Volume (or stereoscopic) images on the screens of standard computer and television displays

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ABSTRACT

The main principles of various *glasses-based* stereoscopic systems and their significances are discussed. Practical results of developed and produced by Russian companies original ready-to-use stereoscopic add-ons (attachments) to standard computer and television displays are described.

Keywords: stereoscopic systems, stereo glasses

1. INTRODUCTION

As it is well known, a human perceives volume of real volume scenes via stereoscopic vision i.e. via parallel observing the two monoscopic images-views at the retinas of two eyes. The volume is determined by human visual system mainly on base of differences of geometrical structures of two pointed "flat" images. So, it is quite enough to use standard monoscopic display to carry stereoscopic information in the form of pair of pointed "flat" images-views. The main problem is to provide independent transmitting of two signals corresponding to pair of image views (while using single standard information channel) and to provide parallel viewing of two images (at single-screen standard displays) separately by two eyes.

Only *glasses-based* methods can right now really provide high quality volume images in various home and professional applications practically for each user. *Glasses-free* methods either require creating special very expensive imaging systems or/and have no enough flexibility now.

The subject of this paper is the brief description of *glasses-based* stereoscopic systems realizing by use of original ready-to-use stereoscopic add-ons (attachments) to standard computer and television displays developed and produced by STEL Corp. (Russia) (*http://3dstereo.ru*).

2. TERMS AND ABBREVIATES

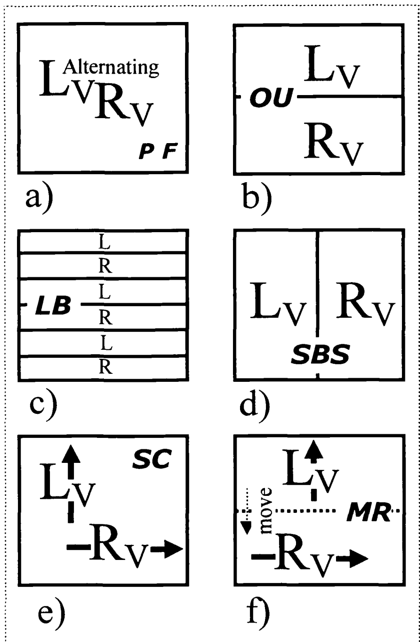
- *3DS* – shortest of "3DStereo" – unambiguous abbreviate of stereoscopic sphere (simple "3D" is not correct because of frequent using this term in the sphere of monoscopic images to underline the presentation of the volume by non stereoscopic methods - by perspective drawings, shadows and so on.
- L_V and R_V – left and right views (two monoscopic images) allowing to view *3DS*-image by fusing L_V and R_V in human visual system.

3. STEREOSCOPIC (3DS) FORMATS AND VIEWING MEANS

3DS formats. Now the following terms are widely used by specialists in this field: "page flipping" (*PF*), "over/under" (*OU*), "line blanking" (*LB*) and "side-by-side" (*SBS*) for 4 versions of presenting left view (L_V) and right view (R_V) of stereoscopic image on the screen of monoscopic display (Fig.1a,b,c,d correspondingly). Here for convenience we give abbreviates– "spatially coinciding" (*SC*), "mutually replacing" (*MR*) for the L_V and R_V on next two *3DS*-formats (Fig.1 e,f).

PF format (Fig.1,a) corresponds to full-screen L_V and R_V which are mutually alternating in time, for example, L_V appears only in odd fields of television-type interlaced video signal, R_V – only in even fields, or (in case of computer VGA-like progressive-scan mode) L_V appears only in odd frames and L_V – in even frames.

Current Research on Image Processing for 3D Information Displays,
edited by Vladimir V. Petrov, Proceedings of SPIE Vol. 5821
(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.612144



OU format (Fig.1,b) - simultaneous presenting of both L_V and R_V in one field (frame) along vertical dimension.
LB format (Fig.1,c) - simultaneous presenting of both L_V and R_V in one frame so that L_V is placed on odd (even) lines, R_V – on even (odd) lines.
SBS format (Fig.1,d) corresponds to simultaneous presenting of both L_V and R_V in one field (frame) along horizontal dimension.
SC format (Fig.1,e) - simultaneous presenting of both full-screen L_V and R_V to be carrying by two corresponding light fluxes (from two projection displays) having differing polarization states.
MR format (Fig.1,f) – full-screen presentation each of L_V and R_V differing by polarization state within single light flux (from single direct-view or projection display) at the cost of moving boundary between L_V and R_V.
Each of L_V and R_V is presented by full-color image (by all three - R,G,B - components) in all abovementioned stereoscopic formats.
Other *3DS*-formats are characterized by using *color* for differing L_V from R_V (Fig.2). The classic format is called as "anaglyph" (Fig.1,a) and relatively new format can be named as "shuttered color" – Fig.1,b).
Anaglyph format corresponds to permanent (in all frames) using, for example, R-component for presenting L_V and G+B components – for R_V.
Color-shutter format corresponds to presenting in odd frames: R-component L_V simultaneously with G+B components for R_V, and in even frames - vise versa: R component for R_V and G+B-components for L_V.

Fig.1. Format variants of presenting left view (L_V) and right view (R_V) of stereoscopic image on the screen of monoscopic display: a) "page flipping"; b) "over/under"; c) "line blanking"; d) "side-by-side"; e) "spatially coinciding"; f) "mutually replacing"

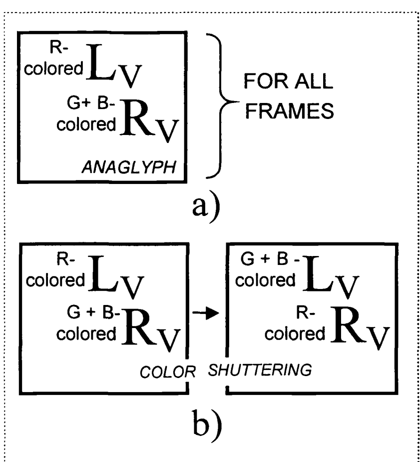


Fig.2. Color differing 3D-formats, a) anaglyph; b) color-shuttering

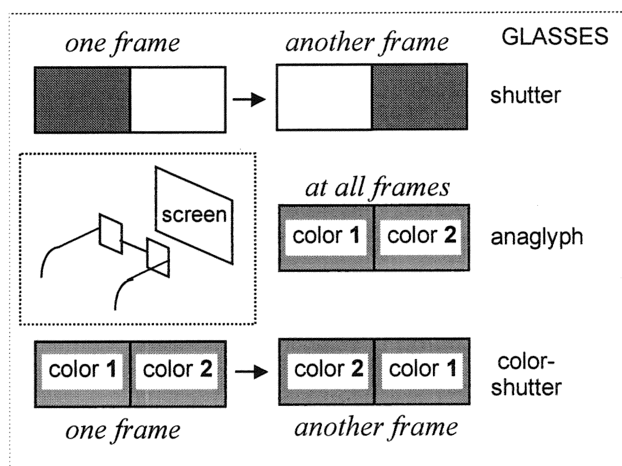


Fig.3. Principle of anaglyph and color shutter 3D-glasses

Viewing means – shutter glasses and panels. *Shutter* glasses perform shuttering of intensity of luminous flux by alternative opening/closing each of its two windows (Fig.3, upper part). *Anaglyph* glasses perform permanent filtering one group of colors (color 1) for one window and another group (color 2) for another window (Fig.3, middle part).
Color-shutter glasses perform shuttering of color (changing from color 1 to color 2 and vise versa) in each window (Fig.3, lower part).
Anaglyph glasses are passive glasses (with nonchanging optical properties of each window).

