

# **Making the Third Dimension a Reality: 3D Video and Home Theater Design**

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Every few years, a new “hot trend” will burst upon the scene in the world of consumer electronics. This emergence will drive a wave of popular new products throughout the market, and push them into the home theater integrator’s world. Generally speaking this will start at the cutting edge with high end enthusiasts, and be swept downward into the rest of the market, as costs decline, and acceptance by the market increases. The last two revolutions that entered the home theater universe are still being felt today; the introduction and adoption of HD video as a standard, and the launch of a new medium to support better quality HD video – the Blu-Ray. Both of these products emerged within the last 10 years, and have become mainstays in any home theater designers’ arsenal. They have literally become a required standard in order to conduct business. We are now faced with another wave of new technologies, introducing another dimension into our design requirements. Of course we are speaking of 3D.

The idea of three dimensional images is not new, in fact, it has existed in various forms since the middle of the 19<sup>th</sup> century. Fast forward to current times; modern versions of 3D technology now allow the average consumer to experience a selection of films in 3D commercial cinema. The quality of this experience has created a demand for the same 3D capabilities in home theater. Manufacturers are rising to the occasion and providing incredible new 3D projectors, screens, players, and of course, the popularity of 3D cinema means we are beginning to have creative content in yet another dimension. The issue that crops up is that implementing 3D in the home is much more complex than the average consumer might imagine and even consider. This means that a home theater integrator wishing to expand their business must not only offer the 3D experience the consumer is demanding, but they must fully understand the technology and complex design philosophy that implementing 3D correctly can require in order to get a positive result for their clients.

## **How We See**

We actually see the world in three dimensions naturally. Our physiology evolved with two forward facing eyes, set into our heads. From the earliest days of mankind, this has provided a huge competitive advantage in seeking food, either through hunting or foraging. Most animals, while they also have two eyes, they will often be set into opposite sides of the head. This allows for the maximum field of vision, sometimes nearly 360 degrees. This is excellent for avoiding

being eaten by a predator, but not very useful for depth perception. Our forward facing eyes, termed *binocular vision*, allow us to have excellent depth perception and to see three dimensions well.

Binocular depth perception works because of how the eyes are arranged. Our eyes are set relatively closely together, but with an important gap of approximately 2.5 inches or 65mm in between them, and they are parallel to each other. They face forward, providing a nearly 200 degree field of view. This provides overlapping vision, the critical method by which our depth perception functions. Each eye is capable of perceiving a 120 degree field of vision, which overlaps with its partner. The gap between the eyes means that each one perceives a slightly different view of the world. Our brain takes this information, and interpolates the vision from each eye, into a single image. This process is known as *stereopsis*, where *parallax*, or the difference in the way an object appears to each eye from differing angles of view, is used by our brain to interpret a precise sense of depth.

Since human vision is intrinsically stereoscopic it makes sense that three dimensional images would appear more natural and immersive to use, even for entertainment purposes. This led to the development of early stereo photography in middle 19<sup>th</sup> century, and is driving modern 3D video technology.

### **The History of 3D Imaging**

The basic concepts of capturing images using silver and chalk appeared in 1724, and in 1826, Joseph Nicéphore Niépce took the first permanent photograph, using a camera built by the Chevalier brothers in Paris. A mere 12 years later in 1838, the founding principles of three dimensional imaging were discovered, by Sir Charles Wheatstone. What Wheatstone discovered was an optical illusion he termed a *stereogram*. A stereogram used a pair of normal 2 dimensional images, set side by side, and a device called a *stereoscope* to create the optical illusion of depth to a viewer, who observed the stereogram through the stereoscope. The first stereoscopes were fairly complex instruments constructed with mirrors and prisms, but the amazing popularity led Oliver Wendell Holmes Sr. in 1861 to develop inexpensive versions. This type of illusion was popular for decades after its introduction. The stereoscope seems very simple by today's standards, but it capitalized on the natural functions of our eyes to create an illusion of depth. Each eye was shown a slightly different view of the subject, which caused the viewer's brain to interpret that as a 3D image. This was advanced thinking, given how simple the understanding of human physiology was, at that time. The most famous example of this technology is the View-Master invented in 1939 and still in production today with over 1.5 billion discs sold to date!



Fig. 1: an example of a stereopticon, and a View-Master, two types of stereoscopes.

From the concept of the stereograph, it was not long before the next generation of 3D imaging emerged. In 1853, Wilhelm Rollmann, in Leipzig, Germany, introduced the first of what would come to be called “anaglyphic” 3D images. This relied on a different methodology than a stereoscope. Two cameras were set up, to imitate the perspective of the left and right eyes, much like a stereogram but the difference lies in the images themselves. They were captured using color filters. One camera was fitted with a red filter and the other with a blue, green, or cyan filter. Viewing anaglyphs through appropriately colored glasses, that match the filters used on the cameras, results in each eye seeing a slightly different picture. In a red-blue anaglyph the eye covered by the red filter sees the red parts of the image as "white", and the blue parts as "black" (with the brain providing adaption for color); the eye covered by the blue filter perceives the opposite effect. True white or true black areas are perceived the same by each eye. The brain blends together the image it receives from each eye, and interprets the differences as being the result of different distances. This creates a stereograph image without requiring the viewer to cross their eyes. Both of these 3D technologies were widely used, but anaglyphic 3D imaging remained dominant for decades longer. These developments led to the first “golden age” of 3D filmography in the 1950s.

