

Michael Starks Professional Bio

After several years of graduate work in cell physiology at UC Berkeley Michael began studying stereoscopy in 1973, and cofounded StereoGraphics Corp (now Real D) in 1979. He was involved in all aspects of R&D including prototype 3D videogames for the Atari and Amiga and the first versions of what evolved into CrystalEyes LCD shutter glasses, the standard for professional stereo, and is copatentee on their first 3DTV system.

In 1985 he was responsible for starting a project at UME Corp which eventually resulted in the Mattel PowerGlove, the first consumer VR system. In 1989 he started 3DTV Corp and made the front page of the Wall Street Journal by introducing the first home 3DTV system with LCD shutter glasses and 3D movies on VHS tape at the 1990 CES. Shortly thereafter, TV pioneer Isaac Blonder used 3DTV hardware and software to broadcast 3D programs for shutter glasses all night every night for about 4 years over the LPTV station at Stevens College in NYC for a handful of enthusiasts within several miles of the Empire State Building.

Subsequently, 3DTV introduced a wide variety of consumer and professional products for 3D video, graphics and Virtual Reality. In 1990 he began work on “Solidizing”-- a realtime process for converting 2D video into 3D. In 1992 3DTV created the first full color stereoscopic CDROM (“3D Magic”) including the world’s first games for the pc with shutter glasses. The system was licensed to Chinon who released “CyberShades”-- the first 3D game system for the pc. In 1992 3DTV made the first consumer wireless LCD shutter glasses system which, like most of its hardware and software, advertising, packaging and trade names, was widely copied. In 1993 he perfected a full color anaglyph -- “SpaceSpex”—and released “StereoMac” the first LCD glasses system for MacIntosh. In the same year 3DTV created the shutter glasses

hardware for the NeoTek 3D CDROM series—still the only common stereoscopic educational software system.

In 1997 3DTV won a bid to produce a compact stereo camera for NASA's Mars program and collaborated with Neotek to produce the first 3D DVDROM system for PC—TriDVD. In 1999 3DTV released the first shutter glasses 3D movies on DVD. From 1998 to 2002 he worked in China (Xian TV), Japan (3DTV Japan), Korea (FourVis Corp.) and USA (C3D Corp.), providing hardware, software and consulting for the first regularly scheduled high quality (i.e., full color with LCD shutter glasses) commercial 3D TV broadcasts by terrestrial and satellite means.

In 2002 he licensed his “Solidizing” patent to X3D Corp. who put some of the algorithms into a set top box, still widely sold as the “Virtual FX 3D Converter”. From 2002 to the present, 3DTV has provided the hardware for TriD, the first and by far easiest to use digital HD 3D record/edit/autoplay video system running on standard Windows pc's.

In 2007 companies to whom 3DTV supplied technology and consulting produced theatrical 3D shutter glasses viewing systems, which are being introduced worldwide in 2008. Also in 2007 3DTV provided consulting and marketing for NewSight Corp, the world leader in autostereoscopic displays and was involved in initiating a project to develop the first large screen outdoor daylight visible glasses-free 3D video displays, 3 of which were installed in China in August, 2008.

In 2008 3DTV introduced the first Universal Wireless glasses and transmitters for Pro/Home/Cinema use, a 3DLANC controller for pairs of SONY HD camcorders and an HD compatible converter box able to convert standard field sequential 3D DVD's for viewing in various formats.

He has been a member of SMPTE, SID, SPIE and IEEE, AAAS and other societies and has published in Proc. SPIE, Stereoscopy, American Cinematographer and Archives of Biochemistry and Biophysics. The SPIE symposia on 3D Imaging seem to have originated due to his suggestion to John Merritt at a San Diego SPIE meeting some 20 years ago.

THE FUTURE OF DIGITAL 3D PROJECTION AND VIEWING

Michael Starks

3DTV Corp. Springfield, OR. USA

mstarks3d@yahoo.com www.3dtv.jp

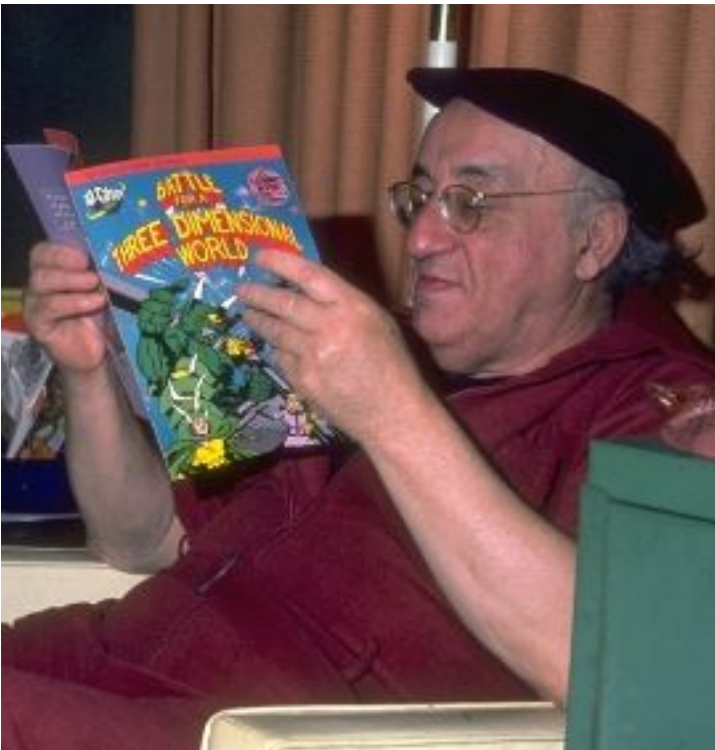
Copyright Michael Starks (2008)

[This article may be reprinted or distributed freely provided the copyright notice remains and nothing is changed, added or removed. Comments welcome.]

There is no question that the current revolution in 3D imaging is due primarily to the commitment of Hollywood to the making of major 3D films and that this has been due principally to Los Angeles Corporation Real D's spending of huge amounts of money to put digital 3D projections systems in place. From my point of view this happened because I saw Arch Oboler's Bwana Devil in 1952 and began researching 3D in 1973 which led to the founding of StereoGraphics Corp in 1979 which was taken over by Real D in 2004. It is truly gratifying and amazing to see the vision I started to pursue in 1973 come to fruition.



World's first stereoscopic motion picture and camera made by William Friese-Green in 1893. Photographed by the author in the British Museum in 1986. At this time there were no sharp frame lines, no perforations and no projectors. The original film of a few seconds, sometimes called "A Walk in the Park," is in the French National Library. I copied a pair from it and it is still possible to see the depth.



Pioneering 3D Movie director Arch Oboler (Bwana Devil, The Bubble, Domo Arigoto) reading a 3D Comic ca 1982. Modern 3D film more or less begins with Bwana Devil (1952) and is directly responsible for my 35 year career in 3D which includes the founding of StereoGraphics Corp (1979), and 3DTV Corp (1989). Photo courtesy Susan Pinsky of Reel 3D.

However, as anyone who has reflected on the causal nexus is aware, there are an unlimited number of other takes on reality, all equally valid. One could say that Arch Oboler is responsible or that Ed Land (founder of Polaroid Corp, one major inventor and marketer of polarized sheets) is, or that it's due to Larry Hornbeck (principal inventor of DLP projection - US 5280277) or the 50,000 or so engineers and chemists who developed digital electronics and liquid crystal (LC) technology, and so on back to the beginning of time. Likewise, we are beholden to the great grandparents of Walt Disney, without whom there would presumably have been no Walt, no Mickey and Donald, no Shamrock Holdings and no \$50M in the bank for Real D. Or, perhaps if Real D had talked to me or to IBM , Thomson or many others mentioned below, they would have had no reason to buy StereoGraphics or ColorLink and there would be burgeoning 3D but no CP switchers.

Even if Liquid Crystals (LC's) or DLP projectors or polarizer technology did not exist it would still be feasible to have a 3D cinema now (e.g., using film with mechanical shutters- as was done 80 years ago- or CRT or light valve projectors such as Eidophor-the king of large screen electronic projection for many years (<http://www.dcinematoday.com/dc/ProjectorHistory.aspx?index=31>) , or with the Infitec system described below). All that was ever required was someone willing to get things started by spending lots of money to establish a 3D projection network and to convince the studios to make content and that just happened to be Real D in the last few years.

