P-68. Glasses-Free Stereoscopic Displays Based on Shutters and Dynamic Polarizers with Moving Boundaries Between Areas with Complementary Optical Properties

Vasily A. **Ezhov**[1], Vladimir A. **Brezhnev**[2], Sergey A. **Studentsov**[2]
[1] Prokhorov Institute of General Physics; 38, Vavilova str., Moscow 119991, Russia, email: ezhov@3dstereo.ru
[2] Volga R&D Institute; 101, 50th Anniversary of October pr., Saratov 410052, Russia, email: lcspectrum@mail.ru

Abstract: It is possible to make *glasses-free* direct-view and projection 3D displays (including multiview ones) based on existing stereoscopic displays using decoding elements with moving boundaries at a certain distance from the observer. The necessity of maintaining this distance is the main limitation but this can be overcome by tracking the observer.

Key Words: Glasses-free, Stereoscopic, Autostereoscopic, Head tracking

1 Autostereoscopic Approach With Moving Boundary

The principle of moving boundaries for 3D Stereo glasses-free imaging was described in [1,2].

1.1 Complementary Optical Properties For Separation Of Left-Right Views

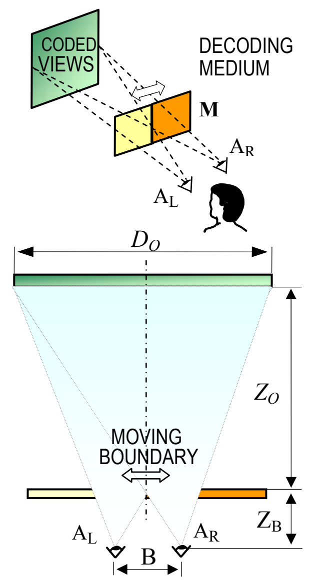


Fig.1 Principle of L-R separation

Practical implementation of stereoscopic displays always involves display of at least two images separately to the two eyes. It is accomplished by displaying at least two viewing areas (zones) A_L and A_R, corresponding to the left and the right eyes.

For creating two viewing areas without help of glasses it is feasible to use a decoding medium **M** (Fig.**1**) at some distance from the observer, having two adjacent areas with complementary optical properties, as shown in (Fig.**2**) :

- full optical transmittance versus zero transmittance;
- two states of controlled birefringence, causing phase shift $\Delta\delta=0$ and $\Delta\delta=\pi$;
- dichroic neutral or color polarizers with orthogonal states of plane polarization;
- spectra with non-overlapping positions along λ-axis.

Separate viewing zones for two eyes are provided by disposing the decoding plane (surface) of medium **M** at the distance Z_B (from the observer) defined by

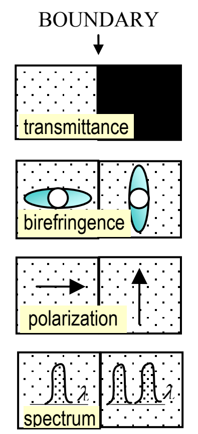


Fig.2 Medium M

$$Z_B \leq \frac{BZ_O}{D_O} \qquad (1)$$

where B is the distance between the pupils of eyes (commonly 60-65 mm), Z_0 is the distance between display screen and the decoding medium M (a shutter, a polarizer, etc.) and D_0 *is the* size of the screen in the horizontal direction.

The vertical boundary between the R and L sides of the decoding medium M can be moved horizontally in order to track the observer.

The main advantage of this method is the ability to transform most existing stereoscopic displays (intended for viewing with glasses) into glasses-free (autostereoscopic) ones practically with little or no change while preserving full resolution of the stereo image (full resolution of the screen for each of left and right views of the stereo pair).

The main limitation of this method is the necessity to maintain a value of required distance Z_B no more than BZo/Do but less values Z_B work with the same success, allowing to decrease the required size of medium M. In another words, in case of a fixed position of medium **M** there is a limitation only on such displacement of the observer's head that leads to INCREASED (MORE FAR) distances Z_B from medium M. But for ANY MORE CLOSED distance Z_B (less than BZo/Do) the separation L from R is reached successfully. In many cases such limitation can be not so important (for example, for sitting observers). This constraint can be relaxed by tracking of the z axis of the observer's head with corresponding automatic z-displacement of decoding medium **M**. Moreover, introducing tracking (which can also work in the horizontal direction) allows multiview stereoscopic displays with quasi-continuous views (i.e., with very fine angular resolution of the reconstructed 3D scene) due to very fine shifts of the moving boundary of **M** in the x and z axes. In this case the additional advantage is a compatibility of the multiview display with standard communication channels (computer and TV) because it is necessary to generate (to transmit) at any instant only the single pair of views that is being presented to the observer (each another pair of views replaces the current one only when the autotracking updates).