All glasses with shuttering (modulating) the physical properties of windows are called <u>active</u> glasses. Active glasses require to employ electronic controllers (dongles) providing the controlling of glasses synchronously with appearing of L_V and R_V on the screen of a display.
Shutter glasses and panels can handle directly only with *PF* – like stereoscopic format (which provides alternating L_V and R_V according with alternating opening/closing of glasses left and right windows). In case of using other stereoscopic formats (in the sources of stereo images, for storing *3DS*-images) it is necessary previously to transform each of them into *PF* format before feeding the signal to display input. Such transformation can be performed by hardware (by dongles) or by software (by computer programs).

<u>Practical need of using various 3DS-formats.</u> The main reason is to provide the compatibility with concrete types of monoscopic displays and with concrete class of electronic sources of stereoscopic image signal.
PF theoretically provides the most high quality stereo image because in this case L_V and R_V are full-screen images whose number of pixels corresponds to full resolution of a display. But, unfortunately, *PF* is characterized by poor compatibility with computer hardware (because here it is difficult in common case to provide absence of mutual merging of adjacent frames causing destroying stereo effect as adjacent frames carry L_V and R_V differing each from other only in case of 3DStereo).
OU, LB and *SBS* formats theoretically have less in twice number of pixels in L_V and R_V in compare with full resolution of a display. But these formats are completely compatible with any computer hardware because they arrange both L_V and R_V in one and the same frame (so mutual merging of frames can't destroy stereo effect). Loss of theoretical resolution can be compensated in practice by using high resolution (XGA, SXGA and so on) computer video modes.

4. PRACTICAL 3DS-SYSTEMS AND THEIR KEY ELEMENTS (STEREO GLASSES, STEREO PANELS, ELECTRONIC DEVICES)

4.1. Projection 3DS-systems.

Practical choice of 3DS-system is determined by necessary quality of *3DS*-image and by possible expenses on creating corresponding system. The high-quality 3DS-image is determined by practical absence of cross-images and absence of noticeability of pixel (line) structure of L_V and R_V. In case of insufficient separation between two viewing channels the cross-images are present: part of intensity of L_V leaks in right eye and of R_V - in left eye.
The highest quality of 3DS-image is provided by the <u>two-channel system</u> (Fig. 4) with two video projectors giving L_V and R_V on common screen in the form of spatially coinciding views (Fig.1,e). The initial video signal from standard source (DVD-player, VCR etc.) is distributed by demultiplexer (demux) so that one video projector receives only L_V , and another video projector – only R_V . Polarizers in the luminous fluxes of projectors have mutually orthogonal states of polarizations (linear or circular). A screen must preserve the polarization of both fluxes. The 3DS-image is viewed with help of passive polariod glasses (linear or circular). The separation of views is determined here by the contrast of polaroids using in filters and passive glasses, and by polarization-preserving properties of screen. Real suppression of cross-images can reach about 300-1000 : 1 in case of standard linear polaroids and about 70-100 : 1 in case of standard circular polaroids.

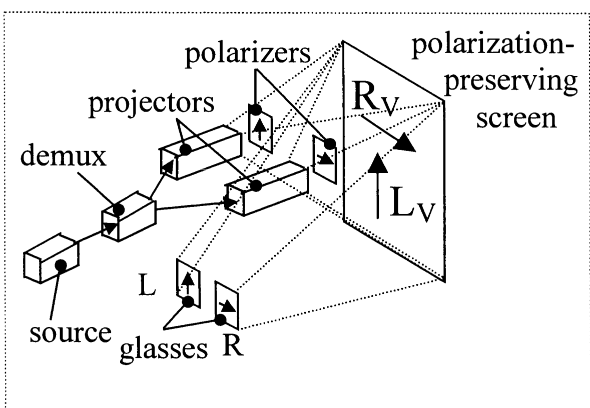
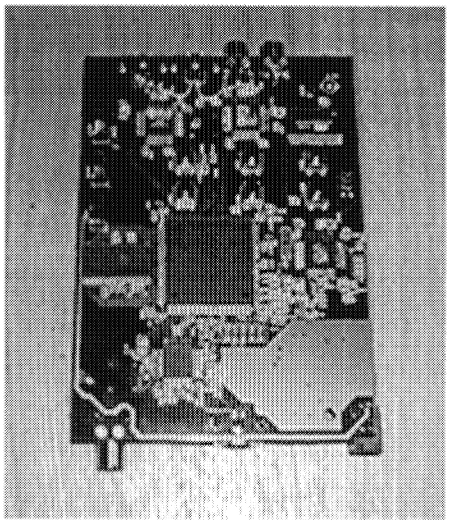


Fig.4. Two-channel 3D-system

Using circular polarization gives more freedom to user (angle turning of head are allowed about to 30^0 without degrading the separation). Using linear polarization allows only about several degrees of head angle turning to avoid decreasing of separation.

The maximum resolution of 3DS-image is determined by corresponding resolution of standard video projectors. Any type of video projectors (TFT LCD, ERT, DLP and so on) can be used here. The only feature should be taking into account – it is desirable to choice projectors either with unpolarized (stochastic) initial luminous flux (as in DLP-projectors) or with linear polarized flux (TFT LC projectors) characterized by equal polarization direction for all three color luminous components.



The key element of such 3DS- system is *the analog-digital demux*. In first the demux must recover initial frame rate for L_V and R_V (divided in twice –f rom 50-60 Hz to 25-30 Hz - as a result of alternative distributing frames or fields on two channels). In second it is highly desirable to have more lines in 3DS-image in compare with original video image. Indeed standard video source provides odd and even fields each with about 250-300 lines (depending on TV system). For projection screen with several tens of meters squared it is desirable to have no less 500-1000 lines in each of L_V and R_V to reach absent of noticeability of line structure of 3DS-image.
Such demux is developed (shown in photo, Fig. 5) in several versions from cheap to advanced one, allowing (by user choice) to perform smart doubling, tripling and quadrupling of number of lines using mathematical (bicubic) interpolation in real time.

Fig. 5. Demultiplexer device (demux), providing mathematical interpolation in real time

One-channel high quality 3DS-system with stereo panel (Fig.6) has one video projector preserving *PF* format (DLP, ERT), a LC panel, a polarization preserving screen and passive polaroid glasses (linear or circular). One-channel 3DS system with shutter glasses (Fig.7) has a video projector (preserving *PF* format), a screen of any type (without requirement to preserve polarization of light) and active stereo glasses. In both systems PF format is realized on the screen. The key 3DS-element of both such systems is the *converter of 50-60 Hz television-type stereo video to 100 Hz SVGA (XGA) stereo mode.* Fixed (50-60 Hz) frame frequency of standard television systems (PAL, NTSC, SECAM) leads to flicker of observed stereo image because of low frame frequency (25-30 Hz) image going in each eye in this case.

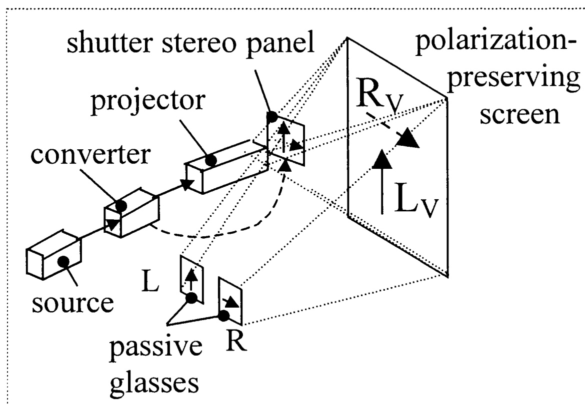


Fig.6. One-channel 3D-system with passive stereo glasses

For example using practically any 100 Hz standard television set can't solve this problem because practically all of them work with algorithm OOEE to double the field frequency, where O – odd field, E – even field but it is necessary to realize the algorithm OEOE in order to get 100 Hz mutual alternating of left and right views (left view corresponds to odd field, right view – to even one). So it was developed and made the electronic converter realizing required OEOE algorithm (its design is the same as for demux that is shown in corresponding photo).
To reach maximum resolution of output image in both pointed systems it is necessary to transform initial standard video signal to computer image mode (VGA, XGA, SXGA etc.) signal with corresponding multiplying of number of lines. Such converter also developed has the same construction as demux (shown in photo 5).

