History of polarized image stereoscopic display

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ABSTRACT

Stereoscopic photography became popular soon after the introduction of photographic processes by Daguerre and by Talbot in 1839. Stereoscopic images were most often viewed as side-by-side left- and right-eye image pairs, using viewers with prisms or mirrors. Superimposition of encoded image pairs was envisioned as early as the 1890s, and encoding by polarization first became practical in the 1930s with the introduction of polarizers in large sheet form. The use of polarizing filters enabled projection of stereoscopic image pairs and viewing of the projected image through complementary polarizing glasses. Further advances included the formation of images that were themselves polarizers, forming superimposed image pairs on a common carrier, the utilization of polarizing image dyes, the introduction of micropolarizers, and the utilization of liquid crystal polarizers.

Keywords: Polarizers, polarization, stereoscopy, dichroism, liquid crystals, stereopticon, circular polarizers, micropolarizers, 3D cinema, 3D projection.

1. INTRODUCTION

The interest in stereoscopic imaging began shortly before the introduction of the first photographic processes, with Charles Wheatstone's investigation of binocular vision and his demonstration in 1838 of depth perception using mirror-reflected pairs of drawings.[1] Stereoscopic photography came about soon after Daguerre and Talbot had each introduced photographic processes in 1839. A number of stereoscopes using mirrors or prisms to facilitate the viewing of stereo pairs of photographs were marketed in England, France, and the United States.[2]

The idea of encoding image pairs, placing one over the other, and viewing them with spectacles that decoded them, was first proposed by Ducos du Hauron in an 1895 patent that described encoding the left- and right-eye images in color and then decoding them by viewing with spectacles that provided a complementary filter for each of the pair.[3] Such images, known as anaglyphs, have been widely used for many years.

The British physicist John Anderton first proposed encoding stereoscopic image pairs by light polarization in 1891-1895.[4] His patents described projection of paired images by magic lanterns equipped with Nicol prisms, tourmaline crystals, or pile-of-glass-plates polarizers and decoding the images with oppositely oriented viewing devices of the same type. It is not known if he ever succeeded in demonstrating such a system.

2. SHEET POLARIZER

A more practical method of encoding stereoscopic image pairs by polarization was first realized when Edwin Land, who would later found the Polaroid Corporation, developed a system for producing polarizers in the form of large sheets. Land had studied the polarization of light and he was intrigued by a report in 1852 by the British physician Herapath, who had described tiny, highly polarized crystals formed when a student had added iodine to the urine of a dog that had been fed quinine. Herapath and others had tried for many years with little success to grow larger crystals of this material, which was identified as a crystalline form of quinine sulfate periodide and named herapathite.[5]

Land had also attempted without success to grow large crystals of herapathite. His new approach was to form microcrystals of herapathite, disperse them in a viscous solution of nitrocellulose, and then orient them by extruding the dispersion through a narrow slit. Land's first patent application, which disclosed the extrusion process, was filed in 1929 and issued in 1933.[6] His co-inventor was Joseph Friedman, who later published a definitive history of color photography.[7] A sheet polarizer of this type, first produced commercially in 1934, was marketed as J-sheet.

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Land described and demonstrated the extrusion process at a Harvard Physical Colloquium in 1932. Shortly afterward he left Harvard and formed a partnership with lab instructor George Wheelwright. In 1934 the Land-Wheelwright company began shipping polarizing sheet to Eastman Kodak for production of camera filters.[8]

In 1938 Polaroid introduced the H-polarizer, a polymeric sheet comprising mechanically stretched polyvinyl alcohol stained with iodine. The new polarizer was described as molecular, rather than microcrystalline, as the structure comprised the stained linear polymer. This technology accounts for contemporary manufacture of sheet polarizers for a wide range of applications. These polarizers, as well as certain dye polarizers, are also described as dichroic polarizers, as their light absorption varies with the polarization of the incident light.[9]

3. STEREOSCOPIC IMAGING

In 1934 Land and Wheelwright met with Smith College art professor Clarence Kennedy, who specialized in the study and detailed photography of Italian sculpture. Kennedy envisioned projecting stereoscopic images of sculpture for both study and teaching. He obtained funding from Carnegie and hired Land as consultant. Land provided Kennedy a large format stereoscopic camera and matching projector that enabled him to share his results. Kennedy is remembered as a master photographer of sculpture and consultant to Land. His collected works, including several thousand photographs, are preserved in the Harvard Fine Arts Archive. Professor Kennedy served as a consultant to the Land-Wheelwright company and later to Polaroid Corporation. Incidentally, it was Kennedy who coined the term “Polaroid” for the plastic sheet polarizer, and that became the name of the corporation formed in 1937.[8]

