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(54) **COMPENSATORS FOR LIQUID CRYSTAL DISPLAYS AND THE USE AND MANUFACTURE OF THE COMPENSATORS**

(75) Inventors: **Richard C. Allen**, Lilydale, MN (US);
                Thomas Bachels, Grenzach-Wyhlen
                (DE); **Jurg Funfschilling**, Basel (CH);
                Martin Schadt, Seltisberg (CH);
                Hubert Seiberle, Weil am Rein (DE)

    Correspondence Address:
    3M INNOVATIVE PROPERTIES COMPANY
    PO BOX 33427
    ST. PAUL, MN 55133-3427 (US)

(73) Assignees: **3M Innovative Properties Company**;
                Rolic AG

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(57)   **ABSTRACT**

Compensation of a liquid crystal display can be achieved using a compensation structure, having, in the following order: a) a first o-plate; b) a first retarder; c) a liquid crystal cell; d) a second retarder; and e) a second o-plate. The first and second retarders can be c-plates or biaxial retarders.
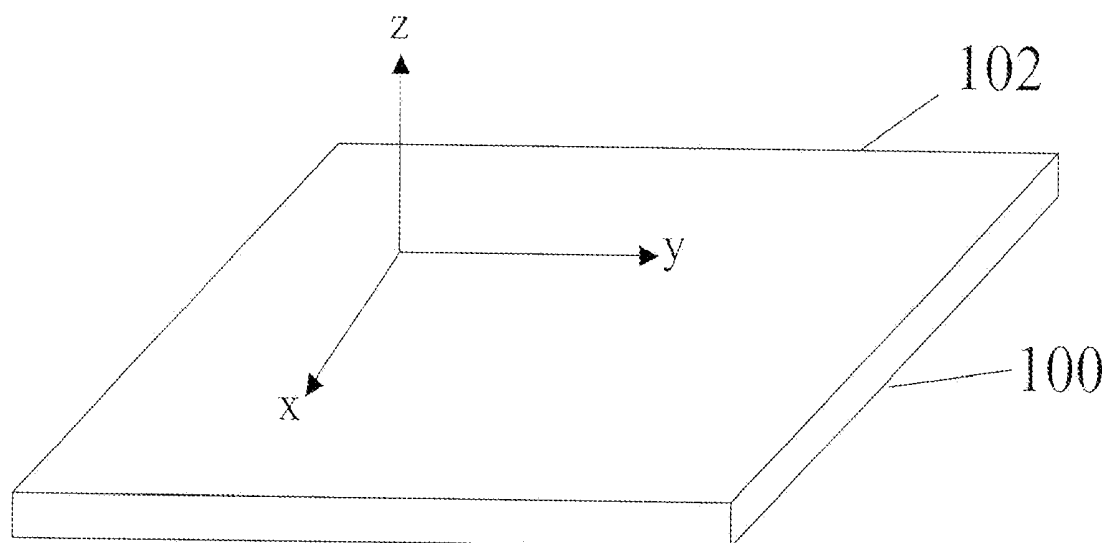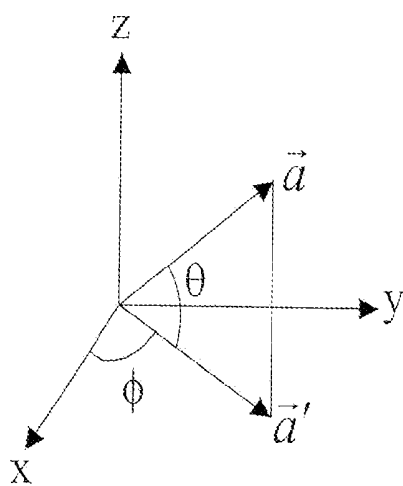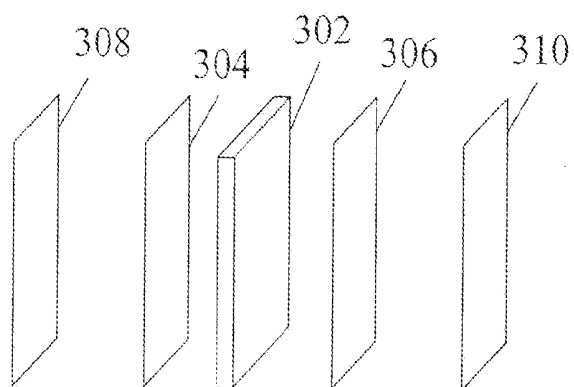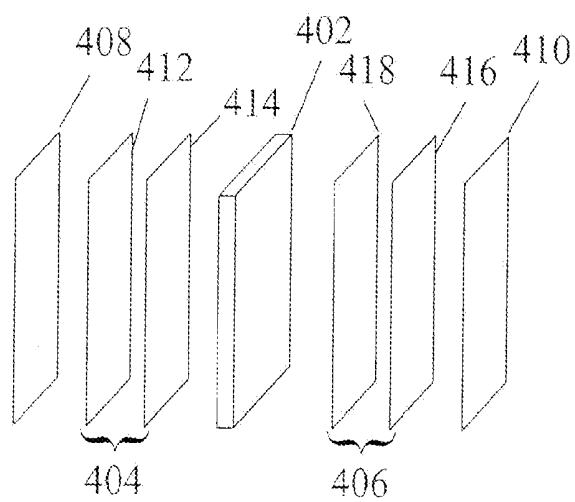
Fig. 1