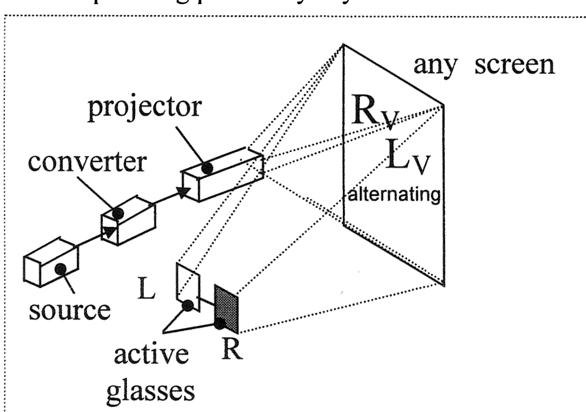


Fig.7. One-channel 3D-system with active stereo glasses

Both devices are made with using PLD (programmed logic devices). A programming skill was used to compensate time delays in cheap PLD used in cheap devices without interpolation (cost about $200).

4.2. 3DS-systems on base of direct-view (non projection) computer monitors

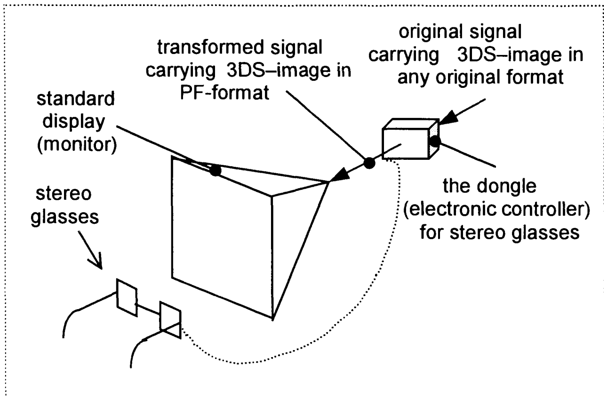


Fig.8. Creating of 3D-system on home or office equipment

As a rule the primary purpose of creating home- or office-oriented 3DS-system is the realizing maximum functional possibilities on base of equipment available at user's disposal. Such systems are successfully made on base of standard computer monitors capable to reproduce images with 100-120 Hz frame rate (Fig.8) to avoid flicker of viewed 3DS-image. The source of image signal can be a computer itself (IBM-PC compatible is the most suitable because of availability a lot of 3DS-ready software) or any source of video signal (DVD-player, VCR, video game console etc.). The dongle (electronic controller for active stereo glasses) is often performs the transformation the original 3DS-format to PF format suitable for using of active glasses.

Transformation of *OU* to *PF* (Fig.9) is accomplished by inserting additional frame sync pulse H_V' to initial sequence of frame sync signals H_V so that additional sync pulse H_V' is arranged in the middle between two adjacent H_V. Resulting sequence of frame syncs is characterized by doubled frequency forcing a display to work at corresponding doubled frame rate. This leads to full-screen alternative displaying of each of L_V and R_V because at doubled frame frequency the display begins to represent in full screen in first the upper half of previous content of the screen and in second - the lower half. Such transformation requires processing only sync signals without concerning information part of video signal. Initial image in each of L_V and R_V must be scaled 1: 2 along the vertical in order to have necessary 1:1 scale in final *PF* image, because each initial half-screen image (from *OU* format) will become full-screen image (in *PF* format).

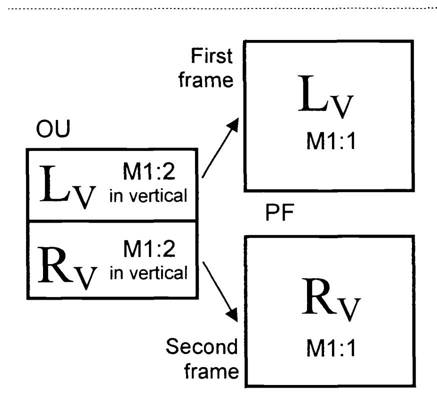


Fig.9. Transformation of *OU* to *PF* 3D-format

Transformation of *LB* to *PF* is accomplished by blanking (deleting) odd lines in odd frames and even lines – in even frames of original (source) image (Fig.10). Such transformation involves processing of information part of video signal.

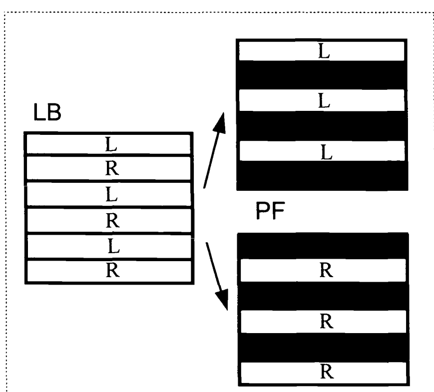


Fig.10. Transformation of *LB* to *PF* 3D-format

PF format (and all abovementioned formats in case of their transforming to *PF*) can be successfully reproduced only if the display itself don't mix adjacent frames i.e. if the luminous flux from previous frame is disappeared practically completely when the luminous flux from next frame is generated by display screen. Such condition is satisfied in case of ERT (electronic ray tube) display, DLP (digital light projector) and some plasma (gas charge) displays.

But this condition is not satisfied in case of practically all TFT (thin film transistor) LCD displays because here artificially each line is prevented from natural decay to get maximum contrast and brightness. Such artificial memory caused by electrical capacity of elementary LCD cell that is prevented from discharge by closed TFT.

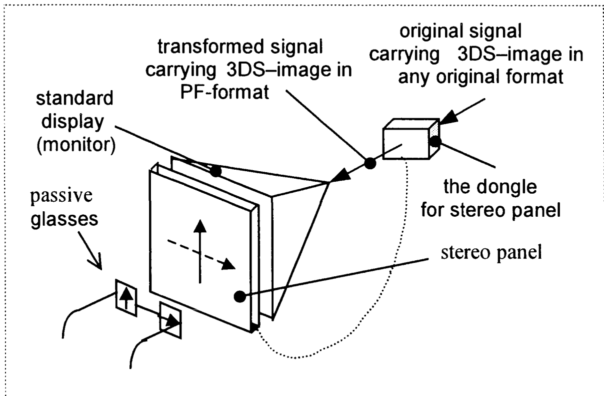


Fig.11. 3DS-system with stereo panel and passive glasses

The information content of each line is refreshed here only at the moment of appearing the next portion of information signal by recharging the capacity. Always at the screen of TFT LCD display there is a mixture of simultaneously presenting lines of previous and next frames so it is impossible to realize *PF* format and to use shutter glasses.
In this case it is worth to use *anaglyph* format that is applicable to all color displays. But using permanent separation of colors between eyes can lead to decreasing of quality of viewed stereo images because of distortion of resulting color transfer function. There several versions of *anaglyph* format, for example red - blue, red – green + blue, orange-blue.

