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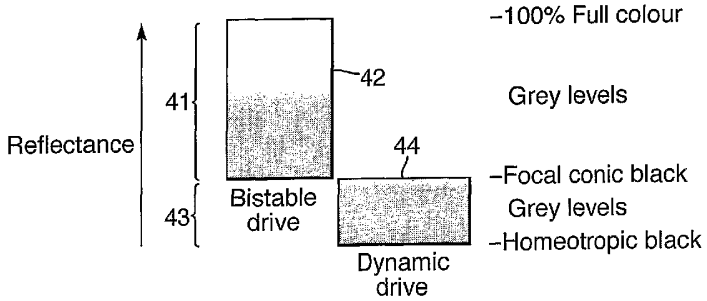
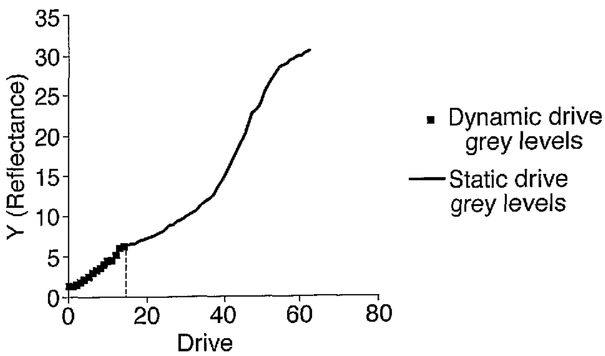
(54) Title: DRIVE SCHEME FOR A CHOLESTERIC LIQUID CRYSTAL DISPLAY DEVICE





(57) Abstract: A cholesteric liquid crystal display device comprises three cells each comprising a layer of cholesteric liquid crystal material and an electrode. arrangement capable of providing independent driving of a plurality of pixels across the layer of cholesteric liquid crystal material by respective drive signals. A drive circuit applies a respective drive signal to each pixel to drive the pixel into states which are variable to provide a reflectance varying within a predetermined range of reflectances. The drive signals involve a combination of two drive schemes to provide reflectances in different portions of the range. In particular, (a) when providing a reflectance in a first portion of higher reflectance, the drive signals comprise a first waveform shaped to drive the pixel into a stable state, the waveform having a shape which is variable to provide a stable state having a varying reflectance; and (b) when providing a reflectance in a second portion of lower reflectance, the drive signals comprise a second waveform shaped to drive the pixel into the homeotropic state and the planar state alternately, the periods of time during which the pixel is driven into the homeotropic and planar states being variable to provide a varying average reflectance as perceived by a viewer. Such a combination of drive schemes allows a good contrast ratio and colour gamut to be achieved because of the use of the homeotropic state but only increases the power consumption by a relatively small amount as the homeotropic state is only used for a portion of the pixels.

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Drive Scheme For A Cholesteric Liquid Crystal Display Device

The present invention relates to a drive scheme for driving a cholesteric liquid crystal display device for providing a range of grey levels.

A cholesteric liquid crystal display device is a type of reflective display device having a low power consumption and a high brightness. A cholesteric liquid crystal display device uses one or more cells each having a layer of cholesteric liquid crystal material capable of being switched between a plurality of states. These states include a planar state being a stable state in which the layer of cholesteric liquid crystal material reflects light with wavelengths in a band corresponding to a predetermined colour. In another state, the cholesteric liquid crystal transmits light. A full colour display may be achieved by stacking layers of cholesteric liquid crystal material capable of reflecting red, blue and green light.

Most development of cholesteric liquid crystal displays has concentrated on use of the stable states of the liquid crystal material, these being the planar state providing a high reflectance and the focal conic state providing a low reflectance, as well as range of mixture states providing intermediate reflectances as a result of the liquid crystal material having domains in each of the planar and focal conic states. The use of the stable states provides the advantage of low power consumption as energy is only needed to drive the change of state, whereafter the liquid crystal remains in a stable state displaying an image without consuming power. All current commercially available cholesteric liquid crystal display devices work in this mode of operation.

For driving to display an image, the display device typically has an electrode arrangement capable of providing driving of a plurality of pixels across the layer of cholesteric liquid crystal material by respective drive signals.

A wide range of drive schemes have been proposed to selectively drive the liquid crystal material into a stable state having the desired reflectance in accordance with the image to be displayed. One drive scheme is to use a drive signal comprising a reset pulse waveform shaped to drive the pixel into the homeotropic state, followed by a relaxation period to cause the pixel to relax into the planar state, followed by a selection pulse waveform shaped to drive the pixel into a stable state, the selection pulse waveform being variable to drive the pixel into a stable state having a varying reflectance. By always driving the liquid crystal into the planar state, the form of the selection signal needed to provide the desired reflectance is predictable, thereby allowing accurate grey levels to be obtained. Other known drive schemes initially drive the pixel into the focal conic state.

Whilst use of the stable states provides a display device with a good contrast ratio, the contrast ratio is limited by the fact that the focal conic state scatters light and this has a reflectance of the order of 3-4%. It has been reported in JY Nahm et al., Asia Display 1998 pp 979-982 and in WO-2004/030335 that a higher contrast ratio can be achieved by use of the homeotropic state of the cholesteric liquid crystal material which has a lower reflectance than the focal conic state. Thus use of the homeotropic state as the dark state instead of the focal conic state has the advantages of increasing the contrast ratio and improving the colour gamut. However, the homeotropic state is an unstable state and thus requires the continuous application of power to maintain display of an image. The homeotropic state has not been used in current commercially available displays.

In summary, the known cholesteric liquid crystal display devices do not provide a high contrast ratio and good colour gamut in combination with a low power consumption. However, this would be desirable.

According to a first aspect of the present invention, there is provided a method of driving a cholesteric liquid crystal display device which comprises at least one cell comprising a layer of cholesteric liquid crystal material and an electrode arrangement capable of providing independent driving of a plurality of pixels across the layer of cholesteric liquid crystal material by respective drive signals, the method comprising applying respective drive signals to each pixel to drive the pixels into states which are varied to provide a reflectance varying within a predetermined range of reflectances, the drive signals comprising:

(a) when providing a reflectance in a first portion of the predetermined range of reflectances, a first waveform shaped to drive the pixel into a stable state, the waveform having a shape which is variable to provide a stable state having a varying reflectance; and

(b) when providing a reflectance in a second portion of the predetermined range of reflectances which is lower than the first portion, a second waveform shaped to drive the pixel into the homeotropic state and the planar state alternately, the periods of time during which the pixel is driven into the homeotropic and planar states being variable to provide a varying average reflectance as perceived by a viewer.

Thus the present invention employs a combination of two different drive schemes each to achieve a different portion of the range of desired reflectances. Thus the drive signal applied to a pixel depends on the desired reflectance of the pixel in accordance with the image to be displayed.