There are at least 5 distinct types of large screen 3D projection in current use. All projection modalities are agnostic regarding the means for taking, editing and compressing the images, so I will not go into the software issues except to mention that there are several codecs being promoted. It appears that Real D, DDD and Sensio are among those touting their own software and custom chips for compressing images into side by side formats (with possible options for over/under) while

TDVision and Neotek (the TriD format mentioned below) eschew the discarding of any lines H or V and have means to compress all the pixels of both images into Windows compatible formats that might be made to run on next generation (and some current gen) TV sets, Set Top Boxes, TV recorders and HD DVD players. Of course the real codec decisions are likely to be made not by SMPTE committees but by tech managers at SONY, Matsushita, Philips, Samsung etc. Personally, I would not throw away the horizontal pixels needed for depth (letting the codec massage them back into place) unless there was really no other way. A similar struggle is going on in the autostereo arena between Philips (who, among other ways, have tried to get their proprietary version of the well known 2D plus depth method adopted as the Chinese national standard by exhortations before a government committee) and nearly everyone else, who want to compress with more standard means the 8 or 9 images most commonly used.

Anaglyph techniques are the oldest of all 3D projection means and are familiar to most people via the red and blue paper glasses. In Europe the glasses are usually red and green but in the last 15 years there have been a variety of entities promoting orange and blue--due to Land's work at Polaroid long ago resulting in the Retinex theory of color vision. The orange/blue was first introduced in a serious commercial way by Li Gang of China who used it for 3DTV broadcasts in the early 90's; next by 3DTV Corp on the net shortly thereafter in the modified and much easier to view SpaceSpex format; and then in the Danish ColorCode glasses for general use including at least one IMAX film and the Japan-only 3D release of Cameron's 'Ghosts of the Abyss' DVD. To minimize ghosting both Li Gang and the Danes used very dark blue which produces severe luminance imbalance and corresponding eyestrain. My SpaceSpex modification fixes this and makes this a feasible method for getting full color stereo with any type of display.

Most people have a poor opinion of anaglyph, but if it is done digitally, and with care, from image creation to final viewing and the display is calibrated for the exact program and glasses being used, and the parallax is minimized, one can get a very nice full color image with more or less balanced luminosity (i.e., comfortable prolonged viewing) with simple two color paper glasses. Use of dichroic filters decreases crosstalk, but dramatically increases cost, and ghosting remains a

problem unless the whole program is edited for minimal parallax or a ghost reduction algorithm is used.

The ultimate in anaglyph quality is the recent triband Infitec system mentioned below and clearly there can be an intermediate system (i.e., in image quality and cost) using two color bands for each eye, with corresponding costly 50 layer curved glass viewers (but see the Bosch patent below). The prime reasons for persistent interest in this old and humble method are the very low cost glasses (ten or even twenty pair/dollar in paper and almost free for multiple use plastic versions) and universal compatibility. Anaglyph can be captured, encoded, edited and displayed with virtually any method possible and if you want to do it over the net and broadcast TV or sell on DVD to billions it's the only way. However, test images for consumer calibration of their displays/personal visual systems (eyes) is essential (and of course highly desirable but almost universally ignored for any 3D or 2D system). Many persons continue to work at improving the anaglyph with new ideas and patents appearing yearly for over a century and most of this work is accessible in patents and web pages, so I will only mention some excellent work I have seen by John Schulze of Brightland <http://www.brightland.com/r/Akumira - Stereoscopic 3D.html> and the anachrome process by Alan Silliphant www.anachrome.com.

All techniques that use sheets of plastic polarizer in the projection path have the limitation that these absorb much of the light (as well as causing some depolarization) and so high brightness projectors are used which require cooling and degrade the polarizer. Some have dealt with this and other limitations by specifying wire grid polarizers (e.g., US 6,831,722, WO2007/070245) and these are just beginning to appear in commercial displays. Conventional TFTs have crucial advantages over current LCOS and so Kodak and others are developing ways to make more complex projectors to enable their use for 3D (WO2007/070245).

The dominant stereoscopic projection system at the moment (marketed by Real D but promised by several others) uses electrooptic switching of circular polarization (CP) with a specially constructed multilayer LC plate (US 2007/258138, WO2007/067493) in front of the projector lens with a silver (i.e., aluminized) screen and passive paper or plastic CP glasses for viewing. Alternation of polarized fields is a very old idea and goes back at least to the 40's when the first sheet polarizers were

invented, at which time it was done via a rotating polarized disc (a system resuscitated and being marketed to the 3D movie industry now).

Kerr cells (electrically switchable polarizing liquids, in principle identical to the CP switching of LCD's by RealD's method and due to the same electrically controlled birefringence), were invented and patented for this purpose about the same time (e.g., US 2002515, US 2118160, US 2417446, US 2616962, US 2638816, US 2665335, US 3358079, DE 736457, DE 2055935, DE 2140944) .

The achromatic (color correcting) properties of triple sets of mutually orthogonal half-wave retarders, discovered long ago by S. Pancharatnam (Indian Academy of Sci. 41A, 137-44(1955)) and subsequently pursued by many, particularly his compatriot P. Hariharan (P.Hariharan and P. E. Ciddor, "An achromatic phase shifter operating on the geometric phase," Opt. Commun. 110(1-2), p.13-17,(1994) ; P. Hariharan and P. E. Ciddor, "Achromatic phase shifters: A quantized ferroelectric liquid-crystal system," Opt. Commun. 117 (1-2), p.13-15, (1995); P. Hariharan, "Achromatic and apochromatic halfwave and quarterwave retarders", Optical Engineering, 35, p.3335-3337, (1996); P. Hariharan and P. E. Ciddor, "Improved switchable achromatic phase shifters," Opt. Eng. 38,6, p.1078-1080, (1999)). It is thus well known in the art, and has been researched frequently, and most vigorously recently by the Colorado company ColorLink (now part of Real D). Work on its components and related or alternative display tech is coming in an avalanche from all the big companies (e.g., Toshiba US7250923) as well as countless smaller ones—e.g., DigiLens (now owned by SBG Labs--- i.e., Switchable Bragg Gratings-- <http://www.sbglabs.com/company.htm>). For one suggested use of DigiLens in a complex Barco dual DLP projection patent see WIPO2005/039192, EP1830585. Among much related tech of interest are the LC products from Rolic, and tunable electrowettable diffraction filters from Nokia (WO 2007/096687). Much of the work uses polarization switchers and it is feasible to use other EO methods such as Pockel's cells to switch polarization, either with classical methods or new ones (e.g., <http://www.photonics.com/content/spectra/2007/May/research/87499.aspx>) but research is required.

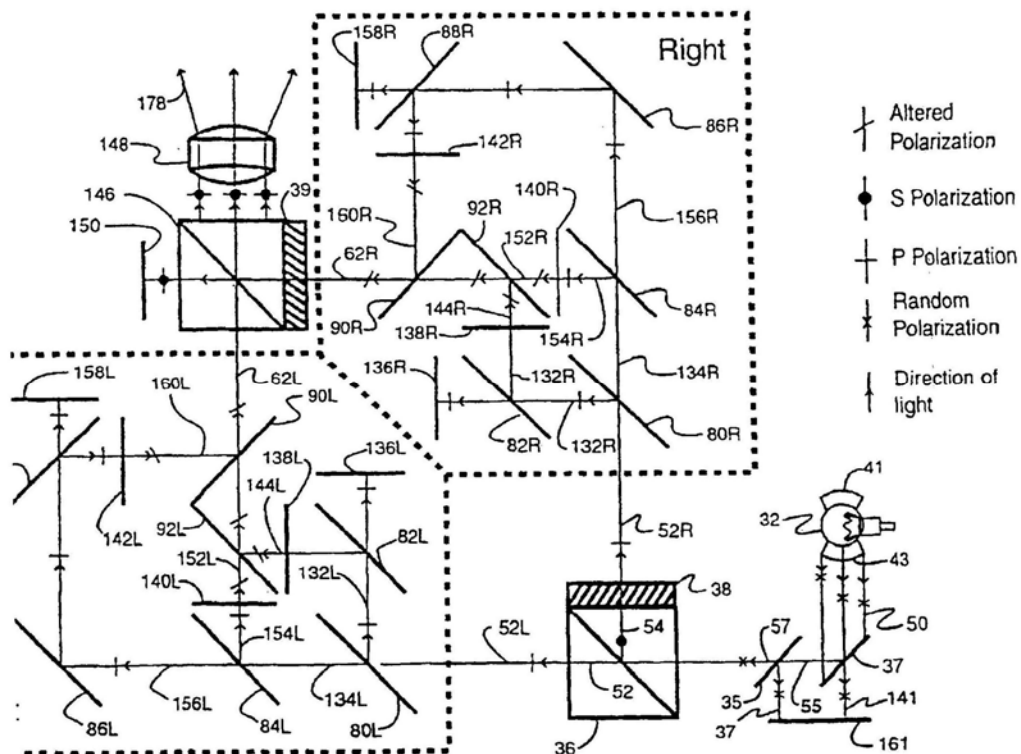
Those interested in details of ColorLink's achromatic polarization switches and related tech may consult their numerous patent applications such as US 2008/0129939, 2008/0129900 , 2007/0188711 , 2006/0291053 and 2006/0285026, WO2007/086952, WO2007/024713,WO2006/135867, WO2007/095476 or their many granted patents for an introduction to the extensive prior art. There is also their book Polarization Engineering for LCD Projection (2005) which can be downloaded for the Kindle reader or viewed (slowly) from Amazon's page. There is also much info in various recent texts such as Yang & Wu—Fundamentals of Liquid Crystal Devices (2006), Khoo--Liquid Crystals (2007), Kato--Liquid Crystalline Functional Assemblies and Their Supramolecular Structures (2008), Scharf--Polarized Light in Liquid Crystals and Polymers (2007), Stewart-- The Static and Dynamic Continuum Theory of Liquid Crystals (2004), Briman et al.--The Physics of Liquid Crystals (1993), Takatoh et al--Alignment Technologies and Applications of Liquid Crystal Devices (2006), Vicari—Optical Applications of Liquid Crystals (2003), Neto et al--The Physics of Lyotropic Liquid Crystals (2005), the long review by Singh-Phase Transitions in Liquid Crystals-- Physics Reports 324 (2000) p107-269 and Singh-Liquid Crystal Fundamentals(2002), all of which I select from a far larger list as they seem to be available on P2P.