4. STEREOSCOPIC MOTION PICTURES 1930-1940

As early as 1934 Land and Wheelwright were experimenting with stereo motion picture photography. Their apparatus included rigs with paired 16 mm. motion picture cameras and paired side-by-side projectors equipped with polarizing filters. A demonstration before Dr. Mees, Kodak’s Director of Research, in 1934 resulted in a generous ongoing supply of Kodak’s Kodacolor additive color film.[10]

Land and Wheelwright presented the first large-screen full-color motion picture demonstration at a meeting of the Society of Motion Picture Engineers in Washington, D.C. in 1935.[11] In 1936 the New York Museum of Science and Industry in Rockefeller Center opened an exhibit of color stereoscopic motion pictures, using paired projectors and polarizing filters and glasses. This exhibit, entitled “Polaroid on Parade,” was shown several times a day for several years.[12]

The manufacture of polarizers and their application to stereoscopic motion pictures was taking place elsewhere as well. In Germany the crystallographer Ferdinand Bernauer had evidently succeeded in growing crystals of herapathite large enough to use as filters, and Zeiss Ikon was marketing 35 mm. diameter Bernotar polarizing filters. as camera accessories. Zeiss conducted stereoscopic demonstrations and commercial presentations using polarizing filters and spectacles in 1936-1939.[13] In America Marks Polarized Corp. also offered commercial polarizers made with microcrystalline cinchonidine herapathite.[14]

During the 1939 and 1940 New York World’s Fair an estimated 5 million visitors to the Chrysler Pavilion saw a 12-minute animated film by John Norling depicting the self-assembly of a Plymouth automobile engine. The animation showed unaided engine parts dancing into position along the assembly line to form the completed engine. The film was shown in black and white in 1939 as *In Tune with Tomorrow* and in Technicolor in 1940 as *New Dimensions*. Polaroid provided many thousands of complimentary cardboard-framed “glasses”. The Technicolor film was re-released in 1953 as *Motor Rhythm* by RKO Radio Pictures.[15]

5. THE VECTOGRAPH PROCESS

Joseph Mahler, a Czechoslovakian stereo enthusiast and inventor, wrote to Land in 1934 suggesting that a new type of stereoscopic image might be created by rendering the image pair in terms of degree of polarization.[16] At Land’s invitation Mahler moved to the U.S. and joined Polaroid shortly before Hitler’s forces invaded his home country. The

Vectograph, jointly developed by Land and Mahler, provided a a left-right polarized image pair printed back-to-back by transfer of iodine ink from a pair of pre-registered gelatin relief images.[17]

In December 1940, Edwin Land set as Polaroid's priority the support of the World War II effort. Over the next several years the company provided the military with many optical devices, including specialized goggles, cast plastic optical elements, an optical ringsight, and a heat-seeking missile system, as well as the Polaroid Vectograph.

To expedite the use of Vectographs for aerial reconnaissance and surveillance, Polaroid established a War School in a historic Cambridge building recognized as the site of Alexander Graham Bell's first long-distance call and later known as the location of Edwin Land's office and laboratory. The Polaroid War School was a classroom and laboratory for training military technicians in the preparation of black-and-white Vectographs.[18] Polaroid conducted a series of two-week courses over several years. Field kits packaged in foot lockers were shipped to air force reconnaissance units in both the Pacific and the European combat regions.

When I joined the Vectograph Research Laboratory in 1944, the War School was conducting its final session. Polaroid Vectographs were utilized to produce stereoscopic images of key industrial and combat sites photographed by reconnaissance planes with aerial cameras that used overlapped consecutive views on continuous 9-inch wide strip film as stereoscopic image pairs. At Guadalcanal in 1942-3 Vectograph images facilitated recognition of camouflaged Japanese sites, detailing placement of guns, bunkers, buildings and planes before the landings. The use of Vectograph images in planning the Normandy beach landings in 1944 is well documented.[19] Altogether some two million dollars worth of Vectograph materials were provided to the military during WW2. Vectograph training manuals illustrating the assembly and servicing of complex military equipment were also produced. Many wartime Vectographs are preserved in the Polaroid archives at the Harvard Business School's Baker Library.