The first drive scheme used in the portion of higher reflectance is to apply a drive signal shaped to drive the pixel in question into a stable state. This drive scheme therefore only consumes power to change the image displayed. After the drive signal has been applied, the stable state is maintained and so the pixel continues to display the image without consuming power. Thus the power consumption is low for all pixels having a reflectance in the first portion of the range. This corresponds generally to the known driving of cholesteric liquid crystal display devices into a stable state, and indeed it is possible to use a known form of drive signal.

However to achieve a better contrast ratio and colour gamut, reflectances in the second portion of the range are provided by a second drive scheme. This drive scheme is to apply a drive signal shaped to drive the pixel into the homeotropic state and the planar state alternately. The periods of time during which the pixel is driven into the homeotropic and planar states is variable. The periods of time are sufficiently short that reflectance perceived by the viewer is a time average of the reflectance of the pixel in each of the homeotropic and planar states. The perceived reflectance is thus variable also, allowing the production of grey scales.

Accordingly, use of the second drive scheme improves the contrast ratio and colour gamut as compared to use of the first drive scheme by itself. Of course, the second drive scheme requires continuous application of a drive signal to drive the pixel into the homeotropic state because this is not a stable state. This increases the power consumption of the display device. However it has been appreciated that contrary to initial expectation the increase in the power consumption is actually quite low. This is because in practice the pixel needs to provide a reflectance in the second portion of the range relatively rarely. Ultimately this depends on the image to be displayed but it has been found for example that for a typical image displayed on the display device described in detail below, on average only 10-15% of the pixels need to be driven with the second drive scheme at any one time.

The first drive scheme may be of any type capable of driving the pixel into a stable state of variable reflectance. This includes various known drive schemes and new drive schemes which may de developed in the future.

The preferred first drive scheme is to use a first waveform which comprises: a reset pulse waveform shaped to drive the pixel into the homeotropic state, followed by a relaxation period to cause the pixel to relax into the planar state, followed by a selection pulse waveform shaped to drive the pixel into a stable state, the selection pulse waveform being variable to drive the pixel into a stable state having a varying reflectance. This drive scheme is in itself known. In this case, one option is that the selection pulse waveform has an amplitude which is variable, but there are other options for example using variable pulse widths.

The first drive scheme may use a selection pulse waveform comprising a single pulse but an alternative option is that the selection pulse waveform comprises an initial pulse shaped to drive the pixel into one of a plurality of initial stable states and, optionally, a tuning pulse shaped to drive the pixel into a final stable state having a reflectance between the reflectances of the initial stable states. The use of an initial pulse and a subsequent tuning pulse has been found in some cases to provide a greater selectivity of grey scales to be achieved than the use of a single pulse.

The second drive scheme operates on the same principle as the drive scheme disclosed by itself in WO-2004/030335. The drive scheme may use a second waveform which has any shaped capable of driving the pixel into the homeotropic and planar states. The preferred second waveform comprises one or more drive pulses shaped to drive the pixel into the homeotropic state alternating with one or more relaxation periods to cause the pixel to relax into the planar state. This drive scheme has the advantage of being straightforward to implement. It may be implemented on a frame basis in which said second waveform comprises, in each of a plurality of frames of predetermined duration, a single drive pulse shaped to drive the pixel into the homeotropic state followed by a relaxation period to cause the pixel to relax into the planar state.

Of course to provide the minimum possible reflectance it is possible that the drive signals further comprise: (c) when providing the minimum reflectance in the predetermined range of reflectances, a third waveform shaped to drive the pixel into the homeotropic state. Similarly to provide the maximum possible reflectance it is possible that the drive signals further comprise: (d) when providing the maximum reflectance in the predetermined range of reflectances, a fourth waveform shaped to drive the pixel into the planar state.

The drive signals may be applied on a frame basis, that is in successive frames of predetermined duration, the first and second waveforms each applied in a respective frame.

As mentioned above, the electrode arrangement is capable of providing independent driving of a plurality of pixels. The reason for this is the use of the second drive scheme which requires the continuous application of a drive signal when driving the pixel into the homeotropic state. Depending on the image, it is necessary to drive different pixels selectively in accordance with the second drive scheme which requires the possibility of driving pixels independently. The electrode arrangement may be of any type which allows this.

The preferred electrode arrangement includes a respective conductive layer on each side of the layer of liquid crystal material, with at least one of the conductive layers being patterned to provide a plurality of separate drive electrodes each capable of providing independent driving an area of the layer of liquid crystal material adjacent the respective drive electrode as one of said pixels. This electrode arrangement has the advantage of simplicity, particularly if one of the conductive layers is patterned to provide said plurality of separate drive electrodes and the other of the conductive layer is shaped as at least one common electrode extending over a plurality of pixels.

To allow the application of the drive signals to the drive electrodes, the electrode arrangement may further comprise a separate track connected to each of the separate drive electrodes and extending to a position outside the array of addressable pixels where the tracks form terminals each capable of receiving a respective drive signal. The provision of tracks in the same conductive layer as the drive electrodes has the advantage of being a simple structure which is straightforward to manufacture as the tracks may be formed in the same manufacturing step as the drive electrodes, for example in a lithographic process. Furthermore connection to the tracks may easily be made at the edges of the display device and operation is straightforward because it merely requires application of drive signals to the tracks.

According to a second aspect of the present invention, there is provided a cholesteric liquid crystal display device having a drive circuit arranged to apply a respective drive signal to each pixel in accordance with the method described above. In this case the drive circuit may be operable to select the drive scheme to be applied to each pixel in accordance with image data applied thereto.

To allow better understanding, a cholesteric liquid crystal display device which embodies the present invention will now be described by way of non-limitative example with reference to the accompanying drawings. In the drawings:

Fig. 1 is a cross-sectional view of a cell of a cholesteric liquid crystal display device;

Fig. 2 is a graph of a typical reflectance spectrum of green cholesteric liquid crystal in the planar state;

Fig. 3 is a cross-sectional view of the cholesteric liquid crystal display device;

Fig. 4 is a plan view of the electrode arrangement of a conductive layer of the cell of Fig. 1;

Fig. 5 is a diagram of the control circuit of the display device;

Fig. 6 is a schematic diagram illustrating the drive schemes used to drive pixels to different reflectances;

Fig. 7 is a graph of a drive signal in accordance with a static drive scheme;

Fig. 8 is a graph of the electro-optical curve of a typical liquid crystal material;

Fig. 9 is a graph of reflectance of the pixel against amplitude of a selection pulse with the drive signal of Fig. 7;

Figs. 10A to 10C are graphs of a drive signal in accordance with a dynamic drive scheme;

Fig. 11 is a graph of the reflectance of a pixel against the period of the drive pulse with the drive signal of Figs. 10A to 10C;

Fig. 12 shows the graphs of Figs. 9 and 11 overlapping each other; and

Fig. 13 is a CIE plot of the colour gamuts achievable by a static drive scheme alone and by the present drive scheme.