1.2 Comparison With Other Autostereoscopic Methods

Practically all known alternative autostereoscopic displays, especially multiview ones intended for **high-resolution or wide field-of-view** imaging, also are characterized by similar limitations which are often over come by autotracking.

It will be considered briefly the various methods of autostereoscopic viewing classified according to stereoscopic format using the universal terminology which is introduced in [3]).

Matrix pair (MP) format. This format is used in nearly all autostereoscopic displays employing lenticular screens [4] or parallax barriers. Vertically aligned (i.e. in parallel with the image columns) lenticular or barrier displays have limitations on viewer position. These limitations are overcome by introducing headtracking. All such displays have decreased (by half or more) resolution of each view. Autostereoscopic displays with image columns (stripes) which are oblique relative to the lenticular lenses [5] or barriers with periodic stepped structure [6] are characterized by multiview capability without using headtracking but there is decreased resolution of each view (determined by dividing full resolution of the screen by the number of views. It has been suggested [7] to use a time-multiplexed multiview system with adjacent viewing zones (Fig.**3**) in which multiplicity K of L and R view pairs are sequentially generated.

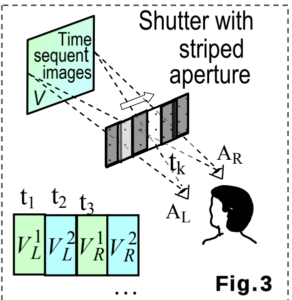


Fig.3
Prior-art auto3Dstereo [7]

The main disadvantage is the very high bandwidth that is the sum of the bandwidths required for generation of each pair of views V_L^k and V_R^k (k = 1,2,…, K).

Mutual filtering pair (MFP) format. MFP format [8] is based on two Z-axis positioned 2D screens one being the adaptive optoelectronic spatial filter for the other. It gives less resolution for each view in comparison with the original screen resolution because of a residual nonzero term in the filtering algorithm. Also it is necessary to overcome moire patterns and light losses (caused by using two sequentially arranged optical intensity matrix modulators).

2 Autostereoscopic Displays Based On The Moving Boundary Principle

2.1 Shutters With Moving Boundary Between Switched Values Of Intensity

The moving boundary method preserves the full resolution of the stereo image for all 3D displays in the **alternating pair** (**AP**) format (usually referred to by the obsolete term *page flipping* which referred to separate pages of PC buffer memory for each view). All of the time-sharing stereoscopic formats (**vertical pair –VP**, **horizontal pair – HP**, **interleaved pair - ILVP**, **interlaced pair – ILCP**) are usually converted, before presenting to the observer, into **AP-**like format (L and R views are arranged in time sequential PC frames or TV fields). So all stereoscopic displays in these formats can be transformed into autostereoscopic ones preserving their inherent advantages (compatibility with all PCs for any type of video cards – for **VP**; parallel transmission of all image lines of both views while preserving compatibility with standard information TV channels - for **HP**; compatibility with standard PAL, NTSC, SECAM systems – for **ILCP**; ease of working with stereo images in a part of the screen – for **ILVP**).

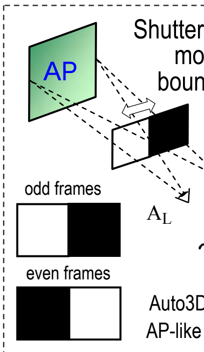


Fig.4
Auto3Dstereo – AP-like formats

One can use a shutter with a vertical boundary between two areas (Fig.**4**) in each of which the value of light intensity is switched from zero to maximum syncronously with frame (field) refresh on the screen of the display. It enables separation of the L and R views if the boundary is positioned symmetrically.

2.2 Dynamic Polarizers With Moving Boundary Between Orthogonal Stationary States of Polarization

Any stereoscopic system employing such formats as **mutually imposed pair** (**MIP**), **joint pair** (**JP**), or **moving boundary pair** (**MBP**), can be converted to glasses-free versions by employing dynamic polarizers with a moving vertical boundary between orthogonal stationary states of polarization (Fig.**5**).

Mutually imposed pair (MIP) format. MIP format is used in stereoscopic systems which code stationary light fluxes of L and R views by orthogonal states of polarization (linear or circular).