### **3D Technology and Film**

The era of stereoscopic filmmaking began in the late 1890s, when William Friese-Greene, a British film pioneer filed the first patent for a 3D moviemaking process. In his patent, a viewer watched a projected film through a stereoscope, which would then converge two side by side projected images, using the same methodology used for still images. Unfortunately, this technique was simply too obtrusive for theatrical use. These early innovations lead to the first application of what we now recognize as “modern” style anaglyphic 3D in cinema. In June of 1915, Edwin Porter and William Waddell presented the first theatrical tests of anaglyphic (red-green) 3D projection at the Astor Theater in New York. The audience was presented with three reels of test material, including nature and rural scenes, actress test shots, dancers, and samples from future film releases. Despite being a successful test, no further developments came from this pair of pioneers, and no further 3D films were shown by them. However, this did provide the principle and proof that 3D in theatrical film could work, and in 1922, the first theatrical film in 3D, *The Power of Love* was shown to a paying audience at the Ambassador Hotel Theater in Los Angeles. Like the original stereoscope and later anaglyphic film tests, this

showing used a dual filmstrip projection system, and the audience was provided with anaglyphic 3D glasses, like the Porter and Waddell tests. Sadly, this film has been listed as lost, but this proved commercial use of 3D films was viable. Public interest began to grow, and many other filmmakers throughout the early 20's began releasing 3D films and developing customized camera and projection setups, using the same anaglyphic processes. One pair of inventors bucked the anaglyphic trend and pioneered a type of sequential 3D imaging that in hindsight seems almost prophetic, as it is the foundation for some of the "advanced" 3D we use in our homes today.

In December 1922, Laurens Hammond and William F. Cassidy unveiled their "Teleview" system. Teleview was the earliest alternate-frame sequencing form of film projection. Through the use of two interlocked projectors, alternating left/right frames were projected one after another in rapid succession. Synchronized film viewers attached to the arm-rests of the seats in the theater open and closed at the same time, and took advantage of the viewer's persistence of vision, thereby creating a true stereoscopic image. Persistence of vision is the property of the brain that allows video to work. This exists when the brain receives images from the eyes, and they "persist" a split second longer after they are seen. The brain interpolates these persistent images into full motion. The only theater known to have installed this system was the Selwyn Theater in New York, and only one show was ever produced for the system.

The continuing evolution in 3D revolved around reducing glare, improving the color performance beyond early anaglyphic efforts, and also eliminating the need for the mechanical shutters of Teleview. While attending Harvard University, Edwin H. Land conceived the idea of reducing glare by polarizing light. He took a leave of absence from Harvard to set up a lab and by 1929 had invented and patented a polarizing sheet. In 1932, he introduced *Polaroid J Sheet* as a commercial product. While his original intention was to create a filter for reducing glare from car headlights, Land did not underestimate the utility of his newly dubbed Polaroid filters in stereoscopic presentations.

In January 1936, Dr. Land gave the first demonstration of Polaroid filters in conjunction with 3D photography at the Waldorf-Astoria Hotel. Using Polaroid filters meant an entirely new form of projection. Two prints, each carrying either the right or left eye, had to be synced up in projection using an external motor. Furthermore, polarized light would not register on matte white screens commonly in use at that time, and only a silver screen or screen made of other reflective material would correctly reflect the separate images.

In the 1940s due to the interruption of World War II, many film companies put 3D on the back burner, but the introduction of anaglyphic 3D technology and the subsequent development of polarization films and polarized 3D set the stage for the first golden age of 3D cinema in the

1950's. Starting in 1952, and progressing to 1955, this time period brought forth a flourishing of 3D cinema, with big name directors, actors, and studios getting involved.

What film buffs consider the "golden era" of 3D began in 1952 with the release of the first color stereoscopic feature, *Bwana Devil*. As with practically all of the features made during this period, *Bwana Devil* was projected dual-strip, with Polaroid filters. During the 1950s, the familiar disposable anaglyph glasses made of cardboard were mainly used for comic books, and low cost film shorts, not mainstream cinema. Because the feature utilized two projectors, a capacity limit of film being loaded onto each projector (about 6,000 feet (1,800 m), or an hour's worth of film) meant that an intermission was necessary for every feature-length film. Quite often, intermission points were written into the script at a major plot point.

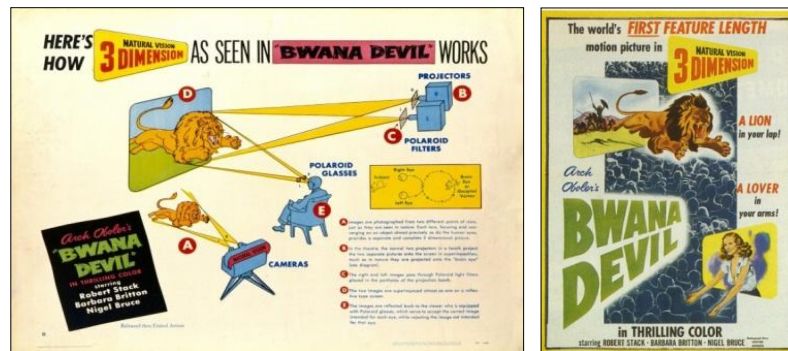


Fig. 2: A movie poster from *Bwana Devil*, and an advertisement showing how 3D for the film worked.

