10.4: World's First Full Resolution (at Each View) Auto3D/2D Planar Display Structure Based on Standard LCD Technology

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Abstract

It is described the first autostereoscopic/2D planar liquid crystal (LC) display design with full resolution Q in each view, where Q is the number of pixels in LC display screen.. Each pixel of display matrix carries information about both (left L and right R) image views: the sum of L and R views is presented by the value of light intensity in each pixel, the ratio of amplitudes of L and R views is coded by light elliptical polarization state. Phase-polarization electronically switchable parallax barrier is used for directly analyzing (decoding) the encoded polarization state of each pixel. The subsequent visualization of such polarization decoding with help of continuous polarization analyzer sheet corresponds to forming two separate (L and R) observing in space.

1. Previous Auto3D display designs

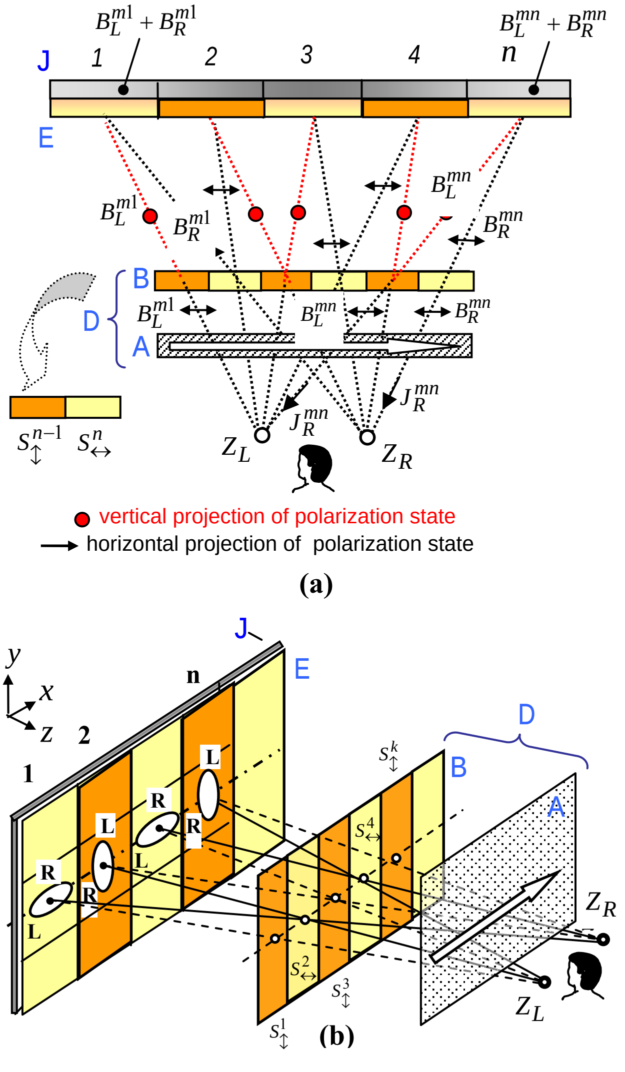
There are well-known autostereoscopic (auto3D) displays with amplitude parallax barriers or lenticular lenses. All of them direct the light from one group of display pixels to one eye of the observer and the light from another group – to another eye. So in the case of two displayed views (L and R) of 3D scene the spatial resolution of each view is $Q/2$, where Q is the total number of display pixels. Resolution is decreased in one direction so it is impossible to preserve standard ratios (4:3 or 16:9) for 3D video or computer images while using standard display matrices for presenting both views. Using slanted lenticular lenses or oblique amplitude parallax barriers overcomes the problem of obtaining the correct ratio. But such methods can work only in case of multi-view 3D image, where the resolution for each view is equal to Q/K, where K is the number of views. For of precise 3D computer modeling (CAD, CAM) it is necessary to have lines with high resolution, in all office applications the text is frequently presented by lines with width as one pixel. So such text or line cannot be correctly reproduced with full resolution. Also it is problematic to switch off the amplitude parallax barrier or lenticular lenses, as all existing suggestions of electrically switchable lenses require additional research.

