Generation of circularly polarized stereoscopic transparencies and prints

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ABSTRACT

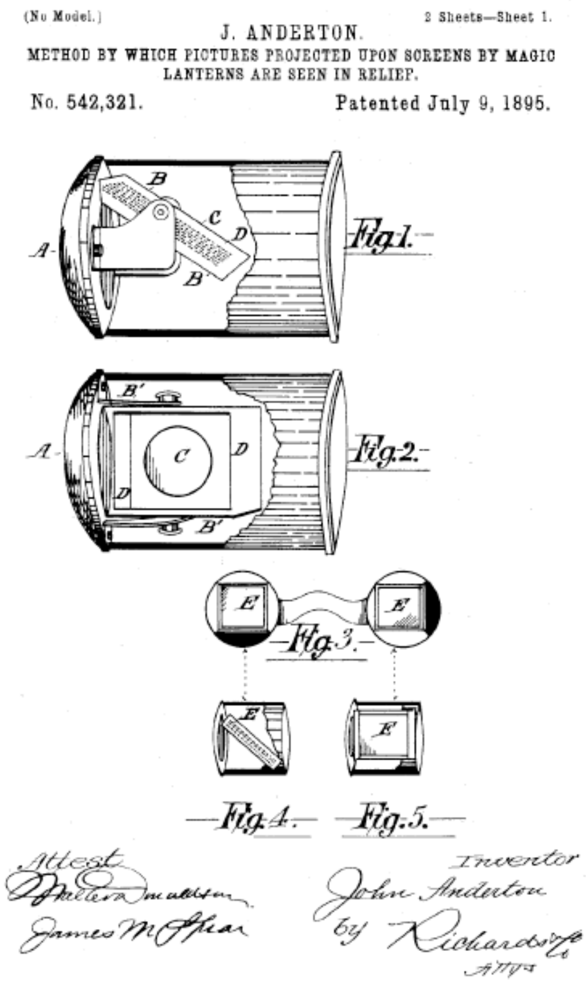
We describe a new iteration of the StereoJet process, which has been simplified by changes in materials and improved by the conversion from linear to circular polarization. A prototype StereoJet process for producing full color stereoscopic images, described several years ago by Scarpetti et al., was developed at the Rowland Institute for Science, now part of Harvard University. The system was based on the inkjet application of inks comprising dichroic dyes to Polaroid Vectograph sheet, a concept explored earlier by Walworth and Chiulli at the Polaroid Research Laboratories. Vectograph sheet comprised two oppositely oriented layers of stretched polyvinyl alcohol (PVA) laminated to opposite surfaces of a cellulose triacetate support sheet. The two PVA layers were oriented at +45 and -45 degrees, respectively, with respect to the running edge of the support sheet. A left-eye and right-eye stereoscopic image pair were printed sequentially on the respective surfaces, and the resulting stereoscopic image viewed with conventional linearly polarized glasses having +45 and -45 degree orientation. StereoJet, Inc. has developed new, simplified technology based on the use of PVA substrate of the type used in sheet polarizer manufacture with orientation parallel to the running edge of the support. Left- and right-eye images are printed at 0 and 90 degrees, then laminated in register. Addition of a thin layer of 1/4-wave retarder to the front surface converts the image pair's respective orientations to right- and left-circular polarization. The full color stereoscopic images are viewed with circularly polarized glasses.

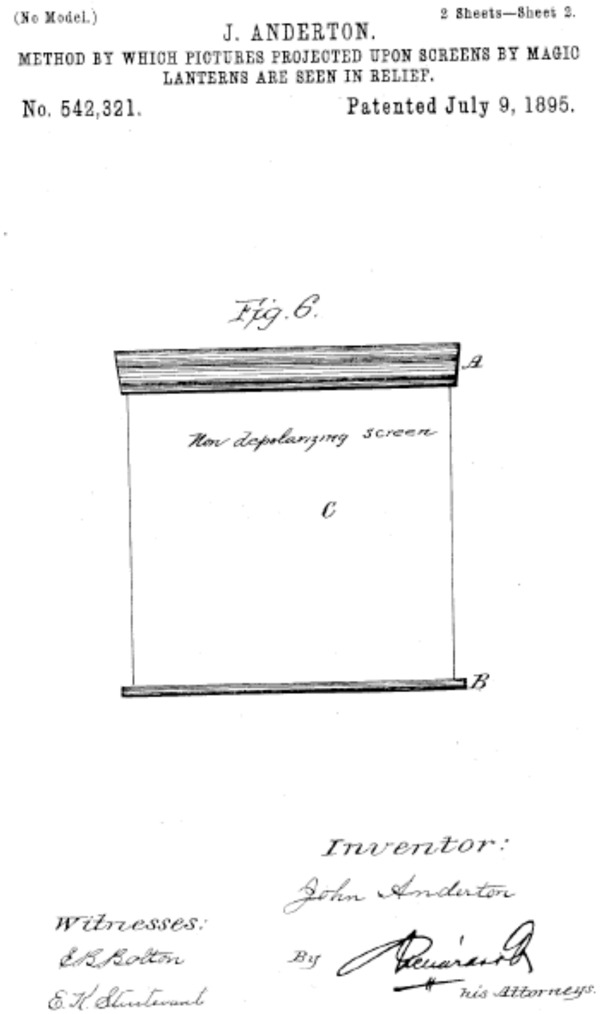
Keywords: stereoscopy, stereoscopic imaging, 3-D imaging, polarization, polarizing images, circular polarization

