# 3-D Displays in the Home

*There are many predictions that the next stage in the commercial evolution of consumer display technology is the widespread availability of stereoscopic 3-D content for viewing on home 3-D displays. This article describes the types of 3-D displays that are currently available, as well as what technologies are on the horizon.*

by Andrew Woods

IN PARALLEL with the widespread deployment of digital 3-D cinema systems and an explosion in the release of 3-D movies into those theaters, there has also been a concerted effort from several consumer-electronics manufacturers to release 3-D TVs and 3-D displays into the consumer marketplace. This article looks at the technologies behind these high-quality 3-D displays that have been released into the consumer marketplace and also answers the often-repeated question: can my existing home TV be used for high-quality 3-D viewing (*e.g.*, by bringing home the 3-D glasses from the movie theater)? While the focus will be mainly on the home-display marketplace for HDTVs or computer monitors, there are a great many more 3-D display products available if the professional-display marketplace is also taken into consideration.

When cathode-ray-tube (CRT) monitors became less commonplace in retail outlets, there was great concern in the stereoscopic-imaging community about what displays could be used for stereoscopic purposes in the future. Up to that point, CRTs had been the mainstay of stereoscopic display (using active shutter glasses), and the alternative displays such as plasma-display panels (PDPs) or liquid-crystal displays (LCDs) were not directly stereoscopic 3-D compatible. Fortunately, several display manufacturers rose to the challenge. Explanations of how those systems work follow later in this article.

In April of 2007, Samsung became the first to release a stereoscopic 3-D-capable large-screen high-definition television (HDTV) into the home marketplace. The displays used a rear-projection digital-light-processing (DLP) engine designed by Texas Instruments.[1] Several things were remarkable about this product: the very competitive pricing (much less than an equivalent 2-D LCD or PDP); the 3-D capability was included at no extra cost (apart from the 3-D glasses, which had to be purchased separately); the very high quality of the stereoscopic image; the high-definition resolution; and, further, the use in some models of an innovative LED light engine that offered richer colors, longer lamp life, and removal of the rainbow effect. Samsung released a selection of models ranging in size from 46 to 72 in. in 2007 and 2008. Mitsubishi also released a selection of these displays in 2007, 2008, and 2009. Over 2 million of these displays are reported to have been sold into homes in North America to date – the only market in which these particular displays have been directly marketed. It is an open question as to how many of these displays have been used for 3-D purposes – possibly less than 1% – but there are still some very happy 3-D users out there!

These displays essentially house a single-chip DLP projector that projects onto the rear of a special screen mounted in the front of the display. A color-sequential technique is used to produce full-color images – as with all single-chip DLP solutions. The stereoscopic 3-D method used by these displays is the time-sequential technique, which involves showing left and right images alternately (in this case at 120 Hz) that are viewed using liquid-crystal-shutter (LCS) 3-D glasses that blank the left and right eyes alternately in synchronization with the left and right images shown sequentially on the display. The fast switching time of a DLP (~2 µsec) makes it particularly well-suited to the time-sequential 3-D method. The 3-D input format accepted by these displays, commonly known as the checkerboard format (see Fig. 1), involves multiplexing the left and right images into a single frame in a checkerboard-like layout. This innovatively allows the two left and right image streams to enter the display within a single regular bandwidth video input (albeit at half-resolution per view).

These rear-projection DLP TVs use a half-resolution digital micromirror device (DMD) to achieve a full-resolution image by way of a process called "wobulation."[2] As shown in Figs. 1(b) and 1(c), in 2-D display mode each frame is broken down into two sub-frames – half of the pixels are displayed in the first sub-

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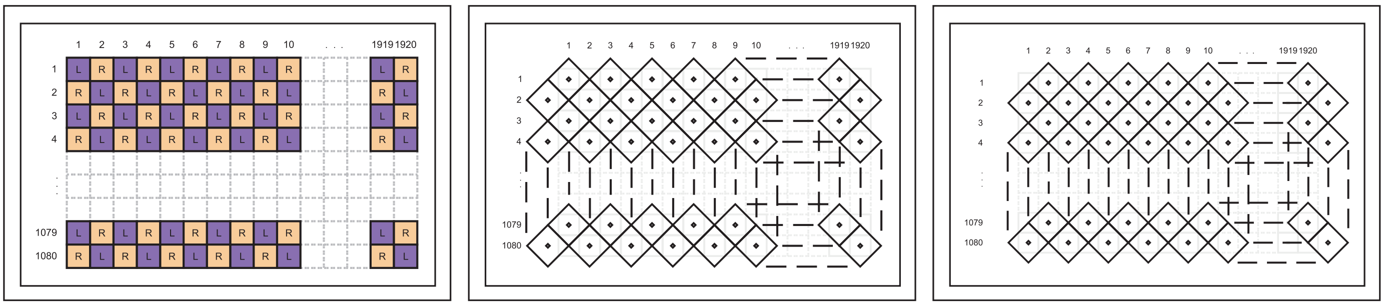

