bayer pattern competition. In addition, Sigma has clearly increased lens quality. Image quality is best determined by examining comparable images made with the various cameras on dpreview.

Sigma released the Sigma SD1 ($6900-8000) in 2010; using a CCD with 15.4 MP-per-layer, for three layers, that they claim as a 46 MP sensor. Each of the 15.4 million pixels has individual red, green & blue pixels stacked on each other producing a full set of RGB values for each pixel. In 2011 they rebadged their system (following the tsunami) as the **SD1 Merrill** and released it for $1700-2200. This could be a candidate for the "second best camera" after the BetterLight 8K scanback (85/254 MP at $18K) which will be discontinued when the supply of 8K Kodak tri-linear array chips are exhausted.

Digital versus film argument continues: digital imaging is now capable of recording spatial and color information at low noise well beyond the limits of even most lenses. However, not all digital imaging meets this standard. Digital technology offers imaging with no intervening technologies to distort the color information such as film-dyes, developer dye-couplers or complex chemical processing. In addition, there is no deterioration of the film base and dyes over time. Any photographer can edit and output at the highest level of competence; this capability was once only reserved for color service bureaus.

1 

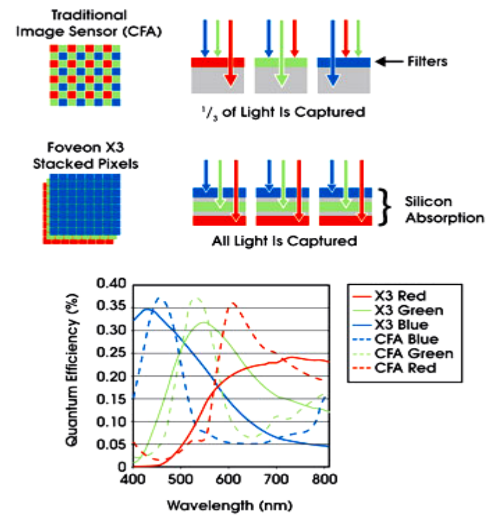
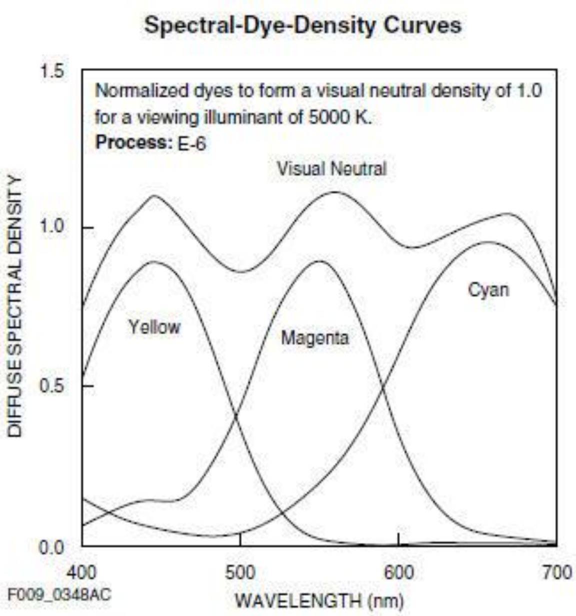
2 

Figure 13 – 1: Comparison of a Bayer Pattern sensor with a Foveon sensor. **2**: Spectral response of Bayer vs. Foveon, note that the red in the Foveon sensor extends out well into the invisible infra red, and that the blue response is quite high compared to other CCDs and the human eye see Figure 3 center-right for the response of human eye and Figure 6, Right side, response of BetterLight sensor Figure 11, left side.

Many photographers who favor film assert that the smooth tonal gradations of midtones found in many early-to-mid-twentieth century images is one of the enduring qualities of film. It is suggested that this property is due to internal lens flare found in earlier uncoated or single-coating lenses. And some say that the noise in film is so high that it blends the normally high contrast differences of the small detail, always found in premium digital systems where noise is averages about 500:1. Neither observation is universally accepted and passionate arguments are ongoing.