A cholesteric liquid crystal display device 24 in which the present drive scheme is implemented will now be described.

Fig. 1 shows a single cell 10 which may be used in the cholesteric liquid crystal display device 24. The cell 10 has a layered construction, the thickness of the individual layers 11-19 being exaggerated in Fig. 1 for clarity.

The cell 10 comprises two rigid substrates 11 and 12, which may be made of glass or preferably plastic. The substrates 11 and 12 have, on their inner facing surfaces, respective transparent conductive layers 13 and 14 formed as a layer of transparent conductive material, typically indium tin oxide. The conductive layers 13 and 14 are patterned to provide a rectangular array of addressable pixels, as described in more detail below.

Optionally, each conductive layers 13 and 14 is overcoated with a respective insulation layer 15 and 16, for example of silicon dioxide, or possibly plural insulation layers.

The substrates 11 and 12 define between them a cavity 20, typically having a thickness of 3μm to 10μm. The cavity 20 contains a liquid crystal layer 19 and is sealed by a glue seal 21 provided around the perimeter of the cavity 20. Thus the liquid crystal layer 19 is arranged between the conductive layers 13 and 14.

Each substrate 11 and 12 is further provided with a respective alignment layer 17 and 18 formed adjacent the liquid crystal layer 19, covering the respective conductive layer 13 and 14, or the insulation layer 15 and 16 if provided. The alignment layers 17 and 18 align and stabilise the liquid crystal layer 19 and are typically made of polyamide which may optionally be unidirectionally rubbed. Thus, the liquid crystal layer 19 is surface-stabilised, although it could alternatively be bulk-stabilised, for example using a polymer or a silica particle matrix.

The liquid crystal layer 19 comprises cholesteric liquid crystal material. Such material has several states in which the reflectivity and transmissivity vary. These states are the planar state, the focal conic state and the homeotropic (pseudo nematic) state, as described in I. Sage, Liquid Crystals Applications and Uses, Editor B Bahadur, vol 3, page 301,1992, World Scientific, which is incorporated herein by reference and the teachings of which may be applied to the present invention.

In the planar state, the liquid crystal layer 19 selectively reflects a bandwidth of light that is incident upon it. The wavelengths λ of the reflected light are given by Bragg's law, ie $\lambda = nP$, where wavelength λ of the reflected wavelength, n is the refractive index of the liquid crystal material seen by the light and P is the pitch length of the liquid crystal material. Thus in principle any colour can be reflected as a design choice by selection of the pitch length P. That being said, there are a number of further factors which determine the exact colour, as known to the skilled person. The planar state is used as the bright state of the liquid crystal layer 19.

Not all the incident light is reflected in the planar state. In a typical full colour display device 24 employing three cells 10, as described further below, the total reflectivity is typically of the order of 30%. The light not reflected by the liquid crystal layer 19 is transmitted through the liquid crystal layer 19. The transmitted light is subsequently absorbed by a black layer 27 described in more detail below.

The reflectance spectrum of the liquid crystal layer 19 in the planar state is shown in Fig. 2 for the example of reflection of green light. The reflectance spectrum has a central band of wavelengths in which the reflectance of light is substantially constant. This is due to the birefringence of the cholesteric liquid crystal material of the liquid crystal layer 19 and corresponds to reflection of light at different angles relative to the ordinary and extraordinary axes, the light at each angle seeing a different refractive index, which causes a different wavelength λ to be reflected.

In the focal conic state, the liquid crystal layer 19 is, relative to the planar state, transmissive and transmits incident light. Strictly speaking, the liquid crystal layer 19 is mildly light scattering with a small reflectance, typically of the order of 3-4%. As light transmitted through the liquid crystal layer is absorbed by the black layer 27 described in more detail below, this state is perceived as darker than the planar state.

In the homeotropic state, the liquid crystal layer 19 is even more transmissive than in the focal conic state, typically having a reflectance of the order of 0.5-0.75%. Use of the homeotropic state has the advantage of increasing the contrast ratio, as compared to use of the focal conic state.

A control circuit 22 supplies a drive signal to the conductive layers 13 and 14 which consequently apply the drive signal across the liquid crystal layer 19 to switch it between its different states. The actual form of the drive signal is described in more detail below, but two general points are to be noted.

Firstly, the focal conic and planar states are stable states which can coexist when no drive signal is applied to the liquid crystal layer 19. Furthermore the liquid crystal layer 19 can exist in stable states in which different domains of the liquid crystal material are each in a respective one of the focal conic state and the planar state. These are sometimes referred to as mixture states. In these mixture states, the liquid crystal material has a reflectance intermediate the reflectances of the focal conic and planar states. A range of such stable states is possible with different mixtures of the amount of liquid crystal in each of the focal conic and planar states so that the overall reflectance of the liquid crystal material varies.

Secondly, the homeotropic state is not stable and so maintenance of the homeotropic state requires continued application of a drive signal.

Fig. 3 shows the display device 24 which comprises a stack of cells 10R, 10G and 10B, each being a cell 10 of the type shown in Fig. 1 and described above. The cells 10R, 10G and 10B have respective liquid crystal layers 19 which are arranged to reflect light with colours of red, green and blue, respectively. Thus the cells 10R, 10G and 10B will thus be referred to as the red cell 10R, the green cell 10G and the blue cell 10B. Selective use of the red cell 10R, the green cell 10G and the blue cell 10B allows the display of images in full colour, but in general a display device could be made with any number of cells 10, including one.

In Fig. 3, the front of the display device 24 from which side the viewer is positioned is uppermost and the rear of the display device 24 is lowermost. Thus, the order of the cells 10 from front to rear is the blue cell 10B, the green cell 10G and the red cell 10R. This order is preferred for the reasons disclosed in West and Bodnar, "Optimization of Stacks of Reflective Cholesteric Films for Full Color Displays", Asia Display 1999 pp 20-32, although in principle any other order could be used.

The adjacent pair of cells 10R and 10G and the adjacent pair of cells 10G and 10B are each held together by respective adhesive layers 25 and 26.

The display device 24 has a black layer 27 disposed to the rear, in particular by being formed on a rear surface of the red cell 10R which is rearmost. The black layer 27 may be formed as a layer of black paint. In use, the black layer 27 absorbs any incident light which is not reflected by the cells 10R, 10G or 10B. Thus when all the cells 10R, 10G or 10B are switched into a transmissive state, the display device appears black.

The display device 24 is similar to the type of device disclosed in WO-01/88688 which is incorporated herein by reference and the teachings of which may be applied to the present invention.

In each cell 10, the conductive layers 13 and 14 are patterned to provide an electrode arrangement which is capable of providing independent driving of a rectangular array of pixels across the liquid crystal layer 19 by different respective drive signals. In particular, the electrode arrangement is provided as follows.