(a) Checkerboard 3-D input format

(b) Wobulated 3-D DLP display format – sub-frame 1; 3-D left image

(c) Wobulated 3-D DLP display format – sub-frame 2; 3-D right image

***Fig. 1:** An illustration of the 3-D input and 3-D display formats of the DLP 3-D HDTVs includes (a) the checkerboard 3-D input format and (b) and (c) the half-resolution DMD with diamond-shaped mirrors that oscillate between two optical positions at 120 Hz to display the full resolution.*

frame and the remaining pixels in the second sub-frame. The mirrors of the half-resolution DMD used in these DLP TVs are oriented in a diamond pattern (as opposed to square pixels in a regular DMD), and the centers of the mirrors match the checkerboard pattern shown in Fig. 1(a). The image of the DMD is optically shifted (wobulated) between the two sub-frames in order to display the full-resolution image. In 3-D mode, the two sub-frames are used for the left and right images, respectively. The pixel arrangement of each sub-frame directly corresponds to the checkerboard pattern used for 3-D input, so, in effect, the display internally converts the checkerboard 3-D input to time-sequential 3-D for display, allowing the viewer to wear LCS 3-D glasses to view the 3-D image.

Also in 2007, another class of 3-D displays started to become more widely available and at price points that were affordable to some home users. The micro-polarizer (μPol) technique was invented by Sadeg Faris in the early 1990s[3] and involves the attachment of a special optical filter to the face of an LCD (Fig. 2), which results in alternate rows of pixels of the display being polarized in two different polarization states – usually left-handed circular and right-handed circular. When the display is viewed using the appropriate passively polarized 3-D glasses, one eye sees all the odd-numbered rows and the other eye sees all the even-numbered rows. When the left and right images are spatially multiplexed onto the odd and even rows respectively, the observer can see a high-quality stereoscopic 3-D image. These types of 3-D displays are now commonly available around the world from manufacturers including Zalman, Hyundai, Pavonine (under the brands Dimen and Miracube), and JVC in sizes ranging from 22 up to 46 in. The smaller monitors are mainly aimed at the stereoscopic 3-D gaming market, whereas the larger sets are intended for 3-D video or movie viewing. In 3-D mode, these displays have half the 2-D resolution in the vertical axis, and there is also some vertical viewing-angle sensitivity. Some products use a μPol variant called Xpol that includes a black mask between rows of pixels to increase the vertical range of the viewing zone and reduce crosstalk. The price premium for the 3-D capability on these sets starts from about 200% on the smaller models and higher for the larger models, so market penetration has not been high.

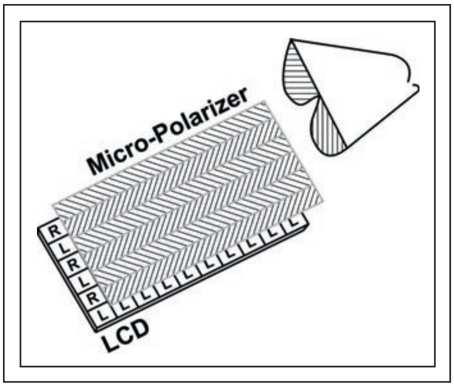


***Fig. 2:** Shown is an optical layout of a μPol 3-D LCD. A micro-polarizer layer over the front of the LCD polarizes alternate rows of pixels into two different polarization states. (Illustration based on Faris.[3])*

In 2008, Samsung achieved another world's first with the consumer release of two stereoscopic 3-D-capable plasma HDTVs (42 and 50 in.) These displays use the time-sequential 3-D display method and the stereoscopic 3-D images are viewed through LCS 3-D glasses – operating at 120 Hz. Unlike the 3-D DLP HDTVs, which were only released in North America, the 3-D plasma HDTVs were released in many international markets. Recently, Panasonic has been demonstrating time-sequential stereoscopic 3-D-capable plasma displays at various trade shows, and many commentators anticipate they will release a product based on this technology in the near future.