1 

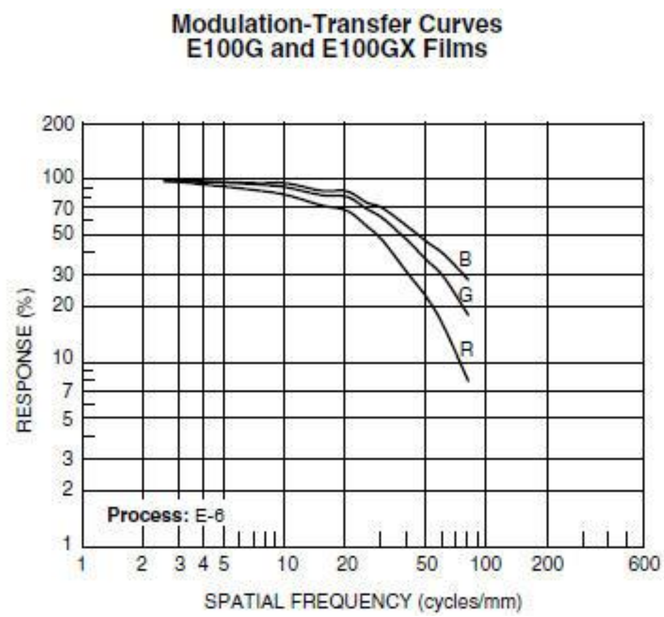
2 

Figure 14 – **1**: normalized spectral response curve for Kodak Ektachrome 100G (2013) showing a very even R, G & B response, unlike the human eye. **2**: the E100G MFT curve (modulation transform function or resolution), which shows a capability of about 3050-ppi-digital-equivalent resolution (60-lp/mm at 30% difference between black and white line pairs); the one thing the curve does not show is sharpening built-in to the film, which would show up a hump above the 100% response (y-axis) line; this is a modern film competing with digital technology.

Collections of film negatives and positives still have incalculable intrinsic value their migration to digital is critical. There are many issues in digital capture: (1) selecting the appropriate capture resolution for your film for the end use, (2) the type of film base (acetate or nitrate) and the stage of deterioration, (3) dealing with the film grain and (4) color correction of faded images. **Cold storage is the only preservation method available** to keep your degrading film archives viable until they can be migrated into the digital domain. Film is kept stable while funding is sought or an ongoing project proceed slowly.

Digitally remastering a film collection is not easy, but must be done. One can show the value of a collection if a portion can be put online so its value to users can be quantified. Funders can be shown statistics that will drive the preservation process via Preservation and Access paradigm. Remastering preserves the image because images can be captured without color or resolution loss, well above the spatial-information bandwidth contained in the film. In addition, there is no deterioration of the digital image file once the file (and two backups) are held in the digital domain on HDDs. The originals need to go into cold storage. When time and money is available the color fading can be corrected by a skilled operator using tools in Photoshop.

The issue of the appropriate resolution is best addressed on a case-by-case basis. Weather to capture at low resolution for online access (only) or at high-resolution for permanent migration into the digital domain requires sound reasoning. An example might be that the first round of digitization could be only the best images at low resolution for use online to generate statistics that can be used to impress funders. Holding images in cold storage allows unlimited time for the development of funding for remastering projects at the pace common to grant-funded projects.

The ability to digitize film is not going away anytime soon although Kodak has discontinued several of its trilinear CCD arrays, and sold the division (see timeline), used in some of the high-end flatbed scanners and scanbacks. Image capture using automated software included with a flatbed scanners components can easily compromise digital images permanently. Although the “automated“ functions make digital imaging easier for the inexperienced, they remove control from the experienced operator and can alter the fundamental image data captured by the sensor (CCD) and analog-to-digital converter (ADC) before the file is even written to memory within the capture device. Even with a neutral gray target (4-8 steps) included in the frame, full tonal range information can be compromised when “automated” functions are left on.

Storage of digital files needs file format that holds the digital image data securely and permanently. Archival storage of image information should be done using the TIFF format, made within well-known imaging software such as those in the Adobe and Apple families. RAW and DNG are both viable born-digital formats. DNG is preferred because it does not use sidecar files for metadata storage. PDF/A is the preservation format for documents with both text and digital images.

Digital images can be stored indefinitely without deterioration, however, they can be lost swiftly through the lack of backup. A digital file can be permanently “lost” if it is stored without regard for basic computer technology (backup) or by using inappropriate storage media, i.e., CD-R/RW or DVD±R/RW. The recommended digital storage medium is the hard drive (HDD). They are usually viable for 5-7 years. Although a HDD can fail, it is usually backed-up on another HDD or stored in an “internally redundant” RAID array (mode 1 or 6; mode 5 is no longer recommended). Storing the same data on multiple 1-2-3 TB HDDs (2-3) appears to be more economically viable than RAID arrays at this time. Network backup on a RAID array can be one or two legs in an acceptable backup protocol, but relying on a RAID array that uses mode 5 has proven catastrophic for some users. Optical media (CD-R/RW, DVD±R/RW) will fail between 3-25 years, however optical disk readers probably won’t be available in 15+ yrs (2030). CD-R with gold reflective layer and phthalocyanine dye layer, recorded at slow speed (8X), can be reliable up to 25 years. A DVD±R with both archival attributes is still not available, no writable DVD are made with phthalocyanine dye, thus DVD+/-R is not considered reliable.

Compression of an image file diminishes the potential image by throwing data away to save space and improve download speed. If the original data is not as important as the space it occupies, or the speed of download, or movement within a network, compression **can be** used.