MIT Professor Jack Rule served Polaroid as a consultant on the design and projection of stereoscopic images. He developed equations to optimize the photographic rendition of three-dimensional subjects and designed a system of drawing stereoscopic image pairs. Many of his drawings were printed as Vectographs for use in teaching celestial navigation. Rule also led the development of Navy gunnery trainers that utilized stereoscopic images to simulate combat situations The military forces procured 110 Polaroid Machine Gun Trainers, which replicated the optical, acoustical, and mechanical conditions of anti-aircraft gunnery to provide a realistic 3-D training experience. A battery of projectors "threw" stereoscopic tracer bullet images toward a 3-D motion picture image of an attacking aircraft. Together the 110 trainers could "fire" 5 million rounds of ammunition per day. [21]

My work in Vectograph research included development of a 2-sided gunnery training film that incorporated a motion picture display of the targeted plane on one surface and on the other surface polarized target circles that could be displayed during training, then rendered invisible during scoring. I also conducted research on high efficiency polarizers and reflective backings for Vectographs.

Others in the Vectograph Research Laboratory included inventor Joseph Mahler, photographer-engineer Samuel Kitrosser, chemist Helen Husek, and design engineer William Ryan, who developed a unique machine that could stretch polyvinyl alcohol, at 45^o to its running edge.[22] The angle stretcher enabled continuous fabrication of 45^o Vectograph sheet and its lamination to the two surfaces of a common support. Helen Husek conducted research on color Vectograph processes, and Samuel Kitrosser set up a Vectograph studio in which he explored applications of the Rule stereoscopic formula to determine optimum taking conditions for effective stereoscopic presentation.[23]

Kitrosser worked with an experimental variable-interaxial camera comprising two 5" x 7" Burke-James view cameras mounted at 90^o to one another and separated by a semi-transparent mirror. He conducted research to determine optimum interocular distances for image presentation with respect to the plane of the stereo window. Kitrosser introduced the concept of the parallax index, the reciprocal of the ratio between the horizontally displaced homologous points and the image width, and he determined that for most images an index of 24 was the most effective. Kitrosser also designed the Polaroid Interocular Calculator, a circular slide rule that facilitated optimization of interocular separation based on the intended width of the image display, the near and far distances, and the chosen lens pair.[24]

For a number of years after WW2 Polaroid provided kits, Interocular Calculators, and instruction manuals for the preparation of black-and-white Vectograph images.[25] Since 1948 the Stereo Optical Company in Chicago has marketed Vectograph image kits to ophthalmologists and optometrists for testing binocular vision and for corrective eye exercises. Similar Vectograph products are also produced by the Vision Assessment Corporation.

Polaroid microscopists made black and white Vectographs from paired scanning electron microscope images for many years. Work also continued on Vectograph color processes. The most successful system was a dye transfer process utilizing successive image transfers to a Vectograph sheet from paired gelatin relief images dyed respectively with yellow, magenta and cyan dichroic dyes – that is, dyes with structures capable of being oriented to become aligned with the oriented substrate.The process was costly and very demanding, as it required producing and dyeing six matrices and transferring each pair successively in perfect register to the Vectograph sheet. Although the process was never marketed, Polaroid continued to print custom color Vectographs for many years. Land showed a series of excellent color Vectograph lantern slides in a presentation before the Optical Society of America in 1953.[26]

6. 3-D CINEMA, 1950-2000

The Festival of Britain in 1951 included the 3-D Technicolor short film *Royal River*, depicting a trip along the Thames River and a short black-and-white film of the ballet *Black Swan.* Both of these films were later shown in U.S. theaters.[27]

The 1952 Hollywood film “Bwana Devil” marked the start of a wave of stereoscopic cinema production.[28] Although a number of 3-D films were produced, problems arose from deficiencies in three-dimensional photography, the difficulty of synchronizing two films in side-by-side projectors, and the shortage of quality content. In December, 1952, a Polaroid team–Sam Kitrosser, Bill Ryan, and I-- demonstrated high quality stereoscopic Kodachrome images, including many created in the Vectograph studio, to executives of several major studios. We used a dual 35 mm projector, with the slide pairs carefully aligned and mounted in a sturdy 2-slide holder. We conducted the demonstrations at the Astor Theater in Times Square, which at that time was the premier theater for showing wide screen and 3-D films. Jack Warner was sufficiently impressed to engage Polaroid’s William Ryan as consultant to the cinematographers who filmed *House of Wax*. That film was recently characterized by Ray Zone as “the gold standard for 3-D movies.” [29]

Unfortunately many 3-D films of the 1950s were not of high quality and the two-projector presentations were fraught with errors in synchronization, with the result that many first-rate films photographed in 3-D –for example, *Kiss Me Kate* and *Dial M for Murder* --were released “flat” in 2-D. Within a few years 3-D cinema was regarded as a novelty that had run its course.