As in any hitech arena, many of these patents get quite esoteric for nonspecialists, e.g., using Poincare' spheres for calculating achromatism, and of questionable utility as practical methods for digital 3D cinema. US 2008/0129900 e.g., attempts to fix artifacts due to the gap between segments of the color wheel in single chip DLP projectors, which produces time sequential color ghosting (see Andrew Woods actual projector tests on frame sequential viewing with DLP), by instantaneously altering the driving voltage and hence the chromatic properties of the multilayered LC pi-cell, to blank gap image frames and smooth out their sequential spectral color. This and other work cited here indicates that the obvious method of affixing polarized pieces on the color wheel is unlikely to work well (e.g., see the Cobalt/3ality patents such as WO2005/112440).

It has been said (e.g., on the Real D page) that one cannot use single chip projectors for any active (i.e., frame sequential) 3D technique, but various single chip projectors operating at 85 or 120hz have been in successful 3D use with shutter glasses for at least 5 years, though they

currently have some limits on image quality. In addition, new tech is being introduced (e.g., US 5490009, US 5612753, US 7180554, US 7241014, WO 2006/038744) and many new models specifically engineered for 3D will appear soon. Scandinavia based Projection Design and also the USA company LightSpeed have released new models suitable for small theaters. Even the king of the large format 3D film IMAX has seen the 3D digital light and is pursuing 3D DLP projection (US 7224411, WO 2007/024313). IMAX has used wireless shutter glasses with stereo headphones in some of their 3D theaters for about 10 years and they noticed that if one uses shutter glasses with silver screen and carefully aligned polarizers on the projectors as well, the figure of merit for on axis extinction rises from 150:1 to perhaps 1500:1 (they say 15,000:1 but this is clearly impossible), essentially eliminating ghosting (EP 0 820606 B1 from 1999) at the cost of a slight drop in brightness. I do not know if they actually used this method in their few shutter glasses theaters. However, if one uses the highest quality polarizers now available (e.g, Nitto 1220 or others in the G series or those from Sanritsu etc.) there would likely be no advantage since contrast loss due to ellipticity of light passing thru the shutter can be eliminated by an inclined quarter wave plate or other anisotropic means. In any case, given a system with silver screen, dual projectors and active or passive glasses it takes only minutes to place HQ polarizers in front of the lenses to see if it improves ghosting. This however, will only be effective if the silver screen is high quality (see comments below).

There are also numerous patents on new projection technology for active or passive glasses. One promising example is an LC light valve method with the unfortunate acronym PEMFVORD (Programmable, ElectroMagnetic wave Field Vector Orientation Rotating Device), patented by Steven Sedlmayer of Arizona for the Taiwanese display company AUO last year, that appears able to produce very high efficiency native dual polarization (US 7,295,371). This could have a major impact on 3D projection due to low cost, brightness, image quality, energy efficiency and compactness. Of course many new technologies are being developed but they are probably years away. Those who want the bleeding edge might talk to Boeing about their quantum dot 3D displays (GB 2,425,673).



Sedlmeyer's 2007 patent for AUO on light valve dual polarized projection.

Regarding patents, we can expect numerous variations of every stereo display modality to appear in the next few years and much overlapping tech in the patents and products since the basics are public domain and, insofar as there are novel claims, patents take about 4 years to issue and meanwhile anyone is free to use them. One can also anticipate some complex patent fights since there is a huge and intricate prior art on all methods. The only part of a patent that matters are the claims and the granting of a patent merely says that they appear to be valid—an issue that only the patent courts can decide. I have studied the 3D patent and technical literature for 35 years and I suspect that more than 95% of all granted claims could not withstand a serious challenge.

CP and LP switching by multilayer LCD plates was specifically patented for 3D by many companies including StereoGraphics, the company I started in 1979, and marketed by them under the name “Z-Screen”, sometimes called “Z-Filter”. LCD shutter glasses and CP switching screens were originally developed and marketed by Tektronix in the 70's and, after poor management destroyed their LCD division--the USA's finest LCD R&D facility--it was licensed to NuVision of USA

and Delta of Taiwan. Independently, various companies worked on this, including the Japanese petrochemical company Idemitsu, who released an all plastic version (i.e., no glass whatsoever) that I used for some time in the late 1990's (EP 0892563 A2 (1999)). A few years ago ColorLink began marketing one and Real D (the new name of StereoGraphics after some Hollywood hotshots bought controlling interest in 2004) solved the problem of competition from a superior product by buying ColorLink (<http://www.reald-corporate.com/story030807.asp>).

A little known aspect of this history is that Tektronix was sued by LC pioneer James Ferguson over pi-cell patents, and, despite assurances from their patent and tech staff that they would win easily, they paid him off rather than pursuing it, since they had a lucrative business selling high end devices such as time domain reflectometers and they did not want to interrupt the cash flow. Possibly this enabled StereoGraphics Corp. to survive since Tek might have sued them for patent violations.

The CP switching method has the same problem as other active or passive (e.g., dual projector) CP methods—more ghosting or crosstalk than LP (Linear Polarizer) methods. Another problem is that the volume accumulation of ions may quickly decrease image quality during the movie, and some of the patents describe quenching techniques for amelioration. In fact there are so many problems that Real D says it will not work for screens wider than 40 feet and has filed a whole series of patents trying to correct them (e.g., US 2008/0206155 and above). This necessitates the preprocessing of all 3D films by Real D to decrease ghosting (US 2008/0268104, US 2007/188602, EP001883835), though they say they will put the algorithms in a chip soon and do it realtime on the projector. Ghost reduction, realtime or not, is a very good idea for every 3D program, regardless of viewing method-provided of course that other aspects of image quality do not take a hit. There is a long history of ghost reduction going back to the days of ghosting in 2D television broadcasting and there have been a number of stereoscopic implementations in the patent and technical literature (e.g, see the patents by Street US 6075555 etc and others in my SPIE article and Konrad et al. --Cancellation of image crosstalk in time sequential displays of stereoscopic video. IEEE Transactions on Image Processing 9:897-908(2000)) and also in the common educational 3D system from Neotek www.neotek.com.

The angle from the projection lens to the edges of the screen for an active polarization switch should not be wider than about 12 degrees as the crosstalk will begin to exceed acceptable limits at the edges of the screen. This is a problem with all polarization methods including passive dual projection but is naturally worse with multilayer active devices and worst of all with the CP switcher favored by Real D. Going to an LP switcher ameliorates the problem somewhat and ColorLink has developed their linear ALPS device for this reason (US 2006/0291053 and Sharp and Robinson—Enabling stereoscopic 3D technology. SPIE vol. 6490(2007). In addition, since the retardation is tuned to the green (which always has highest luminosity) red and blue objects will show greater ghosting in all parts of the screen.