A first one of the conductive layers 13 or 14 (which may be either of the conductive layers 13 or 14) is patterned as shown in Fig. 4 and comprises a rectangular array of separate drive electrodes 31. The other, second one of the conductive layers 13 or 14 extends over the area opposite the entire array of drive electrodes 31 and thus acts as a common electrode.

The first one of the conductive layers 13 or 14 further comprises separate tracks 32 each connected to one of the drive electrodes 31. Each track 32 extends from its respective drive electrode 31 to a position outside the array of drive electrodes 31 where the track forms a terminal 33. The control circuit 22 makes an electrical connection to each of the terminals 33 and a common connection to the second one of the conductive layers 13 or 14. Through this connection, the control circuit 22 in use supplies a respective drive signal to each terminal 33 and thus the respective drive signals are supplied via the tracks 32 to the respective drive electrodes 31. In this manner, each drive electrode 31 is independently receives its own drive signal and drives the area of the liquid crystal layer 19 adjacent that drive electrode 31, which area of the liquid crystal layer 19 acts as a pixel. In this manner, an array of pixels is formed in the liquid crystal layer 19 adjacent the array of drive electrodes 31. As each drive electrode 31 receives a drive signal independently, each of the pixels is directly addressable.

Such direct addressing of each pixel is advantageous for a number of reasons. The electro-optic performance of the liquid crystal is improved as compared to passive multiplexed addressing because each pixel can be addressed independently without affecting or influencing the neighbouring pixels. Also, direct addressing allows compensation of non-uniformity in the parameters of the cell over the area of the display device, for example variation in thickness of the liquid crystal layer due to the manufacturing process, or temperature variation across the display device. Each pixel can be driven with a drive signal adapted, for example by varying parameters such as voltage or pulse time to compensate those variations.

To accommodate the tracks 32 in the first one of the conductive layers 13 or 14, the drive electrodes 31 are arranged in lines (extending vertically in Fig. 4) with a gap 34 between each adjacent line of drive electrodes 31. The tracks 32 connected to a single line of drive electrodes 31 all extend along one of the gaps 34. All the tracks 32 from each drive electrode 31 in the line of drive electrodes 31 exit the array of drive electrodes 31 on the same side, that is lowermost in Fig. 4. As a result, all of the terminals 33 are formed on the same side of the display device 24. This has particular advantage when a plurality of identical display devices 24 are tiled to provide a larger image area because it reduces the gap needed between the individual display devices 24.

For clarity Fig. 4 illustrates the drive electrodes 31 and tracks 32 of only two lines of five pixels. The actual display device 24 may comprise a different number of pixels, more typically 36 lines of 18 pixels or larger. Most useful display devices will have at least three or preferably at least five pixels in each dimension.

The control circuit 22 is further illustrated in Fig. 5. The control circuit 22 receives power from power supply 28. The control circuit 22 also receives image data 29 representing an image. Typically the image data 29 is in LCD format or LVDS format. The control circuit 22 derives a drive signal for each of the pixels of each of the cells

10R, 10G and 10B in accordance with the image data 29 to cause the display device 24 to display the image by switching the liquid crystal material of each pixel into a state having an appropriate reflectance. The form of the drive signals is as follows.

In a typical image, some of the pixels will be in a full bright state, some in a grey level and some in a fully dark state. Thus it is necessary to drive the pixels in each cell 10R, 10G and 10B into a range of reflectances, depending on the image data. For different portions of the range of reflectances, drive signals of two different forms are generated as shown schematically in Fig. 6, in which reflectance increases vertically. In particular, in a first portion 41 of the range of reflectances of higher reflectance, a drive signal is generated in accordance with a static drive scheme to achieve a reflectance as shown by the grey scale 42. On the other hand, in a second portion 43 of the range of reflectances of lower reflectance than the first portion, a drive signal is generated in accordance with a dynamic drive scheme to achieve a reflectance as shown by the grey scale 44.

The static drive scheme is used to drive pixels into a stable state, that is the planar state, the focal conic state or a mixed state having a reflectance between that of the planar and focal conic states. Thus the maximum reflectance of the first portion of the range is in the planar state, labeled as 100% full colour in Fig. 6, whereas the minimum reflectance of the first portion of the range is in the focal conic state, labeled as focal conic black in Fig. 6.

The dynamic drive scheme makes use of the unstable homeotropic state to drive pixels into a state having a lower reflectance than the focal conic state. In particular, pixels may be driven into the homeotropic state continuously to achieve a state of minimum reflectance, this being the minimum reflectance of the second portion of the range. To achieve higher reflectances in the second portion of the range, pixels are driven into the homeotropic state and planar state alternately.

The preferred form of the drive signals in the static and dynamic drive schemes is as follows.

In the static drive scheme, the drive signals are of a known form for driving cholesteric liquid crystal into a stable state with variable grey levels. This is a variant of the conventional drive scheme described first in W. Gruebel, U. Wolff and H. Kreuger, Molecular Crystals Liquid Crystals, 24, 103, 1973 and later in other documents.

The drive signal takes the form shown in Fig. 7 which is a graph of voltage over time. The drive signal comprises a reset pulse waveform 50, followed by a relaxation period 51, followed by a selection pulse waveform 52.

The reset pulse waveform 50 is shaped to drive the pixel into the homeotropic state. In this example, the reset pulse waveform 50 consists of a single balanced DC pulse which may equally be considered as two DC pulses 53 of opposite polarity.

The relaxation period 51 causes the pixel to relax into the planar state. The reset pulse waveform releases quickly so that the relaxation is into the planar state, rather than the focal conic state. The planar state forms within a short time period typically 3ms to 100ms depending on liquid crystal materials and alignment layers used. Accordingly the relaxation period is longer than this.

The selection pulse waveform 52 drives the pixel into a stable state having the desired reflectance. To achieve the maximum reflectance, the selection pulse waveform 52 is omitted altogether so that the drive signal consists only of the reset pulse waveform 50. followed by the relaxation period 51 to leave the pixel in the planar state. To achieve lower reflectances, the selection pulse waveform 52 comprises an initial pulse 54 optionally followed by a tuning pulse 55. In this example, the initial pulse 54 and the tuning pulse 55 each consist of a single balanced DC pulse. Thus the initial pulse 54 may equally be considered as two DC pulses 56 of opposite polarity and the tuning pulse 55 may equally be considered as two DC pulses 57 of opposite polarity.

The amplitudes of the initial pulse 54 and the tuning pulse 55 are variable to drive the pixel into a stable state having a correspondingly variable reflectance. This may be understood by reference to Fig. 8 which shows the electro-optical curve of a typical liquid crystal material. In particular, Fig. 8 is a graph of the reflectance (in arbitrary units) of a liquid crystal initially in the planar state (that is at the end of the relaxation period 52) after application of a pulse of variable amplitude (that is the initial pulse 54), the reflectance being plotted against the amplitude of that pulse. Thus the amplitude of the initial pulse 54 is selected at a point on the curve of Fig. 8 between V1 and V2 or between V3 and V4 to provide the desired reflectance.