April 1953 saw two groundbreaking features in 3D: Columbia's *Man in the Dark* and Warner Bros. *House of Wax*, the first 3D feature with stereophonic sound. The success of these two films proved that major studios now had a method of getting moviegoers back into theaters and away from television sets, which were causing a steady decline in movie theater attendance. The Walt Disney Studios entered into 3D with its May 28, 1953 release of *Melody*, which accompanied the first 3D western, Columbia's *Fort Ti*. Universal released their first 3D feature on May 27, 1953, *It Came from Outer Space*, with stereophonic sound. Following that was Paramount's first feature, *Sangaree* with Fernando Lamas and Arlene Dahl. Columbia released several 3D westerns produced by Sam Katzman and directed by William Castle. Columbia also produced the only slapstick comedies conceived for 3D. The Three Stooges starred in *Spooks* and *Pardon My Backfire*. 20th Century Fox produced their only 3D feature, *Inferno*, starring Rhonda Fleming.

In August of 1953 we saw the first signs of a decline in the theatrical 3D craze. The factors causing this decline were:

- Two prints had to be projected simultaneously.
- The prints had to remain exactly alike after repair, or synchronization would be lost.
- It sometimes required two projectionists to keep sync working properly.
- When either print became out of sync, the picture became virtually unwatchable and accounted for headaches and eyestrain.
- The necessary silver projection screen was very directional and caused sideline seating to be unusable with both 3D and regular films, due to the angular darkening of these screens. Later films that opened in wider-seated venues often premiered flat for that reason.
- The few cartoons made in 3D had a "cardboard cutout" effect, where flat objects appeared on different planes.
- Success of new widescreen formats

Despite the decline, several important 3D films were released in late 1953, including MGM's musical *Kiss Me, Kate*, John Wayne featured in *Hondo*, Columbia's *Miss Sadie Thompson* with Rita Hayworth, and Paramount's *Money from Home* with Dean Martin and Jerry Lewis. Paramount also released the cartoon shorts *Boo Moon* with Casper, the Friendly Ghost and *Popeye, Ace of Space* and as a documentary they released a 3D Korean War film *Cease Fire* filmed on location in Korea in 1953. What we now refer to as the "golden era" was not to last even though Polaroid had created a well-designed "Tell-Tale Filter Kit" for the purpose of recognizing and adjusting out of sync and phase 3D. Exhibitors still felt uncomfortable with the challenges of 3D and turned their focus instead to processes such as Cinemascope and the birth of the widescreen experience. The last 3D feature film to be released during the "golden era" was *Revenge of the Creature*, on February 23, 1955.

Although there were a few 3D films during the early 1960s, the second "wave" of 3D cinema was set into motion by Arch Oboler, the same producer who started the craze of the 1950s. Using a new technology called *Space-Vision 3D*, stereoscopic films were printed with two images, one above the other, in a single academy ratio frame, on a single strip, and needed only one projector fitted with a special lens. This so-called "over and under" technique eliminated the need for dual projector set-ups, and produced widescreen, polarized 3D images that were darker and less vivid. Unlike earlier dual system, it could stay in perfect sync, unless improperly spliced when it needed repair. In 1970 director/inventor Allan Silliphant and optical designer Chris Condon, developed Stereovision a unique 35 mm single-strip format, which printed two images squeezed side-by-side and used an anamorphic lens to widen the pictures through Polaroid filters. Some 36 films worldwide were made with Stereovision over 25 years, using

either a widescreen (above-below), anamorphic (side by side) or 70 mm 3D formats. The artistic quality of the 1970s 3D films was lacking since many were either adult films, horror films, or a combination of both.

Between 1981 and 1983 there was a new 3D craze started by the “spaghetti western” *Comin' at Ya!*. Horror movies and reissues of 1950s 3D classics (such as Hitchcock's *Dial 'M' for Murder*) dominated the 3D releases that followed. The second sequel in the Friday the 13th series, *Friday the 13th Part III*, was released successfully in 3D during this time period. In the mid-1980s, IMAX began producing non-fiction films for its nascent 3D business, starting with "*We Are Born of Stars*" (Roman Kroitor, 1985). A key point was that this production, and all subsequent IMAX productions, emphasized mathematical correctness of the 3D rendition and thus largely eliminated the eye fatigue and pain that resulted from the approximate geometries of previous 3D incarnations. In addition, and in contrast to previous 35mm based 3D presentations, the very large field of view provided by IMAX allowed a much broader 3D "stage", arguably as important in 3D film as it is theatre. In 1986, Disney Theme Parks and Universal Studios began to use 3D films to impress audiences in special venues, with *Captain EO* starring Michael Jackson, being a very notable example. In the same year, the National Film Board of Canada's production *Transitions* (Colin Low), created for Expo 86 in Vancouver, was the first IMAX presentation using polarized glasses. "*Echos of the Sun*" (Roman Kroitor, 1990) was the first IMAX film to be presented using alternate-eye shutter glass technology, a development required because the existing dome screen precluded the use of polarized technology. From 1990 onward, numerous films were produced by all three parties to satisfy the demands of their high-profile special attractions and IMAX's expanding 3D network.