Fig. 2

308   304   302   306   310

Fig. 3

408   412   402   418   416   410

414

404   406

Fig. 4

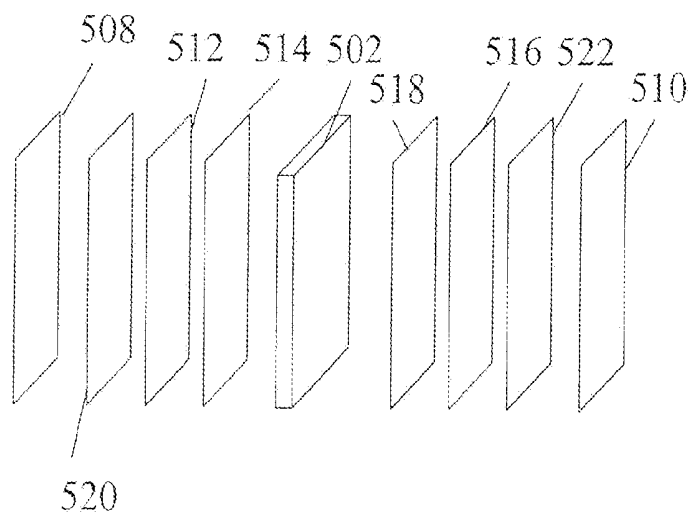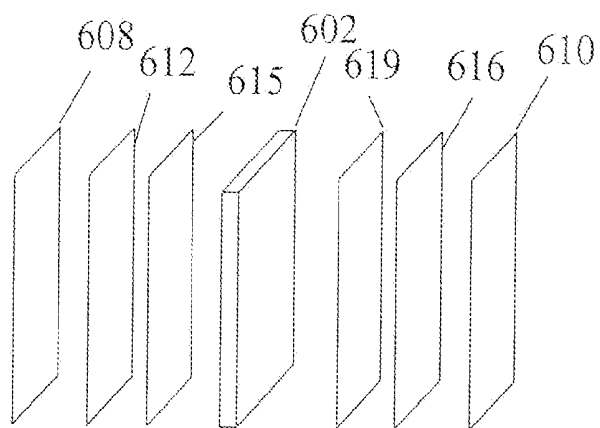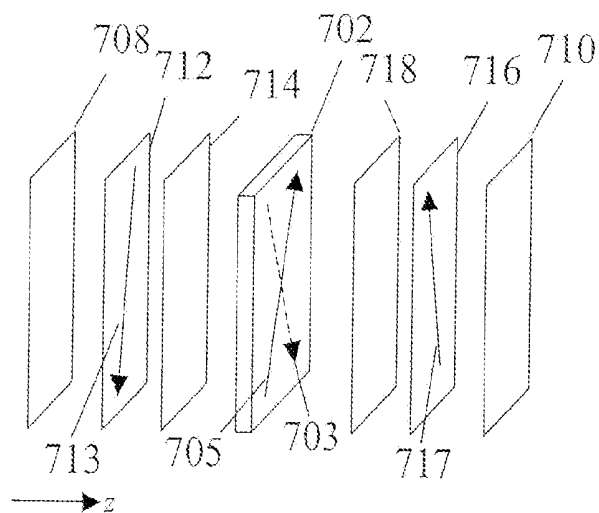508   512   514   502   516   522   510
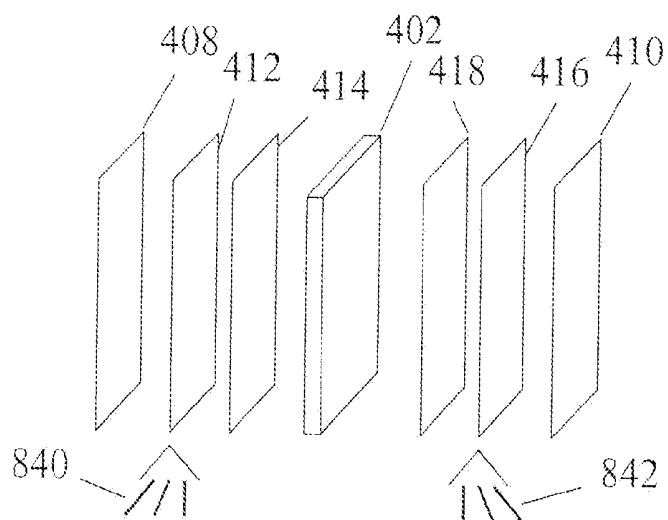
518

520

Fig. 5

Fig. 6

Fig. 7

Fig. 8

COMPENSATORS FOR LIQUID CRYSTAL DISPLAYS AND THE USE AND MANUFACTURE OF THE COMPENSATORS

RELATED APPLICATION

[0001] This application is a continuation of U.S. application Ser. No. 11/005,933, filed Dec. 6, 2004, now allowed, which is a continuation of U.S. application Ser. No. 10/123, 646, filed Apr. 16, 2002, now issued as U.S. Pat. No. 6,919,946 on Jul. 19, 2005, the disclosure of which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] Twisted nematic (TN) liquid crystal displays have inherently narrow and non-uniform viewing angle characteristics. Such viewing angle characteristics can describe, at least in part, the optical performance of a display. Characteristics such as contrast, color, and gray scale intensity profile can vary substantially in uncompensated displays for different viewing angles. There is a desire to modify these characteristics from those of an uncompensated display to provide a desired set of characteristics as a viewer changes positions horizontally, vertically, or both and for viewers at different horizontal and vertical positions. For example, in some applications there may be a desire to make the viewing characteristics more uniform over a range of horizontal or vertical positions.

[0003] The range of viewing angles that are important can depend on the application of the liquid crystal display. For example, in some applications, a broad range of horizontal positions may be desired, but a relatively narrow range of vertical positions may be sufficient. In other applications, viewing from a narrow range of horizontal or vertical angles (or both) may be desirable. Accordingly, the desired optical compensation for non-uniform viewing angle characteristics can depend on the desired range of viewing positions.

[0004] One important viewing angle characteristic is the contrast ratio between the bright state and the dark state of the liquid crystal display. The contrast ratio can be affected by a variety of factors including, for example, leakage of light at different viewing angles.

[0005] Another viewing angle characteristic is the color shift of the display with changes in viewing angle. Color shift refers to the change in the color coordinates (e.g., the color coordinates based on the CIE 1931 standard) of the light from the display as viewing angle is altered. Color shift can be measured by taking the difference in the chromaticity color coordinates (e.g., Δx or Δy) at an angle normal to the plane containing the screen and at any non-normal viewing angle or set of viewing angles. The definition of acceptable color shift is determined by the application, but can be defined as when the absolute value of Δx or Δy exceeds some value, for example, exceeds 0.05 or 0. 10. For example, it can be determined whether the color shift is acceptable for a desired set of viewing angles. Because the color shift may depend upon the voltage to any pixel or set of pixels, color shift is ideally measured at one or more pixel driving voltages.

[0006] Yet another viewing angle characteristic that can be observed is substantial non-uniform behavior of gray scale voltage changes and even the occurrence of gray scale inversion. The non-uniform behavior occurs when the angular dependent transmission of the liquid crystal layer does not monotonically follow the voltage applied to the layer. Gray scale inversion occurs when the ratio of intensities of any two adjacent gray levels approaches a value of one, where the gray levels become indistinguishable or even invert. Typically, gray scale inversion occurs only at some viewing angles.

[0007] Compensators have been proposed to address these issues. One concept includes a compensator film made of discotic molecules. One drawback of current discotic compensators is the typical occurrence of comparatively large color shifts. Other concepts include specific combinations of birefringent layers. There is a need for new compensator structures to provide improved or desired viewing angle characteristics.

SUMMARY OF THE INVENTION

[0008] Generally, the present invention relates to optical compensators for displays, such as liquid crystal displays, as well as the displays and other devices containing the optical compensators and methods of making and using the optical compensators, displays, and other devices.

[0009] One embodiment is a liquid crystal display, having, in the following order: a) a first o-plate having a first azimuthal orientation; b) a first c-plate; c) a liquid crystal cell; d) a second c-plate; and e) a second o-plate having a fourth azimuthal orientation. The liquid crystals at the rear surface of the liquid crystal cell have a second azimuthal orientation and the liquid crystals at the front surface of the liquid crystal cell have a third azimuthal orientation. The first, second, third and fourth azimuthal orientations are disposed in a helical arrangement.

[0010] Another embodiment is a liquid crystal display, having, in the following order: a) a first o-plate; b) a first retarder; c) a liquid crystal cell; d) a second retarder; and e) a second o-plate. At least one of the first and second retarders is a biaxial retarder. The other of the first and second retarders can be, for example, a biaxial retarder or a c-plate.

[0011] Yet other embodiments include methods for the compensation of liquid crystal displays. These methods include directing light through one of the liquid crystal display compensation structures described above.

[0012] The above summary of the present invention is not intended to describe each disclosed embodiment or every implementation of the present invention. The Figures and the detailed description which follow more particularly exemplify these embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

[0014] FIG. 1 is a schematic illustration of a coordinate system with an optical element;

[0015] FIG. 2 is a further schematic illustration of the coordinate system;

[0016] FIG. 3 is a schematic perspective view of a liquid crystal display compensation structure;

[0017]   **FIG. 4** is a schematic perspective view of a first embodiment of a liquid crystal display compensation structure according to the invention;

[0018]   **FIG. 5** is a schematic perspective view of a second embodiment of a liquid crystal display compensation structure according to the invention;

[0019]   **FIG. 6** is a schematic perspective view of a third embodiment of a liquid crystal display compensation structure according to the invention;

[0020]   **FIG. 7** is a schematic perspective view of a fourth embodiment of a liquid crystal display compensation structure according to the invention; and

[0021]   **FIG. 8** is a schematic perspective view of a fifth embodiment of a liquid crystal display compensation structure according to the invention.