Although single-film 3-D camera and projection systems had been envisioned as early as 1853, they did not achieve broad practical application until the early 1950s. By 1983 at least ten single-film camera and projection systems had been designed, but 3-D films were shown only occasionally in theaters. Wide screens and 3-D were sometimes used in combination, Many 3-D films were shorts shown in theme park theaters equipped with well-synchronized projectors. It was not until 1982 that single-strip filming and projection enabled a wide release to over 700 theaters of *Friday the 13th Part III*, with PolaLite 3-D glasses provided by Marks Polarized Corporation.[29]

7. RESTORATION OF *MELODY*

In the early 1950s Polaroid and Technicolor had collaborated in an effort to produce stereoscopic motion pictures by the Technicolor imbibition process, which utilized three color relief images that were dyed and transferred sequentially in register to a single gelatin layer containing a dye mordant. Technicolor matrix pairs were dyed with Vectograph dyes, then printed onto 2-sided Vectograph film, using a small Technicolor pilot machine. Motion picture tests included the western *Taza, Son of Cochise* and the first Disney color cartoon film composed in 3D, *Melody*. However, the collaboration was concluded without the release of any 3D Vectograph motion picture.[30] Technicolor abandoned its complex 3-strip camera, which produced sets of 3 negatives – red, green, and blue -- and shut down its imbibition transfer process in 1975, following its transition to the use of Kodak’s integral 3-color negative and 3-color positive films.

In 1993 Francis Ford Coppola, to whom Dr.Land had shown color Vectograph images many years earlier, explored the feasibility of utilizing the Technicolor imbibition process to incorporate a 3-D Vectograph sequence in a forthcoming Zoetrope feature film. At that time both Technicolor and an independent company, Chromax, were exploring reactivation of the dye transfer process, as later films printed on color positive films, in which dye images were formed during processing, were showing serious instability.

In the course of investigating the technology, Coppola's associate at Zoetrope, Kim Aubry, contacted me to learn if the requisite Vectograph film might be available. I met with them in San Francisco to discuss exploring the possibility of producing the film stock. Kim and Coppola also visited Technicolor and found that the current management was totally unaware of the Vectograph work. However, a long-time employee, Joe Schmit, recalled that Technicolor had utilized a pilot machine to make test prints on Vectograph film, including a print of. the first Disney 3-D cartoon, *Melody*.

Kim Aubry, Prof. Scott Duncan of CalArts, and Lauren Duncan, then a graduate student at CalArts who was exploring the history of 3-D films in the 1950s, managed to track down what remained of the *Melody* print, which had been saved in "dozens of short clips" by someone at Technicolor. Kim Aubry, using a 2D *Melody* print for reference, computer-based matching, and hand splicing, managed to re-assemble the portions of the 3-D *Melody* Vectograph print.[31] Kim arranged to project that *Melody* 3-D Vectograph film for me in 1994, after we had both attended a retrospective showing at the Academy of Motion Picture Arts and Sciences of Technicolor films that had been printed by imbibition transfer. The films were reviewed in connection with the concern about instability of contemporary negative-positive color films.

The Vectograph *Melody* print was later projected as part of the first World 3-D Film Expo at the Egyptian Theater in Hollywood in 2003. Jeff Joseph, who organized the 3-D Film Expo, very kindly sent me a taped interview with Dr. Goldberg, long-retired Technicolor Director of Research, who had conducted the work with Polaroid and described the project in some detail. Jeff had recorded Dr. Goldberg's comments after projecting the restored *Melody* Vectograph film for him. The Expo also included the 1940 3-D Technicolor films *Motor Rhythm* and *House of Wax*, both discussed earlier.

8. STEREOJET

In the early 1980s the introduction of color inkjet printing suggested experiments in its application to color Vectograph printing. Tests at Polaroid with a Canon printer confirmed that it was indeed feasible to print by inkjet onto Vectograph film with dichroic dyes.[33] Later work at the Rowland Institute for Science, led by Jay Scarpetti, resulted in the development of the first StereoJet process, in which the paired 3-color images were printed successively on the respective surfaces of the two-sided Vectograph sheet. The process produced excellent stereoscopic images, and a few laboratories were licensed to print and market StereoJet images as part of a pilot program. Jay Scarpetti presented a paper introducing StereoJet at the 1997 Stereo Displays & Applications (SD&A) Conference.[34] I reported on some refinements at the SD&A Conference in 2000.[35] However the project ended when the Rowland Institute merged with Harvard University in 2002. Production of the 45^o Vectograph sheet was discontinued by 3M after it had purchased Polaroid's Polarizer Division.

StereoJet, Inc., formed in 2008 by a group of Polaroid "alumni," has undertaken development of an improved process based on the use of conventional polarizer substrate, which has stretch direction parallel to the running edge of the sheet.[36] The new StereoJet images may utilize either linear or circular polarization.