Known 3D displays with full resolution in each view can work only with help of glasses [1,2]. Autostereoscopic displays with full-screen resolution for each view, suggested in [3], cannot be made in the form of planar structures because field lenses with distantly disposed light sources are used inside the display structure, such schema are more suitable for video projection.

It is highly desirable to have glasses-free universal display, combining auto3D, 3D with glasses and 2D modes and means to achieve this is described in this paper.

2. Novel Autostereoscopic Display Layout

The scheme is shown in **Fig.1**, where the top part **(a)** of the drawing corresponds to (x, y) cross-section of the whole display structure illustrated by the bottom part **(b)**. Matrix **J** is an intensity matrix, forming in its $mn-$th pixel the sum $B_L^{mn}+B_R^{mn}$ of $mn-$th resolvable elements of both views. Matrix **E** is a polarization encoding matrix, performing modulation of light polarization state according with the ratio of the two views B_L^{mn}/B_R^{mn} in each display pixel. Such simultaneous encoding of



Фиг.1 Autostereoscopic display structure

(a) – cross-section on the level of m -th row,

(b) – isometric view.

L and R views in joint elliptical polarization state allows us to obtain their independent presentation in the first and the second mutually orthogonal polarization components P_L and P_R of the elliptical polarization. It is essentially that the polarization components P_L^n and P_R^{n-1} (in adjacent columns of the matrix **E**) be interchanged. In another words, elliptical polarization states in adjacent columns of the encoding matrix **E** are complementary (mutually orthogonal) relatively the encoded L and R views. Such condition is necessary for subsequent spatial polarization decoding fulfilled by a static columnar phase-polarization parallax barrier **B** The phase-polarization parallax barrier **B** is characterized by mutually orthogonal states $S_{\updownarrow}^{n-1}$ and $S_{\leftrightarrow}^{n}$ of optical anisotropy in its adjacent ($n-1$ and n) columns. The optical anisotropy can be a birefringence and/or an optical activity (alone or in combination). The pure birefringence leads to optical retardation $\Delta\delta$, the pure optical activity corresponds to optical rotation of polarization ellipse circumference on angle $\Delta\varphi$ without changing this circumference, where $\Delta\delta = \delta_o - \delta_e$ and δ_o , δ_e are phase factors for ordinary o and extraordinary e rays in birefringence media (plate), $\Delta\varphi = \varphi_1 - \varphi_2$, where φ_1 and φ_2 are the initial and resulting angles of the rotated polarization ellipse circumference. The optical retardation and/or optical activity have signal-controlled $\Delta\delta_s^{mn}$ and $\Delta\varphi_s^{mn}$ values if they used in encoding matrix **E.** The controlling signal s, feeding to the electronic input of the encoding matrix **E**, carries information about the ratio B_L^{mn} / B_R^{mn} .

The polarization analyzer **A** is a polarization filter which passes light fluxes with one polarization state (with $S_{\leftrightarrow}^{n}$ state) and rejects light fluxes with another ($S_{\updownarrow}^{n-1}$) polarization state. Thus, if the input light flux has elliptical polarization with mutually orthogonal components $S_{\updownarrow}^{n-1}$ and $S_{\leftrightarrow}^{n}$, the output light flux (behind the polarization analyzer **A**) will be a light flux with polarization state $S_{\leftrightarrow}^{n}$ only.. The polarization analyzer **A** has the same polarization state for all display pixels. i.e. it can be fulfilled as an uniform polarization analyzer sheet. The parallax barrier **B** and polarization analyzer **A** together comprise the polarization decoder **D** which forms two observation zones Z_L and Z_R for left and the right views accordingly. It is important that the hollow arrow on the plane of the polarization analyzer **A** designates the generalized polarization selection direction and can correspond to any kind of selection polarization filter including linear, circular, elliptical polarization one. The kind of the polarization analyzer **A** depends on the nature of polarization modulation in encoding matrix **E** and on initial conditions of this polarization modulation