[0022]   While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0023]   The present invention is believed to be applicable to optical compensators for displays, such as liquid crystal displays, as well as the displays and other devices containing the optical compensators and methods of making and using the optical compensators, displays, and other devices. While the present invention is not so limited, an appreciation of various aspects of the invention will be gained through a discussion of the examples provided below.

[0024]   The optical compensators can be formed using a variety of different optical elements. Among these optical elements are o-plates, c-plates, a-plates, biaxial retarders, twisted retarders, and other retarders. Information regarding o-plates, c-plates, and a-plates can be found, for example, in Yeh et al., *Optics of Liquid Crystal Displays*, John Wiley & Sons, New York (1999), U.S. Pat. Nos. 5,504,603, 5,557, 434, 5,612,801, 5,619,352, 5,638,197, 5,986,733, and 5,986, 734, and PCT Patent Applications Publication Nos. WO 01/20393 and WO 01/20394, all of which are incorporated herein by reference.

[0025]   The optical elements are configured in combinations as described below to form optical compensators. **FIG. 1** illustrates an axis system for use in describing the optical elements. Generally, for display devices, the x and y axes correspond to the width and length of the display and the z axis is typically along the thickness direction of the display. This convention will be used throughout, unless otherwise stated. In the axis system of **FIG. 1**, the x axis and y axis are defined to be parallel to a major surface **102** of the optical element **100** and may correspond to length and width directions of a square or rectangular surface. The z axis is perpendicular to that major surface and is typically along the thickness direction of the optical element. A vector a (such as an optical axis) in this coordinate system can be characterized, as illustrated in **FIG. 2**, by an azimuthal angle ϕ,

corresponding to the angle at which the vector deviates from the x axis in the x-y plane, and a tilt angle θ, corresponding to the angle at which the vector deviates from the x-y plane.

[0026]   The term "front", as it relates to any of the optical elements described below, shall refer to the side of the optical element that, when in a display device, is nearest to the viewer. The term "rear", as it relates to any of the optical elements described below, shall refer to the side of the optical element that, when in a display device, is opposite to the front of the optical element and typically the furthest from the viewer. For convenience, the convention in the Figures has the front as the right-most side of the optical elements.

[0027]   A "c-plate" denotes a birefringent optical element, such as, for example, a plate or film, with a principle optical axis (often referred to as the "extraordinary axis") substantially perpendicular to the selected surface of the optical element. The principle optical axis corresponds to the axis along which the birefringent optical element has an index of refraction different from the substantially uniform index of refraction along directions normal to the principle optical axis. As one example of a c-plate, using the axis system illustrated in **FIG. 1**, $n_x = n_y \neq n_z$, where n_x, n_y, and n_z are the indices of refraction along the x, y, and z axes, respectively. The optical anisotropy is defined as $\Delta n_{zx} = n_z - n_x$.

[0028]   A variety of materials and methods can be used to make c-plates. For example, positively birefringent c-plates (where Δn_{zx} is greater than zero) can be formed using vertically-aligned films of rodlike molecules, such as, for example, positive optical anisotropy liquid crystals. Uniaxially compressed materials can also be used to make c-plates. Examples of suitable negatively birefringent c-plate materials (Δn_{zx} less than zero) include cellulose triacetate (available from, for example, Fuji Photo Film Co. (Tokyo, Japan), Konica Corp. (Tokyo, Japan), and Eastman Kodak Co. (Rochester, N.Y.)), polycarbonate (available from General Electric Plastics), acrylic polymers, and polyesters including polyethylene terephthalate, polyethylene naphthalate and the like. Negative c-plates can also be realized by using twisted a-plates, for example, rodlike molecules with a very high helical twisting power as described by H. Seiberle et al., Eurodisplay '99 Digest, 121-125 (1999). Furthermore, untilted discotic molecules may be used to generate a negative c-plate.

[0029]   An "o-plate" denotes a birefringent optical element, such as, for example, a plate or film, having its principle optical axis tilted with respect to the surface of the optical element.

[0030]   An o-plate can be made by a variety of methods and using a variety of materials. For example, an o-plate can be formed using a liquid crystal material disposed on an alignment layer, where the alignment layer induces a pretilt in the liquid crystal material. As one example, a liquid crystal polymer (LCP) can be used, such as a liquid crystal polymer having vitrified, polymerized, or cross-linked liquid crystal moieties. Examples of suitable materials include polymerizable liquid crystal materials, which are well known to those skilled in the art. Examples of such materials and methods of making and using the materials can be found in, for example, U.S. Pat. Nos. 5,567,349, 5,650,534, and 5,978,055, European Patent Application Publication No. 331233, and PCT Patent Applications Publication Nos.

95/24454, 00/04110, 00/07975, 00/48985, 00/55110, and 00/63154, all of which are incorporated herein by reference. Examples of other suitable materials include discotic materials as disclosed in, for example, European Patent Application Publication Nos. 646829 and 656559, both of which are incorporated herein by reference. In one embodiment, the liquid crystalline polymer is aligned during manufacture by a photoorientation technique, which is able to induce a predetermined tilt angle in the subsequently deposited polymerizable liquid crystal. Among the different known methods, particularly well suited are methods that use linear photopolymerization (LPP) materials, also sometimes referred to as photooriented polymer networks (PPN). Examples and manufacture of such materials and structures are disclosed in, for example, U.S. Pat. Nos. 5,389,698, 5,838,407, and 5,602,661, European Patent Applications Publication Nos. 689,084 and 756,193, and PCT Patent Applications Publication Nos. 99/49360, and 99/64924, all of which are incorporated herein by reference.

[0031] An "a-plate" denotes a birefringent optical element, such as, for example, a plate or film, having its principle optic axis within the x-y plane of the optical element. Positively birefringent a-plates can be fabricated using, for example, uniaxially stretched films of polymers such as, for example, polyvinyl alcohol, or uniaxially aligned films of nematic positive optical anisotropy LCP materials. Negatively birefringent a-plates can be formed using uniaxially aligned films of negative optical anisotropy nematic LCP materials, including for example discotic compounds.

[0032] A "biaxial retarder" denotes a birefringent optical element, such as, for example, a plate or film, having different indices of refraction along all three axes (i.e., $n_x \neq n_y \neq n_z$). Biaxial retarders can be fabricated, for example, by biaxially orienting plastic films. Examples of biaxial retarders are discussed in U.S. Pat. No. 5,245,456, incorporated herein by reference. Examples of suitable films include films available from Sumitomo Chemical Co. (Osaka, Japan) and Nitto Denko Co. (Osaka, Japan). In plane retardation and out of plane retardation are parameters used to describe a biaxial retarder. As the in-plane retardation approaches zero, then the biaxial retarder element behaves more like a c-plate. Generally, a biaxial retarder, as defined herein, has an in-plane retardation of at least 3 nm for 550 nm light. Retarders with lower in-plane retardation are considered c-plates.

[0033] The range or solid cone of desired viewing angles can be manipulated depending upon the exact nature of the application. For example, in some embodiments, it is desirable to have a large solid angle of acceptable viewing. In other embodiments, it is desirable to strictly control the range of acceptable viewing (for example, for privacy purposes) to a narrower range of angles than is normally associated with an uncompensated display.