1. INTRODUCTION

The concept of encoding stereoscopic image pairs by polarization has a long history. A British physicist, John Anderton, patented such a plan (Figs 1 & 2), using a magic lantern equipped with polarizers comprising piles of glass plates and then viewing the image with orthogonal pile-of-plates viewers.[1] He also proposed similar designs with polarization by Nicol prisms and by tourmaline crystals. However, encoding images by polarization did not become practical until the development of large continuous sheet polarizers by Edwin Land during the 1930s (Fig 3).[2] In 1934 Land filed a patent describing stereoscopic motion picture projection using polarizing images.[3] Following the formation of Polaroid Corporation in 1936, there were several notable demonstrations of stereoscopic motion pictures using polarizers as filters over paired projection lenses and providing Polaroid glasses to observers. These demonstrations included a presentation before the Society of Motion Pictures in May, 1936, and thereafter an exhibit for several years at the Museum of Science and Industry in New York's Rockefeller Center. At the 1939-40 World's Fair in New York, an estimated 5 million visitors were given cardboard Polaroid "glasses" to view a 12-minute stereo motion picture (Fig 4) depicting the production of a Plymouth on the 1/2-mile long assembly line at the plant in Detroit, Michigan.[4]

In 1938 the Czech inventor Josef Mahler proposed to Land that instead of using polarizing filters, polarization could be produced imagewise. Land invited Mahler to join the Polaroid research team, and together they developed and patented the Polaroid Vectograph process (Fig 5).[5, 6] The Vectograph substrate is a two-sided sheet with stretched and oriented polyvinyl alcohol (PVA) on each side of a support. The two respective imaging layers are oriented at +45 and -45 degrees. To produce a black-and-white Vectograph image, right-eye and left-eye relief images were produced in gelatin wash-off relief film, then stained with iodine. A "sandwich" comprising the Vectograph sheet between the two stained relief images was passed though a wringer to effect transfer of the iodine images into the orthogonally oriented PVA layers, providing, in effect, image versions of the Polaroid H polarizer. The resulting stereoscopic image was viewed with Polaroid +45/-45 glasses.





Figs 1 & 2. John Anderton's invention for forming stereoscopic image pairs

During World War II Polaroid provided Vectograph field kits and operated a school where over 1500 military personnel were trained to produce Vectograph images in the field as a complement to aerial reconnaisance.[7] Such 3-D images were used in briefing sessions before the D-day landing on the Normandy coast and later in the Pacific theater. Following the war, Polaroid chemists developed a color Vectograph process based on dye transfer technology, using dichroic dyes, i.e., dyes capable of aligning with the oriented PVA to form polarizers or polarizing images.[8] Although the color Vectograph process provided excellent stereoscopic color images, the process was laborious and costly, and Polaroid did not develop a commercial version.