Another 3-D LCD product that has been gaining popularity, particularly in the 3-D gaming market over the last couple of years, uses an innovative dual-panel LCD technique – also known as a variable-polarization-angle display – and is viewed using passive polarized 3-D glasses.[4] In a conventional LCD, each subpixel in the LCD panel is used as a light-valve controlling the amount of light that travels from the backlight to the observer. But in these 3-D LCDs, the optical function is very different – the optical layout is illustrated in Fig. 3. The first (back) panel (Mod LCD) operates in a somewhat conventional light-valve approach to modulate the brightness of the light at each pixel, except that the image sent to this first panel is an amalgam of the left and right images. Essentially,

$$\sqrt{L^2 + R^2}$$

[see Figs. 4(a)–4(c)]. The second (front) panel (Ang LCD) acts to control the output polariza-

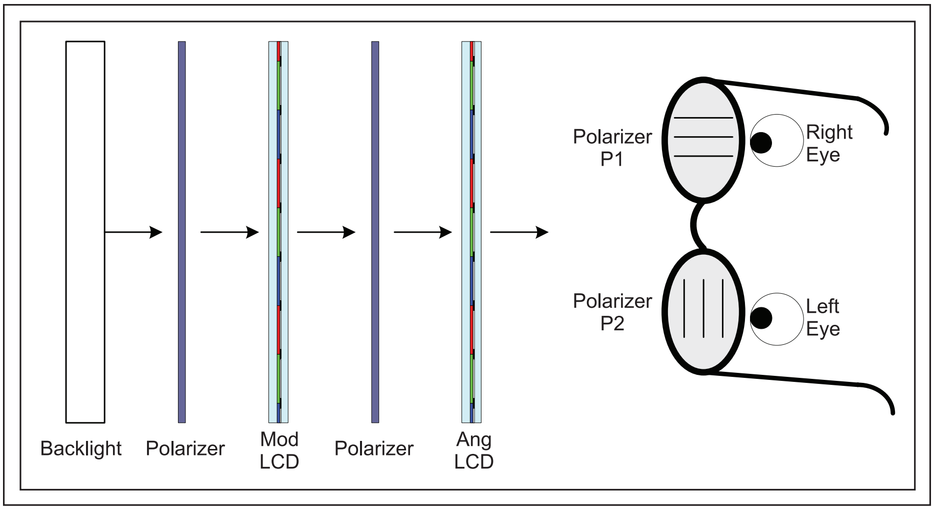


***Fig. 3:*** *A basic optical layout of a variable-polarization-angle display is depicted. The modulo LCD controls pixel brightness and the angulo LCD controls the polarization angle of each pixel. (Illustration based on Gaudreau.[4])*

tion angle of each subpixel (using the fundamental function of a liquid-crystal cell as a polarization rotator) and by virtue of this, sending the light from each subpixel to one eye, the other eye, or a mixture of both. The drive signal to the second layer is calculated for each pixel and is approximately *arctan*(*L*/*R*).[5] As can be seen in Fig. 4(d), if the image on this second panel was viewed individually, it would be a rather strange experience, but when the display is viewed using the appropriate passive polarized 3-D glasses, the resultant stereoscopic 3-D image can be remarkably good. In 3-D mode, these displays are full resolution (no resolution is sacrificed), but some models do suffer from relatively high amounts of crosstalk (ghosting). Consumer displays using this technique are available from iZ3D, and displays intended for professional applications are available from MacNaughton, Inc., and Polaris Sensor Technologies.

The most recent consumer 3-D display to hit the market was masterminded by NVIDIA and released as 22-in. 3-D LCDs from Samsung and ViewSonic. These displays use the time-sequential 3-D-display technique and have been specially engineered to be viewed in 3-D by using custom LCS glasses – operating at 120 Hz. The developers had to make some fairly smart changes to the LCD design to allow them to work with LCS 3-D glasses – most LCDs cannot. Again, these displays have been mainly aimed at the 3-D gaming market and they also retain the full resolution of the LCD panel in 3-D mode.

There is also a selection of 3-D displays aimed at the professional and semi-professional markets, available from suppliers including Planar, Christie, DepthQ, projectiondesign, and others. Large-screen autostereoscopic displays (3-D displays not requiring glasses) are also available in the professional marketplace, but they are believed to be a long way off from being a home consumer-deployed product (especially with Philips having abandoned this market in March 2009[6]). Mobile devices with autostereoscopic displays have been released in Asia by Sharp, Samsung, and Hitachi – but not as yet in the U.S. This article does not even touch on 3-D projection, which is starting to get very exciting with consumer/prosumer product offerings and announcements from ViewSonic, Mitsubishi, Infocus/DepthQ, BenQ, Sharp, and others. (A full summary of all the 3-D displays mentioned above is available from: www.3dmovielist.com/3dhdtvs.html.)