[0034] In one embodiment, brightness and contrast are generally enhanced and color shifts and gray scale inversion are generally reduced for a range of horizontal viewing angles relative to an uncompensated display. In another embodiment, brightness and contrast are generally enhanced and color shifts and gray scale inversion are generally reduced for a range of vertical viewing angles relative to an uncompensated display. In yet another embodiment, bright-

ness and contrast are generally enhanced and color shifts and gray scale inversion are generally reduced for a range of both horizontal and vertical viewing angles relative to an uncompensated display. In another embodiment, brightness and contrast are generally enhanced and color shifts and gray scale inversion are generally reduced for a narrow range of horizontal viewing angles and brightness and contrast are generally enhanced and color shifts and gray scale inversion are generally reduced for a desired (for example, narrow or broad) range of vertical viewing.

[0035] FIG. 3 illustrates one example of an arrangement 300 for compensation of a liquid crystal cell 302 using a symmetrical compensator structure with o-plates 304, 306. The liquid crystal cell 302 can be, for example, a twisted nematic (TN) liquid crystal cell which uses associated polarizers, for example, a rear polarizer 308 and front polarizer (analyzer) 310. Other liquid crystal cells can also be used. The liquid crystal cell can be operated in any mode, but the selection of a compensator structure may depend on the operational mode of the liquid crystal cell. For example, a TN liquid crystal cell can be operated in the e-mode, where the pass polarization direction of the front and rear polarizers is aligned parallel with the liquid crystal director of the corresponding front or rear surface of the liquid crystal cell, or the o-mode, where the pass polarization direction of the front and rear polarizers is aligned orthogonal to the liquid crystal director at the corresponding front or rear surface of the liquid crystal cell.

[0036] A variety of polarizers may be used in combination with the compensator structures. The polarizers can be absorbing or reflective or a combination thereof. One example of a suitable polarizer (particularly suitable for rear polarizer 308) is a combination dichroic and reflective polarizer as described, for example, in U.S. Pat. No. 6,113, 811, incorporated herein by reference. This polarizer can include more than one layer. One or more components of the compensator structure can be incorporated into the polarizer, if desired. In one embodiment, a reflective polarizer, for example a circular polarizer which substantially transmits one hand of circularly polarized light and substantially reflects the other hand, can incorporate a quarter wave plate to convert the circularly polarized light to linearly polarized light.

[0037] FIG. 4 illustrates one example of a compensation arrangement 400 with compensator structures 404, 406 and a liquid crystal cell 402 with associated polarizers 408, 410. The compensator structures 404, 406 each include an o-plate 412, 416 and a c-plate 414, 418 with the c-plate positioned between the liquid crystal cell 402 and the corresponding o-plate. In other words, the c-plates 414, 418 are situated between the respective o-plates 412, 416 and the liquid crystal cell 402 and not between the o-plate and the front or rear polarizer, respectively. Preferably, in this configuration and the other configurations described below, the o-plate/c-plate arrangements behind and in front of the liquid crystal cell have the same properties, so that only one type of o-plate and one type of c-plate is used. In one embodiment, the o-plates 412, 416 are positive o-plates and the c-plates 414, 418 are negative c-plates.

[0038] The retardation value (Δnd, where Δn is the difference in indices of refraction for the extraordinary and ordinary light beams and d is the physical thickness of the

optical element) of the o-plates and c-plates can be selected to provide particular optical properties, ease of manufacture, or other properties. As an example, the o-plates have retardation value in the range of ±30 nm to ±1000 nm, more preferably between ±50 nm and ±750 nm, and most preferably between ±60 nm and ±500 nm. The c-plates have a retardation value in the range of ±10 nm to ±1000 nm, more preferably between ±20 nm and ±750 nm, and most preferably between ±20 nm and ±500 nm. Higher or lower retardation values can be used, as desired.

[0039] In some embodiments, the c-plate can act as a substrate upon which the o-plate can be formed. Optionally, the c-plate can act as an alignment layer for the o-plate. In other embodiments, a separate substrate can be used for the o-plate with the c-plate being an independent optical element or formed on an opposing side or the same side of the substrate.

[0040] Optionally, other retarder elements, such as additional o-plates, c-plates, a-plates, or biaxial retarders, can be added to the basic configuration illustrated in **FIG. 4**. For example, additional c-plates **520**, **522** can be added between the respective o-plates **512**, **516** and the front or rear polarizer **508**, **510** respectively. This is in addition to the c-plates **514**, **518** between the o-plates **512**, **516** and liquid crystal cell **502**. Optionally, one or more a-plates can be positioned between any of the elements in either of the configurations illustrated in **FIGS. 4 and 5**. The c-plates **514**, **518** can be positive or negative c-plates. In one embodiment, the c-plates **514**, **518**, **520**, **522** are negative c-plates. In another embodiment, the c-plates **520**, **522** are positive c-plates and the c-plates **514**, **518** are negative c-plates.

[0041] In other embodiments, one or both of the c-plates in **FIG. 4** can be replaced by biaxial retarders. **FIG. 6** illustrates one example of a configuration having biaxial retarders with a liquid crystal cell **602**, front and rear polarizers **608**, **610**, o-plates **612**, **616**, and biaxial retarders **615**, **619** between the o-plates and the liquid crystal cell. The configuration illustrated in **FIG. 5** can also be modified with at least one biaxial retarder replacing one or more of the c-plates, preferably replacing at least one or both of the c-plates between the o-plates and the liquid crystal cell. In one embodiment, the biaxial retarders have a negative out-of-plane birefringence and the o-plates are positive o-plates. Configurations having biaxial retarders with positive out-of-plane birefringence can also be formed.

[0042] The in plane retardation and out of plane retardation values of the biaxial retarders can be selected to provide particular optical properties, ease of manufacture, or other properties. The biaxial retarders are characterized by two retardance values: $(\alpha nd)_{op}=(n_z-(n_x+n_y)/2)\cdot d$ and $(\Delta nd)_{ip}=(n_y-n_x)\cdot d$, where $(And)op$ describes the out-of-plane retardance and $(And)ip$ specifies the retardance occurring within the film plane. As examples, the biaxial retarders can have an in-plane retardation value in the range of ±3 nm to ±500 nm and an out-of-plane retardation value in the range of ±10 nm to ±1000 nm. Higher or lower retardation values can also be used as desired.

[0043] The relative orientations of the optical axes of the various optical elements can affect the compensation properties of the liquid crystal display. Suitable orientations for the various optical elements can be selected to obtain desired characteristics. In some embodiments, the o-plates and liq-

uid crystal cells are selected so that the azimuthal orientation of a) the rear o-plate, b) the director of the liquid crystal material at the rear surface of the liquid crystal cell, c) the director of the liquid crystal material at the front surface of the liquid crystal cell, and d) the front o-plate define a helical arrangement with a uniform twist sense. In other words, these four azimuthal orientations increase or decrease monotonically in the order listed. For example, this stepwise change in azimuthal angle can be approximately 90±5 degrees, although changes in the range of, for example, about 75 degrees to about 105 degrees are also suitable.