Compression should not be the default option, such as always making or using JPEG images. Use compression only when necessary. Some compression formats may not be available in the future.

Lossy compression (throwing original data away as in the JPEG protocol) is more effective for reducing file size and increasing download speed. JPEG lossy compression used Discreet Cosign Transform compression technology.

Lossless compression as found in the “best color” mode of JPEG2000 wavelet compression technology (J2K-C-LL) is superior to any level of the lossy JPEG DCT compression technology. Some forms of the JPEG2000 compression format can be truly lossless.

Archival use of JPEG2000 format is still in its tentative state, however it may become common because opinions are evolving. Institutions such as the Library of Congress and the National Archives http://www.digitalpreservation.gov/formats/content/still.shtml have massive amounts of valuable historic materials that are being digitized and backed-up twice (once off-site) and they are driving the exploration of JPEG2000 format. As of May 2009, a University of Conn questionnaire revealed continuing resistance to the JPEG2000 format. Much of that resistance is from equating the old JPEG name with the new JPEG2000 format. Adobe CS6 Photoshop includes support for JPEG2000; free plug-in are online.

Curators, archivist, preservation providers and users are rethinking their concept of storage. Storage protocols have been based on preserving physical artifacts. In the digital domain, however, perfect examples of the original file are always possible. The perfect object doesn’t need to be keep at a specific temperature and humidity in acid-free materials and without exposure to light. Digital files are continually migrated to larger storage media, newer HDD (hard drives), each copy is as perfect as the original.

Migration of digital files goes on forever as they are perpetually being moved to newer storage media. Digital files cannot be tucked away and forgotten in benign storage (CD-R) as was done in the past with physical artifacts such as photographs. Digital collections must be actively managed, as are computers and networks. The good news is that most digital collections don't require the physical space or energy required to keep physical artifacts stable over decades and centuries. After physical artifacts are migrated to digital, the physical artifacts still need to be stored in an archival manner, cold storage in compact storage systems is certainly an economical option. Bally Box style walls for room-size non-humidity controlled freezers once they are cold and never opened are energy efficient compared to HVAC constrained to 70°F +/- 10° and 50% RH +/- 10%.

Digital workflow has put all imaging processes into the hands of one operator. In contrast, the film workflow utilized at least three skilled crafts to bring a color image from the studio, to complex and critical chemical processing and then printing on photographic media followed by complex and critical chemical development, which often leaves the creator out of the important final print-creation stage. The differences between digital and film-based workflows are revolutionizing how images are captured, stored, viewed and accessed. Most digital photographers do all processing and printing themselves. Further, the decrease in size and the onboard processing makes photography a fairly simple task. The quality of image produced is declining while the sophistication of the equipment and software to manipulate the marginal-quality images produced by miniature lenses and CCD chips, with minuscule pixels sizes and noise that must be compensated for, is revolutionizing photography. Everyone in now a photographer, while professional are getting lazy with ever more automated systems.

Figure 15 - AIC Guide.

"***The AIC Guide to Digital Photography and Conservation Documentation***" *by* Jeffrey Warda (editor), Franziska Frey, Dawn Heller, Dan Kushel, Timothy Vitale and Gawain Weaver. 2011. 223 pp with 150+ ill., found at Amazon.com ($80). It is a exhaustively created by an un-paid committee of preservation professionals to help conservators create color images that have the best possible color accuracy within the limits of professionals with moderate imaging skills.

Photographic targets should be added to the frame of all images made for documentation or remastering. The photographic target market has exploded. It began with the GretagMacbeth Classic and Mini ColorChecker, 24-patches (Macbeth was bought by X-Rite) with its 6 neutral-gray patches that was $60 and has now been added (i) the x-Rite Passport (3-in-1, includes mini-CC) for $100 with free camera DNG profile software; (ii) the QPcard's 203 Book, which is a less expensive Passport-type device in a cardboard wallet ($50) also with free DNG camera profile software; (iv) the SpyderCheckr that is also a Passport-type device at 4-times the size for $140 with free software.

The AIC's PhD [PhotoDocumentation] target comes in 3 sizes arranged as linear placard meant to fit nicely next to an artwork for documentation: small $75, medium $100 & large $150, which used X-Rite patches similar to the CC Classic. Stouffers makes superior calibrated B&W 12-step to 37-step reflective scanner targets for $25 to $35; for B&W transmission step wedges http://www.stouffer.net/ TransPage.htm sold in a wide range of step-counts and step-widths, from $25 to $75. Many workers use the Kodak No1A, transparent 11-step wedge (B&W only), now available again in a 14-step configuration. Robin Myers has measured many of the modern (and older too) targets in his Spectral Library http://www.rmimaging.com/ spectral_library /library_index.html.