9. CIRCULAR POLARIZATION

In 1937 Land proposed the use of circular polarization in stereoscopy.[37] With glasses having linear polarization (0^o,90^o or $+45^o$,-45^o), a viewer must hold his head erect to avoid crosstalk between the two images. Circular polarization maintains image discrimination over a wide angular range and this provides more comfortable viewing, a particular advantage when viewing feature-length cinema. Polaroid introduced circular polarizing glasses, identified as the Polaroid II system, in some theaters showing Jaws III in 1983. A survey conducted by Polaroid at that time failed to show a significant preference for circular over linear polarization.

I presented a paper on the properties and advantages of circular polarization at a 1983 conference on "Three-Dimensional Display Techniques." and at SPIE's 1984 conference "Optics in Entertainment II".[38] The use of circular polarization for cinema became widespread in 2005 with the incorporated of this convention in the RealD 3-D cinema system.

10. LIQUID CRYSTAL POLARIZERS

The 3-D application of reversible polarization of liquid crystals was introduced by Lenny Lipton, founder of Stereographics Corporation and inventor of CrystalEyes, which utilized high-speed modulation of liquid crystals to create high-resolution flicker-free 3-D computer displays.[39] In 2005 Stereographics was acquired by RealD. The RealD system incorporates the Z-screen, a rapid modulator of liquid crystal orientation. [40]

Rapidly reversed polarization of liquid crystal polarizers is also used in the so-called active glasses coordinated with presentation of rapidly cycled left-right images in 3-D television displays.

11. MICROPOLARIZERS

Another alternative to sheet polarizers described thus far is a micropolarizer array with alternating orientation on a small scale matched to the dimensions of a rastered stereoscopic image comprising alternate left and right-eye stereoscopic image pairs. Sadig Faris of Reveo, Inc. introduced the MicroPol system at the SD&A Conference in 1994.[41] The system utilized patterned microretarders for spatial multiplexing of left- and right-eye polarization. Several such micropolarizer imaging systems were marketed as V-Rex products.

In 2010 the LG company introduced its film-type patterned retarder (FPR), which utilizes a thin liquid crystal patterned layer to provide 3-D television and computer displays for viewing with passive glasses, as described below.

12. CONTEMPORARY 3-D CINEMA

OmniMax theaters, designed to project motion picture images onto a dome that would fill the spectators' entire field of view, were introduced in 1967. The first IMAX theater, similarly constructed and equipped to present perfectly synchronized stereoscopic films projected with polarizing filters and viewed with polarizing glasses, opened at the 1986 Vancouver Expo.[42] There are now several hundred IMAX dome theaters worldwide. Current IMAX technology includes both digital and film presentations, each utilizing glasses with linear polarization.

The RealD stereo system, introduced in 2005 with the release of the Disney cartoon *Chicken Little*, marked the start of digital 3-D cinema. The projector, using digital light processing (DLP) mirror technology and a triple-flashing Z-screen, delivered 72 frames per second to each eye. The glasses have plastic circularly polarized lenses. The replacement of film with digital 3-D has greatly simplified accurate 3-D image presentation. As of July, 2012, RealD had equipped over 21,000 theaters in 70 countries.[43]

13. 3-D TELEVISION AND 3-D DISPLAYS

The introduction of 3D-ready television sets has given rise to new competition between systems using active glasses and those using passive glasses. Active glasses, which are costly and somewhat cumbersome, provide rapid switching of liquid crystal polarization coordinated with the alternating orientation of display image pairs. Passive glasses, which, like the RealD glasses, incorporate circularly polarized lenses, are used for viewing TV screens that incorporate liquid crystal film-type patterned retarder (FPR) coordinated with the rastered image display. Although this system cuts the vertical resolution in half, it appears adequate, and the light weight and low cost of glasses make the systems strongly competitive with those utilizing active glasses.

In addition to displaying 3-D programs and recorded 3-D films, stereo-ready television sets are used to display 3-D still image "slide shows" and video images through simple cable connections. A number of consumer cameras produced by

Fuji, Panasonic, Sony and others for still and video photography have made these applications popular with both amateur and professional 3-D photographers.

The introduction of thin LED edge-lit panels has expedited effective display of 3-D still transparencies. StereoJet, Inc.aims to provide both full color stereoscopic transparencies for such display and full color stereoscopic reflection prints.

14. EI DEMONSTRATION SESSION

The author’s exhibit at the EI 2013 demonstration session includes examples ranging from early black-and-white Vectograph 3-D images to recently produced StereoJet 3-D images.

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