[0044] **FIG. 7** illustrates one example of such an arrangement with the azimuthal orientations **713**, **717** of the o-plates and director **703** at the rear surface and director **705** at the front surface of the liquid crystal cell **702** being represented by arrows. These arrows specify both the azimuthal orientation of the optical axis and the direction of its tilt, and as such define a vector, $\vec{a}$ (see **FIG. 2**). The arrows shown in **FIG. 7** correspond to the vector $\vec{a}'$ (see **FIG. 2**) which results from a projection of the vector $\vec{a}$ (the vector reproducing the optical axis) onto the x-y plane. The front and rear polarizers **710**, **708** and c-plates **714**, **718** are also present. In this illustrated example the azimuthal orientations of the o-plates and liquid crystal cell are, in an arbitrary coordinate system, approximately 135° for the first o-plate, approximately 225° for the rear surface director, approximately 315° for the front surface director, and approximately 45° for the second o-plate. It can be seen that these four azimuths rotate in approximately 90° steps in the same direction of rotation or, in other words, describe an approximate 90° increment helical arrangement. The direction of rotation or twist sense can be, for example, clockwise or counter-clockwise as observed by a viewer in front of the display.

[0045] Preferably, the azimuthal orientations increase or decrease in this helical arrangement by substantially the same increment. The degree to which the increments differ can depend upon the application, the angularly dependent set of desired viewing angles, and the desired brightness, contrast, color shift and gray scale inversion characteristics. In one embodiment where good horizontal viewing is desired with good brightness and contrast and reduced color shift and gray scale inversion, the increments preferably differ by no more than about five degrees and, preferably, by no more than about two degrees.

[0046] Preferably, the azimuthal orientations between i) the first o-plate and the director at the rear surface, ii) the director at the rear surface and the director at the front surface, and iii) the director at the front surface and the second o-plate differ independently by 75 to 105 degrees, more preferably, by 85 to 95 degrees, and, in one embodiment, by about 90 degrees.

[0047] In addition to the effects of the azimuthal orientation of the o-plates, the tilt angle θ of the o-plates can alter the compensator characteristics. Typically, the tilt angle of the o-plates is in the range of about 2 to about 85 degrees and preferably in the range of about 5 to about 70 degrees. The tilt angles for the two o-plates can be different or substantially the same value.

[0048] In some embodiments, the tilt of the optical axis (θ of **FIG. 2**) of the o-plate retarders is not uniform but varies

across the thickness of the o-plate, preferably according to a predefined tilt profile. The tilt angle for the o-plate can increase or decrease from the front of the o-plate to the back of the o-plate where the front of the o-plate is defined as the surface positioned nearest the viewer of the liquid crystal display. The range of the variation in tilt angle typically depends on the desired viewing angle characteristics. For example, in some embodiments, the tilt angle varies (either front-to-back or back-to-front) from a value in the range of 0 to 10 degrees to a value in the range of 25 to 55 degrees. In other embodiments, the tilt angle varies from a value in the range of 0 to 10 degrees to a value in the range of 75 to 90 degrees. It will be understood that other ranges can be selected and that these examples are not meant to be limiting.

[0049] FIG. 8 illustrates one embodiment of the configuration of FIG. 4 (where like reference numbers refer to similar elements) with inserts 840 and 842 that illustrate the variation in tilt angle across the o-plates 412, 416. In this illustrated example, the tilt angle increases from front to back of the rear o-plate and from back to front of the front o-plate (where the front is the rightmost surface of the optical element). In some embodiments, both o-plates can increase or decrease in tilt angle, preferably, with substantially the same tilt angle profile. In other embodiments, the tilt angle profile of the two o-plates is independent with, for example, one o-plate having an increasing or decreasing tilt angle profile and the other o-plate having a decreasing or increasing, respectively, tilt angle profile or, alternatively, a homogeneous or uniform tilt angle across the o-plate.

[0050] If desired, compensator configurations can be formed that lead to good viewing angle dependence of the contrast ratio, reduce the color shift for some or all viewing angles, or both as compared to an uncompensated twisted nematic liquid crystal display or to twisted nematic liquid crystal displays containing commercial compensators.

[0051] Generally, it should be noted that for best performance the optical retardations of the c-plates and o-plates, the azimuthal orientations of the o-plates, and the mean tilt angle within the o-plates may need to be adapted to the properties of the TN cell and the desired specifications regarding contrast performance. The parameters, such as retardation value, azimuthal angle, and tilt angle, of the o-plates, c-plates, biaxial retarders, and other optical elements in the compensator can be adjusted, if desired, to achieve or alter the characteristics of the compensator.

EXAMPLES

[0052] The following examples illustrate liquid crystal cell and compensator configurations indicated in the Tables.

[0053] Table 1 specifies the properties of a twisted nematic LC cell used to generate Examples 1-58. It should be noted that the Examples described herein are not limited to this particular display configuration.

TABLE 1

LC cell characteristics	
Cell gap:	5 μm
Δn at 550 nm	0.082
Optical Retardation:	410 nm

TABLE 1-continued

LC cell characteristics	
Azimuthal Angles of the LC directors at the rear and front surfaces of the LCD (ϕ_r, ϕ_f)	225°, 315°
Tilt Angle:	3°
Dielectric Constants:	ϵ_e = 10.5 ϵ_o = 3.6
Elastic Constants:	k_{11} = 15 pN; k_{22} = 8 pN; k_{33} = 21 pN

[0054] For Examples 1-24, each of Tables 2-7 provides the azimuthal orientation for the directors at the rear and front of the TN liquid crystal cell, designated ϕ_r and ϕ_f. In addition, the optical retardation (the product of the difference between the ordinary and extraordinary refraction indices and the thickness, d, of the particular plate) is provided for both the o-plates and c-plates. All retardation values are specified for light with a wavelength of 550 nm. The Tables also indicate if the tilt angle profile for the o-plates was uniform (indicated by "no"), increasing from front to back, where the front is the surface nearest the viewer of the liquid crystal display (indicated by "+") or decreasing from front to back (indicated by "−").Additionally, the tilt angles at the front (θ_f) and rear (θ_r) of the o-plates which determine the tilt angle profile are specified. For the purposes of these Examples, the tilt profiles were the same for the two o-plates, unless otherwise noted.

[0055] This configurational information was used to calculate the contrast ratio and color shifts at various angles for the particular configuration using the simulation software package DIMOS 1.5c (available from autronic-Melchers, (Karlsruhe, Germany)), which utilizes Berreman formalism. The contrast and color shift were then qualitatively rated on a scale of 1 to 5, with 5 being the best.

[0056] Examples 29-58 include tables that describe the retardation values of the corresponding o-plates, c-plates, TN liquid crystal cells, and biaxial retarders; the azimuthal orientation, ϕ, of the o-plates (the TN cells have the same azimuthal orientations as in Examples 1-28), and the front tilt angles, ϕ_f, and rear tilt angles, ϕ_r, for the o-plates. Calculations were made using the DIMOS software package.

[0057] The Examples are also identified according to the mode of the display: e-mode displays, where the pass axis of the front and rear polarizers is parallel to the director at the nearest surface of the liquid crystal cell (as illustrated in FIG. 7), and o-mode displays, where the pass axis of the front and rear polarizers is crossed at about 90° with respect to the director of the nearest surface of the liquid crystal cell.

Examples 1-3

E-mode Configurations with Helical Arrangement of Azimuthal Orientations

[0058] Table 2 describes three different compensator configurations with a helical arrangement of the azimuthal orientations of the o-plates and liquid crystal cell with 90° increments.