Crosstalk is always present in any polarized system and it gets worse the further off the axis from projector to screen. Thus one should always sit in the middle of the theater and to the back if possible and particularly avoid seats to the extreme right and left close to the screen. Sitting in the rear of the theater is always a good idea to minimize stereoscopic errors (including the horizontal parallax so beloved by stereo cinematographers). To calculate acceptable screen width in a Real D theater, just measure the throw from the front of the projection lens to the screen and use trigonometry to determine width for 12 degrees.

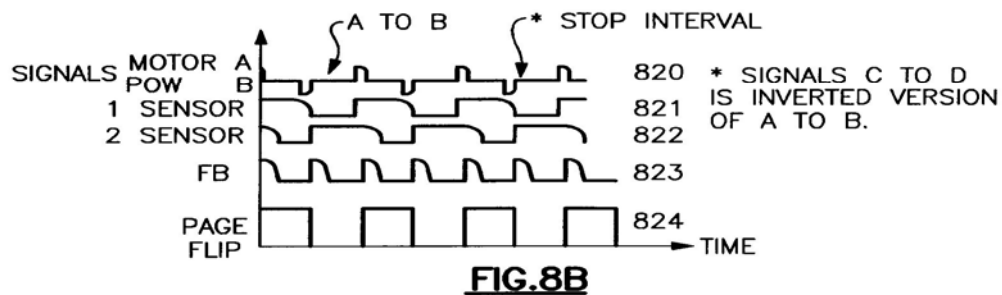
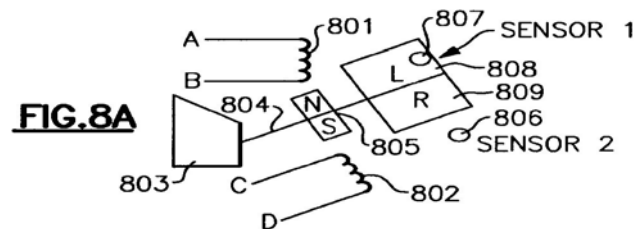
From the earliest days of LC's in the 60's to the present, there is a massive body of literature (tens of thousands of patents and papers) relevant to polarization switching and there is no possibility that anyone has a fundamental blocking patent on LCD shutter glasses, or CP or LP switching. Countless companies worked on this in the 70's and 80's and you can get a good sampling in the SPIE review paper I published over a decade ago, which is also on my page www.3dtv.jp as the Stereoscopic Imaging Tech article, but this only relates to certain areas of 3D and barely touches on the much larger literature relevant to polarization switching and related issues.

Consequently, it is clear that active CP (or LP) switching for active glasses or projector StereoPlates (the name I have long used for these devices when placed in front of a projector or CRT) is a public domain technique, though possibly some companies have protectable refinements. Real D claims they will release a new XL version of the

ColorLink CP switch in late 2008 with double the brightness (which can be achieved e.g., with sufficiently rapid switching, by eliminating the polarizers and using a cholesteric LC layer that can theoretically convert to CP 100% of the unpolarized light).

This technology is well understood by thousands of engineers in the LC industry and new products from other companies are already appearing, but it is possible that one of the mechanical LP or CP alternating systems (see below) will obsolete them all. The simple rotating CP disk system works, but has problems which will be obvious to any EO engineer, but modern tech provides other options and they are being pursued by many.

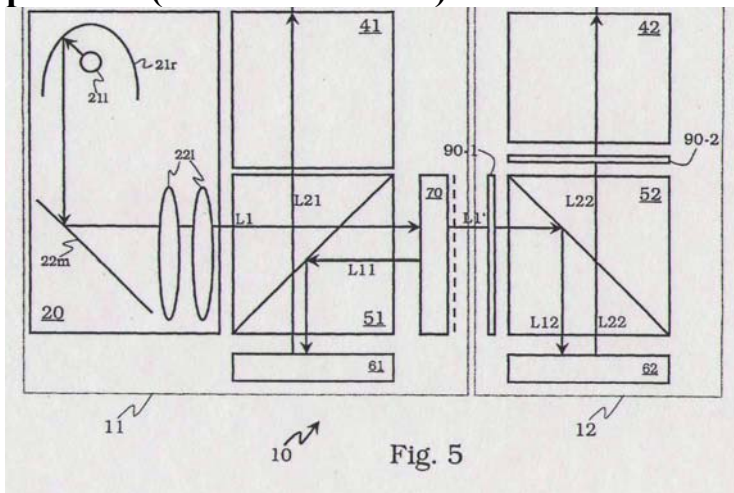
E.G., one promising improvement in frame sequential polarized technology prototyped over the last 3 years and patented by IBM (US 2008/555402, 2008/555401, 2008/0055546) uses small pieces of magnetically oscillated polarized filters placed at the internal focal point of the projector with magnetic bearings and magnetic or air core solenoid damping. I estimate a parts cost of about \$20 and it can be modularized for quick install by unskilled personnel. However, the same IBM researchers are hedging their bets with a conventional rotating polarized wheel (WO 2007/071614). All methods which place optical components internally near the focal point have to dissipate heat very rapidly. This is less scary than it seems as it is normal for videogamers to cool their overclocked processors with special thermal units including some with liquid coolants and advanced cooling tech is readily available.



IBM 2008 patent application on magnetically controlled frame sequential polarized 3D projection with the polarizers, sensors and dampers in Fig 8A and the timing diagram in 8B.

With these devices, internal or external, it should be easy to retrofit theaters currently using a CP switcher or other means, thus eliminating the need for preprocessing, expensive glasses and licensing fees. Like most of the other methods, it should also work with GLV (Gated Light Valve) projectors (<http://www.siliconlight.com/brochure1.pdf>), a laser addressed MEMS technique that has been exclusively licensed to SONY for display applications. Perhaps SONY will finally recover its investment on the PlayStation 3 this year and be able to afford developing GLV, which, blindsided by the 3D revolution, they sorely need, as their high end projector is LCOS, incompatible with all frame sequential methods. Of course this is a problem with all types of LCD's and much research has gone into attempts to increase the speed (e.g., WO 2007/021456, WO 2007/021457) but there are no commercial FS compatible panels or projectors (though NVida/ViewSonic have shown a prototype). SONY has however not been idle with other approaches and what appears to be a very nice patent (WO 2005/101821) shows how to use dual LCD's in a modular projector with native cross polarization using only one lamp and a reflective electronic color filter (RECS) of unspecified nature; the wasted light from one image being

used to illuminate the other. With the 3D market booming, Thomson's dual LCOS projector also looks feasible (US7192139, US 7204592, WIPO2004/051994). However the Lagrange invariant limits light flux for high brightness projectors using small imaging chips so Kodak has described methods using larger TFT LCD's with such amenities as wire grid polarizers, glass fresnel lenses and dichroic filters to solve this problem (WO 2007/070245).



Sony's modular, single lamp, dual LCD projector uses polarizers, two half wave plates (90-1 and 90-2) and the RECS (70) to reduce energy use and heat and increase image quality by reducing binocular illumination asymmetries.

In this connection one should keep in mind that the single camera, single projector simultaneous cross polarized technique used so successfully with 3D film for over 30 years may again appear for 3D video. LCOS and other modalities already have 4Kx2K resolution so a split lens with top/bottom images will give a 4Kx1K pair, sufficient for modest sized cinemas. SONY has recently started using a split lens for projecting LCOS 3D. It is well known that split lenses for cameras and projectors, either top/bottom or right/left, have been widely used for 3D for some 50 years. If one uses anamorphic lenses to film and project (e.g., as the standard CinemaScope format for theatrical 2D has done for decades), then one does not need to throw away any pixels or use complex image-degrading codecs. Anamorphic lenses have often been used for video and SONY even sold them for use with camcorders and consumer projectors a decade ago. I have described many of these formats for 3D in my previous articles and there are whole books and websites devoted to widescreen.

It is feasible to use a single imaging chip of 8Kx4K with high brightness lamp and high quality lenses to compete in terms of image quality and cost with the other projection approaches, and to create hires single chip or dual chip or frame sequential 3D lenses for video cameras that will avoid the horrific problems of matching all parameters of twin cameras.

NHK (the Japanese entity that uses government money to buy up the 3D rights to the Olympics and other world sporting events for their own amusement and never shows them to anyone) has been using 8Kx4K ((7680x4320 or 32M pixels with 4320 scan lines) UHD cameras and projectors since the Aichi Expo in 2005—the same Expo where NewSight Corp. installed an 180 inch autostereoscopic video wall—and it's use for single camera, single projector 3D should be very straightforward. There is of course a substantial prior art on single camera techniques (e.g., see the SIT article on my page) and work continues (e.g., US 7215809, US 7181136, US 7170547).