Red-blue version is worth to use in case of such ERT television sets where side emission of undesirable colors by phosphor triads doesn't allow to use more wideband anaglyph glasses because of contrast losses. Red – green + blue version is suitable for LCD displays providing satisfactory reproduction of colors in viewed stereo image. Orange-blue version is under investigation now. All these anaglyph formats are realizing as particular modes of operation of abovementioned video-SVGA converter.
Color-shutter format can be considered as alternative to *anaglyph* format in case of fixed and low frame frequency of standard television system - in order to essentially improve color transfer function without appearing essential flicker of stereo image (appearing in case of direct using of *PF* format in this case). The versions of *color-shutter* glasses on base of dichroic dye filters and LC shutters are proposed in [3]. Now such glasses under further development and investigation. The preliminary experiments were made in Stel Corp. with using dichroic film filters, and the considerable suppression of 3DS-image flicker was observed at low (50-60 Hz) of frame rate. But practical using of such glasses is a problem now because of unsufficient degree of L_V and R_V separation (caused by low color contrast of dichroic filters).

3DS-system with stereo panel and passive glasses is shown in Fig.11. The stereo panel is the LC modulator occupying the whole aperture of the display screen and changing the state of output light polarization that is analyzed by external passive glasses.
It is interesting that LC active shutter stereo glasses always give more contrast (better separation) in compare with stereo panel (in case of equal optical properties of LC) because only in case of glasses each LCD works inside the mutually orthogonal polarizer and analyzer for these both devices (see 6.1).

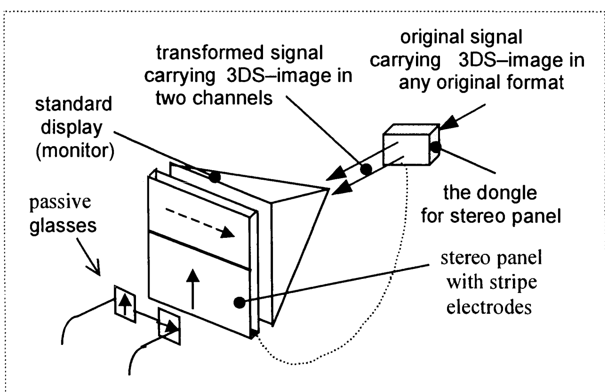


Fig.12. 3DS-system with stereo panel with stripe horizontal electrodes and passive glasses

At last, point a way of realizing a stereoscopic format [4], allowing to represent both L_V and R_V at full screen using a display with two scanning beams and dynamic polarizer with moving boundary between two orthogonal states of polarization (Fig. 12). Such stereoscopic display can be made on base of modified standard two-beam ERT projection display (see A3 of Appendix). Dynamic polarizer can be realized on base of LCD stereo panel with stripe horizontal electrodes. Such system has some theoretical advantages (for example, automatic matching of geometric characteristics of L_V and R_V because of using the same deviation system for both rays), but its application can be found only in specific fields.

Design of stereo glasses. Need of wearing stereo glasses forces to develop various models suitable for various people and applications. It is impossible to develop one universal style of stereo glasses to satisfy all the users and suitable for all applications (as well as it is impossible to create one universal style of usual sun glasses suitable for all people).

Another item is the creating of modern electronic dongles (interfaces) between glasses and electronics providing as well corresponding controlling of glasses as modifying if necessary the stereoscopic image signal to transform initial stereoscopic format to *PF* format.

World's first stereo glasses with one big continuous LC visor for both eyes (shown in two photos, Fig.13). The advantage is the absence of light-blocking barrier in the middle of field of user's view (such barrier is present in all rest stereo glasses having two separate visors – one for each eye). So the user will merge in observed volume virtual world easier. Especially it is advantageous for users wearing own dioptric glasses because in this case any other stereo glasses (usually with arms) will be displaced on the width of dioptric glasses frame far from the user's face increasing by this the disturbing action of middle light-blocking barrier.

Fig.13. World's first stereo glasses with one big continuous LC visor for both eyes

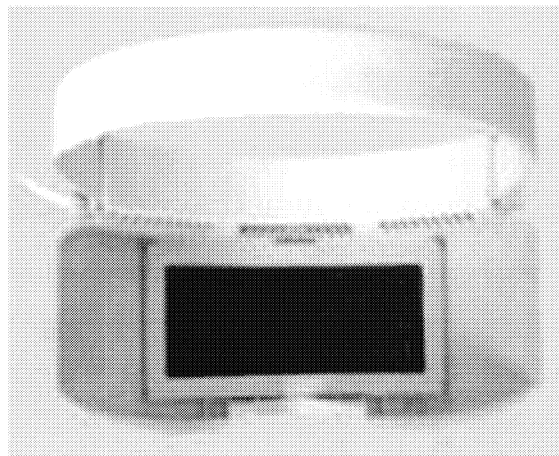


Fig.14. The back view of glasses from Fig.13

To reach comfort air condition inside this frame there are louvers in upper part of the frame (shown on the photo 14) and two slots in the lower part of the frame passing the air and blocking the light.

Prototype of stereo glasses with ergonomic headband (shown in photo Fig.15). Usual headband works according with the principle of tightening of bend around user's head. Such tightening can disturb user during long professional work. Also stereo glasses with arms can disturb the user by constant press on the nose (taking practically all weight of glasses). Here we see the *ergonomic* headband allowing wearing stereo glasses without any press on the nose and without any tightening of bend around the head. Such original headbend consists of horizontal plastic headbend itself and additional upper oblique plastic strip. The role of the strip is the holding the weight of the glasses on the upper part of user's forehead without tightening of the headband. Horizontal headband prevents shifting glasses to the sides without essential pressure on the head.

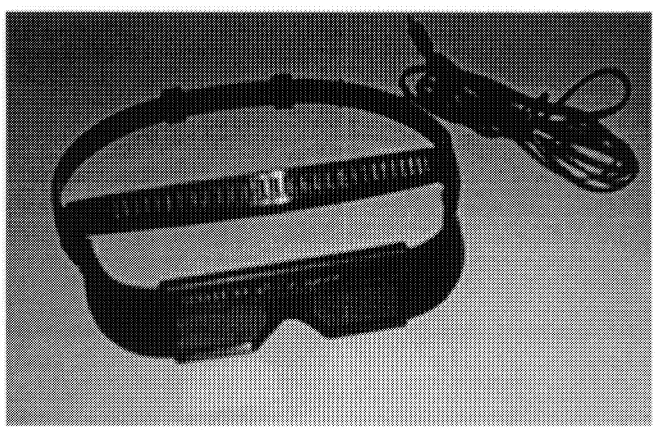


Fig.15. Prototype of stereo glasses with ergonomic headband

3DS-sets. There are developed cheap 3ds-sets using various stereo glasses with computer dongle (see photo, Fig.16) to work with IBM-PC sources of 3DS-image signal. Such dongle allows to work with OU, PF formats with possibility to adjust (by pressing buttons) the relative vertical positions of L_V and R_V in PF format transformed from OU format. Such adjustment allows to remove undesirable vertical parallax between pointed views originated from nonstandard positions of these views in OU format. 3DS-sets allow to have high-quality stereoscopic images in various games, photo, video and professional applications.

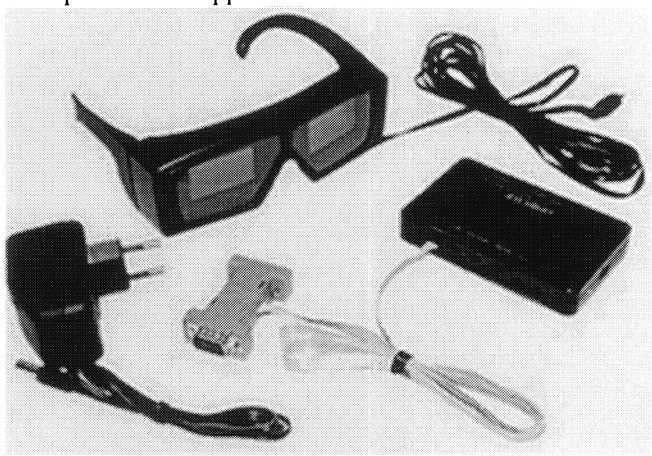


Fig.16. Cheap 3ds-sets using various stereo glasses

It is shown the 17-inch stereo panel (on the photo, Fig.17) having two LC layers and allowing to work as well with linear passive glasses as with circular polaroid glasses (the mode of operation is determined by the corresponding regime of the electronic controller).