TABLE 2

Ex.	o-plate tilt profile θ_r/θ_f φ	neg. c-pl.	TN φ_r / φ_f	neg. c-pl.	o-plate tilt profile, θ_r/θ_f φ	o-plate Δnd	c-plate Δnd	Contrast	Color Shift
1	no 14°/14° 135°	X	225° 315°	X	no 14°/14° 45°	190 nm	−180 nm	5	5
2	− 0°/20° 135°	X	225° 315°	X	+ 20°/0° 45°	330 nm	−170 nm	5	5
3	+ 36°/0° 135°	X	225°.. 315°	X	− 0°/36° 45°	140 nm	−185 nm	5	5

[0059] As indicated in Table 2, all three examples have very good contrast and color shift properties, irrespective of the tilt angle profile of the o-plates.

Examples 4-6

O-Mode Configurations with Helical Arrangement of Azimuthal Orientations

[0060] Table 3 describes three different compensator configurations with a helical arrangement of the azimuthal orientations of the o-plates and liquid crystal cell with 90° increments.

[0061] As indicated in Table 3, all examples give acceptable contrast and very good color shift. The best contrast is found for configurations where the tilt angle of the o-plates increases from front to back for the rear o-plate and from back to front for the front o-plate.

Examples 7-9

E-mode Configurations with Non-Helical Arrangement of Azimuthal Orientations

[0062] Table 4 describes three different compensator configurations with a non-helical arrangement of the azimuthal orientations of the o-plates and liquid crystal cell.

TABLE 3

Ex.	o-plate tilt profile θ_r/θ_f φ	neg. c-pl.	TN φ_r / φ_f	neg. c-pl.	o-plate tilt profile θ_r/θ_f φ	o-plate Δnd	c-plate Δnd	Contrast	Color Shift
4	no 16°/16° 135°	X	225° 315°	X	no 16°/16° 45°	165 nm	−80 nm	4	5
5	− 0°/22° 135°	X	225° 315°	X	+ 22°/0° 45°	220 nm	−100 nm	3	5
6	+ 34°/0° 135°	X	225° 315°	X	− 0°/34° 45°	160 nm	−90 nm	5	5

TABLE 4

Ex.	o-plate tilt profile θ_r/θ_f φ	neg. c-pl.	TN φ_r / φ_f	neg. c-pl.	o-plate tilt profile θ_r/θ_f ,φ	o-plate Δnd	c-plate Δnd	Contrast	Color Shift
7	no 50°/50° 45°	X	225° 315°	X	No 50°/50° 135°	75 nm	−170 nm	3	1
8	− 0°/70° 45°	X	225° 315°	X	+ 70°/0° 135°	100 nm	−130 nm	3	1
9	+ 70°/0° 45°	X	225° 315°	X	− 0°/70° 135°	55 nm	−150 nm	3	1

Examples 10-12

O-Mode Configurations with Non-Helical
Arrangement of Azimuthal Orientations

[0063] Table 5 describes three different compensator configurations with a non-helical arrangement of the azimuthal orientations of the o-plates and liquid crystal cell.

TABLE 5

Ex.	o-plate tilt profile θ_r/θ_f ϕ	neg. c-pl.	TN ϕ_r ϕ_f	neg. c-pl.	o-plate tilt profile θ_r/θ_f ϕ	o-plate Δnd	c-plate Δnd	Contrast	Color Shift
10	no 75°/75° 45°	X	225° 315°	X	no 75°/75° 135°	200 nm	−100 nm	2	1
11	− 0°/80° 45°	X	225° 315°	X	+ 80°/0° 135°	160 nm	−25 nm	2	1
12	+ 72°/0° 45°	X	225° 315°	X	− 0°/72° 135°	80 nm	−35 nm	2	1

[0064] Contrast and color shift are not as good as Examples 4-6.

Examples 13-18

E-Mode Configurations with the O-Plates
Positioned Between the Liquid Crystal Cell and
Negative C-Plates

[0065] Table 6 describes three different compensator configurations with o-plates positioned between the c-plates and liquid crystal cell.

[0066] Typically, color shift and contrast are not as good as Examples 1-3.

Examples 19-24

O-Mode Configurations with the O-Plates
Positioned Between the Liquid Crystal Cell and
Negative C-Plates

[0067] Table 7 describes three different compensator configurations with o-plates ioned between the c-plates and liquid crystal cell.

TABLE 6

Ex.	neg. c-pl.	o-plate tilt profile θ_r/θ_f ϕ	TN ϕ_r ϕ_f	o-plate tilt profile θ_r/θ_f ϕ	neg. c-pl.	o-plate Δnd	c-plate Δnd	contrast	color shift
13	X	no 27°/27° 135°	225° 315°	no 27°/27° 45°	X	85 nm	−180 nm	3	3
14	X	no 80°/80° 45°	225° 315°	no 80°/80° 135°	X	220 nm	−330 nm	4	1
15	X	− 0°/70° 135°	225° 315°	+ 70°/0° 45°	X	60 nm	−240 nm	3	3
16	X	− 0°/70° 45°	225° 315°	+ 70°/0° 135°	X	150 nm	−20 nm	2	1
17	X	+ 70°/0° 135°	225° 315°	− 0°/70° 45°	X	150 nm	−160 nm	3	3
18	X	+ 80°/0° 45°	225° 315°	− 0°/80° 135°	X	20 nm	−175 nm	3	1

TABLE 7

Ex.	neg. c-pl.	o-plate tilt profile θr/θf φ	TN φf φr	o-plate tilt profile θr/θf φ	neg. c-pl.	o-plate Δnd	c-plate Δnd	contrast	color shift
19	X	no 20°/20° 135°	225° 315°	no 20°/20° 45°	X	165 nm	−50 nm	3	4
20	X	No 67°/67° 45°	225° 315°	No 67°/67° 135°	X	155 nm	−150 nm	2	1
21	X	− 0°/64° 135°	225° 315°	+ 64°/0° 45°	X	140 nm	−130 nm	3	4
22	X	− 0°/72° 45°	225° 315°	+ 72°/0° 135°	X	125 nm	−75 nm	2	1
23	X	+ 56°/0° 135°	225° 315°	− 0°/56° 45°	X	160 nm	−75 nm	3	5
24	X	+ 76°/0° 45°	225° 315°	− 0°/76° 135°	X	85 nm	−85 nm	2	1

[0068] Typically, color shift and contrast are not as good as Examples 4 and 6, but Example 23 is comparable to Example 5 in both color shift and contrast and Examples 19 and 21 are comparable to Example 5 in contrast.

Examples 25-28

Other O-mode Configurations

[0069] Tables 8 and 9 illustrate o-mode compensator configurations with variations in the o-plate and c-plate parameters.

TABLE 8

	o-plate				c-plate	TN	c-plate	o-plate			
Ex.	Δnd	φ	θr	θf	Δnd	Δnd	Δnd	Δnd	φ	θr	θf
25	159	135	30	3	−95	410	−95	159	45	3	30
26	171	135	27	3	−106	410	−105	175	45	3	28

[0070]

TABLE 9

	c-plate	o-plate				c-plate	TN	c-plate	o-plate				c-plate
Ex.	Δnd	Δnd	φ	θr	θf	Δnd	Δnd	Δnd	Δnd	φ	θr	θf	Δnd
27	−40	140	135	39	3	−80	410	−80	140	45	3	39	−40
28	−44	152	135	36	3	−73	410	−79	152	45	3	35	−40

[0071] The compensators of Examples 25 and 27 have better contrast than the compensators of Examples 26 and 28, respectively. Color shift is substantially similar for all four Examples. The compensator of Example 25 has somewhat better contrast than the compensator of Example 27.