All this points to the fact that the real reason for Real D's current dominance in 3D digital projection is not possession of a special technology but the \$100M or so invested. They would almost certainly have the same dominance if they had promoted any of the 4 common 3D projection technologies instead. However the apparently proprietary and simple nature of the CP switcher was undoubtedly appealing. It appears that in addition to the approx. \$75 to \$150K cost of the hardware and screen (most for the 3 chip projector), Real D requires theaters to pay a \$30K/year licensing fee and to buy the expensive (ca \$3/pair-but see below) plastic CP glasses, the cost of which, in the fastidious and rich USA at least, is passed onto the customers. A family of 4 seeing 5 3D films a year will spend about an extra \$60 for Real D glasses, \$10 for paper glasses (i.e., theaters often add 50 cents to the ticket price) vs. nothing (presumably) for shutter glasses or recycled paper or plastic glasses. Incidentally, I have submitted this article to four Real D execs for comment, but they have decided that silence is the safest option. I agree.

The economics for theater owners may be impressive. There are about 6 circuits in the USA with over 1000 screens and I have heard of recent purchases of 500 3D projectors by an Indian company and 700 by GDC

of Singapore. Assuming that a dual projector setup with equal brightness and image quality costs about half the \$100K of a high end 3 chip, this would be about \$50 million in savings for 1000 screens and if there is a \$30K/year licensing fee that is another \$30 million. On the other hand, \$100 each for active glasses in a 300 seat theater equals \$30K and supposing a very busy theater with 1000 shows/year with replaceable batteries and very durable 1000 use glasses (or the ca. \$100 Infitec glasses), this costs the theater \$30/show or approx. 10 cents per customer. \$50 glasses or ones that last twice as long lowers this to about 5 cents vs ca. 30 cents with the XPAND throw away glasses, but breakage and cleaning/battery costs will occur. A more realistic projection is 100 shows/year and this translates to \$1/customer so the theater owners who do the math should be strongly motivated to use dual projectors with passive glasses or active glasses with replaceable batteries or perhaps the Infitec system if the cost of projectors and glasses is modest, the image is sufficiently bright, and the color asymmetry is tolerable for a two hour film. Of course it is very likely that soon they will have even better options with some version of the new stereoscopic projectors referenced here.

Passive LP or CP glasses can be made for about 30 cents each, or as little as 5 cents for LP in paper, and of course reused so that customers do not need to pay a premium. It is true that if one tips the head about 10 degrees to the side, the ghosting advantage of LP over CP disappears, but few find it necessary to watch 3D movies with head tilted and even with 2D virtually everyone keeps their head vertical. With shutter glasses there are no extra charges and no problems with head tipping but of course there will be some breakage and the theater must clean the glasses and replace dead batteries. Batteries in new glasses from 3DTV Corp should last for over 500 hours, based on the actual in-theater performance so far and 1000 hours if a smaller LCD is used. As with the XPAND glasses, a simple method permits assessment of remaining battery voltage to prevent their failure during shows.

The current generation of wireless shutter glasses incorporates a microprocessor, which enables many desirable functions including power management, which extends battery life, and easy check on battery level. This renders the venerable CrystalEyes obsolete.



3D WINDOW™ Universal Cinema System from 3DTV Corp with microprocessor controlled LCD shutter glasses that sync to any professional or cinema emitter from any company, and an emitter that works with any kind of professional wireless glasses.

Image brightness is always a major consideration with 3D and the active CP technique (e.g., StereoPlate, Z-Screen) passes about 25-27% in the case of double LC layer (for pi-cells or surface mode LC with LC layer thickness about 5 mcm). Of course in multilayered (super high contrast—i.e., low ghosting) LC pi-structures the optical efficiency will drop further. The LCD shutter glasses (with a single LC layer as a rule) pass about 32-35% in case of pi-cells and about 20-25% in case of pi-cells doped with cholesteric LC. These will have an overall contrast about 100:1 (uncompensated) with a driving voltage no more than 12V in comparison with a contrast between 10 and 30:1 in uncompensated undoped pi-cells with driving voltage about 20V. Dual polarized DLP or LCD projection can pass up to a max of 38% (but probably typically below 30%) and up to ca 60% with dual LCD polarized internally (eg by Barco) or with use of special external filters (e.g., <http://www.advisol.co.il/StereoBright%20home.html> or http://www.silverfabric.de/html/sf_polarizers.htm). Standard LCD projectors have significant chromatic aberration and existing polarization but the latter can be largely eliminated simply by a layer or

two of common clear acrylic in front of the lens. There are many efforts to improve dual LCD polarized projection (e.g., WO 2005/121867, WO 2006/088275, WO 2007/070245).

Uncompensated CP and LP methods (i.e., normal theatrical paper or plastic 3D viewing glasses with just one layer of the plastic polarizer) used with CP or LP on projectors give a typical stereo separation ratio of up to 100:1 while the compensated (pi-cell or surface mode LC) active glasses currently used can give up to 500:1 on axis. ColorLink has reported up to 5000:1 contrast in compensated systems (e.g., see their glasses patent WO 2007/024713) which is better than the best Nitto Denko LP plastic sheets. Many others can quickly issue such products as the entire LCD display industry of necessity researches polarization tech, but until recently only a few have given serious attention to 3D issues (e.g., WO 2007/043153). In practice however, such complicated compensation is not used for active glasses. For example, the StereoGraphics CrystalEyes active shutter glasses use one rotated half-wave retarder to transform the elliptical polarization caused by residual birefringence of the liquid crystal into quasi LP for increased on-axis contrast (i.e., with the eyes looking straight ahead perpendicular to the LCD shutter), but with little increased contrast off axis, so the eyes see the periphery with poorer stereo contrast (i.e., more crosstalk) and the result averaged over the whole image should be about the same 100:1 contrast as with uncompensated passive glasses.

However, the bottom line is whether any of this makes a difference in the image quality and enjoyment by the average viewer, and it is my view that they will be equally satisfied with the cheapest method. For example, my own observations on a variety of monitors with the various types of wireless IR shutter glasses driven by our Universal Emitter show essentially identical image quality (ghosting, color, contrast) of the cheapest and most expensive models (i.e., \$30 vs \$800).



Universal Transmitter introduced by 3DTV Corp in 2008 with 3 of the many kinds of wireless LCD shutter glasses compatible with it.

The biggest problem with all techniques (ignored by virtually everyone) is fingerprints on the glasses. Based on my own observations over 35 years, I expect that, regardless of the method used, more than 50% of all viewers put a serious fingerprint in the viewing area of at least one lens by the time the film starts (assuming, contrary to common practice, that they are clean to begin with!). This detracts greatly from the experience as anyone can demonstrate. All viewers should be told to avoid touching the lenses and to check them carefully for prints just before the movie starts. \$100 million for the film and \$20M for the theater and \$200K for the projection system can be defeated by a single fingerprint!

In addition, for all polarized methods, it is essential to QC every batch of glasses, as well as the projector polarizers and silver screens. Silver screens, even from major manufacturers, can have very uneven polarization properties, to the point of being useless, and projector polarizers can burn out quickly. I have never seen data on the lifetime of active CP switchers. Uneven glasses quality is always a problem as well. I recently received (from a very well known 3D company) a shipment of LP glasses of which 30% were totally useless, along with a silver screen that depolarized the image almost completely and when they sent me the remetalized screen it still depolarized irregularly and

was full of hot spots. QC problems also exist for the polarizers used in StereoPlates or in active shutter glasses. I suspect that nearly all 3D theaters have a significantly higher degree of ghosting (crosstalk) than necessary.

All frame sequential techniques (i.e., CP rotating discs, CP or LP switchers, active Infitec or LCD shutter glasses) suffer from motion artifacts due to the fact that the right and left images are not presented to the two eyes simultaneously (as they are in the real world) and this is worse if the two images are not captured by two cameras in perfect sync. The problem worsens with faster object motion but should not be present with frame simultaneous presentation with any dual projector technique (unless demultiplexed from a low frame rate sequential format) and likewise should not appear if demuxed from a high frame rate file (e.g., dual 60hz shot with twin video cameras with progressive scan preferably) or played from HD DVDROM in TriD format in dual out mode (see 3DTV page), or demuxed by using 3DTV Corp's new high frame rate HD Demux which will also be the first device to convert standard field sequential DVD's (SD or HD) for viewing on 3D ready TV sets.