2. POLARIZER PROPERTIES

Polarized light can be used to present superposed left- and right-eye stereoscopic images because oppositely polarized beams of light do not interfere with one another. The early presentations described above, as well as many of the 3-D motion pictures of the 1950s, utilized linear polarization, generally represented as sinusoidal waves vibrating in a single plane. Although this system provides fine stereoscopic images, it requires the viewer to maintain an erect head position, and this can result in fatigue during long viewing sessions. An alternative polarization system utilizes circular polarization, which is easily produced by passing linearly polarized light through a quarter-wave retarder (Figs 6-8). The left-eye and right-eye images will thus be encoded as oppositely oriented circular polarizing images. The use of circular polarization for motion picture viewing is much more forgiving than linear polarization with regard to head position.[3, 9]

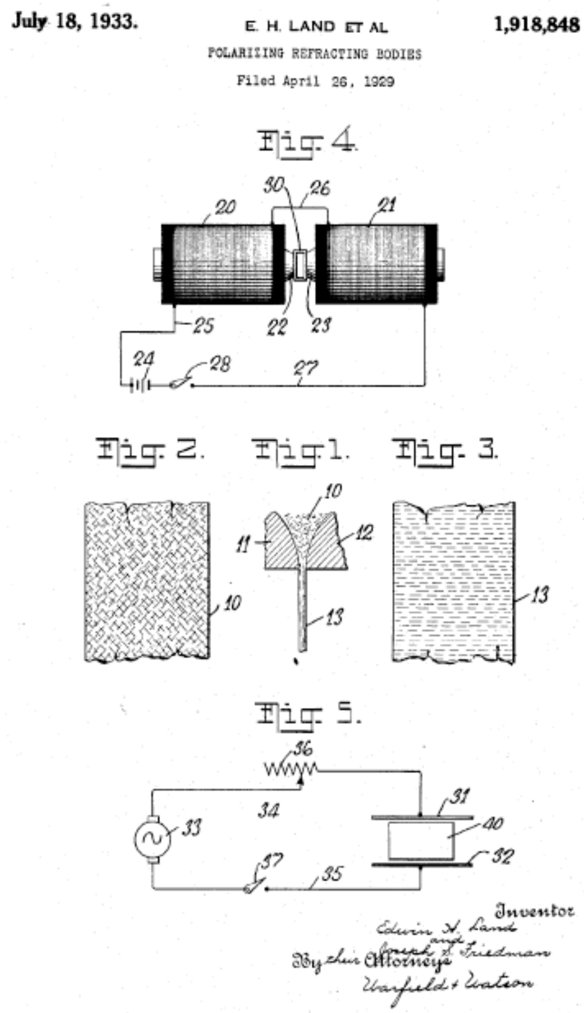


Fig 3. First patent for continuous production of polarizing film (Land and Friedman)

In 1983 Polaroid introduced glasses with circular polarizing lenses, designated as Polaroid II glasses, and a few theaters tested the system in showings of the 3-D film Jaws II. However, it was not until the introduction of digital stereoscopic motion pictures by Real D that utilization of circular polarization became widespread. Particularly with long feature films the comfort in viewing stereoscopic images with circular polarization offers a real advantage over linear polarization.

3. STEREOJET I

Following the early work on printing inkjet 3-D images on Vectograph substrate, Jay Scarpetti and his associates at the Rowland Institute for Science further developed materials and processes for producing full-color stereoscopic displays from digital image pairs and printing with inks formulated with dichroic dyes.[10] Later developments included anti-ghosting procedures, precision registration, and large format displays.[11] The process was used to print images provided by a number of outstanding stereo artists and photographers, as well as scientists and engineers engaged in technical

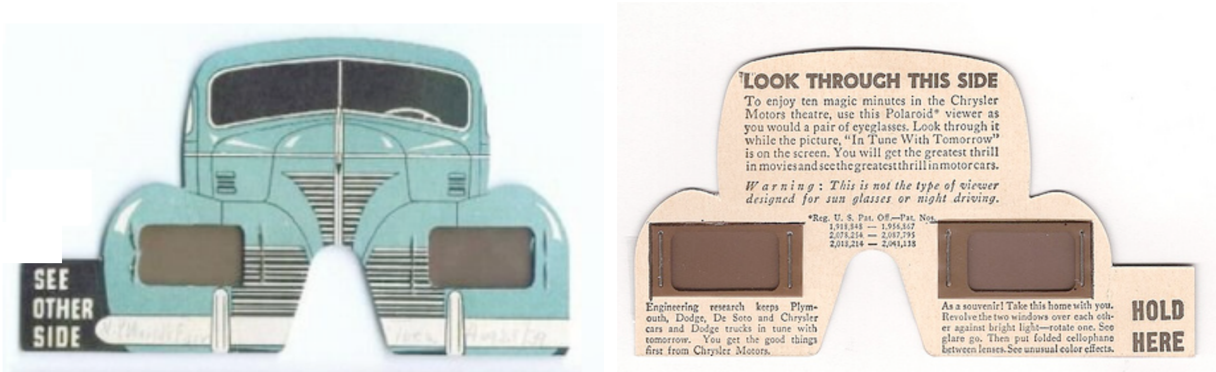


Fig 4. Polaroid 3D glasses (front and back) given out at the 1939-40 New York World's Fair for viewing Polaroid 3D movie