The slope of the curve between V1 and V2 or between V3 and V4 allows many grey level states to be achieved. For example, Fig. 9 is a graph of reflectance (arbitrary units) which may be achieved against the voltages of the initial pulse 54 of the selection pulse waveform for a liquid crystal material having the electro-optical curve of Fig. 8.

The tuning pulse 55 may be omitted so that the selection pulse waveform 52 comprises a single pulse, that is the initial pulse 54. As an alternative, the tuning pulse 55 may be included. In this case, the initial pulse 54 drives the pixel into an initial stable state and the tuning pulse 55 drives the pixel into a final stable state. The tuning pulse 55 preferably has a lower amplitude than the initial pulse 54. The advantage of using the tuning pulse 55 is that it can improve the resolution by allowing the pixel to reach a number of different final stable states between the initial stable states. This improves the static image quality.

In some implementations there is always a tuning pulse 55 regardless of the desired reflectance. In other implementations, the tuning pulse 55 is variably either (1) absent if the desired reflectance is equal to the reflectance of one of the initial stable states or (2) present if the desired reflectance is equal to the reflectance of one of the final stable states.

As an alternative to the amplitude of the selection pulse waveform 52 being variable, the duration of the initial pulse 54 and/or the tuning pulse 55 may be variable, as shown by the dotted lines in Fig. 7, to achieve a variable reflectance. This works in a similar manner to variation of the amplitude.

The actual amplitudes and durations of the reset pulse waveform 50 and the selection pulse waveform 52 vary in dependence on a number of parameters such as the actual liquid crystal material used, the configuration of the cell 10, for example the thickness of the liquid crystal layer, and other parameters such as temperature. As is routine in cholesteric liquid crystal display devices, these amplitudes and durations can be optimised experimentally for any particular display device 24. Typically, the reset pulse waveform 50 might have an amplitude of 50V to 60V and a duration of from 0.6ms to 100ms, more usually 50ms to 100ms. Typically the initial pulse 54 and/or the tuning pulse 55 might have an amplitude of from 10V to 20V and a duration of from 0.6ms to 100ms.

In the above example, the pulses 52, 54 and 55 are all balanced DC pulses. In general any of these pulses 52, 54 and 55 may alternatively by DC pulses or AC pulses. In general it is preferred that the pulses are DC balanced to limit electrolysis of the liquid crystal layer 19 which can degrade its properties over time. Such DC balancing may be achieved by the use of balanced DC pulses, AC pulses or else DC pulses which are of alternating polarity in successive frames.

The drive signals of the static drive scheme are only supplied when the liquid crystal layer 19 is required to change reflectance. Thus the power consumption for pixels in the first portion of the range of reflectances is low.

In the dynamic drive scheme, the drive signals take the form shown in Figs. 10A to 10C which are graphs of voltage over time. These drive signals are supplied on a frame basis, that is the drive signals are applied each of successive frames of a predetermined duration. Typically, the frame period might be in the range from 10ms to 30ms, for example 13ms as shown in Fig.10A. The drive signals of the static drive scheme may be applied in the same frame period.

To drive the pixel into a state of minimum reflectance, the drive signal takes the form shown in Fig. 10A comprising drive pulse 60 which drives the pixel into the homeotropic state for the entire frame, that is continuously without allowing relaxation into the planar state.

To drive the pixel into a state of higher reflectance, the drive signal takes the form shown in Fig. 10B comprising drive pulse 61 of duration Th which drives the pixel into the homeotropic state and a relaxation period 62 of duration Tp which allows the pixel to relax into the planar state. Thus the pixel is driven into the homeotropic state and the planar state alternately. The durations Th and Tp are variable to vary the amounts of time spent by the pixel in the homeotropic and planar states. As a result of persistence of vision, the viewer perceives the pixel as having a reflectance which is the average of the reflectance over the entire frame. Thus the reflectance perceived by the viewer varies as the durations Th and Tp vary. This allows the production of grey levels in the second portion of the range of reflectances.

In fact, the change in the reflectance over the frame is quite complicated. At the end of the drive pulse 61, the liquid crystal material of the pixel starts to change back into the stable planar cholesteric state within this cycle and reflects some light. This relaxation is a complex process and proceeds via a metastable transient planar state that has about twice the pitch length (in fact the pitch of transient planar texture is equal to K33/K22 x the pitch of final planar state where K33 is the liquid crystal bend elastic constant and K22 is the twist elastic constant) of the stable planar cholesteric phase (as explained for example in D-K Yang & Z-J Lu, SID Technical Digest page 351, 1995 and in J Anderson et al, SID 98 Technical Digest, XX1X page 806, 1998). Although this produces some non-linearity, it is nonetheless the case that the average reflectance increases with increase in the ratio of the amounts of time in the planar and homeotropic states, that is Tp/Th in this case. The actual change in reflectance is difficult to model but can be plotted by experiment. For example, Fig. 11 is a graph of the reflectance (arbitrary units) achievable for different durations Th and Tp for a cell 10 of the same type as that to which Figs. 8 and 9 apply. In Fig. 11, the horizontal axis is the duration Tp of the relaxation period 62 measured as a number of time slots. Each time slot has a length of approximately 0.3ms in this example so the maximum reflectance in Fig. 11 is achieved when the duration Tp of the relaxation period 62 is approximately 4ms. More points could be plotted if desired.

Furthermore, the selection of the durations Th and Tp is made so that the maximum value of the duration Tp of the relaxation period 62 provides the pixel with an average reflectance which is the maximum reflectance of the second portion of the predetermined range, that is equal to the reflectance of the focal conic state which is minimum reflectance of the first portion of the predetermined range. Again this is difficult to model but is easily determined by experiment in respect of the display device in question. For example, for a cell 10 of the type to which Figs. 8 and 9 apply this might typically correspond to the duration Th of the drive pulse 61 being 9ms. Thus it is possible for a continuous range of reflectances to be achieved by the static and dynamic drive schemes as shown for example in Fig. 12 which shows the graphs of Figs. 9 and 11 overlapping each other.

In the drive signal shown in Fig. 10B, there is a single drive pulse 61 in each frame. This is preferred to minimise the power consumption and the stress on the liquid crystal material of the pixel. However, it is not essential to utilize a single pulse 61 in each frame and as an alternative, drive pulses may alternate with relaxation periods in each frame.

To facilitate digital implementation, the frame is divided into a predetermined number of time slots and the drive pulse 61 (or plural drive pulses, if used) are applied in a variable number of the time slots. This means that the change in reflectance occurs in discrete steps and thus the length of the time slots is chosen to provide an appropriate resolution in the resultant grey scale.