Figure 16 – **Left**: The X-Rite Mini-CC 24 (formerly Gratag-Macbeth Mini ColorChecker) with 24-patches, the lower six neutral gray patches are the backbone of making a good color image. **Center**: small icon-sized image of the X-Rite Passport shows two of the three targets inside the 4"x 6" hard plastic pocket holder. **Upper Right**: The AIC PhD photographic documentation target in the large, medium and small size (about 4" long); they used X-Rite color patches and are manufactured by Robin Myers. **Lower Right**: An image of the Kodak 1A Step Wedge (older 11-step target) B&W film transparency target. Credits to RMI and AIC.

Color fidelity requires color management that uses input and an output profiles. A profiled and calibrated monitor is absolutely compulsory. ICC and ICM profile are created using measurement tools and software to characterize the performance of the components of the color system. Once a profile is created and applied each component is color managed.

Most digital cameras, including the **(a)** BetterLight scanback, most **(b)** medium-format systems and **(c)** even some flatbed scanners can output files in the in the DNG or RAW formats. These files can be developed by the software that is supplied with the included software or it can be digitally developed in a Photoshop or Lightroom modules such as

Adobe Camera Raw, or, in Apple Aperture, Bibble and DxO Optics Pro. Using DNG profiles, made in the same system from the required color targets, are used to develop and adjust the digital images.

ICC profiles are used for all (i) input (camera and scanner), (ii) output of the image such as inkjet printers and (iii) monitors. Most current general profiling packages, such as i1Profiler (free with i1Pro and i1Pro2), don't produce camera profiles except for the more expensive versions (about $1.5- 2K), but still make monitor and printer profiles.

Camera profiles are generally made today using software supplied with modern color target such as X-Rite Passport ($100), QpCard 203 ($50) and Datacolor SpyderCheckr ($110). The software is commonly packaged free with the targets. In the past, PictoColor inCamera made excellent ICC profiles from 24-patch ColorChecker, the Digital ColorChecker SG target with 240-patches, GretagMacbeth ColorChecker DC with 238-patches or the HitchColor HCT target with 638 patches. In practice the CCD arrays in cameras are usually quite linear so the 24-patch CC Classic work very well.

There are limits to color management because it was designed by 'equipment and software" manufacturers in 1993 to differentiate the levels of system performance ($700 to $6-8K) based on basic and expert designations. Now, with the consolidation of most of the color management equipment and software manufactures by X-Rite, and with Apples' acquiescence of Color-sync support presumably because they see iPad, iPhone and table-based-platform OS (which are less robust) as more significant in the marketplace, the goals appear to have change. Since 1992-3 Apple "ColorSync" technology, that was built-in to all Macintosh systems and used to sell those system to color professionals. After the economic downturn, however, PC were found by many to be more economical. They had always been more adaptable and easier to customize since day one, because Apple (generally) wanted to maintain control over hardware.

Apple stopped spending the time necessary to develop ColorSync for each new OS generation, sometime around 2008. ColorSync issues went unsolved until the next OS generation was released, if ever. The iPhone and iPad don't support color management protocols, and also, make up a large portion of sales. Apple seems to have forgotten ColorSync. The ICM protocols used in the PC were never as good, but it was as good enough. Using profiles, color fidelity can only approach 95%-goodness, at best, of what is promised by color management. Even with the limitations, it is better than pre-1993 "closed shop" color adjustments. I is not as good as it could be, as good as design at Apple, before ICC was created. Mike Collect of BetterLight briefly sold an excellent tool called Color Sage, that was made in partnership with HP. It was outside the ICC protocols, and created very good color matches when using a system consisting of a **(i)** BetterLight scanback, **(ii)** HP i1Pro-managed printer and **(iii)** Color Sage software, for about $3K and the cost of BL and HP equipment.

NOTE on ICC and DNG: The ICC is the generic color management protocol generally used in Apple systems, defined by a color consortium with extensive standards. ICM is the set of protocols used for the Windows OS. They are similar, but not parallel. As of today, there is no color management on iPhone, iPad or other mobile OS formats. **ICC** was created in 1993/4 as the Internal Color Consortium at http://color .org/index. xalter. **ICM** was created in 1997 as the Image Color Management protocol <http://en.wikipedia.org/wiki/Color_ management>. **DNG** is the Digital NeGative image format related to the RAW format, developed by Adobe for royalty-free use. Most modern digital image capture devices support the DNG format including (i) flatbed scanners, (ii) SilverFast drivers for flatbeds, (iii) the BetterLight scan back and (iv) all dSLRs that support the creation of RAW image files. Digital cameras in phones, tablets and other mobile systems don't support the RAW protocol and thus do not support DNG protocol. It is unlike that they ever will because the style of photography does not call for critical image control, but rather the creation of a visually pleasing compositions. DNG profiles are different from ICC/ICM profiles and cannot be used interchangeably, at the present.