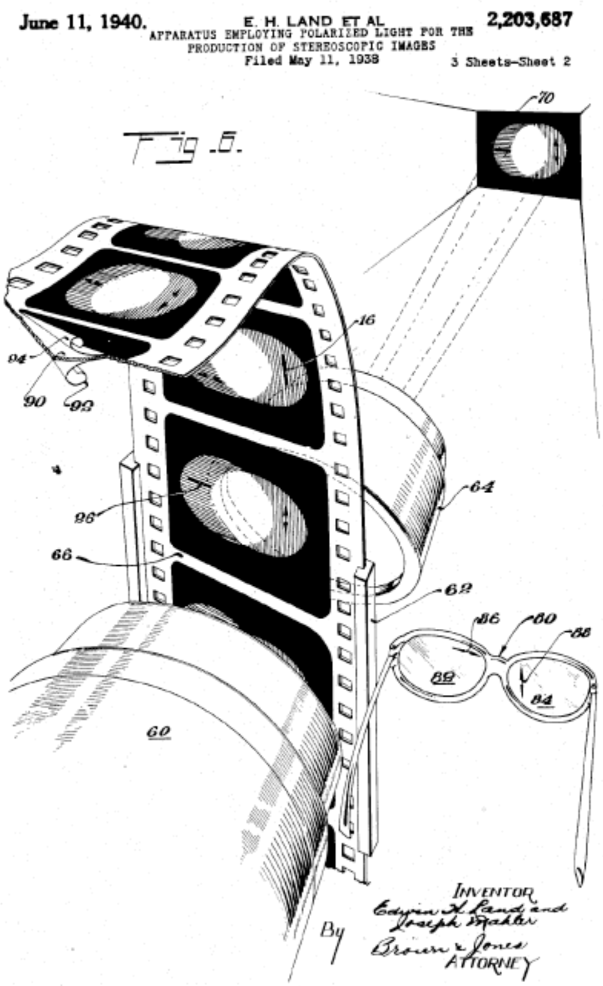


Fig 5. Land-Mahler Vectograph process

applications of stereoscopic imaging. The system was trademarked StereoJet, and a few outside laboratories were provided with materials and licensed to print prototype StereoJet images. In addition, the Scarpetti lab hosted and trained several users. The collection of stereoscopic images produced included work by David Burder, Jim Gasperoni, John Toeppen, Al Richards, Lynn Butler, Robert Bloomberg, Simon Bell, Jon Golden, David Klutho, Mark Blum, Clark Heist, Franklin Londin, Jay Scarpetti, and Vivian Walworth. Several of the artists had museum exhibits featuring their StereoJet images. Applications explored included industrial design, architecture, medical sciences, space exploration, and geographical surveys. However, the program was suspended when the Rowland Institute merged with Harvard University in 2002.

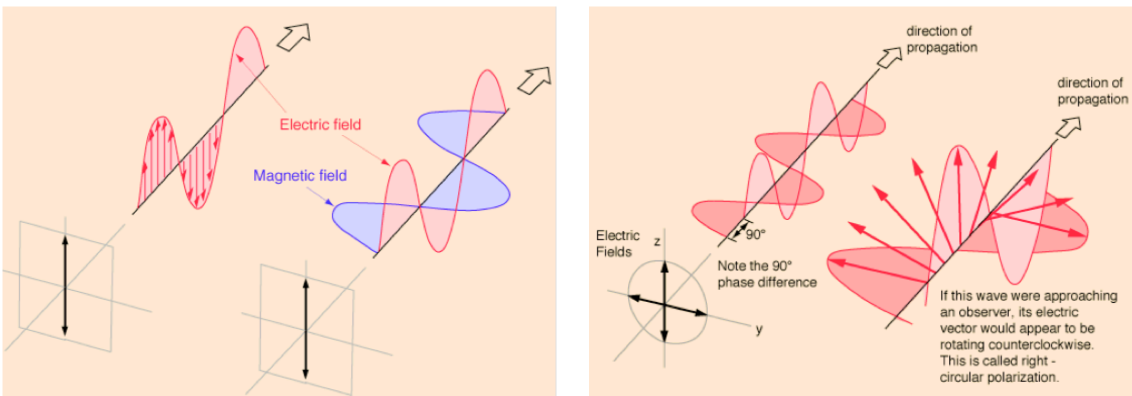


Fig 6. Graphical description of linear polarization (left) and circular polarization (right) (http://wwwhyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html)