Though Real D's huge bankroll, early start, and inside position in Hollywood has given them the lead, the Infitec system now marketed by many projector companies, and most aggressively for the big screen at the moment by DOLBY and BARCO, is quite superior in terms of image quality (10,000 to 1 stereo separation with essentially ZERO ghosting) and, like active shutter glasses, permits the use of any kind of screen (i.e., no need for a silver one). Created by a German team at Daimler-Chrysler a few years ago and then spun off, it is a triple anaglyph notch filter method and they offer both dual projector and single projector versions (i.e., Active Infitec, a frame sequential anaglyph with rotating or switching internal filters (EP 1 830 585), which can be retrofitted to existing projectors http://www.dolby.com/assets/pdf/specsheets/Dolby_3D_Digital_Cinema.pdf). With the many advances in light generating displays (e.g., MEMS systems from Kodak etc) it is not out of the question that native Infitec flat panels (e.g., see ColorLink's WO 2007/095476) and projectors will be produced in the next decade. Bose Corp has several patents on an active 3D color wheel method with triple anaglyph filter glasses very similar to the Infitec system (WO2007/118114, WO2007/118075), which

gives details on the construction of what might be low cost lightweight glasses and, if there is no barrier to their implementation, they could greatly expand the Infitec market. However the very complex (up to 30 layers) sputtered dielectric interference filters that have to be rolled into flexible polymers could be extremely difficult. Likewise with the interference polarizing triple anaglyph filters described by ColorLink (WO 2007/095476) wherein the polarizer is placed on the display (or projector) and the retarder stack is in front of the analyzer in the glasses. So, the well known methods for multilayer (apparently up to 50) curved (necessary for filtering) glass interference filters used by Infitec are likely to persist and though they could be made much cheaper if done in the millions in China, Infitec may have no motivation to do so.

Major downsides of Infitec are: that it loses even more light than polarizers, passing only about 7% with one http://www.barco.com/projection_systems/downloads/Active_Infitec_brochure_dec06.pdf or up to 27 % with dual projectors according to Barco <http://www.barco.com/entertainment/en/stereoscopic/lumens.asp>, with minimal flicker (55Hz/eye with their Galaxy projector); the fact that the glasses cost about \$100 –though Dolby recently announced wholesale prices of under \$30 USD; and the fact that active Infitec will show the same motion artifacts as CP or LP switching or LCD shutters, as well as some unique color artifacts (as admitted in several Barco patents cited here). Also, as with any anaglyph technique, there is a different tint to the two images and this causes a small but noticeable color aberration and luminance asymmetry, which could produce a bit of eyestrain during a 90 minute film. However, all the techniques produce some demands on the visual system and there has never been a careful controlled study of relative comfort of the various 3D projection systems, nor I believe, even one comparing 2D and 3D. There is a vast psychological literature on stereo perception, but most is difficult to relate to the home viewing or 3D cinema parameters, and in any event it is totally ignored by Hollywood and the rest of the 3D industry.

Unlike all the other methods, the basics of which clearly lie in the public domain, the triple interference filters used by Infitec seem to me a good patent (though I would not be surprised that a careful search found prior art). However, the basic idea has long been known and I have on my desk the two-color orange/blue interference filter glasses I used with my SpaceSpex anaglyphs in 1993. Clearly, it is feasible to use dual

image anaglyph projection with single or dual notch filters on the projector and the glasses with either the active or passive technique (i.e., the one and two color homologs of the active and passive Infitec system). Corresponding one or two notch filter viewing glasses will be less expensive than the Infitec ones. If the projectors have the notch filters it is also possible to use the extremely cheap (about 2 cents each in large qty) paper (i.e., colored cellophane) anaglyph glasses for viewing, thus getting the cost down to almost free and of course all these methods ought to avoid the Infitec patents.

The home 3D-ready one piece DLP rear projection TV's introduced by Samsung and Mitsubishi in 2007 and several 3D ready plasma panels from Samsung also produce 120hz frame sequential projection with active LCD shutter glasses. However these do NOT take in the normal field sequential 3D signal but rather the 60hz Texas Instruments checkerboard stereo format (US 2008/0036854, WO2008/021856) that facilitates conversion of 60hz to 120hz, so files must currently be reformatted by software on a pc.

3DTV Corp. will soon release the world's first Universal wireless glasses transmitter with the standard VESA stereo plug for use with these sets (and also for any of the high end video cards from Nvidia, 3D Labs etc, or with the ubiquitous 3D gaming hardware including wired shutter glasses sold by the hundreds of thousands by X3D, I/O, 3DTV, etc.). The plasma flat panel tv's recently released by Samsung have an unacceptable degree of ghosting but the DLP one piece rear projection tv's are quite acceptable and apparently almost a million have been sold in the USA alone in less than a year. They are much lighter, cheaper and brighter than plasma or LCD panels and some models have very long life white LED "bulbs". It is feasible to produce models with polarization preserving screens for viewing with passive glasses (see e.g., patents cited here). Larger sizes with higher luminance could replace projectors in small theaters.

Dual polarized TV sets or monitors have been used at least since Dumont sold them in the 1950's and recently normal looking LCD panels with dual inputs viewable with passive polarized glasses have been marketed by half a dozen companies including Miracube, Zalmon, Hyundai (ca. \$3000 for a 42 inch model) and JVC. Image quality is quite good but they face tough competition from the 3D DLP sets.

The Universal Transmitter in home or 3D Cinema versions can be used with most wireless shutter glasses –e.g., the new 3D Window Model from 3DTV Corp, CE (CrystalEyes) from StereoGraphics (Real D), NV (NuVision/Xpand) and X3D (I/O, Razor)-- (though only one of the 4 standards works at a time). The 3D WINDOW™ glasses also automatically sync with NV or CE transmitters allowing Pro or Cinema users to painlessly replace their more expensive glasses or to deal with emergencies. With suitable interfaces it will also work with the common low cost DLP projectors running at 60, or 85hz or higher-- such theaters have become common during the last 5 years. Australian engineer Andrew Woods has researched this extensively and there are lists of frame sequential compatible models from others on the net as well. As expected, all the projector companies are now introducing lower cost 120Hz (or frame and timing rate variable-- like the high end 3 Chip ones) DLP projectors which will further stimulate the market.

In this context one should note a simple technique for reducing flicker with active glasses and 85hz projectors. Removing the front layer of polarizer from the glasses and putting it in front of the projector greatly reduces or eliminates flicker due to ambient light and may increase contrast, but necessitates the silver screen and special glasses. This occurred to me many years ago and I have seen it patented several times so it is somewhat surprising to see this idea recently presented as a novelty in one of SG/Real D's many vanity patents as "partial shutters" (US 2008/0062259), and as a display modality for monitors with no mention of projectors. As with most patent applications, this one fails both the tests of no prior art and of non-obviousness. Likewise with Real D's application for making cheap CP glasses by combining LP and retarder in one frame, rather than buying laminated CP (US 2008/0018851). Though clearly not patentable, this is possibly sensible in large quantity as it might reduce the cost to near that of LP and give more uniform quality.

There have also been many innovations in shutter glasses techniques recently implemented such as universal glasses able to sync to any of the various transmitters (the new 3D WINDOW™ glasses from 3DTV Corp) and a nifty design intended for ophthalmic use that displays personal

messages (a natural for advertising or in-theater paging)-- US
2008/0062338.

Most of the world cannot afford \$100K projection systems and is not able to pay huge licensing fees nor \$3/pair for glasses, so if they have a choice, they will go for shutter glasses systems (perhaps 200 theaters large and small so far), mechanical rotating CP discs (apparently half a dozen installations), or dual polarized projection (possibly 300).

Presumably, all the cinema servers are compatible with two projectors, which has the great advantage of lower cost, wide range of choices, and easier backup as well as the ready availability of cheap LP glasses, which also have lower crosstalk than CP. With dual projectors you should be able to avoid the annoying motion artifacts that may occur with fast movement in sequential systems and the binocular color asymmetry of Infitec. It is clearly easier and cheaper to find two projectors (LCD, DLP, LCOS etc), which combine to make a suitably bright image, than to be forced to buy one top of the line high brightness unit. With dual projectors, it is also feasible to maintain a backup unit and to source and change projectors quickly. It may also be feasible to stack the projectors (i.e., use two or more for each eye for higher brightness as is often done in 2D), though the need for front surface mirrors, polarization reversal issues, geometric distortion etc are problematic.