The amplitude of the drive pulses 60 and 61, and the frame duration, needed to drive the pixel into the homeotropic state in general vary in dependence on a number of parameters, in a similar manner to the parameters of the drive signal of the static drive scheme. The amplitude of the drive pulses 60 and 61 may be determined experimentally for a given display device 24 but the amplitude is typically in the range from 50V to 60V.

In Figs. 10A to 10C, the drive pulses 60 and 61 are shown as unipolar pulses. For

DC balancing, the drive pulses 60 and 61 have alternating polarity in successive frames. As an alternative to provide DC balancing, the drive pulses 60 and 61 may be AC pulses or balanced DC pulses.

The advantage of the use of the dynamic drive scheme in combination with the static drive scheme improves the contrast ratio and the colour gamut. Considering the static drive scheme, the focal conic state is the dark state but this still scatters light typically having a reflectance of from 3% to 4%. As a result the contrast ratio of the liquid crystal layer 19 is typically from 10 to 15, and with a conventional multiplex addressing electrode arrangement this gives an overall contrast ratio for the cell 10 of from about 6 to 8. However, use of the dynamic drive scheme allows use of the homeotropic state as the dark state. As the homeotropic state has a very low reflectance, this improves the contrast ratio. For example, the contrast ratio of the liquid crystal layer 19 is typically 50 or above and the contrast ratio of the overall display device 24 in which the fill factor of the drive electrodes 31 (i.e. the area of the drive electrodes as a proportion of the area of the display) of 95% is about 30.

The colour gamut is also better as follows. In general in a cholesteric display device consisting typically of three stacked cells, the colour of each pixel within a cell is influenced by those pixels above and below it. For example if the lowest pixel has to be at its 100% colour then the pixels above it must be in a transparent state to show the lower pixel optimally. With a known static drive scheme, when the upper pixels are switched into the focal conic state which is largely transparent but not fully transparent, the lower pixels will show a colour that is a mixture of the 100% colour and some white light scattered from upper (or lower) layers. In other words the colour is less saturated than is ideal and the colour gamut is degraded. However, the use of the dynamic drive scheme allows the dark state to have a lower reflectance, hence improving the colour gamut and providing purer colours. This is illustrated in Fig. 13 which is a CIE plot of the colour gamut for the same display device 24 driven solely by a static drive scheme and by the drive described above.

The drive signals of Figs 10A to 10C are applied repeatedly in successive frames until the image is changed. Thus power is continuously consumed by pixels having a reflectance in the second portion of the predetermined range. However, in practice the overall power consumption of the display device is relatively low as typical images require only a fraction of the cell 10 to be in the black state, typically of the order of 10% to15% although this is of course entirely dependent on the nature of the image. The rest of the picture can be driven using a bistable mode.

Various modifications to the drive scheme described above may be made. One possibility is for the dynamic drive scheme to be used to drive pixels to higher reflectances, either by increasing the boundary between the first and second portions of the predetermined range or by making the first and second portions of the predetermined range overlap. However this is not preferred as the dynamic drive scheme consumes more power than the static scheme.

Similarly operation is possible with a restricted range of reflectances, for example by the static drive scheme not using the planar state or the dynamic drive scheme not driving pixels continuously into the homeotropic state, but this is not preferred due to the reduction in the contrast ratio achievable.

Claims

1. A method of driving a cholesteric liquid crystal display device which comprises at least one cell comprising a layer of cholesteric liquid crystal material and an electrode arrangement capable of providing independent driving of a plurality of pixels across the layer of cholesteric liquid crystal material by respective drive signals, the method comprising applying respective drive signals to each pixel to drive the pixels into states which are varied to provide a reflectance varying within a predetermined range of reflectances, the drive signals comprising:

(a) when providing a reflectance in a first portion of the predetermined range of reflectances, a first waveform shaped to drive the pixel into a stable state, the waveform having a shape which is variable to provide a stable state having a varying reflectance; and

(b) when providing a reflectance in a second portion of the predetermined range of reflectances which is lower than the first portion, a second waveform shaped to drive the pixel into the homeotropic state and the planar state alternately, the periods of time during which the pixel is driven into the homeotropic and planar states being variable to provide a varying average reflectance as perceived by a viewer.

2. A method according to claim 1, wherein said first waveform comprises:

a reset pulse waveform shaped to drive the pixel into the homeotropic state,

followed by a relaxation period to cause the pixel to relax into the planar state,

followed by a selection pulse waveform shaped to drive the pixel into a stable state, the selection pulse waveform being variable to drive the pixel into a stable state having a varying reflectance.

3. A method according to claim 2, wherein the selection pulse waveform has an amplitude which is variable.

4. A method according to claim 2 or 3, wherein the selection pulse waveform comprises an initial pulse shaped to drive the pixel into one of a plurality of initial stable states, followed by a gap, followed by a tuning pulse shaped to drive the pixel into a final stable state having a reflectance between the reflectances of the initial stable states.

5. A method according to claim 2 or 3, wherein the selection pulse waveform comprises an initial pulse shaped to drive the pixel into one of a plurality of initial stable states, followed by a gap, followed by variably either no further pulse to maintain the pixel in the initial stable state or a tuning pulse shaped to drive the pixel into a final stable state having a reflectance between the reflectances of the initial stable states.

6. A method according to claim 4 or 5, wherein the initial pulse is of duration 0.6ms to 100ms.

7. A method according to any one of claims 4 to 6, wherein the tuning pulse is of duration 0.6ms to 100ms.

8. A method according to claim 2 or 3, wherein the selection pulse waveform comprises a single pulse.

9. A method according to claim 8, wherein the single pulse is of duration 0.6ms to 100ms.

10. A method according to any one of claims 2 to 9, wherein the reset pulse waveform comprises a single pulse.

11. A method according to any one of the preceding claims, wherein said second waveform comprises one or more drive pulses shaped to drive the pixel into the

homeotropic state alternating with one or more relaxation periods to cause the pixel to relax into the planar state.

12. A method according to claim 11, wherein said second waveform comprises, in each of a plurality of frames of predetermined duration, a single drive pulse shaped to drive the pixel into the homeotropic state followed by a relaxation period to cause the pixel to relax into the planar state.

13. A method according to any one of claims 4 to 12, wherein each of the pulses is a DC pulse, a balanced DC pulse or an AC pulse.

14. A method according to any one of the preceding claims, wherein the second portion of the predetermined range of reflectances is above the minimum reflectance in the predetermined range of reflectances, and the drive signals further comprise:

(c) when providing the minimum reflectance in the predetermined range of reflectances, a third waveform shaped to drive the pixel into the homeotropic state.