Measuring the 'color of things' has become very easy and economical in the digital age. In the past one used (a) the Munsell color patch books ($1-2K) and a good eye (difficult in practice) or (b) a spectrophotometer costing between $6K (Minolta portable) to $30K (benchtop scientific instrument with variable in/out angles and spectral include/exclude for measurements of high texture samples). Munsell Color publishes 1600-patch books of standard color swatches for $945 ea., in matte or gloss versions, but not both together. The glossy swatch book samples rest in pockets so they can be pulled out (with tweezers) and laid on an artifact for color matching. One reports the color patch number from before and after fading. One had to be sure to use the same light source for all visual measurements and the operator skill varied. Software for conversion to Lab and XYZ can be purchased for under $20. Bruce Lindbloom has an excellent online CIE Color Calculator and valuable information on Lab and XYZ (the foundation color space) color.

X-Rite has a visual color test online: the **FM100 Hue Test**. The more one uses color in a critical manner the better score you can achieve. Color profession routinely achieve "zero," when out of practice they score 5-10.

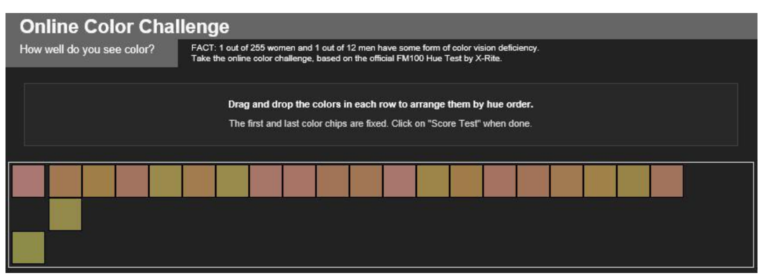


Figure 17 - X-Rite online FM 100 Hue color test.

The **handheld color spectrophotometer is a good tool for preservation professionals.** An X-Rite i1-Pro or the newer i1Pro2 is attached to a computer via USB. It is not yet ported to the iPad. Measurements are reported as either **(a)** RGB numbers within a specific Color Space such as <Adobe RGB 1998> or <sRGB> or as **(b)** Lab color numbers (L*a*b*), which use an internal color standard so the values are color space and device independent. The X-Rite i1-Pro/i1Pro2 and ColorMunki use 45°/0° geometry. These handheld spectrophotometer ($1200-2200) uses an internal incandescent, 2850°K, light source [smooth and featureless spectra, but a little heavy on the red end of the visible spectrum] that is corrected in the units firmware.

Since the i1Pro2 came out, the older i1Pro units have been selling used on eBay for $350-650, depending upon what is included with the i1. The UV-cut version has little value to color professional except for very esoteric application, so don't look at them. The X-Rite ColorMunki is a basic spectrophotometer ($450-500) using a LED light sources that will influence the measurement. X-Rite has yet to release a SDK for the ColorMunki system so it has not been ported to any color measurement software outside X-Rite packages.

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Figure 18 – 1: i1Pro2 with the incident light measurement cap, used for measuring light intensity (Lux) and color temperature (CCT) in degrees Kelvin (°K). **2**: i1pro2 off its base showing the calibration tile. **3**: i1Pro2 being used to measure paint swatch. **4**: Comparison of i1Pro (left) and i1Pro2 (right) not on their bases, which has the calibration tile. **5**: i1Pro2 being used to calibrate a monitor. **6**: X-Rite ColorMunki ($450) spectrophotometer measuring a color target for printer calibration.

X-Rite i1Pro2 the brand new (4/13/2012 for $1600-2100) <http://www .luminous-landscape.com/reviews/accessories/eye_one_pro_ii.shtml> spectrophotometer has a new lighting system with a UV-LED (along with the tungsten source) to produce analysis lighting with a larger UV component capable of measuring OBA (optical brightening agents) found in many inkjet papers, using the M0, M1 & M2 conditions for making profiles which are more accurate. However, since humans can't see UV light, but machines can, the most accurate protocol is yet to be determined. ICC has yet to define a technology to emulate human vision. As simple as that sounds, the basic work done in 1931 on the tristimulus [CIE] XYZ protocol was just not enough. The developing protocol, CIECAM02**,** has been active for 10 years, and a decade before under a different designation but it still hasn't defined human vision sufficiently to create a human response to UV brighteners in paper that can be emulated by hardware.