Fig.3: Captain EO poster and Kodak Magic Eye Theater

Shortly thereafter, high quality computer generated animation, competition from DVDs, digital projection, digital video capture, and the use of sophisticated IMAX 70mm film projectors, created an opportunity for yet another wave of 3D films. In 2003, *Ghosts of the Abyss* by James

Cameron was released as the first full-length IMAX 3D feature filmed for the first time with the latest HD video cameras built for Cameron to his specifications. In November 2004, the animated film *The Polar Express* was opened in 3,584 theaters in 2D, and as full-length 3D feature to only 66 IMAX locations. The return from the limited 3D release was about 25% of the film's total gross and the 3D version earned about 14 times as much per screen as the 2D version. This pattern continued and prompted an intensified interest in 3D and 3D animated films. In June 2005, The Grauman's Chinese Theatre in Hollywood became the first commercial movie theatre to be equipped with the Digital 3D format

The strong attendance and revenue numbers suggests that both filmmakers and exhibitors have regained interest in 3D filmmaking and in the process they are building excitement for a new visual experience. There is now an ample supply of 3D creation and exhibition equipment, and more films being shot in 3D formats and 2D conversions than ever before. This is due in no small part to the use of digital projection and digital post production equipment to replace classic film stock, mechanical projection, and the laborious post production and editing process. Today, shooting in 3D is less limited than before, and the results are more stable. Another incentive is that while 2-D ticket sales are in a state of decline, attendance and revenues from 3D ticket sales continue to grow. New technologies have been developed that allow for functional conversion from 2D to 3D, and digital post production processing has spawned a new wave of 2D conversion films. Big budget blockbuster films are being designed and filmed in 3D and since 2005; an average of 3 new films per month is being released in 3D. It is rapidly becoming the norm for new theatrical releases. 2010 has definitely become the year of 3D films in cinemas worldwide and from its rich history spanning over 100 years; it is finding its way into the modern living room and home theater as the next phase in the evolutionary process.

### **The Problem of Modern 3D Technologies**

Moving the 3D experience from the cinema to the home presents us with a new set of challenges. We are tasked with designing home theater solutions to meet the demands of increasingly 3D savvy customers and they are calling for the immersive 3D experiences like the ones in the movie theaters. There are several different schools of thought on 3D technologies in the home, and there are specific display and screen design criteria to address, before we consider the performance of the system acceptable. Many of the new technologies we have available to us, are based on concepts begun long ago in the 19<sup>th</sup> century! It is our job to "decode" these technologies, and learn the nuances of each, so that we can select the best products, and design the optimal home theater environment for our customers.

## **Anaglyphic**

Surprisingly, despite the state of the art technologies available in passive and active 3D systems, the concept of anaglyphic is still sometimes used. It has advanced considerably since those early days back in the 1800's, and modern anaglyphic systems can produce an agreeable 3D image. The improvements that have been made in the color processing as well as the glasses themselves aside; the concept of using a color filter to split up the left eye and right eye images remains the same fundamental concept as it has since its inception. The original red/blue or red/green glasses produced a perception of depth, but really were only capable of handling a black and white image with any quality. Later developments into color filters saw a change to a red/cyan system, that allowed for a perception of color, albeit a poor one. This evolved into the anachrome and mirachrome dark red/cyan systems that further improved color viewing, although it was still lacking in red reproduction.

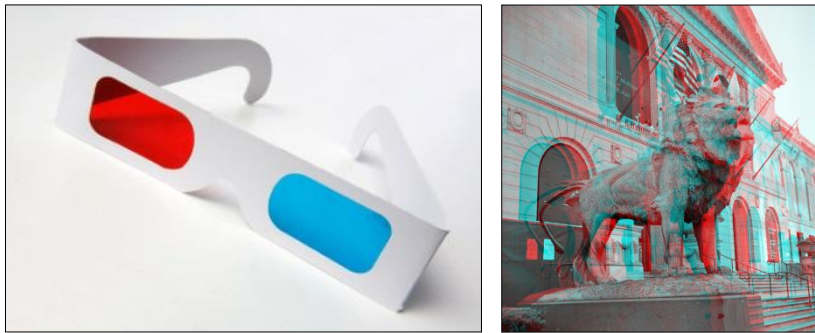
The most recent advances include a change from the traditional lens colors to pure magenta and green, as well as an inversion of which eye is used with which filter. This improved performance, with better reds, oranges, and an improved range of blues over red/cyan lenses. TriOviz 3D and ColorCode 3D are two newer types/brands of anaglyph technology that have emerged as the highest performance 3D of their type. Both rely on more complex optical color filtering to produce a nearly full natural color image and much improved depth perception.