15. A method according to any one of the preceding claims, wherein the first portion of the predetermined range of reflectances is below the maximum reflectance in the predetermined range of reflectances, and the drive signals further comprise:

(d) when providing the maximum reflectance in the predetermined range of reflectances, a fourth waveform shaped to drive the pixel into the planar state.

14. A method according to any one of the preceding claims, wherein the drive signals are applied in successive frames of predetermined duration, the first and second waveforms each applied in a respective frame

15. A method according to any one of the preceding claims, wherein the electrode

arrangement includes a respective conductive layer on each side of the layer of liquid crystal material, at least one of the conductive layers being patterned to provide a plurality of separate drive electrodes each capable of providing independent driving of an area of the layer of liquid crystal material adjacent the respective drive electrode as one of said pixels.

16. A method according to claim 15, wherein one of the conductive layers is patterned to provide said plurality of separate drive electrodes and the other of the conductive layer is shaped as at least one common electrode extending over a plurality of pixels.

17. A method according to claim 15 or 16, wherein the at least one of the conductive layers which is patterned to provide a plurality of separate drive electrodes further comprises a separate track connected to each of the separate drive electrodes and extending to a position outside the array of addressable pixels where the tracks form terminals each capable of receiving a respective drive signal.

18. A method according to any one of claims 15 to 17, wherein the at least one cell comprises two substrates defining therebetween a cavity in which said a layer of liquid crystal material is disposed, the respective conductive layerseach being formed on one of the substrates

19. A method according to any one of the preceding claims, wherein the plurality of pixels comprises a two-dimensional array of pixels.

20. A cholesteric liquid crystal display device comprising:

at least one cell comprising a layer of cholesteric liquid crystal material and an electrode arrangement capable of providing independent driving of a plurality of pixels across the layer of cholesteric liquid crystal material by respective drive signals; and

a drive circuit arranged to apply a respective drive signal to each pixel to drive the pixel into states which are variable to provide a reflectance varying within a predetermined range of reflectances, the drive signals comprising:

(a) when providing a reflectance in a first portion of the predetermined range of reflectances, a first waveform shaped to drive the pixel into a stable state, the waveform having a shape which is variable to provide a stable state having a varying reflectance; and

(b) when providing a reflectance in a second portion of the predetermined range of reflectances which is lower than the first portion, a second waveform shaped to drive the pixel into the homeotropic state and the planar state alternately, the periods of time during which the pixel is driven into the homeotropic and planar states being variable to provide a varying average reflectance as perceived by a viewer.

Fig.1.

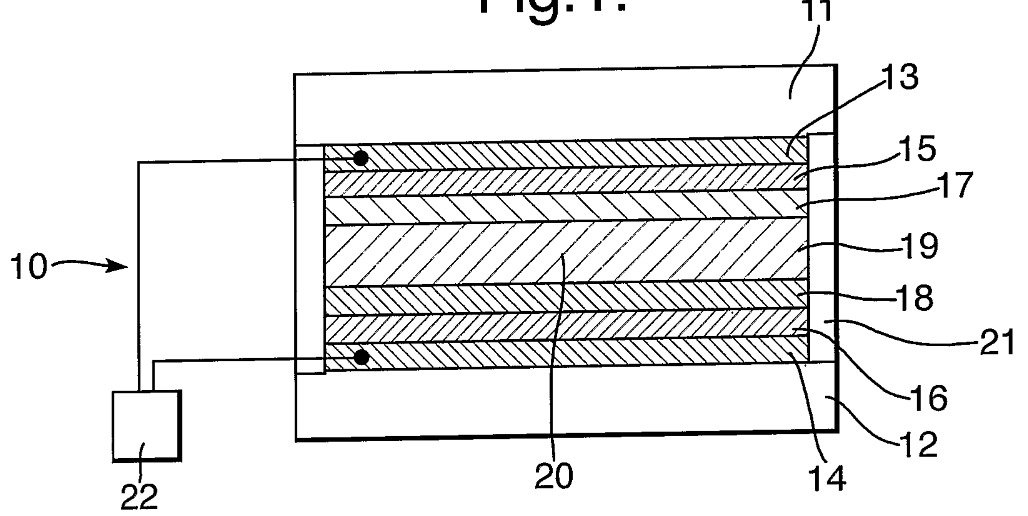

11
13
15
17
19
18
21
16
12
14
20
10
22

Fig.2.

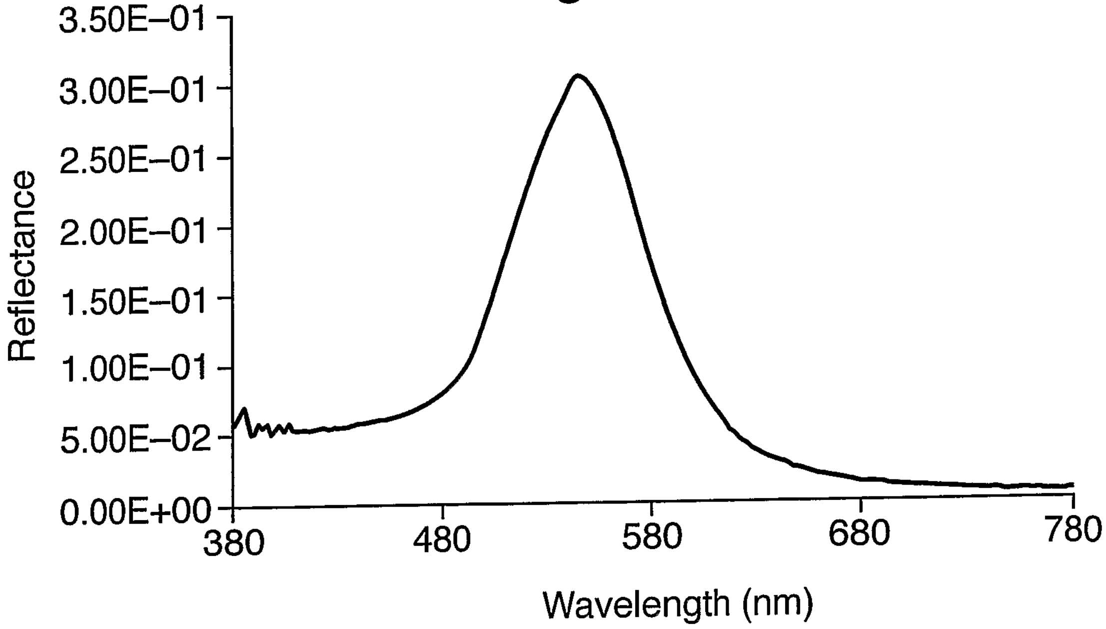

3.50E–01
3.00E–01
2.50E–01
2.00E–01
1.50E–01
1.00E–01
5.00E–02
0.00E+00
Reflectance
380
480
580
680
780
Wavelength (nm)

Fig.3.