The degree of separation of views (suppression of cross-images) is determined here by contrast K and by values of transient time (T_R, T_D) of shutter stereo panel (for systems on Fig.6,11) or corresponding K, T_R, T_D of shutter glasses (for systems on Fig.7,8). Here the contrast K is the ratio of light intensity for open state of the shutter to the light intensity for its closed state. T_R is a reaction time, i.e. time of transition from initial (relaxed) state to excited state (under applying voltage). T_D is decay time, i.e. time of transition from excited state to initial (relaxed) state.

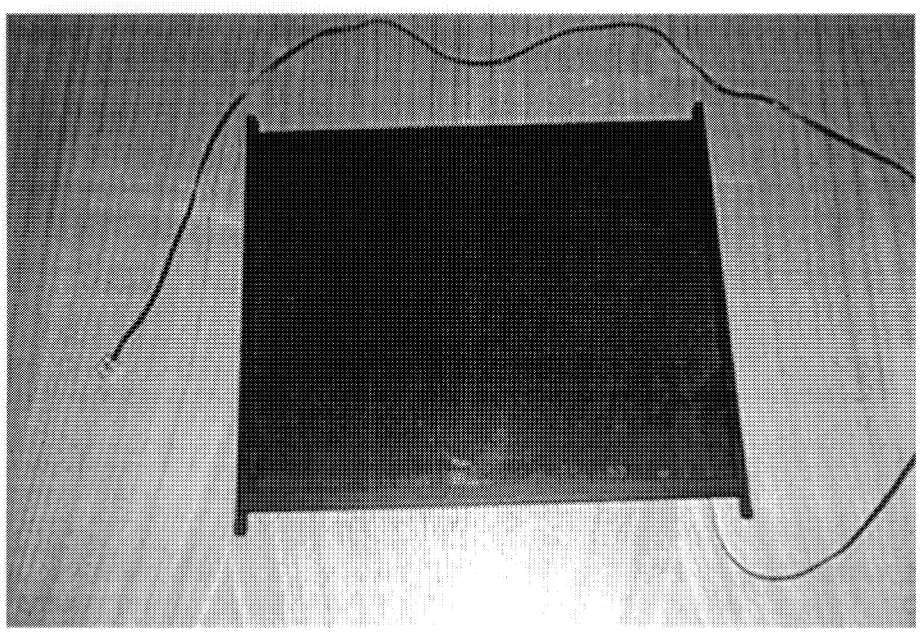


Fig.17. 17" –stereo panel with two LC lays (push-pull modulator)

The value of contrast, transient time and optical efficiency for shutter glasses and panel are contained in Table 1. For nematic LC as a rule T_R is 0,5-0,1 ms depending on value of applied voltage (12-40V), T_D is usually 1,5-3 ms regardless of value of applied voltage (depends on physical properties of LC and thickness of its value).

In practice LC is used in the form of thin (3-6 mkm) layers with nematic molecules oriented by special dopants inside the LC layer or/and treatment of adjacent surfaces forming the gap for the layer. So-called π-cell is the base of LC stereo panel, and $3\pi/2$ super twist nematic cell is used in stereo glasses.

Table 1. Technical parameters of LC stereo glasses and panels.

Technical parameter	Stereo glasses LCDs	Stereo panel LCDs	
		Circular polarization mode	Linear polarization mode
Contrast ratio	70-100 : 1	50-70 : 1	30-40 : 1
Optical transmission in open state	20-25%	25-28%	25-28%
Time $\mathbf{T_{OFF}}$ - of transition from open to closed state	0,3-0,5 ms	0,5 ms	0,15-0,2 ms
Time $\mathbf{T_{ON}}$ of transition from closed to open state	2-2,5 ms	0,5 ms	0,15-0,2 ms

About future 3DS-devices. There under development (on base of double LC layer) wireless stereo glasses having contrast no less than 100:1, optical response time T_{OFF} =T_{ON} = T_R = 0,2-0,5 ms, that is better in compare with CrystalEyes-3 (produced by Stereographics – http://www.stereographics.com), having long T_{OFF} = T_D = 2,5-3 ms. Fast T_{OFF} is highly desirable at high frame rate (120-160 Hz), allowing to eliminate flicker of viewed stereoscopic image. If T_{OFF} = 2,5-3 ms, it will be a drop of contrast in upper part of display screen (about one fourth of screen square at 120 Hz and about one third – at 160 Hz). In case of T_{OFF} =T_{ON} = T_R = 0,2-0,5 ms there is no any drop of contrast at all because such small time is less than the time (about 1 ms) of reciprocal path of electron ray of display.
Also a number of advanced electronic controllers (dongles) are under development to reach automatic recognition of image codes (generated by computer programs) for automatic going to proper 3DS-format.
Also it was discovered lately self-compensating structure in nematic LC layers [5] having contrast K of optical switching about several hundred at the cost of realizing optical memory (time of duration is about ten of milliseconds). Now this effect is under investigation relatively development of high-contrast optical shutter as well for eye-protection application as for 3DS-applications.

5. SOURCES OF STEREOSCOPIC IMAGE

5.1. Simplest and cheapest original method of creating quasi stereoscopic video image [1]
We mean by term “quasi stereoscopic image” (shortly “quasi stereo image”) the some kind of artificial stereo video image obtained from original monoscopic video image with help of some transformation of its geometrical structure allowing to “extract” information about the volume of viewed real scene (shot by monoscopic video camera to get this initial monoscopic video image). We intentionally avoid the term “pseudo stereoscopic image” because it sounds too similar to other term “pseudoscopic image” from the sphere of holography where the last term designates the image with inverse volume (in the sense that the most far points of the true volume object are viewed as the closest points and vise versa).
Such quasi-stereo transformation can be made at any video image (from any source – television type or computer mode).

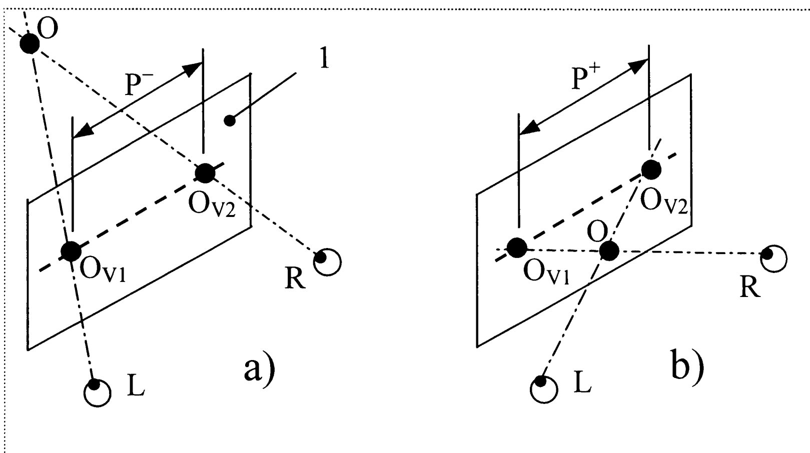


Fig.18. Forming of rear (a) or front (b) image of object O on 2D-screen

What is the natural way of such transformation? As well known, the painter solves the analogous problem trying to represent impression of volume scene on the flat desk. He represents more distant objects in the form of smaller objects and more close objects in the form of larger ones. In another words the painter creates the picture with linear geometrical distortions of size of objects according with their position in real scene relatively the viewer.
Anybody can see that the image shot by the monoscopic video camera contains already all necessary geometrical transformations of the objects due to natural perspective projection of all points of volume scene at the plane of camera photo sensor. But stereoscopic tools provide powerful additional degree of freedom - possibility to create *artificial stereoscopic model of natural space by required geometrical transformation of the value of artificial parallax.* It is very easy to get such model ! Enough to remember that, as a rule, upper part of the picture represents the farthest objects (sky with clouds), lower part - the closest objects (ground), and the middle part of the picture represents middle-distance objects. To perform modeling of such space it is enough to create artificial view (additional monoscopic image) differing from original monoscopic image by the linear-varying parallax (and to provide the simultaneous viewing of both images separately by corresponding eyes). The artificial parallax must has maximum at the top of the screen and the minimum – at the bottom of it. The most nice feature of such simple method is the practical absence of undesirable inclination of the viewed objects because there are preserved initial geometrical proportions of all parts of all objects of