Examples 29-32

Other E-Mode Configurations

[0072] Tables 10 and 11 illustrate e-mode compensator configurations with variations in the o-plate and c-plate parameters.

TABLE 10

	o-plate				c-plate	TN	c-plate	o-plate			
Ex.	Δnd	φ	θr	θf	Δnd	Δnd	Δnd	Δnd	φ	θr	θf
29	143	135	40	3	−185	410	−185	143	45	3	40
30	131	135	40	3	−166	410	−167	130	45	3	43

[0073]

TABLE 11

	c-plate	o-plate				c-plate	TN	c-plate	o-plate				c-plate
Ex.	Δnd	Δnd	φ	θ$_r$	θ$_f$	Δnd	Δnd	Δnd	Δnd	φ	θ$_r$	θ$_f$	Δnd
31	−40	167	135	90	3	−194	410	−194	167	45	3	90	−40
32	−36	184	135	97	3	−176	410	−182	184	45	3	92	−38

[0074] The compensators of Examples 29 and 31 have better contrast than the compensators of Examples 30 and 32, respectively. Color shift is substantially similar for all four Examples. The compensator of Example 29 has somewhat better contrast than the compensator of Example 31.

Examples 33-37

Variation in Azimuthal Orientation

[0075] Table 12 illustrates changes in azimuthal orientation of the o-plates for compensators of o-mode TN liquid crystal displays. In Examples 33-35, the front and rear polarizers have azimuthal orientations of the pass axis of the polarizers of 133 and 47 degrees, respectively. In Examples 36 and 37, the front and rear polarizers have azimuthal orientations of the pass axis of the polarizers of 134 and 46 degrees, respectively.

TABLE 12

	o-plate				c-plate	TN	c-plate	o-plate			
Ex.	Δnd	φ	θ$_r$	θ$_f$	Δnd	Δnd	Δnd	Δnd	φ	θ$_r$	θ$_f$
33	159	133	30	3	−95	410	−95	159	47	3	30
34	159	137	30	3	−95	410	−95	159	43	3	30
35	159	135	30	3	−95	410	−95	159	45	3	30
36	159	134	30	3	−95	410	−95	159	46	3	30
37	159	136	30	3	−95	410	−95	159	44	3	30

[0076] The optical compensator of Example 33 has somewhat diminished contrast, but relatively similar color shift, when compared to the optical compensator of Example 35. The optical compensator of Example 34 has substantially reduced contrast, but relatively similar color shift, when compared to the optical compensator of Example 35. The optical compensators of Examples 36 and 37 have somewhat diminished contrast, but relatively similar color shift, when compared to the optical compensator of Example 35.

Examples 38-46

Comparison of E-mode Optical Compensators with C-Plates and Biaxial Retarders

[0077] Tables 13 and 15 illustrate optical compensators that utilize c-plates and 14 and 16 illustrate optical compensators having biaxial retarders in the place c-plates positioned between the o-plates and the TN liquid crystal cell.

TABLE 13

	o-plate				c-plate	TN	c-plate	o-plate			
Ex.	Δnd	φ	θ$_r$	θ$_f$	Δnd	Δnd	Δnd	Δnd	φ	θ$_r$	θ$_f$
38	307	135	0	19	−177	410	−177	307	45	19	0
39	143	135	40	3	−185	410	−185	143	45	3	40
40	133	135	77	3	−213	410	−213	133	45	3	77

[0078]

TABLE 14

	o-plate				biaxial	TN	biaxial	o-plate			
Ex.	Δnd	φ	θ$_r$	θ$_f$	(Δnd)$_{ip}$/(Δnd)$_{op}$	Δnd	(Δnd)$_{ip}$/(Δnd)$_{op}$	Δnd	φ	θ$_r$	θ$_f$
41	307	135	0	19	3/−169	410	3/−169	307	45	19	0
42	117	135	77	3	26/−216	410	26/−216	117	45	3	77

[0079]

TABLE 15

	c-plate	o-plate				c-plate	TN	c-plate	o-plate				c-plate
Ex.	Δnd	Δnd	φ	θ$_r$	θ$_f$	Δnd	Δnd	Δnd	Δnd	φ	θ$_r$	θ$_f$	Δnd
43	−40	287	135	0	19	−212	410	−212	287	45	19	0	−40
44	−40	167	135	90	3	−194	410	−194	167	45	3	90	−40

[0080]

TABLE 16

	c-plate	o-plate				biaxial (Δnd)ip (Δnd)op	TN	biaxial (Δnd)ip (Δnd)op	o-plate				c-plate
Ex	Δnd	Δnd	φ	θr	θf	(Δnd)op	Δnd	(Δnd)op	Δnd	φ	θr	θf	Δnd
45	−40	292	135	0	18	9 −211	410	9 −211	292	45	18	0	−40
46	−40	161	135	90	3	10 −200	410	10 −200	161	45	3	90	−40

[0081] The contrast and color shift of the c-plate optical compensator of Example 38 and the biaxial retarder optical compensator of Example 41 are substantially similar. The optical compensators of Example 39, 40, and 42 have substantially similar contrast and color shift, with the color shift being slightly worse than the compensators of examples 38 and 41. The same can be said for Examples 43 and 44, except that the color shift and contrast of these compensators is worse than in Examples 38 and 41.

[0082] Examples 44 and 46 had comparable color shift and contrast to Examples 39, 40, and 42. Examples 43 and 45 had somewhat worse contrast and color shift.

Examples 47-58

Comparison of O-Mode Optical Compensators with C-Plates and Biaxial Retarders

[0083] Tables 17 and 19 illustrate optical compensators that utilize c-plates and Tables 18 and 20 illustrate optical compensators having biaxial retarders in the place of the c-plates positioned between the o-plates and the TN liquid crystal cell.

TABLE 17

	o-plate				c-plate	TN	c-plate	o-plate			
Ex.	Δnd	φ	θr	θf	Δnd	Δnd	Δnd	Δnd	φ	θr	θf
47	149	135	0	29	−92	410	−92	149	45	29	0
48	159	135	30	3	−95	410	−95	159	45	3	30

[0084]

TABLE 18

	o-plate				biaxial (Δnd)ip/(Δnd)op	TN	biaxial (Δnd)ip/(Δnd)op	o-plate			
Ex.	Δnd	φ	θr	θf	(Δnd)ip/(Δnd)op	Δnd	(Δnd)ip/(Δnd)op	Δnd	φ	θr	θf
49	115	135	0	73	62/−144	410	62/−144	115	45	73	0
50	98	135	57	3	53/−134	410	53/−134	98	45	3	57

[0085]

TABLE 19

	c-plate	o-plate				c-plate	TN	c-plate	o-plate				c-plate
Ex.	Δnd	Δnd	φ	θr	θf	Δnd	Δnd	Δnd	Δnd	φ	θr	θf	Δnd
51	−40	112	135	0	34	−76	410	−76	112	45	34	0	−40
52	−40	107	135	0	24	−81	410	−81	107	45	24	0	−40
53	−40	140	135	39	3	−80	410	−80	140	45	3	39	−40
54	−40	114	135	26	3	−84	410	−84	114	45	3	26	−40

[0086]

TABLE 20

| | c-plate | o-plate | | | | biaxial | TN | biaxial | o-plate | | | | c-plate |
Ex.	Δnd	Δnd	ϕ	θ_r	θ_f	$(\Delta nd)_{ip}$ $(\Delta nd)_{op}$	Δnd	$(\Delta nd)_{ip}$ $(\Delta nd)_{op}$	Δnd	ϕ	θ_r	θ_f	Δnd
55	−40	105	135	0	80	39 −125	410	39 −125	105	45	80	0	−40
56	−40	85	135	0	85	47 −134	410	47 −134	85	45	85	0	−40
57	−40	127	135	86	3	51/ −132	410	51 −132	127	45	3	86	−40
58	−40	117	135	90	3	54/ −133	410	54 −133	117	45	3	90	−40

[0087] The contrast of the optical compensators of Examples 47, 48, 49, and 50 are substantially similar. The color shift of Examples 48 and 50 is somewhat better than that of Example 49 which is, in turn, somewhat better than that of Example 47. The contrast and color shifts of Examples 51-58 are substantially similar.