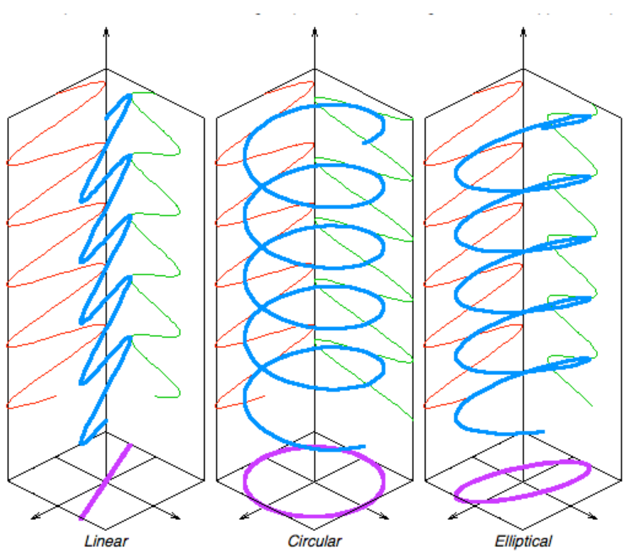


Fig 7. Comparison of different forms of light polarization, showing the vector sum of the orthogonal components of linear, circular, and elliptical polarized light. Linear polarization is a special case in which the resolved (orthogonal) vectors are in phase, while difference in amplitudes determines the direction of the vector sum. Circular polarization is another special case that results from a ±90 degree phase shift between orthogonal components of equal amplitude (left or right "handedness" is determined by one of the components leading or lagging the other). The most general case is elliptical polarization, in which the phase shift and amplitude have any values other than those for linear or circular polarization (http://www.physicsdaily.com/physics/Polarization)

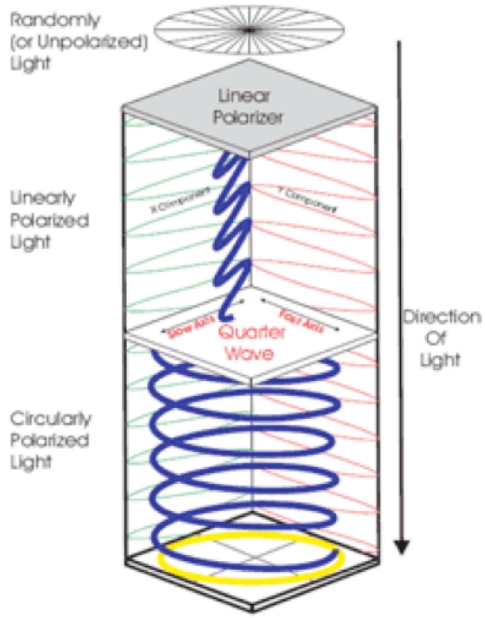


Fig 8. Introduction of a ¼-wave retarder after the output of a linear polarizer results in a 90-degree phase shift ('retardation') of one of the orthogonal vectors, establishing the conditions for circular polarization shown in. Fig 7 (http://www.apioptics.com/quarter-wave-retarders.html)

4. STEREOJET II

StereoJet, Inc. is working to create a new, simplified version of the StereoJet process. Unlike the earlier version, which was based on Vectograph sheet, StereoJet II will utilize more economical single-sided oriented PVA substrate of the type used in the commercial production of linear polarizers. In this material, the PVA is stretched parallel to the running edge of the support sheet. Large left- and right-eye images are printed successively, and smaller images can be printed side-by-side. The paired images are aligned and registered after printing, then laminated to form a complete stereoscopic image. Addition of a 1/4-wave retarder overlay converts both left- and right-eye images from linear to circular polarization, and the completed image is viewed with circular polarizing glasses. Our startup operations include evaluation of substrates from various polarizer manufacturers, testing and qualification of new dichroic dyes, mechanization of registration and lamination, and optimization of the printing technology to increase speed of throughput. We are working with new, higher resolution printing equipment. We are utilizing existing images produced by the StereoJet I process to test and demonstrate the utility of circular polarization in stereoscopic image display. We are also engaged in developing a technical application of StereoJet technology.

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