X-Rite ColorMunki is a budget ($450) spectrophotometer with an internal LED light source; spectra of source is spiky making measurement a little problematic. The ColorMunki is packaged with X-Rite Photo ColorPicker software that can be used to make spot measurements in Lab [color space] or sRGB, but there is no way to change the other color space. Working in Adobe RGB (1998), as most color professional do, it difficult. The sRGB color space emulate most monitors, this suggests the tool is designed for the amateur market. ColorMunki measurements can be exported in the "comma delimited columns" format, which can be opened in MS Excel, Apple Numbers or SpectraShop and BabelColor CT&A for comparison to other i1-Pro2, or i1Pro-measured spot colors, or compared to the artifact standards found in the RMI Spectral Library. X-Rite is not yet distributing a development SDK so third-party code-writers cannot add the device to their software.

NOTE on Color Measurement: The 45°/0° measurement protocol (i1Pro, i1Pro2 & ColorMunki) cannot accurately evaluate the color of textures (textiles or sand) or glossy surfaces such as shiny plastic or very glossy paint. The more expensive scientific instruments (Hunter Labs) and have technologies developed over years of measurement studies, that have 360-degree measurement spheres, specular-include & -exclude protocols and variable angle-of-light and angle-of-measurement options all designed to solve some of the complex color measurement problems that professional encounter.

SpectraShop (v4 is $95) was created and is distributed by Robin Myers http://www .rmimaging.com/ to make color measurements and to calculate and demonstrate the difference between other [spectral] color measurements or for comparisons to known spectra from the RMI Spectral Library. Custom color targets (of your design) can be created and measured on a routine basis. The conversion and output format is fantastic. However, do look at Bruce Lindbloom's online Java CIE Color Calculator. Most spectrophotometers are supported in SpectraShop; with limited indirect support for the ColorMunki via import of coma-delimited text files. The entry level version of the software is free, including access to online Spectral Library that Robin Myers has measured over the decades from real materials, paint swatches, pen inks, watercolor set and color standards. Most color users could not work without this tool. If nothing else, the ability to measure your own color targets, so that you can adjust images you make to the exact target, is profoundly helpful.