viewed space (only parallax between the objects is subjected here to geometrical transformation). For example, if to make such artificial stereoscopic model of the flat letters running from the bottom to the top in the plane of the screen as a result we will see three-dimensional scene consisting of flat vertically oriented letters running along the inclined plane from closely-distanced bottom to far-distanced top of the scene (Fig.18).

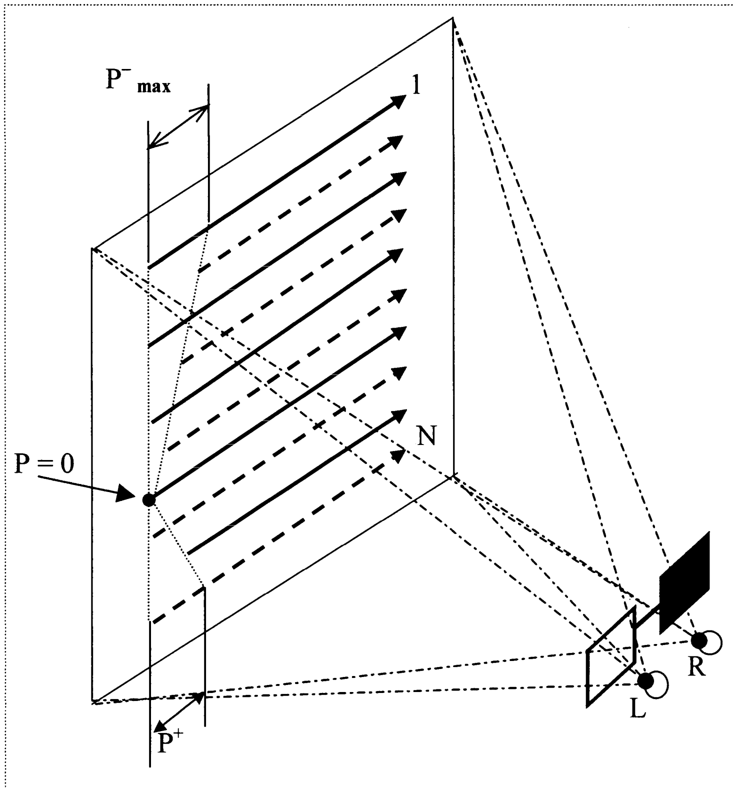


Fig.19. Influence of object position on multilane TV screen for volume scene

If the image carrying natural scenes is subjected by such transformation it will be rather realistic quasi stereoscopic representation of the volume of natural scenes especially impressive in case of dynamic scenes. Consider how to realize this method in electronic display in simplest and cheapest way.

Let to point object O_{V1} corresponds the same point object O_{V2} and both of them are on the same horizontal line (Fig.18). The property of binocular human vision such that if left eye L sees only object O_{V1} and right eye R - only object O_{V2} the human vision perceives the single object O arranged behind the plane 1 of the screen (Fig.18,a). On the contrary if left eye L perceives only object O_{V2} and right eye R - only object O_{V1} the human vision perceives the single object O arranged before the plane 1 of the screen (Fig.18,b). The value P^- of artificial parallax determines the value of perceived depth behind the screen, the value P^+ - the depth before the screen.

In the case of multiline television raster image (Fig.19) the varying the value of artificial parallax from maximum negative value P^-_{max} on the top of the screen to some positive value P^+ on the bottom 0f the screen leads to perceiving of volume scene with the most far object on the top and with closest object on the bottom.

How to realize the linear changing of artificial parallax along the vertical of the screen? The ways of processing information content of initial monoscopic image are suitable but involve analog-digital processing. Alternative method was found [2] on base of simple processing of horizontal sync pulses (see chapter 6.2). If to perform linear varying shift (Fig.19) for lines of odd field (shown by dashed lines) above point P=0 and linear varying shift for lines of even fields (shown by solid lines) the viewer with help of glasses (directed light from odd fields to left L eye and from even fields to right R eye) will see required quasi stereoscopic image (as it shown in Fig.20).

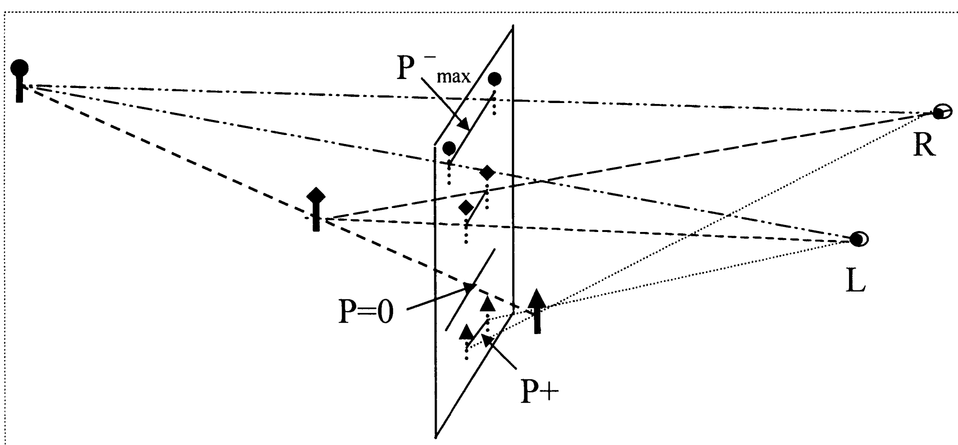


Fig.20. Quasi-stereo image scheme

3DS-video. It is enough to have DVDs in PF format in order to meet requirements of compatibility with computer hardware at the cost of using corresponding software (program DVD player) allowing to transform input PF format in practically any output format – OU, anaglyph (various modes). The most advanced program is freeware stereoscopic player by P.Wimmer (http://mitglied.lycos.de/stereo3d). There are 3DS-DVDs of IMAX (http://www.i-glasses.com/) and DVDs and VHS cassettes by 3DTV Corp. (http://www.3dmagic.com).