TriOviz 3D, developed by the TriOviz company, is a patent pending system first demonstrated in 2007, but deployed in 2010. They use what are called "complex" color filters in magenta and green. This allowed for an almost full natural color image, including skin tones, and improved depth perception when viewed with the 3D glasses. This also brought about something that makes this form of technology appealing, the ability to watch the 3D image in 2D with only a slight doubling effect from the processing, allowing the movie to be watched without glasses.

ColorCode 3D relies on a completely different color scheme to produce its 3D image. ColorCode uses an amber and pure dark blue lens to create a nearly full color perception. Sometimes called yellow/blue or ochre/blue, this system launched in the early 2000s and produces much better color rendering than the norm for anaglyphic, but left the image very dark, due to the processing for a dark blue lens. Also, the left filter (yellow) was darkened to match the brightness perceived by the right eye, behind the dark blue lens. This equalized the image to both eyes, but required either a very dark room, or a very bright image.

Anaglyphic 3D is not completely obsolete. It has the advantage of having cheap replaceable glasses, and can be viewed through a standard video playback system, without replacing the

display, screen, or any source devices. However, it does require that the content be created for it, and it will need to be matched with the specific glasses that it was designed to utilize. In 2008, Disney released its first 3D Blu-Ray, *Hannah Montana* utilizing anaglyphic 3D in red/cyan, and it was aired in 3D utilizing the same paper glasses on the Disney Channel. This brings a level of 3D flexibility that keeps it in use on websites, DVDs, comics, and scientific graphics, even to this day. However, there are few major films still produced that use this system, and it should not be a major design consideration. Any system capable of showing 2D, and performing well, will be capable of handling an anaglyphic 3D display, provided the viewers have the correct glasses.



*Fig. 4: Anaglyphic red/blue glasses and an anaglyphic image showing red/blue separation.*

### **Active Shutter**

The next generation of 3D technology beyond anaglyphic was the active shutter system based on the principles from the 1922 Televue system. Active shutter 3D relies on persistence of vision in our brains. It is that split second “processing” time where the mind blends together rapidly shown still images into a smooth moving picture. This is accomplished by using a physical shutter in front of the eyes, alternating between the images to be seen by each eye and synchronized to the display of the appropriate left eye/right eye image on the screen. To perform this task, the 1922 system used mechanical shutters, not unlike the ones in a camera. Today we have more modern, faster, lighter, and more durable options available to us, in the form of liquid crystal shutter glasses.

Liquid crystal or LC shutter glasses use a much simplified version of the same liquid crystal technology utilized in an LCD display. Each eye glass will contain liquid crystal material that becomes opaque when a voltage is applied, but in the normal state is transparent. Because LCD technology is faster than we the human eye can see, the switching on and off of the LC shutter can take place invisibly to the viewer, while appearing transparent, but allowing only the appropriate eye to see the correct image. The glasses must be synchronized and controlled by the display, either through infrared or radio frequency, or something like DLP-Link or Bluetooth. The transmitter will send a timing signal to synchronize the darkening of the appropriate eye in

time with the refresh rate of the display device. The display, using a technique called alternate frame sequencing, will show the alternating images for each eye.



*Fig. 5: Xpand shutter glasses and 3D laptop*

This technology is one of the most common in home 3D systems and is used with both projection and flat panel displays. It is what most home consumers will encounter when they look at 3D in the big box retailers. Active shutter systems require only one imaging device, making the cost for the display lower, and they can use a standard screen, with flexibility in gain and viewer positioning. This active shutter system allows for 2D and 3D content to be shown on the same screen. Active shutter systems also eliminate the “ghosting” or crosstalk effect found in other forms of 3D imaging, such as polarization or anaglyphic. This type of 3D technology does suffer from some significant drawbacks, since there is no universally perfect system when dealing with 3D. The first major issue, common to all 3D systems, is one of brightness. The liquid crystal material in the shutter glasses act as a polarizer to the light passing through them. This causes a light loss of up to 80% of the original brightness on screen. This is not due to the display, or the screen, but only the effect of the liquid crystal material in the lenses. Liquid crystal of all types, either in shutters like these, or displays, will polarize light. That is the fundamental principal that allows the transparent LC material to rotate its molecular structure when exposed to electricity and to block light from passing through it. Also, because each eye is only seeing the screen half of the time, the light is further reduced. This means that to achieve an acceptable image to the viewer’s eye, you will require much more projector brightness than you would under normal circumstances.

Additional problems may arise by the act of the shutters operating in a direct manner relative to each eye. The result is a visible flickering that can be present to the viewer. Much like the DLP color wheel producing color breakup artifacts around the edges of moving objects some limited number of viewers may see a perceptible flicker from the LC shutters operating. Also, poor quality glasses, or low refresh rates on the display device, can introduce visible flickering. Most display manufacturers push 120 Hz and above, with 240 Hz as ideal, for a vertical refresh rate. This allows each eye to perceive a full 60-120 Hz of refresh, bringing smooth video.

Another consideration is frame rate. Since each eye is covered for a single frame of video, to produce an acceptable 30 frames per second, per eye, the display device must be capable of showing 60 frames per second, 30 for each eye. If synchronization to the glasses is lost, the shutters may not line up, causing visible “stuttering” of the image. A user may go out of range of a wireless transmitter, or have an obstruction temporarily block the beam of an infrared transmitter, thus inducing the same potential “stuttering”, or it may stop the 3D effect completely.