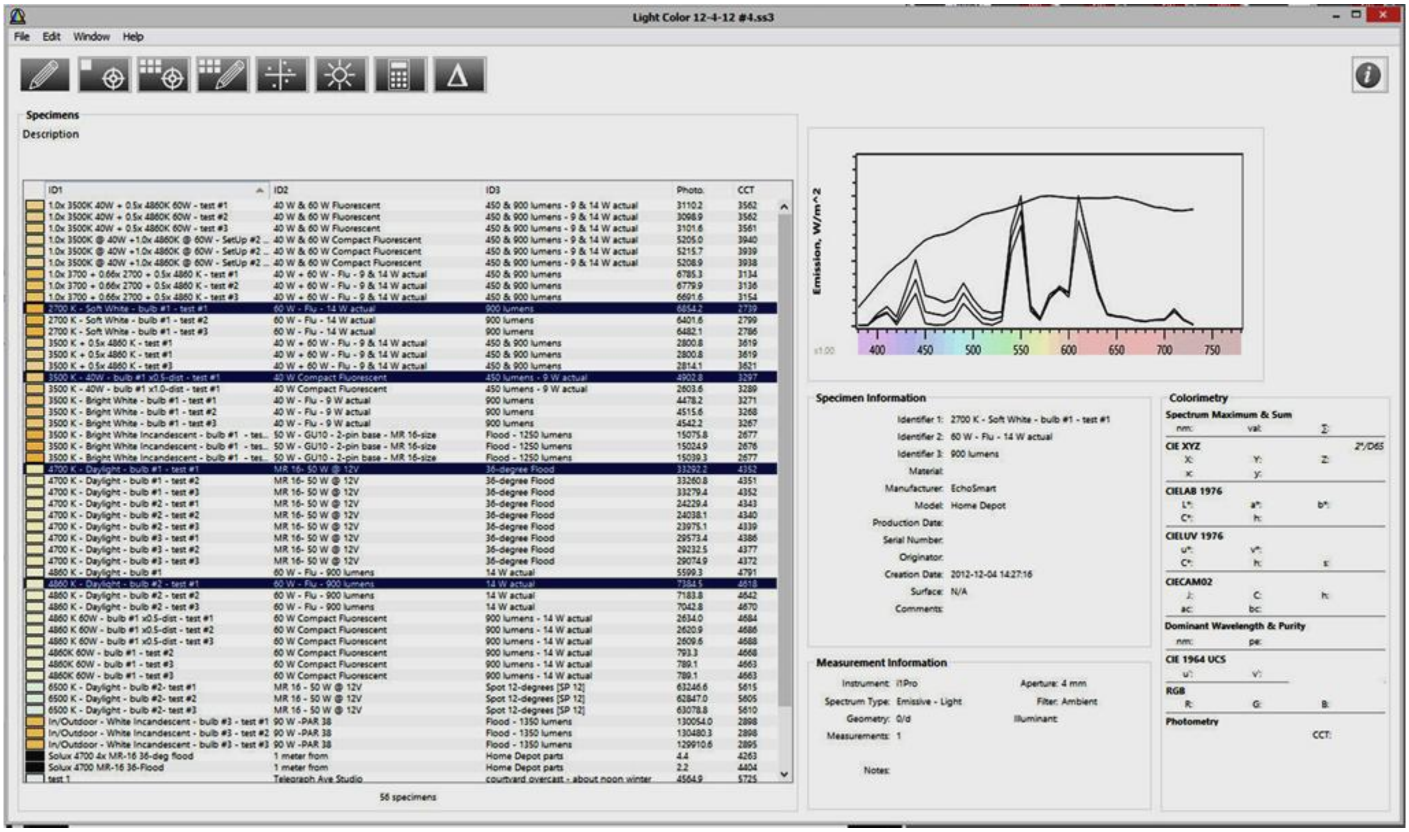

Figure 19 – In SpectraShop v4.0.1, working with a collection of light bulb spectra currently use in my Conservation Studio, for color matching while inpainting artworks or of matching an original artifact to its digital facsimile. Note the 4 spectra open in the spectral viewer **(i)** the top smooth hump is a MR-16 quartz-iodine bulb with a diachronic reflector and (sometimes) a filter on the sealed front, this particular bulb is labeled 4700°K delivering 4352°K at roughly 33,000 Lux intensity 12" from the bulb; **(ii-vi)** are modern compact fluorescent (CF) bulbs from Home Depot labeled **(top)** 60W-Daylight, delivering 4618°K CCT at 7384 Lux with many characteristic phosphor spikes in the spiky spectra, **(middle)** 40W-3500°K and delivering 3239°K CCT at 4903 Lux with the same spiky spectra and **(bottom)** 60W-Soft White delivering 2739°K CCT at 6854 Lux with the same spiky spectra. Spiky spectra often yield poor Color Rendering Index (CRI) values, while smooth spectra with a color temperature near 5000°K have high CRI.

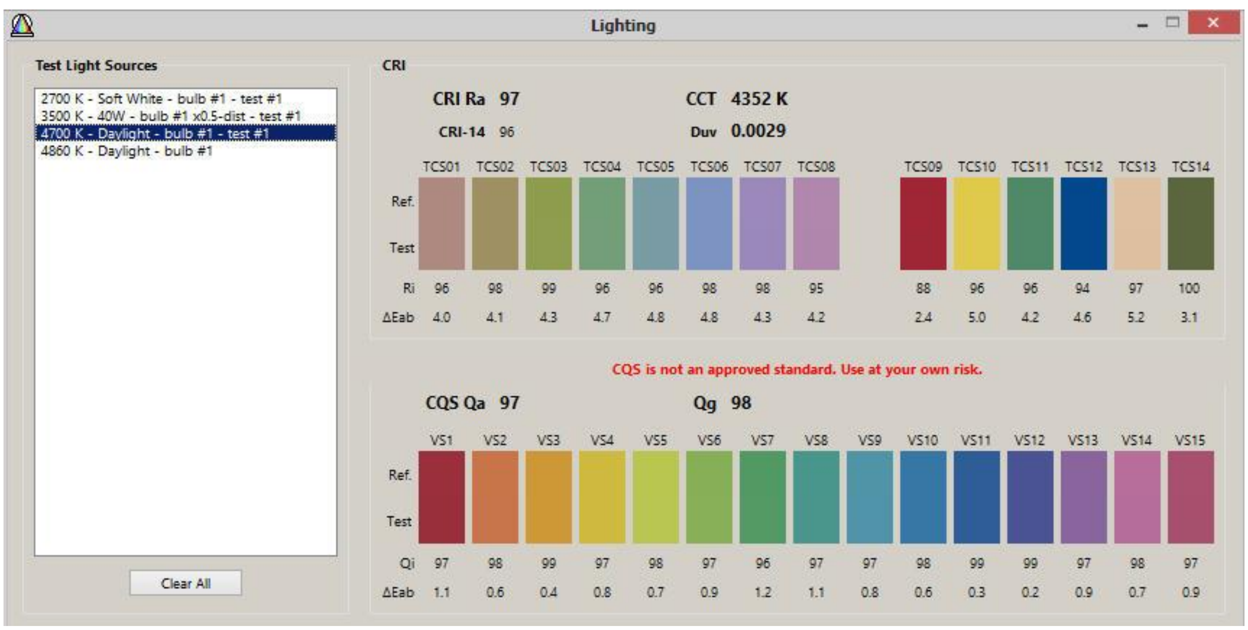

Figure 20 – In SpectraShop v4.0.11, using the 'Test List for calculating Color Rendering Index (CRI)' the 4700°K-rated MR-16 bulb delivering 4342°K has a CRI of 97; the daylight CF delivering 4791°K CCT has a 86 CRI, not poor but not good; the Soft White CF bulb has a poor 82 CRI.