The formal description of separate observation of left L and right R views in corresponding viewing zones is as follows. Each of left L and right R views has $Q = M \ x \ N$ resolvable elements and each of matrices **J** and **E** has $Q = M \ x \ N$ pixels where $m = 1, 2, \ldots, M$; $n = 1, 2, \ldots, N$ . . and M , N - numbers of rows and columns in each matrix.. The separate elementary light fluxes, reaching left and right viewing zones Z_L and Z_R, are designated J_L^{mn} and J_R^{mn}. These light fluxes should be equal to elementary luminosities B_L^{mn} and B_R^{mn}. We use the summary reproduction of L and R views in a single display pixel of intensity matrix **J**

$$J_o^{mn} = J_L^{mn} + J_R^{mn} = B_L^{mn} + B_R^{mn} \ ., \qquad (1)$$

where J_o^{mn} is the total intensity of light flux originated from $mn-$th pixel of the matrix **J**. viewing Proportionality constants are omitted in equation (1) for simplicity. The polarization encoding by the matrix **E** is made according with the condition

$$J_L^{mn} / J_R^{mn} = B_L^{mn} / B_R^{mn} \ . \qquad (2)$$

From two algebraic equations the desired condition (of mutual separation of L and R views) follows

$$J_L^{mn} \square B_L^{mn} \ ; \qquad J_R^{mn} \square B_R^{mn} \qquad (3)$$

In order to meet condition (2) it is necessary to find the proper form of controlling signal s which, in turn, gives the corresponding values of $\Delta\delta_s^{mn}$ and $\Delta\varphi_s^{mn}$ in the encoding matrix **E**. First it is necessary to define the values of $\Delta\delta_s^{mn}$ and $\Delta\varphi_s^{mn}$ as the desired encoding functions allowing to meet condition (2). Then, from knowing the relation between the values of $\Delta\delta_s^{mn}$ and $\Delta\varphi_s^{mn}$ and s values, the required form of s is calculated.

The procedures of finding $\Delta\delta_s^{mn}$ and $\Delta\varphi_s^{mn}$ from solving general equation of light polarization and the choice of polarization analyzer kind are described in [2,4,5]. Here we present two characteristic examples of using concrete anisotropic effects in encoding matrix **E** and phase-polarization parallax barrier **B** with choice of corresponding kinds of polarization analyzer **A** for each case.

2.1. Encoding by Controlled Phase Shift (Birefringence) $\Delta\delta_s$

Set the anisotropic media in encoder matrix **E** as a birefringent layer with controlled phase shift $\Delta\delta_s^{mn}$ **(Fig. 2)** that is adjacent to a linear polarizer sheet (the latter can be polarization analyzer of the intensity matrix **J**)..The polarization state of the light, leaving pixels of the encoder matrix **E,** corresponds to an elliptical polarization whose form (ellipse circumference) is determined by the controlled phase shift $\Delta\delta_s^{mn}$. The $k-$column of phase parallax barrier **B** has zero value of phase shift δ^k , the $k-1$ column has phase shift $\delta^{k-1} = \pi$. ($k = 1, .. K$, where K is the number of parallax barrier columns) The polarization analyzer **A** is a circular polarization filter that passes light components with counterclockwise rotation and rejects light components with clockwise rotation The polarization state of light after $m(n-1)$ pixel corresponds to elliptical polarization with