One final consideration for the prospective system designer is one of cost. Active shutter glasses cost much more than passive 3D glasses because of the electronics and liquid crystal material that is used. Where most anaglyph or polarized 3D glasses can be purchased for around \$1USD for basic models, active glasses will sell for over \$100 and upwards, depending on the type of wireless used. Active shutter glasses are also proprietary to a given manufacturer, being built with a specific wireless communication protocol and a particular language used to synchronize with the display. This means that these glasses will be paired with a particular brand of display, oftentimes even a specific model of projector, and will not work with other systems.

### **Passive Polarized**

Building on the technology introduced by Polaroid in 1936, the other mainstream school of 3D technology is passive polarization. Passive polarized systems, either linear, or circular, are the mainstays of commercial 3D cinema, and are starting to emerge in consumer grade projection devices, such as Runco’s 3Dimension projector, with their proprietary CSV linear polarization. This type of technology works well in commercial cinema, but can pose some particular design challenges for the home theater user. Despite that, it offers several clear advantages, and we will see many more home theater polarized systems as projectors and the all-important screens improve.

### **Linear**

Linear polarization systems have a long history, starting with Polaroid’s original polarized 3D system. They rely on the polarization capability of light, and that it can be polarized into a single direction, and that light can be controlled accurately to block or transmit it through a filter. The original concept was to use two projectors simultaneously, with each device projecting the content to be viewed by a single eye, onto the same screen. These images were projected through an orthogonal polarization filter, with each eye having a different plane of polarization where one would be horizontal, and the other would be vertical. This meant that when equipped with a matching set of linear polarizing glasses, a viewer’s eye would only see the content that matched the plane of polarization of the lens in front of that eye. This provides a

positive experience for the user, since the glasses are much lighter, more comfortable, and the glasses are now universal so any glasses that have an appropriate set of filters in them will work with the system, regardless of manufacturer. Also, because no transmitter or “pairing” of the glasses to the projector is required, many more people can use it simultaneously, and the system can never lose sync with the glasses, resulting in flicker and visible anomalies. These passive glasses are also, as previously stated, inexpensive in comparison to active shutter glasses.

Since a linear polarization system has two planes of polarization, it will require two distinct imaging devices, each equipped with a polarizing filter appropriate for a single eye viewing. These projectors must be carefully converged to be perfectly overlapping. This has been a problem with adoption in the home, as it adds significant cost. However, we are seeing integrated dual display products emerge, such as Runco’s D73d 3D projector, that hybridize two projectors into a single factory converged unit, eliminating some of the cost, and lot of the installation challenge in the convergence of displays. Advanced projector systems will have a mode allowing the projectors to switch from 3D to 2D, in which case the converged projectors will provide increased brightness on screen.



*Fig. 8: Runco CSV glasses and D-73d 3D projector.*

As noted before, there are no universal perfect solutions when it comes to 3D. Linear polarization systems also have their issues when it comes to design and function. The main concern with any polarized system is one of brightness. For example when we deal with an active shutter system, the act of polarizing light can reduce its brightness by up to 80%. This means that to effectively use the polarized projector, much more brightness is needed. Also, with a 3D system that relies on light polarized at the projector, and reflected to the viewer, the screen becomes incredibly important. The screen, reflecting the light back to the viewers from the projector, must be able to preserve the polarization of light being shone onto it. This is normally accomplished by using a silver “polarization preserving” screen, that will do just what its name implies.

Due to the nature of its polarization, linear polarization suffers from a unique problem, which can prove objectionable to some users. Because the polarizers are a fixed direction, when the viewer's head is perfectly level, the image is excellent. But if the viewer tilts their head from side to side, some of the polarization is lost, allowing the image from the opposite eye to "bleed through" and create ghost images. This will quickly teach a viewer to hold their head quite still when watching a linear system and depending upon the severity, may prove uncomfortable.

### **Circular**

Another type of polarized 3D is circular polarization, which works nearly like its linear brother. Companies have attempted to address the problems inherent in the original linear system by changing how the polarization is accomplished. Instead of an orthogonal polarization filter system, a circular polarizer is applied to the projector's lens, which will allow the light to be polarized with either a clockwise or counterclockwise rotation. The most famous example of this technology is the RealD system in use in many commercial cinemas today. The RealD system utilizes what they term a ZScreen, or a variable polarizer which can switch the direction of its operation. By having a polarization system capable of switching, and coupled with a display technology like DLP, that makes active shutter systems possible, the elimination of one of the projectors used in linear polarization systems can be achieved. The digital projector technology can display a refresh and frame rate to allow sequential imaging to be used. The display rapidly switches between frames for left and right eyes, coupled to the switching of the polarization conversion system. This allows for the benefits of a passive glasses system, while eliminating the second projector. The circular nature of the polarization also eliminates the head tilt "ghosting" apparent in a linear passive system. The downsides are also nearly identical to that of a linear passive system, with the brightness needing to be high enough to overcome the light lost in polarization, and the screen must be able to preserve that polarization. Also, one final factor needs to be considered when dealing with this type of passive system and that is cost. Circular polarizers do eliminate the need for a second projector, but this cost savings is offset by the more advanced optics required to switch the polarization. Movie houses like this type of technology because they can retrofit existing 35MM film projectors to use an over/under dual image single frame, and a special lens to converge, with the polarizer, but the cost at the consumer level for a system like the RealD circular polarizer can be prohibitive.