Several companies have developed 3D Cinema shutter glasses systems, and I have been instrumental in the creation of several products. The 3DTV Corp 3D WINDOW™ Universal 3D Cinema Viewing system costs about \$5000 and comes with sophisticated microprocessor controlled wireless glasses (ca \$100 each) that will sync automatically with the 3D Window emitter or with the emitters for any NuVision/Xpand or CrystalEyes system. These have replaceable batteries, so cost per film should be at most 5 US cents or about 20 movies to the dollar

There are currently at least 4 types of wireless cinema systems which I will call 3D Window, C (China), CE(CrystalEyes) and X (NuVision/XPAND). They do not employ the same glasses or driving methods as previous personal wireless systems in order to prolong battery life, reduce emitter power, sync to various servers and

projectors, and add glasses features. Three of them are mutually incompatible but 3DTV Corp's 3D WINDOW™ system is universal. CE are only used for small theaters due to the very high cost (ca \$800 each). The NuVision/XPAND glasses cost about \$100 and have a nonreplaceable sealed battery, so they are thrown away when it runs down, with a putative cost of about 30 cents per film or 3 movies to the dollar—roughly the cost of one-use paper LP glasses in the USA but up to 5 or 10 times that of the lowest cost one-use paper glasses or cleanable plastic LP or CP glasses or of active glasses with replaceable batteries.

The active glasses technique is compatible with some 1 chip or most 3 chip projectors up to 144hz (the maximum frequency often used by Real D and others) and should work well with large or medium venue projectors from NEC, Panasonic, Digital Projection, Barco, Christie, Projection Design and others (but not the well known Sony high end unit which is not DLP but LCOS).

It is not out of the question to equip theaters for wired active glasses with a plug at each seat since total costs could be significantly less than any other method. This harkens back to the very beginnings of the commercial electronic stereocinema in the 1920's when mechanical shutter glasses were affixed to each seat. I will not delve into the vast literature on 3D film projection but one can see how surprisingly advanced things were at that time by looking at the 3DTV patents of Hammond US 1725710, filed in 1923, or Adsit US 1796420 from 1928, which get field sequential color and stereo using Nicol prisms, polarization and other means.

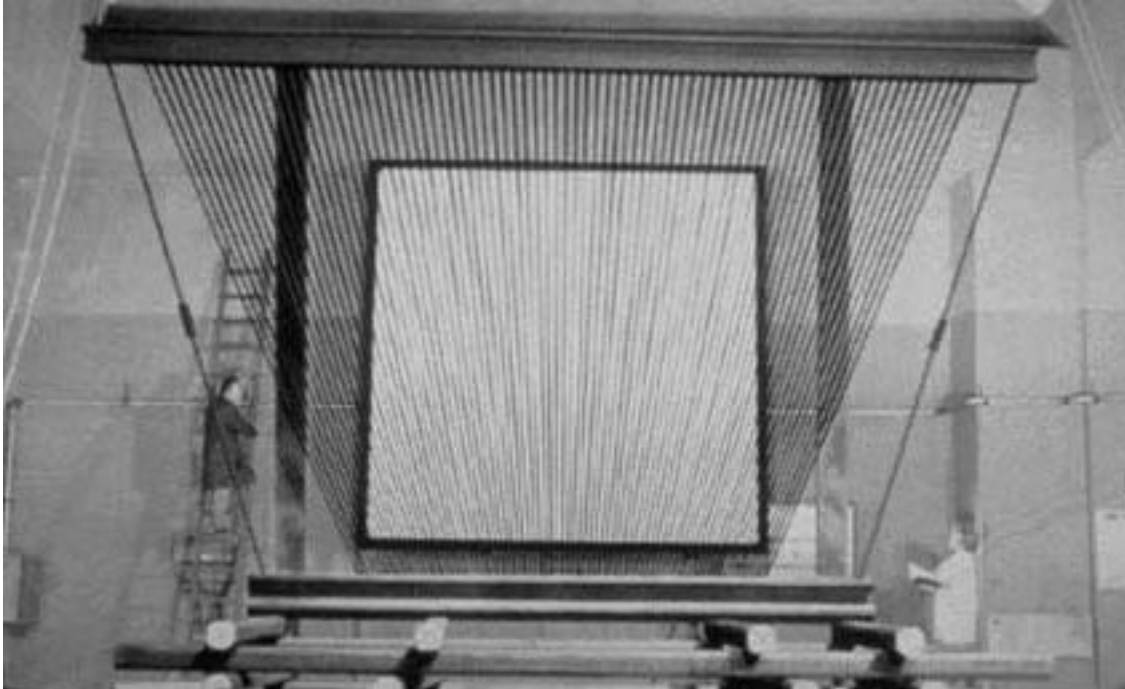
There are a variety of options for live 3D projection, but perhaps the cheapest and easiest is the TriD software sold by 3DTV Corp. which lets you display/record/edit/compress/playback all the pixels of two cameras in frame sequential or dual projector mode with a small executable program running on a standard pc or even a good laptop. It is highly intuitive and can be learned in an hour.

IMAX 3D theaters, which use very large screens with high brightness projection, afford a unique experience which, due to screen size and brightness, emphasizes problems with filming, editing and projection, and everyone interested in the field should see as many of the films as possible, removing the glasses frequently to observe the mistakes. I

have written several articles on IMAX 3D in which I discuss the films and the technology (www.3dtv.jp or in my booklet Stereoscopic Imaging Technology). They have used bicolor anaglyph occasionally, but mostly active and passive one and two projector polarized or shutter glasses methods.

Laser projection has seen sporadic use for both polarized and frame sequential methods for over 30 years, and with native polarization, zero optical distortion, highly saturated colors, highly flexible distances and screen sizes due to almost limitless depth of focus and resolution, extremely rapid decay and electrooptic switching, it should be the sharpest, brightest, highest contrast, truest colored of all, but perhaps because of safety issues, need for water cooling, and the need to eliminate the speckle interference by screen vibration, passing through an LCLV or other means, no large entity has consistently championed it, so it remains a rarity. However work has been done by Mitsubishi and others which attempts to combine the advantages of laser addressing with those of DLP and so polarized lasers may yet appear in theatrical projectors (US 2008/0049197).

Autostereoscopic (no glasses) 3D projection has a long history but only the Soviet Union had any large screen commercial theaters, with headrests for the no glasses seats (they projected simultaneously with LP for people in the bad viewing zones). They used screens made of slanted piano wire and later some made of glass, but these are long gone.



Russian autostereoscopic movie screen developed at NIKFI in Moscow in 1960's and used in a few theaters until the early 80's. Slanting was necessary to match viewing zones on the slanted theater floor.

There have been countless varieties of autostereo projection displays since the 1930's, most using special screens made with more conventional materials and methods, to direct the images and this work continues (e.g., US 6,533,420, US 2006/0066810, US 2008/0049282, W0 98/43441 WIPO 2005/122595, WO 2007/062644, US 7,230,759, US 2007/0296920). One of the more intriguing recent multicam, multiprojector, multiview autostereo patents comes from Mitsubishi (US 2008/0043095, US 2008/0043096).

There were also some holographic screens created by Komar at NIKFI in Moscow in the 1970's but these were never commercialized. Many others have described autostereo projection using holographic films and HOE's or more conventional screens (beginning of course with Gabor--see my articles for references) and work continues from many quarters (e.g., US 2008/0007809, US 7142232). Recently NewSight Corp (www.newsight.com) (formerly X3D) has created POLO, a large venue holographic projection system WO 2004/008779, US 2006/0103932 and has begun work on POLO-2 --an improved version. 3DTV Corp has provided consulting and technology for NewSight--including my patent for realtime 2D to 3D video conversion US 6108005, US 7254265--

incorporated in the well known Virtual FX 3D Converter. I have recently helped to generate a project to produce the first outdoor useable autostereo LED displays and the first one was installed in Beijing in time for the Olympics. Both these technologies can be tiled to any size.



The author and his wife with the 3D WINDOW™ -the world's first commercially available autostereoscopic LED display in Tianjin, China August, 2008.

In addition, NewSight Corp (www.newsight.com) has recently introduced a digital signage mode for autostereo which eliminates the “dead zones”, at the cost of reducing the depth, and realtime synthesis of multiview autostereo with correction of various camera parameters, on a standard pc, from right and left live cameras or image files. This may be of special interest to the movie industry since it also provides a means of showing 3D trailers in theater lobbies and malls and of course they can be updated over the net. NewSight has also made very high quality autostereoscopic trailers from 2D films.