It should be noted that there is a considerable variation in image quality and resolution between these various 3-D displays. For some of the displays, the 3-D resolution is half that of the 2-D resolution. Other image-quality aspects to consider include the amount of crosstalk or ghosting present in the display, display brightness in 3-D mode, as well as regular 2-D measures of image quality.

### Can Existing Home TVs Be Used for 3-D Purposes?

A parallel phenomenon with the increased penetration of 3-D displays, and the general consumers' recognition of 3-D TV in the home, is the regular question as to whether a consumer's existing home display(s) can be used for 3-D purposes. For the time being, the short answer is that unless the display is advertised as being "3D-Ready" or "3-D compatible" (see www.3dmovielist.com/

(a) Right stereoscopic image (b) Left stereoscopic image (c) Modulo (first panel) (d) Angulo (second panel)

***Fig. 4:*** *A left/right stereoscopic image pair [(a) and (b)] is converted to modulo/angulo [(c) and (d)] for display on a variable polarization angle display. (Drive images from Gaudreau.[4])*

3dhdtvs.html) it unfortunately will not be able to be used for high-quality flicker-free full-color stereoscopic 3-D viewing (except in the case of older CRT monitors). Consumers may be tempted to take home the 3-D glasses from the various high-quality 3-D movie screenings, but unfortunately they simply will not work on their conventional home TV. Ignoring the displays that are advertised as being stereoscopic 3-D capable, here is why conventional displays cannot be used for high-quality stereoscopic 3-D viewing.

First, consider the three types of 3-D glasses being used in the theaters – passive polarized glasses, active LCS glasses, and Infitec (Dolby 3-D) glasses.

Polarized 3-D glasses will not work with conventional displays because they output light either in a single polarization direction (*e.g.*, LCDs) or they are unpolarized (*e.g.*, PDPs). An optical filter would need to be added to these displays to provide two polarization states (for the left and right views) – but currently this is not a customer-deployable solution.

LCS 3-D glasses do not work with conventional LCDs for a range of reasons,[7] but the most significant reason is the image-update method. Unlike CRTs, LCDs are a hold-type display, meaning that each pixel of the display outputs light over the entire frame period – *i.e.*, there is no blanking period. But similiar to a CRT, the image on an LCD is updated row by row from the top of the display to the bottom. The time taken to address the entire display is almost one frame period. What this means is that there is no one time, or period of time, when the display shows one image exclusively across the entire display; *i.e.*, there is no one time when the shutters in a pair of LCS 3-D glasses could be opened so that a left (or right) image would be seen across the entire screen. Figure 5 shows the image-update method of conventional LCDs, which illustrates the problem. As mentioned above, ViewSonic and Samsung have implemented an as-yet-undisclosed modification in their 3-D LCDs to overcome this problem.

Unfortunately, conventional plasma displays also cannot be used with LCS 3-D glasses to produce a high-quality flicker-free 3-D image.[8] Unlike CRTs or conventional LCDs in which updated pixels are presented sequentially over the course of the frame (see Fig. 5), plasma displays have the nice feature that all of the updated pixels in a frame are illuminated simultaneously. However, the long phosphor persistence of conventional plasma displays means that crosstalk (ghosting) will be high. Additionally, conventional plasma displays can only be driven with a 60-Hz video signal, meaning that even if the crosstalk was ignored, the image seen through the LCS 3-D glasses would flicker excessively. Samsung's 3D-ready plasma displays make use of the checkerboard 3-D input method to deliver the 3-D video signal and presumably use custom phosphors to reduce the amount of crosstalk due to phosphor persistence.

Even displays that are advertised as being 120 Hz do not solve the problem – 120-Hz (and 240-Hz) technologies are being implemented with a range of LCDs and plasma displays to reduce the problem of image smear in scenes containing fast image motion. Many people recognize that "120 Hz" is often associated with stereoscopic 3-D viewing, but unfortunately the inclusion of 120-Hz refresh rates does not solve all the problems for successfully using time-sequential 3-D on these displays. The most obvious problem is that there is no way of driving them with a true 120-Hz video signal, containing 120 distinct frames per second. Usually, the display accepts only a conventional 60-Hz video signal and the display internally interpolates extra frames. The inability to send 120 unique frames per second to the display would mean that it could not be used for 120-Hz 3-D purposes. So, unless the display is labeled as "3-D-ready" or "3-D compatible," any mention of 120 Hz currently will not be an advantage to time-sequential 3-D compatibility.[9]

The Infitec system employed in Dolby 3-D cinemas uses special interference filters to divide the visible color spectrum into six narrow bands called R1, R2, G1, G2, B1, and B2 for the purposes of this description.[10] The R1, G1, and B1 bands are used for one eye image and R2, G2, and B2 for the other eye. The human eye is largely insensitive to such fine spectral differences, so this technique is able to generate full-color 3-D images with minimal color differences between the two eyes. Unfortunately, conventional displays lack the ability to modulate light wavelengths at this fine scale, so Infitec/Dolby 3-D glasses also will not work on conventional displays. This may be a possibility in the future with multiprimary-color displays, but there is nothing like this currently in the consumer market.