Fig. 6: RealD glasses and ZScreen polarizer system

## Infitec

The final example of 3D technology in use today is the new kid on the block. Infitec technology, short for interference filter technology, is produced by Infitec GmbH, a German company specializing in 3D technology. It has been used in partnership with Dolby Labs as Dolby 3D.

Infitec relies not on polarization, but on color filtration to create the visible image. Special interference filters, also known as dichromatic color filters, are placed in the glasses, and at the projector's lens. These filters divide the complete color spectrum into 6 color "bands", two regions for each of the primary colors, R1-R2, G1-G2, and B1-B2. The R1, G1, and B1 bands are used for a single eye image, with the other three being used for the opposing eye. The filters then block out all light frequencies but those narrow color bands, allowing each eye to see only the portion of the image they are supposed to. This also relies on a single imaging device, like the circular polarizer system, using sequential imaging and a rotating color wheel to handle the image.

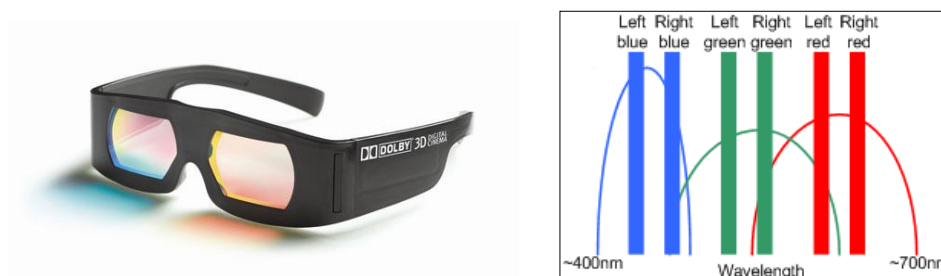


Fig. 7: Dolby 3D Infitec glasses and wavelength chart.

The glasses from an Infitec system provide the same benefits as a passive polarized system, because they are also passive with no batteries, no synchronization, and lower cost. In addition, they do not suffer from the head tilt issues present in linear passive systems, and they provide a

better quality image than with polarized glasses. One downside is that the glasses are much more expensive than a polarized passive pair, at \$40-50 a pair due to the more expensive hard plastic optics needed for the dichromatic filters. Obviously they are not viewed as disposable, like other passive glasses. This also makes the glasses more fragile and prone to damage than a passive polarized system, but not as fragile as active shutter glasses.

Infitec projection systems require only one imaging device, but like a circular polarizer, the cost savings is offset with the need for more expensive optics, and precise color filters are not cheap. This can be somewhat offset by the two biggest benefits of the Infitec system; because it is not polarized, it does not lose as much light, allowing for brighter images, and that also since it is not polarized, you can use a standard white screen.

### **Environment and Design Concerns**

Since we now understand the benefits and drawbacks of each of the 4 major types of 3D projection technology, we need to turn our attention to the design concerns that should form a checklist when selecting the appropriate 3D technology to recommend in a particular application. The selection of 3D technology will drive the selection of a projector, and the selection of the appropriate screen. It is important to balance factors like cost, ambient light, projector brightness, system purpose, viewer comfort, and screen type, to arrive at an optimal design for a 3D home theater. Our goal is to formulate a process by which the designer of a system can analyze the room, the goals of the owner, and the budget available, and arrive at a quality design.

- Room design and brightness
  - The first thing to evaluate is the room itself. Is it going to be a dedicated home theater space, or does the homeowner want to configure a 3D capable system in a shared space? Since we are focusing on projection, the likelihood is that the owner will have a dedicated space, but be prepared for any situation. This becomes important when establishing proper overall system brightness. In a dedicated home theater room, the ambient light can generally be controlled. Make the room as dark as possible, to compensate for the light lost to the 3D projection system due to polarization loss or screen blanking. If total darkness is not possible, you will need to examine how much ambient light is present at the worst possible viewing time or in other words, the brightest it will be in that room when viewing 3D and determine if you can add a bright enough projector to deliver an acceptable image. A rule of thumb in design is to approximate 20% of the brightness that is achieved in 2D for the 3D mode. This first step in design will help drive the selection of the 3D technology and screen.

- Viewing angle
  - The same rules for design in a standard theater tend to apply to a 3D space. Most 3D screens tend towards higher gain, and as such, this lends itself to a longer, narrow space, rather than a wide, shallow one. Also, consider the limitations of the 3D technology, particularly active shutter. Active shutter glasses are dependent on the synchronization signal from the display, and this transmitter will have a limited range, or in the case of infrared, be limited to certain angles. Ensure that you have acceptable reception for all viewers. Also, if you are facing a situation where having multiple displays are in the same space, they may very well interfere with each other.
  