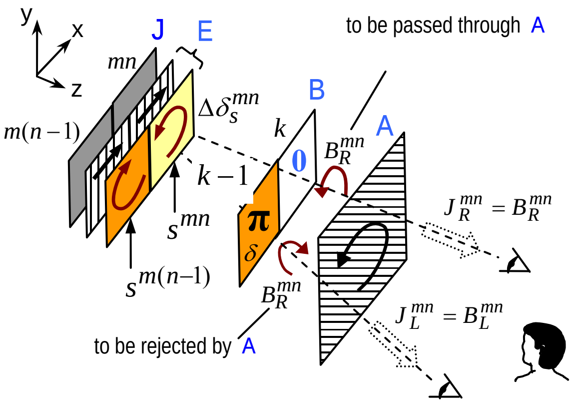


Fig.2 Phase shift in encoding and decoding

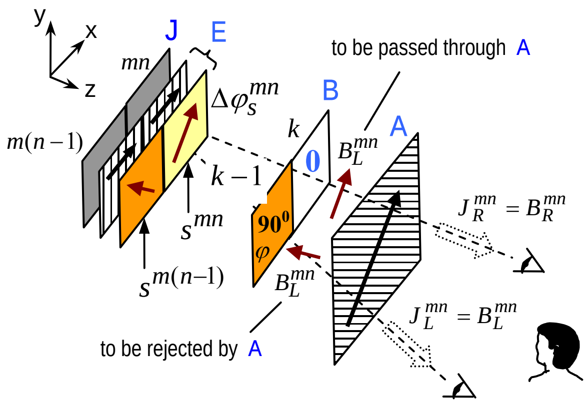


Fig.3 Optical rotation in encoding and decoding

clockwise rotation. Behind the k-th column of phase parallax barrier **B**, the luminosity B_R^{mn} polarization preserves initial counterclockwise rotation so passes through the analyzer A and goes to the right observation zone Z_R. The same B_R^{mn} after passing through the ($k-1$)-th column of barrier **B** gets clockwise rotation so is rejected by analyzer **A**,

The light flux with luminosity $B_R^{m(n-1)}$ after $m(n-1)$ pixel of matrix E is characterized by clockwise polarization rotation (opposite to rotation of B_R^{mn}) . The light flux with luminosity $B_R^{m(n-1)}$ does not change its polarization rotation direction behind the k-th column of barrier B so $B_R^{m(n-1)}$ is passed through the analyzer **A** and goes to the right viewing zone Z_R. The light flux with $B_R^{m(n-1)}$ is rejected by the analyzer A on the optical path to the left observation zone Z_L because light with $B_R^{m(n-1)}$ behind the $k-1$ column of barrier **B** gets opposite polarization rotation. Analogously, light flux with B_L^{mn} goes to the left observation zone Z_L and light flux with $B_L^{m(n-1)}$ is rejected by analyzer A on the optical paths to the right observation zone Z_R .

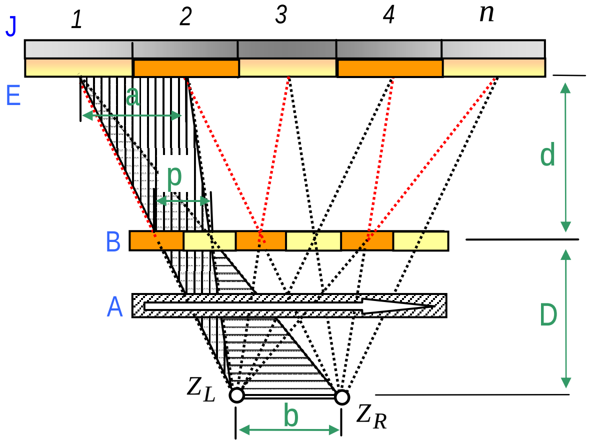
2.2. Encoding by Controlled Optical Activity (Optical Rotation) $\Delta\varphi_S$

Set the anisotropic media in encoder matrix **E** as an optical activity layer with controlled optical rotation $\Delta\varphi_S^{mn}$ (**Fig. 3**).

The polarization state of the light, leaving pixels of the encoder matrix **E**, corresponds to linear polarization with various directions defined by $\Delta\varphi_S^{mn}$ values. . The k–column of phase parallax barrier **B** has zero value of optical rotation $\Delta\varphi^k$, the $k-1$ column gives optical rotation $\Delta\varphi^{k-1} = 90^0$. The polarization selection in this case is analogous to polarization

2.3. Geometry of a Planar Structure Autostereoscopic Display

The suggested display has planar structure due to the fact that the required distance **d** (**Fig. 4**) between the encoder matrix E and the parallax barrier B (polarization analyzer A is small, and the polarization analyzer **A** can be disposed in immediate proximity from the parallax barrier B). Let us paper, refer to citations by numbers in brackets like this **Fehler! Verweisquelle konnte nicht gefunden werden.**, evaluate the required value of distance **d**, taking into account that **D** – the distance from the observer before the display structure, **a** – period of pixel location in matrices J and E, **p** –period of column location in parallax barrier B, **b** – interocular base (the distance between the centers of an observer's eyes).