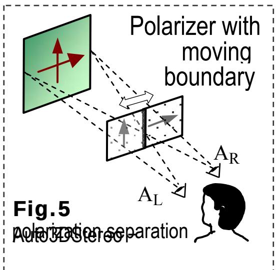


Fig.5
polarization separation Auto3Dstereo

Joint pair (JP) format. JP format is used in innovative stereoscopic direct-view flat LC displays based on two adjacent LC matrices, one of them the intensity modulator and the other the polarization-coding modulator. This format in liquid crystal (LC) twisted matrix is described for the first time in [9], and a general description in [10].

Moving boundary pair (MBP) format. MBP format [1,2] can use separate moving horizontal and vertical boundaries.

One can use this format for viewing stereo images on the screens of LC displays if the decay time is less than (or equal to) the frame time. A "sample-and-hold" method of image formation is employed in all modern LC TFT (thin-film-transistor) matrix displays where each line of image is presented on the screen during frame time, and image refresh is accomplished by replacing the previous frame by the next frame on line-by-line basis (Fig.**6** top left) so the front of this change can be treated as a

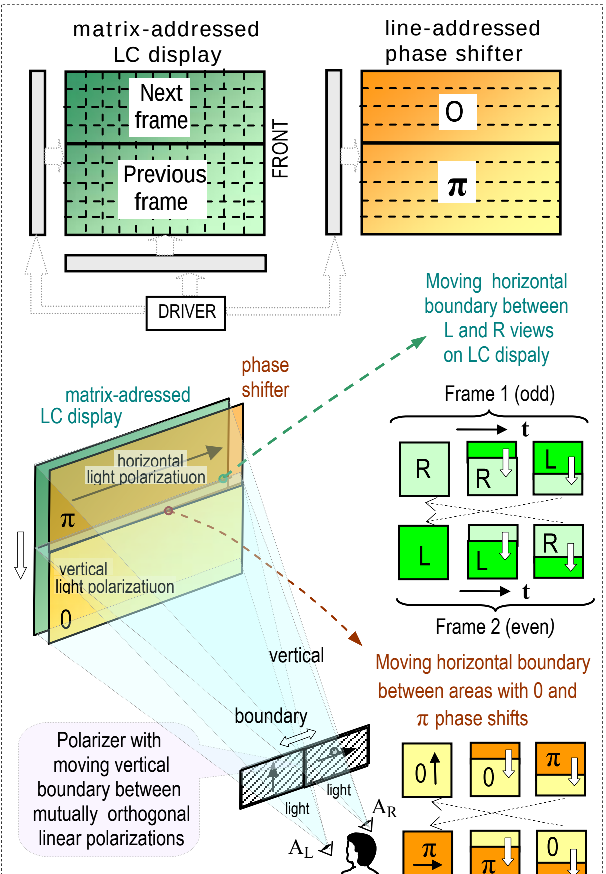


Fig.6 Auto3DStereo – LC matrixes provided by line-addressed phase shifter

moving boundary between the previous frame information and the next frame. Analogously, if one uses an external phase shifter for changing phase coding of its lines (Fig.**6** top right) then the linear polarized light (emanating from the outer polarizing film of LC matrix) will have orthogonal polarization (after passing through this phase shifter) in the two areas above and below the front-moving boundary (Fig.**6** right). As a result, the polarizer with moving vertical boundary (disposed near observer's head) will separate the L and R views (Fig.**6**, left) which are contained in adjacent (in time) frames.

A further development employs a single shutter having combined moving horizontal and vertical boundaries (Fig.**7**). In such case there is no necessity to use a wide-aperture phase

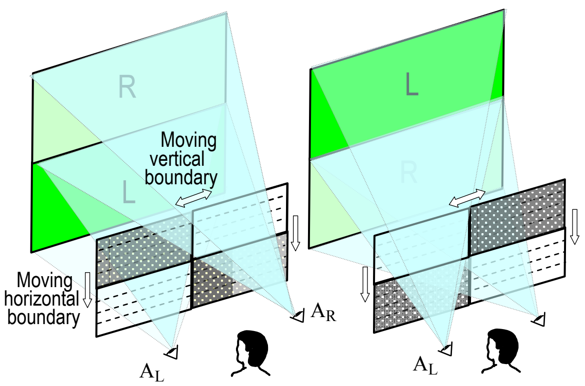


Fig.7 Auto3DStereo – the shutter with two moving boundaries

shifter but it is necessary to have matched (averaged in their vertical angles) local relaxation times of the LC matrix and the shutter.