A major problem with common autostereo displays is the reduction in resolution, but Vasily Ezhov has just patented (PCT/RU2008/000233) and is prototyping what I think is the world's first planar auto 3D display using exclusively standard LCD technology (i.e., COTS) with

full display resolution in each eye and this should greatly stimulate applications. It is also fully 2D compatible. In addition, he has another application pending on a more general universal auto 3D method that can be realized on practically any type of LC matrix (IPS, FFS, VA, MVA, PVA, ASV and so on, including bistable ones – FLC etc). I recommend his recent articles (http://3dstereo.ru/ezhovpublications_e) as the best extant short overview of 3D display methods, in which he defines several modalities that have never been built or even named.

Readers of my articles over the last 25 years are aware of the work on autostereo projection by Robert Collender, whom I have called the Einstein of 3D for solving the problem of glasses-free stereo for large audiences. He gave up trying to make the world listen long ago but, after a 20 year hiatus, recently did another patent with his son, extending his stereoptiplier ideas, and anyone with lots of money and good R&D capabilities should take a look (US 7,180,663, US 2003/0234909A1). This may look like questionable stuff or even crackpot to many but I have seen it work and once you understand the principles it's clear his ideas are solid. Completely understanding this patent should be considered essential for any stereocinema expert.



Robert Collender of California in 1978 with a model of his autostereoscopic StereoMultiplexer theater.

The time has also come to dispose of the projection booth entirely by installing flat panel screens. We are familiar with these in outdoor advertising and sports arenas but cost and other factors have limited

theatrical use. It only requires an investment from one of the current leaders in this field such as SONY, Mitsubishi or Panasonic to become a commercial reality. No more lens distortions, blurred images, failed projectors, or even projectionists and either one large panel or a matrix of abutted and edgeblended panels can work with anaglyph or polarized active or passive means. Autostereoscopic panels or automatically switchable 2D/3D panels (there is a large literature on this) and the web delivery of content would eliminate the need for viewing devices and in-theater servers as well. Addition of ATM's for payment, vending machines and nightvision cameras for monitoring would result in a totally automated system running at a fraction of the cost of current theaters.

Finally, I must note that any technique is only as good as the available software and that minimization of binocular asymmetries (e.g., image skew on any axis, zoom discrepancies or color or luminosity imbalance), avoidance of violations of the stereo window, minimal horizontal parallax, minimal divergence of in focus objects, and no vertical parallax, should be strictly observed. Even those regarded as experts are given to oracular pronouncements that are often quite confused or blatantly mistaken (rarely citing studies, but relying on their own prejudices and anecdotal reports). It is for example wrong to permit frequent and prolonged breakdown of the accommodation/convergence relationship (the IMAX "standard" wherein the entire image is often placed in audience space during much of or even the whole film) if it can be avoided. This happens when objects are given large negative parallax and pushed into audience space, forcing the eyes to converge well in front of the screen while maintaining focus on the screen. It was shown by Russian researchers (e.g., Amelianova) many years ago that this tends to make the eyes focus on the convergence plane, leading to blurry images and eyestrain as the visual system tracks in the attempt to focus. Divergence and jump cuts between shots with very different parallax are also bad ideas. It is essential to have stereo experts at all stages of the 3D process, but one must keep in mind that those used to viewing stereo frequently become inured to mistakes which will bother the stereo naïve, particularly since these mistakes add to all the others and cumulate during a two hour film.

Stereo errors of every kind are unavoidable in live action with even the best system, and these add to those from projection and viewing which

sum and cumulate over time. That is, orthostereoscopy is unobtainable (even orthoscopy in 2D eludes us as well---like a perfectly frictionless surface) but one must try. With even the best technique it is near universal to have some mild discomfort from prolonged stereoscopic viewing and this is likely to increase with age. This is, of course, also true of 2D!

Some good human factors (i.e., psychophysics or stereo perception) work was done with HMD's in the early years of the Virtual Reality industry but its relevance to theatrical film or even home viewing is unknown.

The only study known to me that attempts a comprehensive (i.e., about a dozen asymmetries in 35 conditions) examination of projected binocular asymmetries is that of Kooi and Toet on a dual polarized system published in *Displays* in 2004, which can be downloaded from Amazon for \$6 http://www.amazon.com/Visual-comfort-binocular-3D-displays/dp/B000RQZGRE/ref=sr_1_291?ie=UTF8&s=books&qid=1221202265&sr=1-291.

However, even this study is very limited as they used large asymmetries with only 5 second viewing, still images, a subjective 5 level discomfort scale, a maximum of two simultaneous asymmetries, often no truly quantitative instrumental measurement of perceptible distortion (i.e., what the eyes see coming through the viewing devices), one type and size of display screen, and ambient brightness (theaters vary alot). There needs to be (ideally) a 90 minute viewing time with each of the common projection methods compared, with at least 10 instrumentally measured simultaneous asymmetries of varying amounts with moving images with various screen and ambient brightnesses, fields of H and V view that match theaters, and more detailed subjective reports and objective measures of before and after function such as balance, visual acuity and visual tracking etc. The theses of Seuntiens (*Visual Experience of 3DTV—Eindhoven University Press 135p(2006)*) and Van Eijk (*Beyond the flat screen: Minimal and Optimal camera base distances for viewing 3D images-Eindhoven University of Technology masters thesis 87p(2003)*) make some efforts in these regards but suffer from the same problems as Kooi and Toet.

One type of error rarely attended to are “minor” differences in the brightness of the two images. It was shown e.g., by Diner and Fender (Human Engineering in Stereoscopic Viewing Devices –Plenum (1993)) that luminosity differences so small only a photometer could detect them produced significant flicker perception. Quite apart from small asymmetries that might be seen by a careful operator there are the subliminal asymmetries that are always present. There is a huge literature on subliminal perception but almost nothing for stereoscopy. Careful research is needed with real display situations on discomfort produced by various degrees of binocular asymmetry for luminosity, color, zoom, focus, and contrast, and for skew, negative parallax, and divergence, additively over a two hour period.

Meanwhile, every attempt at symmetry using objective instrumentation should be made during shooting, editing and projection and fully engineered 3D cameras, editing software and projectors would make such dynamic corrections automatically. There is a significant literature on automated stereo image rectification from fields such as robotics, photogrammetry and stereoscopy but little specifically on automated reduction of binocular asymmetries during shooting, editing and viewing and I will only cite here one of Kodak’s recent patents (WO 2007/084267) and one by Fuji on automated camera brightness matching (EP 1081504).

In any case, it seems most unwise to permit three people (i.e., the DP, the editor and the projectionist)—usually with no stereoscopic training at all -- to make all the decisions by eye from the moment of shooting until final viewing by the public. Professional stereoscopists should have input throughout, but they are often inured to liminal and subliminal errors and not representative of the viewing public. Consequently, any serious ongoing 3D production effort should be vetted by a well controlled study using people with little stereo viewing experience. In this regard, it is also clear that the manufacture of active and passive glasses (e.g., polarizer alignment, final QC for minimal ghosting etc.) and theatrical installations should be automated as well. Barco, Christie, Real D, Dolby etc should all have personnel doing QC of all their 3D installations on a regular basis, but, so far as I know, it is rare for anyone to check after the initial install.

In addition, the best results will be obtained only if the silver screen is very high quality. I suspect there is rarely careful instrumental checking for degree of depolarization or hot spots for screens even by the best manufacturers and they are very easy to damage during installation. I doubt that a thorough check for slight degrees of depolarization over the entire surface of the installed screen is ever performed. Even the best glasses and polarizers will be defeated by a less than perfect screen and so I think that higher than necessary ghosting over part or all of the screen is nearly universal.

In 2008 Pierre Boher of the French metrology instrument company Eldim <http://www.eldim.fr/> created the world's first stereoscopic metrology device, the VCMMASTER-3D. Though specifically intended for multiview autostereo displays, it is clearly adaptable for other uses and is a splendid example of the kind of care and precision in R&D, manufacturing and use of stereo displays that has hitherto been largely absent.

This is only a brief survey of some of the relevant art with most references freely available online, and leans heavily on patents as most of the R&D and products are never detailed in journal articles or books and these are in any case expensive and often unavailable online. The interested reader can search the net and in particular the patents for the avalanche of work sure to come. I recommend www.getthepatent.com for rapid one click download of world patents in markable form for about 50 cents each. I also commend to your attention the monthly 3D Newsletter from Visus et Veritas http://www.veritasetvisus.com/3rd_dimension.htm and, for those with the money, the superb reports of Insight Media <http://www.insightmedia.info/>.

I thank Vasily Ezhov for his many comments and corrections.