There are other color measurement and analysis software tools. Explore the CT&A on the BabelColor website for spot measurement and analysis software.

Chromix ColorThink is Another great tool. It is a software package that allows users to examine and tweak IIC/ICM profiles. The profile is opened, contents examined and tables check for errors of all types and to make modification of output curves, white point and primaries. In addition, any image file can be imported and the colors [inside] displayed in three-dimensional (3D) color display. This is valuable when one is correcting dye fading in digital surrogates from film images, trying to return the image to something resembling the real world, within any of the existing color spaces. In addition, any image's colors can be displayed, placed within any working color space and juxtaposed with any ICC profile, an example of which might be an inkjet paper intended to print for printing; see below. This is most valuable when the blacks are darker than a paper-inkset can support, so that, a more suitable paper can be discovered. The (display of) colors can be altered in Photoshop to fit within the dynamic range of the chosen profile (the L–axis), usually 2.1 D to 2.4 D (density), of the printer-inkset-paper combination. This can be beneficial because the printer driver will do this for you, if you let it. This can result in clipping the highlights (bunching the colors at the limits of the system) rather than scaling them [yourself] to so that the detail in the highlights will be preserved. In addition, rendering intent can be explored. There are two versions: ColorThink v2.3 ($149), used by most of us, or ColorThink Pro which has many more options, statistical routines and feature some of us have yet to discover, all for $399 per system (Mac or PC).

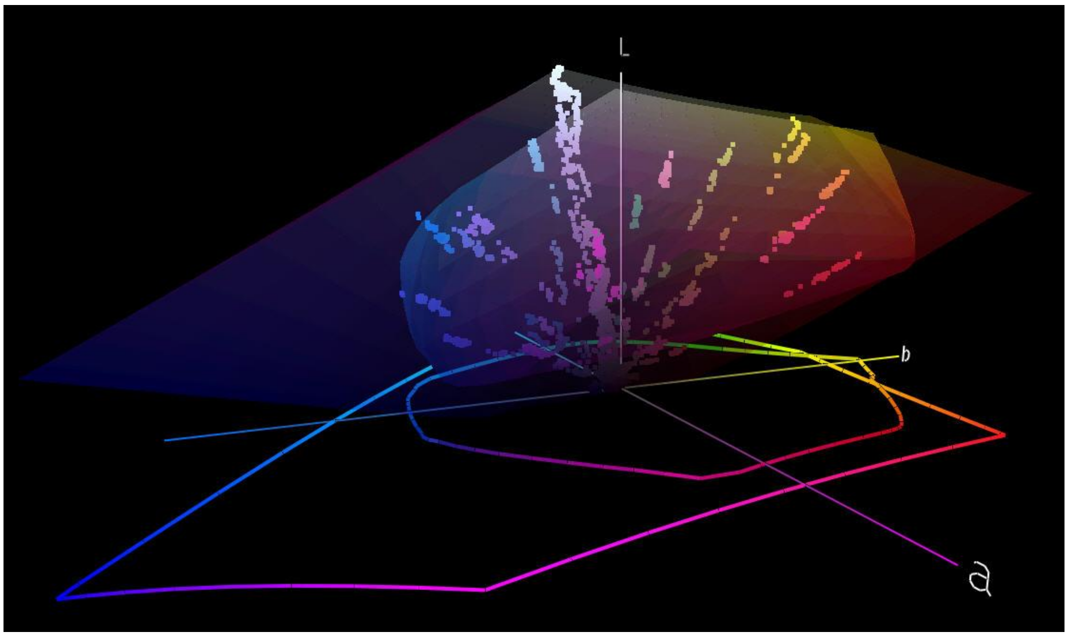

Figure 21 – In ColorThink v2.3, using '3D color display' to exhibit the **(i)** ColorChecker 24-patch Classic target (tiny squares that follow a specific straight color ray), (ii) within the larger [more translucent] <Adobe RGB 1998> color space, **(iii)** also showing the ICC printer profile [smaller somewhat more opaque shape] made for a very high quality, wide-dynamic range, semi-gloss paper using pigmented inks. Note that some of the patches cannot be printed by the specific paper, they are outside the smaller shape, but all colors fit within the < Adobe RGB 1998> color space, the larger shape; note the L-axis, the paper profile does not match the axis of the color space. Note the three axis are labeled L, a, b that is a device independent color system, where **L** = light - dark axis, **a** = red -green axis and **b** = blue - yellow axis. The display will auto-rotate with adjustable speed, while allowing viewing of the axes from any angle.

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Wikipedia is a constant source of information that is always double-checked with other sources. However, I have not found that many inconsistencies; I still like Wikipedia because it is a fabulous information resource.

All comments and corrections are always welcomed. [20,020 words – sorry, it just keeps getting longer]

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