2.3 Dynamic Dichroic Polarizers With Moving Boundary Between Orthogonal States of Polarization (Stationary Or Switched)

Any stereoscopic system employing **anaglyph pair** (ANP) or **alternating anaglyph pair** (AANP) can also be transformed into a glasses-free system using dynamic dichroic polarizers with the vertical moving boundary between two states of orthogonal polarization – stationary or switched (Fig.**8**). In practice it is seldom worth building such systems because of poor image quality. However, with all digital imaging **ANP** can approach the quality of polarized images. So, **ANP** is primarily for simplest and cheapest stereoscopic displays but has the great advantage of compatibility with any color display and is quite good on all digital LCDs (the red/cyan pair and the orange/blue one give the most quality images). **AANP** (the principle suggested in [11]) is suitable for flicker suppression in cases of low frame rate. There are two disadvantages of this approach. The first is color artefacts on fast moving objects and the second the low contrast (no more than 10-30:1) of color dichroic filters leading to appreciable ghosting. It is possible to use "guest-host" effects in LC layers as switching color filters for separation, but this is also has low color contrast.

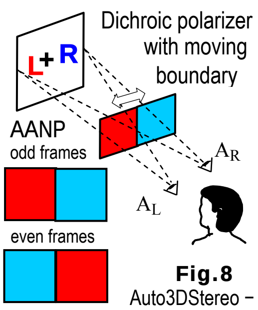


Fig.8 Auto3DStereo – spectral separation

2.4 Panoramic Stereo Imaging With Moving Vertical Boundary

With curved surfaces of decoding medium **M** with a moving boundary it is possible to realize panoramic stereo systems (Fig.**9**) by image stacking with video projectors on a cylindrical screen.

The simplest way to make a cylindrical medium **M** is to use a sheet of linear polarizer bent into a cylinder, whereas the complementary state of polarization is made by using a sheet of π-retarder optically glued on half the surface of polarizer cylinder. The edge of the π-retarder (parallel to the cylinder axis) forms the boundary between orthogonal states of polarization. If one rotates the cylinder syncronously with anglular position of the observer's head, it will be a mechanically moving boundary.

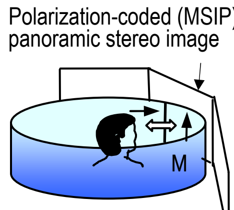


Fig.9 Cylindrical separator

An electronic version of a cylindrical medium **M** (or a part of the cylindrical surface) can be made by using a layer of LC disposed between two flexible substrates (for example, polycarbonate) provided with striped vertical electrodes. Development of such flexible substrates is in the mainstream of modern display technology . The employment of flexible curved substrates is promising for making decoding filters with moving boundaries (especially for multilayered ones giving high quality of separation of L-R views and wide field-of-view).

One can imagine a stereoscopic system with arbitrary form (cylindrical, conical, etc.) of the surface of the active medium **M** (Fig.**10**).

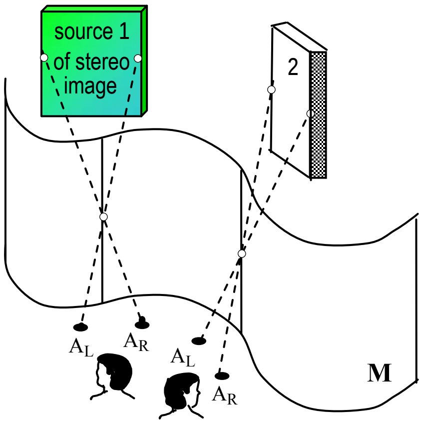


Fig.10
Auto3Dstereo: separation media M of arbitrary form - can be repaced by a multiplicity of personal small submediums M_1-M_K

3 Implementation Of Shutters And Dynamic Polarizers With Moving Boundaries

We have created prototypes of moving vertical boundary *shutters* and *dynamic polarizers* using striped transparent electrodes for addressing the LC π–cells or chiral doped supertwist nematic cells (Fig.**11**). The dynamic polarizers and shutters have fast response time (30-100 us) at rising electrical field E and moderate decay time (2-4 ms) at E=0. The contrast