[0088] The present invention should not be considered limited to the particular examples described above, but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the present invention may be applicable will be readily apparent to those of skill in the art to which the present invention is directed upon review of the instant specification.

What is claimed is:

1. A liquid crystal display, comprising:

a first o-plate having a first azimuthal orientation;

a first c-plate;

a liquid crystal cell comprising a rear surface and a front surface, wherein the liquid crystals at the rear surface have a second azimuthal orientation and the liquid crystals at the front surface have a third azimuthal orientation and wherein the first c-plate is disposed between the first o-plate and the liquid crystal cell;

a second c-plate; and

a second o-plate having a fourth azimuthal orientation, wherein the second c-plate is disposed between the second o-plate and the liquid crystal cell;

wherein the first, second, third and fourth azimuthal orientations are disposed in a helical arrangement, wherein

the second azimuthal orientation differs from the first azimuthal orientation by an angle in the range of 75 to 105 degrees in a first rotational direction,

the third azimuthal orientation differs from the second azimuthal orientation by an angle in the range of 75 to 105 degrees in the first rotational direction, and

the fourth azimuthal orientation differs from the third azimuthal orientation by an angle in the range of 75 to 105 degrees in the first rotational direction.

2. The liquid crystal display of claim 1, wherein the first and second o-plates are positive o-plates.

3. The liquid crystal display of claim 1, wherein the first and second c-plates are negative c-plates.

4. The liquid crystal display of claim 1, further comprising

a rear polarizer positioned with the first c-plate and first o-plate between the rear polarizer and the liquid crystal cell; and

a front polarizer positioned with the second c-plate and second o-plate between the front polarizer and the liquid crystal cell.

5. The liquid crystal display of claim 4, wherein the rear polarizer, front polarizer, and liquid crystal cell are disposed in an e-mode configuration.

6. The liquid crystal display of claim 4, wherein the rear polarizer, front polarizer, and liquid crystal cell are disposed in an o-mode configuration.

7. The liquid crystal display of claim 1, wherein the optical axis of the first o-plate varies in tilt angle from the front to the back of the first o-plate.

8. The liquid crystal display of claim 7, wherein the optical axis of the second o-plate varies in tilt angle from the front to the back of the second o-plate.

9. The liquid crystal display of claim 8, wherein the tilt angle of the first o-plate increases from the front to the back of the first o-plate the tilt angle of the second o-plate decreases from the front to the back of the second o-plate.

10. The liquid crystal display of claim 1, wherein the optical axis of the first o-plate is tilted at a substantially uniform value.

11. The liquid crystal display of claim 1, further comprising a third c-plate positioned so that the first o-plate is between the third c-plate and the liquid crystal cell.

12. The liquid crystal display of claim 11, further comprising a fourth c-plate positioned so that the second o-plate is between the fourth c-plate and the liquid crystal cell.

13. A liquid crystal display, comprising:

a first o-plate having a first azimuthal orientation;

a first c-plate;

a liquid crystal cell comprising a rear surface and a front surface, wherein the liquid crystals at the rear surface have a second azimuthal orientation and the liquid crystals at the front surface have a third azimuthal orientation and wherein the first c-plate is disposed between the first o-plate and the liquid crystal cell;

a second c-plate; and

a second o-plate having a fourth azimuthal orientation, wherein the second c-plate is disposed between the second o-plate and the liquid crystal cell;

wherein the first, second, third and fourth azimuthal orientations are disposed in a helical arrangement and increase or decrease monotonically in the order listed.

14. The liquid crystal display of claim 13, wherein the first and second c-plates are negative c-plates.

15. The liquid crystal display of claim 13, wherein the first and second o-plates are positive o-plates.

16. The liquid crystal display of claim 13, further comprising

a rear polarizer positioned with the first c-plate and first o-plate between the rear polarizer and the liquid crystal cell; and

a front polarizer positioned with the second c-plate and second o-plate between the front polarizer and the liquid crystal cell.

17. The liquid crystal display of claim 13, further comprising a third c-plate positioned so that the first o-plate is between the third c-plate and the liquid crystal cell.

18. The liquid crystal display of claim 17, further comprising a fourth c-plate positioned so that the second o-plate is between the fourth c-plate and the liquid crystal cell.

19. The liquid crystal display of claim 13, wherein the optical axis of the first o-plate is tilted at a substantially uniform value.

20. The liquid crystal display of claim 13, wherein the optical axis of the first o-plate varies in tilt angle from the front to the back of the first o-plate.

21. The liquid crystal display of claim 20, wherein the optical axis of the second o-plate varies in tilt angle from the front to the back of the second o-plate.

22. The liquid crystal display of claim 21, wherein the tilt angle of the first o-plate increases from the front to the back of the first o-plate the tilt angle of the second o-plate decreases from the front to the back of the second o-plate.

23. The liquid crystal display of claim 13, further comprising a third c-plate positioned so that the first o-plate is between the third c-plate and the liquid crystal cell.

24. The liquid crystal display of claim 23, further comprising a fourth c-plate positioned so that the second o-plate is between the fourth c-plate and the liquid crystal cell.

25. A liquid crystal display, comprising:

a first o-plate having a first azimuthal orientation;

a first c-plate;

a liquid crystal cell comprising a rear surface and a front surface, wherein the liquid crystals at the rear surface have a second azimuthal orientation and the liquid crystals at the front surface have a third azimuthal orientation and wherein the first c-plate is disposed between the first o-plate and the liquid crystal cell;

a second c-plate; and

a second o-plate having a fourth azimuthal orientation, wherein the second c-plate is disposed between the second o-plate and the liquid crystal cell;

wherein the first, second, third and fourth azimuthal orientations are disposed in a helical arrangement and a) the first and second azimuthal orientations, b) the second and third azimuthal orientations, and c) the third and fourth azimuthal orientations, respectively, differ by substantially the same increment.

* * * * *

专利名称(译)	液晶显示器补偿器和补偿器的使用和制造		
公开(公告)号	US20060221286A1	公开(公告)日	2006-10-05
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申请(专利权)人(译)	3M创新有限公司 ROLIC AG		
当前申请(专利权)人(译)	3M创新有限公司 ROLIC AG		
[标]发明人	ALLEN RICHARD C BACHELS THOMAS FUNFSCHILLING JURG SCHADT MARTIN SEIBERLE HUBERT		
发明人	ALLEN, RICHARD C. BACHELS, THOMAS FUNFSCHILLING, JURG SCHADT, MARTIN SEIBERLE, HUBERT		
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摘要(译)

使用补偿结构可以实现液晶显示器的补偿，补偿结构具有以下顺序：a）第一o-板；b）第一缓速剂；c）液晶盒；d）第二个缓速器；和e）第二个o盘。第一和第二延迟器可以是c板或双轴延迟器。