3DS in PC-games. In case of nVidia video cards (http://www.nvidia.com) there are the most versatile and quality set of functions – video, games, photography – in PF format because of existence of corresponding stereoscopic driver, allowing to realize true stereoscopic images in several hundred of ordinary most popular PC games. Such possibility is caused by three dimensional modeling of scenes in almost all modern games even in case of outputting of monoscopic image; the last is in essence only the single view of virtual video camera, and going from one image to another one is reached by changing the position of this video camera... The role of stereoscopic driver is to output two views (two monoscopic images) by corresponding manipulation of virtual video camera position. In this case the player will be observe stereoscopic image of the virtual volume world generated by game engine. Attractive 3DS-software is supposed by X3D group (http://www.x3dwolld.com).
For non-nVidia video cards it is developed a stereoscopic driver by E-Dimensional(http://www.edimensional.com), allowing to realize stereoscopic image in OU format.
3DS-photo. In case of nVidia video cards an installation of a corresponding stereoscopic driver is automatically accompanied by installation of nVidia stereoscopic image viewer allowing to view in PF format the stereoscopic pictures stored in files with JPS extension. There is also an interesting freeware stereoscopic picture viewer (by M.Suto – http://www3.zero.ad.jp/esuto/stvmkr/indexe.htm), allowing "on-fly" to transform practically any input stereoscopic format to any output one. Very impressive high-resolution (1280 x 1024) stereo photos (exotic flora and fauna) are proposed on site http://www.virtual-adventure.net. Excellent photos in aviation sphere are in http://really.ru
Some professional applications. Comprehensive review of various professional applications – in site of StereoGraphics. It can be added - in medicine – to physics amblyopia (http://www.amblyopia.ru, http://astro.ru). Neotek group (http://www.neotek.com) proposes various educational programs in the sphere of medicine, cosmos and so on.

6. STEREOSCOPIC DEVICES

6.1. The structure and work of double-LC-layered shutter stereo panel

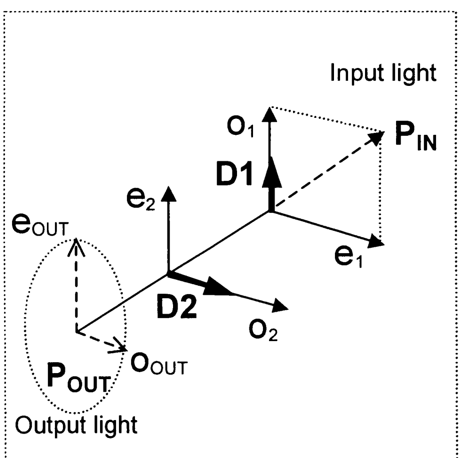


Fig. 21. The principal structure of stereo panel

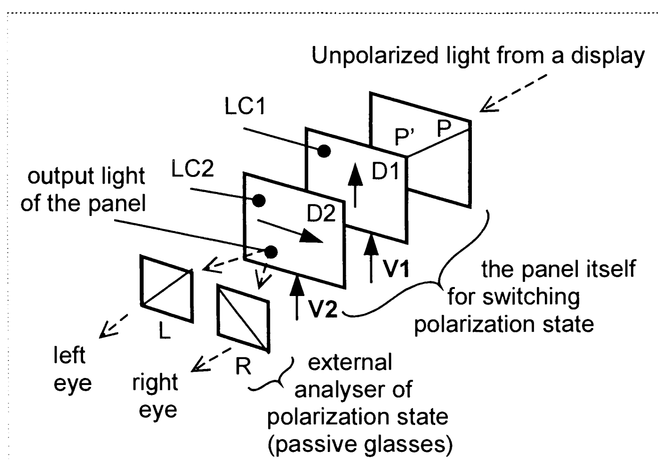


Fig.22. Optical scheme of stereo panel

The principal structure of stereo panel (Fig.21) comprises input polaroid film with polarization axis P-P', the first liquid crystal layer LC1 with optical axis D1, the second liquid crystal layer LC2 with optical axis D2 and two external (relatively the construction of this panel itself) polaroids for analyzing the polarization state of output light. These external polaroids with mutually orthogonal polarization states are arranged in two windows of passive glasses wearing by a user. The case of linear polarizers (as analyzers in passive glasses) is considered for the definiteness although circular polaroids can be used as analyzers at corresponding mode of stereo panel operation whereas linear polarizer always remains as input polaroid film.

The panel works as follows. Input unpolarized light (carrying stereo image in PF format) passes input polaroid film acquiring linear polarization along P-P' axis. D1 and D2 are main crystallographic axes of LC1 and LC2 layers. The output light (after passing both LC layers whose optical states are controlled by applied V1 and V2) will have two possible states of linear polarization one of them coincides with analyzer L (in left window) another one – with analyzer R (in right window). One combination of V1 and V2 leads to passing output light to left window, another combination – to left window, providing separate viewing L_V and R_V of by corresponding eyes of the viewer.
Pointed double-layered structure of LC panel allows to have achromatic transfer function (absence of noticeable color distortion of viewed image), to realize very fast switching of light intensity (with T_R transient time for both fronts of switching) in case of linear output polarization and to realize two mutually orthogonal circular polarization of output light switching with transient time about 0,5 ms.

Achromatic properties are explained by mutual compensation of chromatic dispersion of two LC layers with mutually orthogonal optical axes D1 and D2 (Fig. 22). Input light with linear polarization direction P_{IN} creates inside the LC1 with optical axis D1 two elementary rays – ordinary o_1 and extraordinary e_1. The phase difference $\Delta\varphi_1$ between phase φ_{e1} of extraordinary ray and phase φ_{o1} of ordinary ray determines the polarization state of light after passing LC1.
Chromatic dispersion of LC1 is the dependence of φ_{e1} on light wavelength λ (φ_{o1} is practically not dependent on λ and on voltage V1). The ordinary ray o_1 creates only extraordinary ray o_2 (inside LC2) because of having the same polarization direction. Analogously extraordinary ray o_1 creates only ordinary ray o_2 inside LC2. So the total $\Delta\varphi_2$ of output light contains difference between φ_{e2} and φ_{e1} which is practically zero in case of equal optical properties of LC1 and LC2. So the reason of chromatic dispersion is excluded in such double-layered structure.
Each of LC1 and LC2 is so-called π-cell, i.e. has two values of $\Delta\varphi$ is 0 orπ. At $\Delta\varphi = 0$ output polarization state for each layer is the same as for input light, at $\Delta\varphi = \pi$ output polarization state is orthogonal. It is easy to see that such two-layered structure due to considered mutually compensation (between φ_{e2} and φ_{e1}) does not change the state of output light if to change simultaneously in the same way the values of V1 and V2. For example, when each layer creates π-value of phase shift (at V1=V2=0) or 0 value (at V1=V2=V_{max}) the resulting total phase shift will be equal to 2π or 0 correspondingly so due to equivalency of these values the polarization of output light will not changed if simultaneously to vary each of V1 and V2 from 0 to V_{max}. The polarization state P_{out} of output light will be changed if to vary voltage only at one layer, for example, if at LC1 voltage V1 is varied from 0 to V_{max} remaining the same voltage at another layer (V2=0). Such property allows to realize fast switching of polarization state of output light with transient time T_R (fast reaction time on rising applied voltage) regardless on time T_D (slow decay time of relaxation process of LC layer after removal of applied voltage). The algorithm of corresponding voltage control for both LC layers is illustrated by Fig. 23. It is shown here that slow decay time T_D is excluded from the process of switching (both fronts of outputting optical signal is determined by fast reaction time T_R. The value of T_D limits only the maximum frequency of switching of stereo panel.