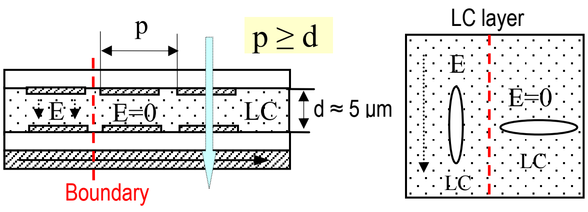
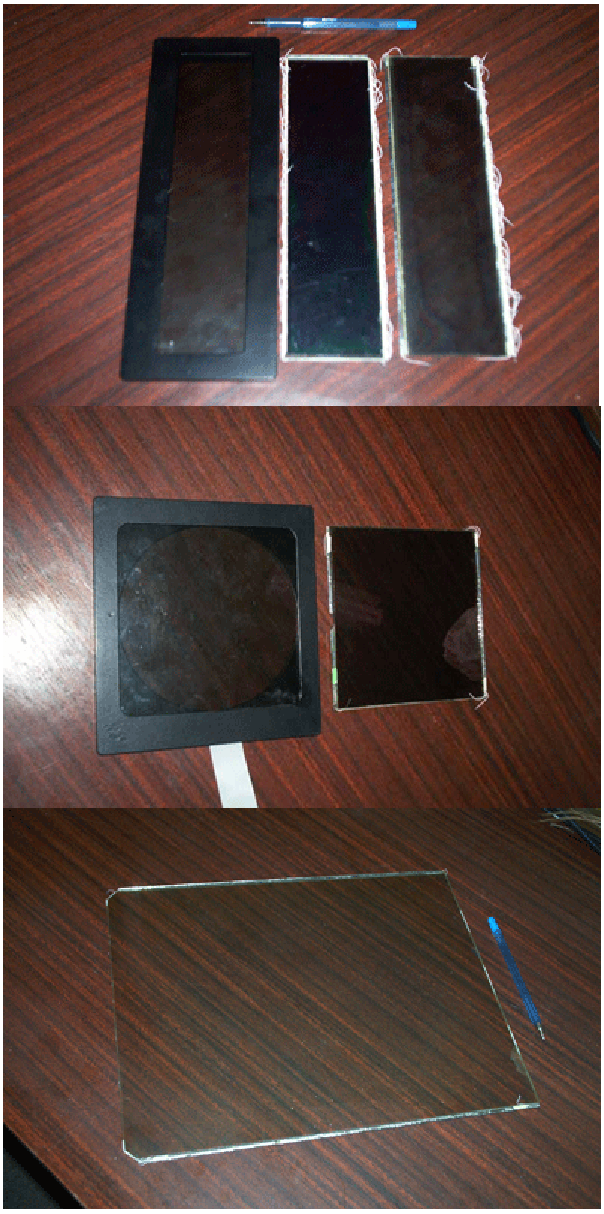


Fig.11 Cross-section of column-adressed LC shutter

is about 70-100:1 in case of *supertwist shutters* and 40-50:1 in case of the *π–cell dynamic polarizers* (where one view is separated in crossed polarizers and another one – in parallel polaroids). In case of the *π–cell shutter* (when both views are separated in crossed polaroids) the contrast can be about 60-100:1 for push-pull mode of operation in twin-LC-layer structure (in such mode both rise and decay times can be about 30-100 us) or 200-300:1 for twin π–cell *shutter* with three polaroids. Using optical compensation methods (various achromatization means) can give essential increasing of the contrast. The most promissive is using several LC layers with equal characterisics but with different anizotropic axes orientations. Such method will be especially suitable in case of using thin (hundreads of micrometers) flexible substrates in possible future designs.

Photos of LC prototypes (with glass substrates) are below.



References

[1] V. Ezhov, S. Studentsov, *RU patent granted (the application № **2006103457**,* filed 07.02.2006).
[2] V. Ezhov, S. Studentsov, *RU patent granted (the application № **2006103460**,* filed 07.02.2006).
[3] V. Ezhov, *3D Displays: Fundamental Physical Classification....*, this issue.
[4] H. Ives, *US Patent **1916320***, filed 12.08.1931.
[5] D. Winnek, *US Patent **3409351***, filed 07.02.1966.
[6] F. Doerfel, A.Grasnick, A.Holz, et al., *US Patent **7046271***, filed 24.01.2001.
[7] J. Son, V.Smirnov, V.Novoselsky, *US Patent **6178043***, filed 23.11.1999.
[8] A. Putilin, *US Patent **6717728***, filed 15.10.2001.
[9] J. Gaudreau, *US Patent **5629798***, filed 07.03.1997.
[10] V. Ezhov, *A new approach of stereo imaging...*, this issue.
[11] G. Street, *US Patent **4641178***, filed 07.08.84.