Фиг.4 Basic geometrical parameters of the display structure.

From the triangular (**Fig. 4**) with vertical hatching the algebraic ratio follows

$$\frac{a}{p} = \frac{d+D}{D} \qquad (4)$$

From the triangular with horizontal hatching

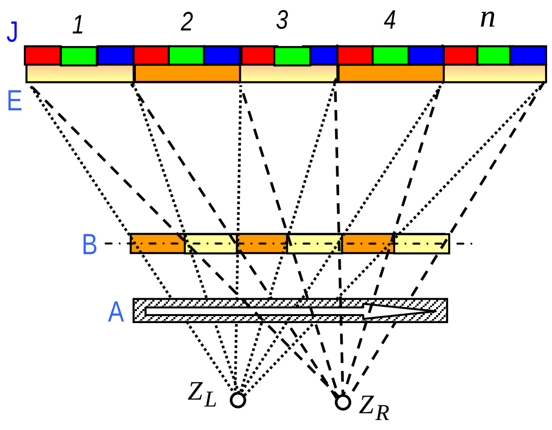
$$\frac{b}{p}=\frac{D+d}{d} \qquad (5)$$

From equations (4) and (5)

$$\frac{D}{d}=\frac{b}{a}\,. \qquad (6)$$

Let us select the following values for the parameters: **D** = 1500 mm, **b** = 65 mm, **a** = 0,25 mm. From (6) **b** = Da/b = **5,76** mm. Thus, the suggested display structure is indeed the planar one.

The color version of the display structure can use R, G, B elements **(Fig. 5)** each with independent electronic control according with corresponding color components of video signal (carrying information about the views of 3D scene). One and the same column of parallax barrier **B** for this triad of color elements since the latter is considered one full-color display pixel.



Фиг.5 Color-image version of the display structure.

Time-sequential color reproduction in one display pixel can also be implemented, giving the maximum spatial resolution in displayed views.

3. Using Standard LCD Technology

LC matrices are the best choice for polarization encoder matrix **E** because the majority of commerce LC displays is based on using optical activity and/or birefringence for image formation via modulation of light polarization; so polarization modulation is a native modulation for LC matrices. Thus, it is enough to remove polarization filters from standard LC displays to obtain polarization encoding matrix **E**. The LC $\pi-$cell [6] or VA-mode LC cell are the perfect optical retarders. The LC twist cell [7] is a perfect optical rotator for input light with linear polarization. Such LC structures can be used in encoding matrix **E**. Switchable phase-polarization parallax barrier **B** has a simpler structure because it is column-addressed only (not a matrix-addressed one) and functions as a static device (it is enough to use constant value of bias voltage to the electrical inputs of the columns). Moreover, if it is regarded a satisfactory to have not switchable parallax barrier **B**, it can be made in the form of passive sheet of anisotropic material with initial complementary optical properties in adjacent columns (for example, in the form of polymer LC) or even without LC if one makes parallax barrier in the form of orthogonally alternating stripes of polarization material.

The LC $\pi-$cell can be used as the work medium in phase-polarization parallax barrier **B**, since the $\pi-$cell can work correctly (its performance can be calculated analytically) with arbitrary state of elliptical polarization (with arbitrary ellipse circumference) in light arriving from the encoding matrix **E**. Using a twist-cell in phase-polarization parallax barrier **B** is complicated by the fact that a LC twist-structure has easily predicted (analytically calculated) performance only at two definite states of polarization in incident light: namely, a linear polarization with direction coinciding with the direction (or orthogonal to it) of the surface LC molecules from the nearest (i.e. nearest to the incident light) side of LC layer. It is possible to solve this problem by using the linear system theory [8].

It is important that a display matrix of any type can be used as intensity matrix **J** because there are no any special requirements to the algorithm of intensity image formation including time response. Naturally, for sake of technology matching it is the best to use LC matrices as intensity matrix **E** also. However, using, for example, OLED displays for this purpose is very attractive (especially for mobile 3D/2D displays, for example, for cell phones).

4. Referencies

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