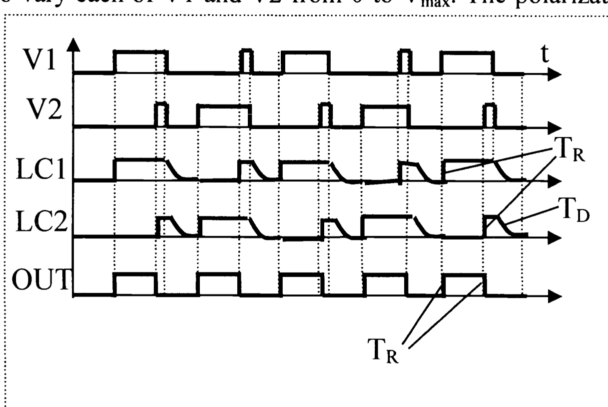


Fig.23. Electrical algorithm (V1&V2) and optical response of stereo panel

LC active stereo glasses always give more contrast (better separation) in compare with stereo panel. The reason is the working of each LC layer (in left and right windows) of stereo glasses only in mutually orthogonal polaroids. In stereo panel its double-LC-layer works in mutually orthogonal polaroids (input polarizer and output analyzer) only for one eye (window) whereas for another eye the LC layer works in parallel polaroids where the contrast is always less because here the closing of the shutter is accomplished at the condition of one unenergetized LC layer (at V1=0) and one energitized LC layer (at V2=V_{max}) to have π phase shift (between e_{out} and o_{out}) to rotate polarization of input light on 90^0 to block the resulting light by an analyzer with polarization axis parallel with input polarizer axis. Absence of voltage (at unenergetized LC layer) leads to disappearing of electrical force providing orientation action on LC molecules. So the sharpness of π value is determined exclusively by the sharpness of initial orientation of LC molecules having some angle dispersion leading to dispersion of π value and as a sequence to decreasing the degree of light blocking by output analyzer. Also such big (maximum) value of phase shift exists only in one LC layer (another LC layer creates 0 phase shift) and it has its own chromatic dispersion also contributes in decreasing the degree of light blocking.

At mutually orthogonal polarizer and analyzer the blocking of light corresponds to both energetized LC layers to have 0 phase shift in order to leave polarization of passing light unchanged to be crossed with analyzer. Presence of $V=V_{max}$ at both LC layers creates strong electric field with proper orientation effect for practically all LC molecules leading to sharp 0 value. Also it is obvious that chromatic dispersion of phase shift value will vanish because of vanishing value of phase shift itself.

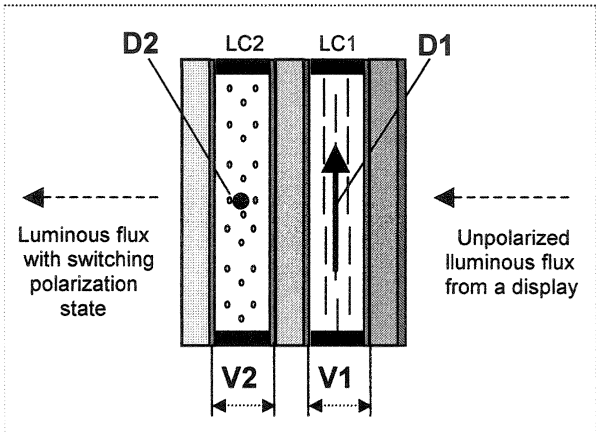


Fig.24. Cross-section of elementary cell of stereo panel

Cross-section of elementary cell of stereo panel is shown in Fig.24. LC layers (6 mkm thickness) are arranged between transparent electrodes ($Sn0_2$ or In_20_3) adhered on surfaces of three glass substrates (each of 1,1 mm thickness). The orientation of nematic LC molecules are determined by special micro grooves made (by mechanical way) on the surfaces of polymer layers adhered on surfaces of transparent electrodes. Each LC molecule has the properties of electrical dipole interacting (changing its orientation) under action of electrical field induced by transparent electrodes under applying of external voltages V1 and V2.

6.2. The way of realization of artificial parallax by shift of line sync pulses

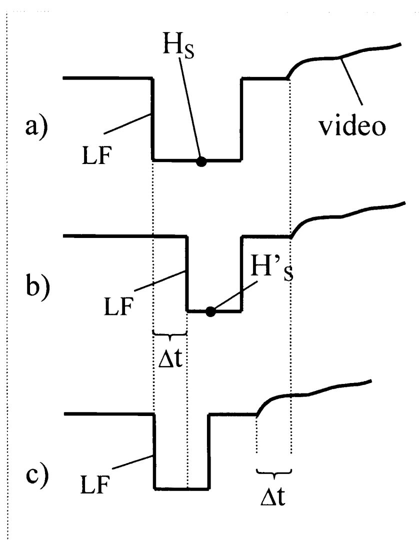


Fig. 25. The mechanism of appearing of parallax between images in odd and even television fields

The mechanism of appearing of parallax between images in odd and even television fields is the following. Video signal on each sweep line in odd television fields is unchanged in compare with initial one (as shown in Fig.25,a). But in even television fields the leading edge (front) LF of each line sync pulse of a video signal is delayed in time on the value Δt relatively initial position of the leading edge of this line sync pulse (Fig. 25,b) by the shortening of this sync pulse. The horizontal sweeping system of any standard television set is synchronized only by the leading edges of line sync pulses. So in even television fields leading front LF goes in the same position as in odd fields (Fig.25,c). As a result, time delay Δt will occur in this case between the information contents of corresponding image lines of odd and even fields.

6.3. 3DS-system with two-ray ERT and stereo panel with moving boundary

The upper ray impinges the phosphor layer over the moving boundary (between two states of polarizations giving by dynamic polarizer), the lower ray – under this boundary. the upper ray scans left image lines simultaneously the lower ray scans right image lines. The boundary moves down with a speed equal to speed of vertical deviation of both rays. The independent reproducing of two images on single screen is provided by choice of vertical separation between the rays according with time of phosphor decay (Fig.26). So the following left image replaces the preceding right image without parasite cross-effects.

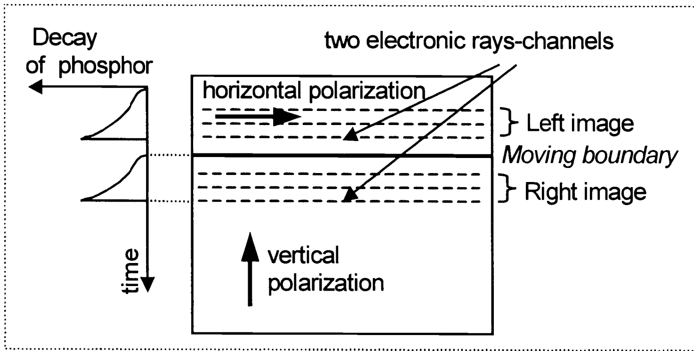


Fig.26. Vertical separation of image between the rays according with time of phosphor decay

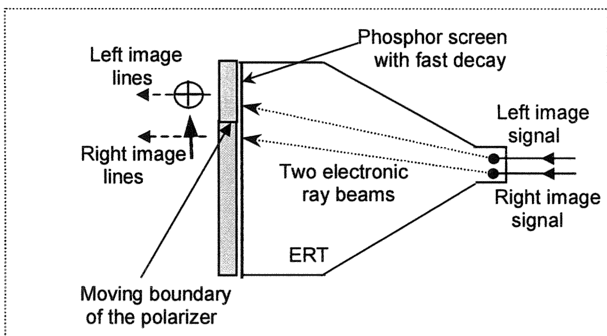


Fig.27. Effect of vertical parallax between left and right images

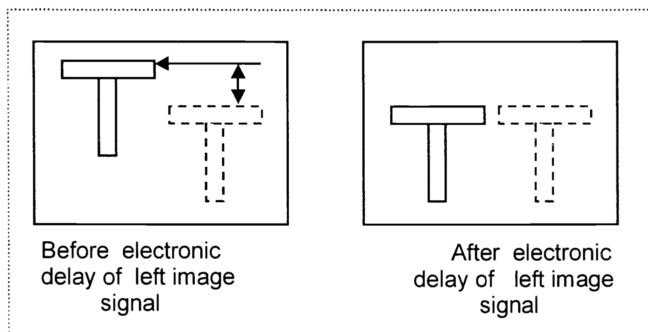


Fig.28 Method of removing of undesirable effect of vertical parallax between left and right images

Naturally it will be vertical parallax between left and right images (Fig.27) if corresponding signals of these images are fed to two inputs of display synchronously. In order to remove this undesirable effect it is enough to delay electronically the signal of left image relatively the signal of right image (Fig. 28).

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