The only 3-D solution that can be widely deployed to any consumer color display is the anaglyph 3-D method. The anaglyph has been around since the 1800s, and for modern full-color displays involves sending the left and right image views into one or two complementary color channels, respectively. For example, the most common anaglyph technique involves the left perspective image being stored in the red color channel and the right perspective image being stored in the

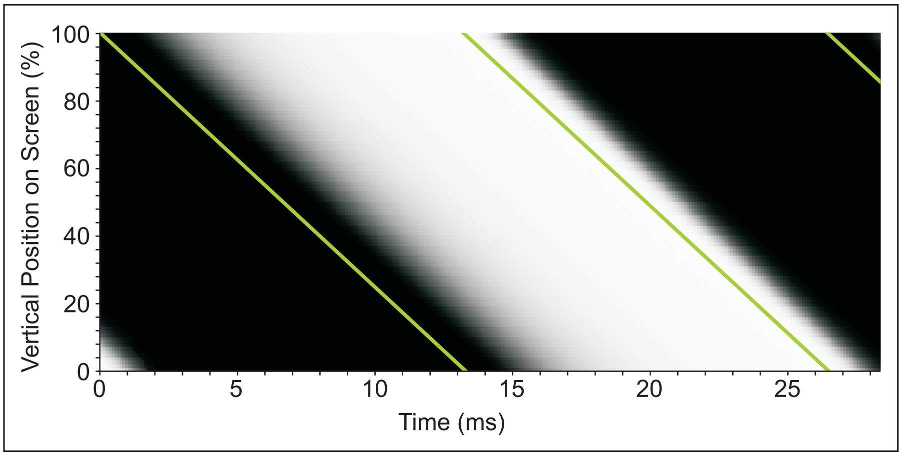


***Fig. 5:*** *Time-domain response of an example conventional LCD monitor (with 5.7-msec pixel response rate alternating between black and white frames at 75 Hz). The green line represents the time each row is addressed. It can be seen that there is no point in time when the entire screen shows one image across the entire screen.*[7]

blue and green (cyan) color channels. The viewer wears red/cyan 3-D glasses to decode the correct image to each eye and sees a 3-D image. Other primary color combinations are possible, including blue/yellow and green/magenta. The main advantages of the anaglyphic 3-D method are its simplicity and low cost. All that is required is an anaglyphic 3-D image source, any full-color display, and a corresponding pair of anaglyphic 3-D glasses. Unfortunately, the anaglyph 3-D method usually suffers from fairly low 3-D image quality – due to fairly high ghosting levels, retinal rivalry, and the inability to reproduce a completely full-color 3-D image.[11] Despite these limitations, anaglyph 3-D remains a commonly used format as evidenced by the widespread release of many 3-D DVDs and Blu-ray discs in anaglyph format – albeit leaving many shaking their heads and yearning for something better.

## Conclusion

A good (and expanding) range of high-quality 3-D displays is gradually penetrating the home consumer market. The successful roll-out of 3-D cinemas and 3-D movies is probably greatly responsible for the increasing consumer interest in this display category. The next part of the equation that needs attention is the availability of stereoscopic 3-D content for viewing on home 3-D displays. The consumer game market is the greatest source of 3-D content at the present time, with over 300 PC game titles available to be played in stereoscopic 3-D – enabled by 3-D game-software solutions available from NVIDIA, DDD, and iZ3D. There is also talk of game consoles supporting high-quality 3-D displays in the not too distant future. However, probably the most anticipated form of 3-D content is high-definition 3-D movies. Over 300 3-D movies and shorts have been publicly exhibited from 1915 until 2009, but unfortunately only a handful of 3-D movie content is commercially available at the present time (see www.3dmovielist.com) – and none in a high-quality high-definition format. At the present time, most content owners appear to be waiting for the much-talked-about Blu-ray 3-D format to be standardized, which is addressed in another article in this issue. Once that format is standardized, we will probably see another jump in the uptake of stereoscopic 3-D displays.

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