- Screen selection
  - Screen selection is as important as the 3D projection technology, and can make or break a 3D home theater. When picking out a screen, the first issue is that of polarization preservation. A polarization based passive system will require a silver screen that can reflect the light back to the viewer polarized in the same manner it was projected from the lens. The reason this causes a problem lies in how such screens are able to handle 2D images. Silver screens are often high gain, to compensate for the brightness loss in 3D and designed specifically for the polarization in 3D. This results in a great 3D screen, with poor 2D performance. A high quality 2D matte white or gray screen will provide excellent 2D capabilities, but is unable to completely handle the polarization necessary for some 3D technologies, and will give poor 3D performance. In some cases, it may be acceptable to use two screens, with one being motorized to retract when not in use. This adds additional cost, not only for the screen and its installation, but adding a control system to make this agreeable to the user. A commercial theater may be able to allow for 3D only systems, but this is not really practical in the home, since regular movies and television will likely be watched, as well. 2D only is not really possible, since the customer wants a 3D solution. This leaves one of three options;
    - 1. Go ahead and dedicate the system to 3D, and allow for poor 2D performance,
    - 2. Use a potentially very costly projection system like Infitec, or utilize active shutter glasses based systems that do not require a silver screen.
    - 3. Use one of the newest screen technologies emerging onto the marketplace that is a hybrid of 2D and 3D.

Obviously solution number 3 is the most attractive. The prime example of such a hybrid screen is Stewart Filmscreens 5D Screen fabric (2D+3D=5D). This screen

provides good performance in both types of projection, providing a slightly lower gain, but improving its viewing cone and uniformity. It also addresses the color shift problems brought about by the high gain silver screens in 2D applications. This seems to be the best kind of solution when dealing with a passive polarized (either linear or circular) system.

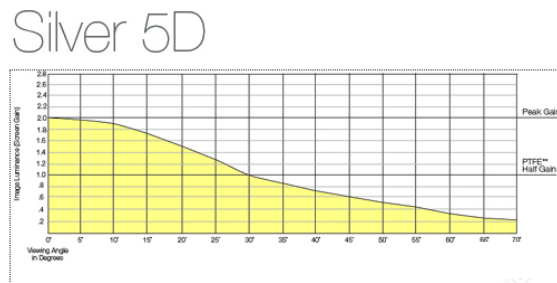


Fig. 8 Stewart 5D screen material gain chart showing 2D/3D hybrid capabilities.

- Screen Sizing
  - The goal of 3D video is to immerse the viewer into the story on the screen. The screen size in a 3D system is not unlike watching a production on a theater stage. The 3D effect, when done correctly, appears to extend the size of the room by the depth of the 3D effect in the image, creating the illusion of a much larger space. This is amplified even further when a curved screen is used, which will add more implied depth. As the physical size of the screen increases, the size of that virtual space increases in size exponentially. The virtual space is measured in a volume of space, not just in square inches of screen surface. This means that the screen must be large enough to provide enough virtual volume to maintain the immersive 3D illusion. Smaller screens in 3D can look like a diorama, with the screen edge compromising the 3D illusion of depth. The screen should fill enough of the viewer's field of vision to provide a convincing illusion.
- Input compatibility
  - Due to the wide range of 3D "ready" devices, at varying levels of capability, try to ensure that the source devices are fully HDMI 1.4a compliant, and that the selected display device has a proper 3D processor, allowing for the widest range of content compatibility.

- Comfort
  - It may go without saying, but try to ensure the viewer is going to be comfortable with the use of the system. Heavy and bulky active shutter glasses may be fine for a short demo, or for watching a half hour television program, but a 2+ hour film may tax the comfort levels of anyone. Trying out the fit and feel of several different manufacturers' 3D glasses can give you a chance to experience the comfort level firsthand. Also, consider the type of technology, and the comfort possibilities. Will the customer be one of the small percentages that can suffer from eyestrain using 3D from any technology? A small percentage of the population suffers from defects in their 3D vision, and will not be able to enjoy 3D video regardless of how it is built. Will they be able to comfortably watch an active shutter system? Will the stiff head position requirements of a linear polarizer passive system be a problem?

By taking this journey of understanding into the third dimension we have illustrated the historical precedence and evolution of 3D. By looking at the history we not only gain respect for what has gone on before, we see key elements that are still the foundations that we work from today. We work with binocular vision from which our perception of 3D comes. Concepts like persistence of vision, parallax, and polarization have been revealed and we see how the silver screen fits into the picture of 3D. We now clearly understand the lessons learned from the pioneers of the 3D industry dating back to the 1800s and see how our modern film makers are able to capitalize on the successes and failures of all those that have gone before. Think of it as over 100 years of experimentation leading to where we are today.

From the most recent part of the journey we have been exposed to the different types of 3D and the ways to watch this visual expansion of what has for the most part been a 2D film world. We also see that 2D is no longer enough and that 3D is not a "flash in the pan". It is here to stay and is rapidly migrating from the big screen at the local cinema to the big screens at home. Issues certainly remain and there are obstacles to overcome but progress is no longer coming in baby steps. We are seeing exciting developments in projectors, screens, and 3D glasses all aimed at replicating the "perfect" 3D experience. One thing we know for sure is that the closer we get to "perfection" and with each new development, the viewing public is anxiously awaiting and ready to embrace what we have to offer.