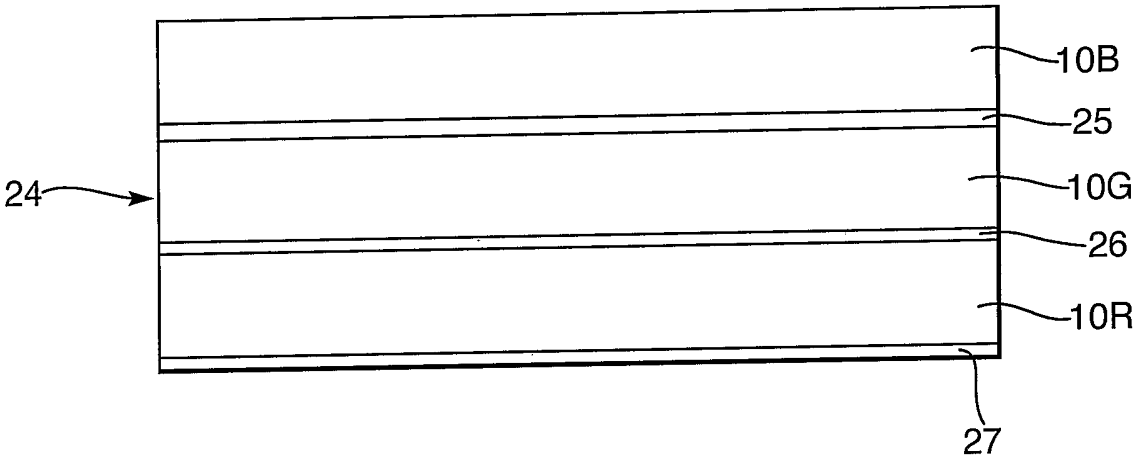


Fig.4.

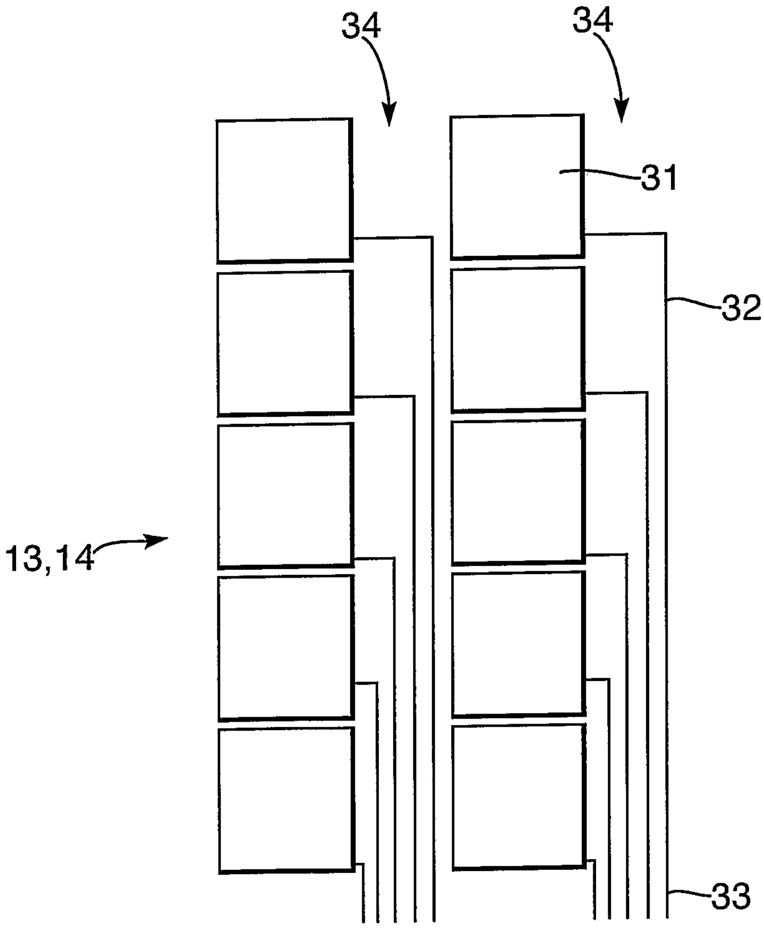


Fig.5.

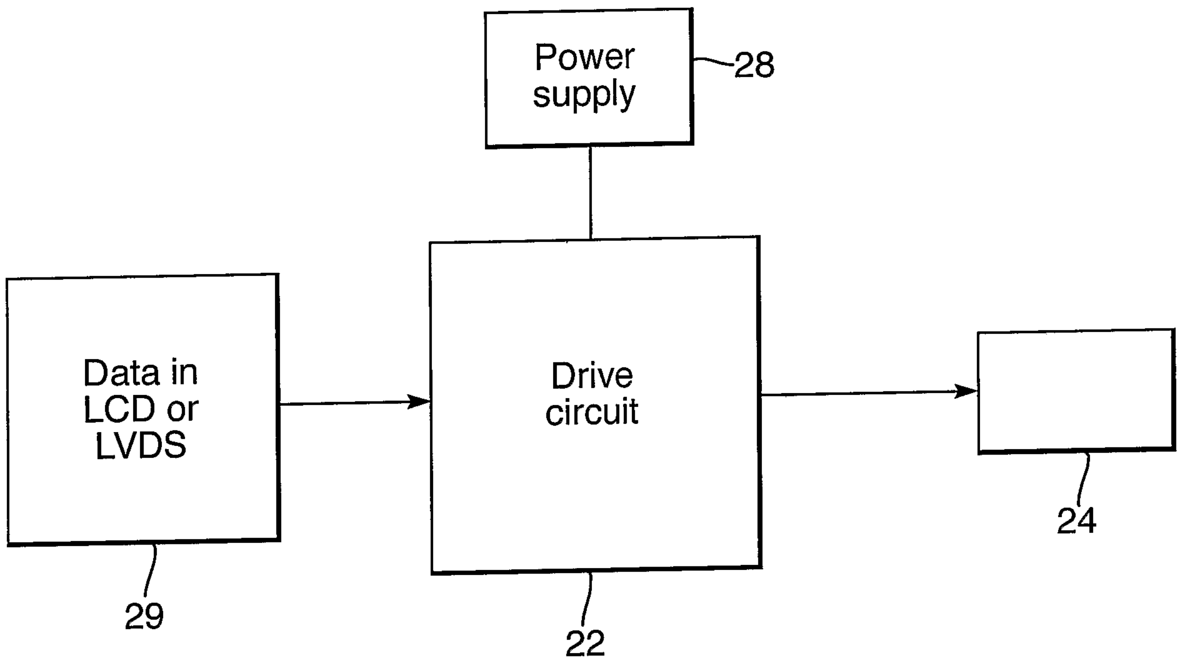

Power supply
28
Data in LCD or LVDS
Drive circuit
24
29
22

Fig.6.

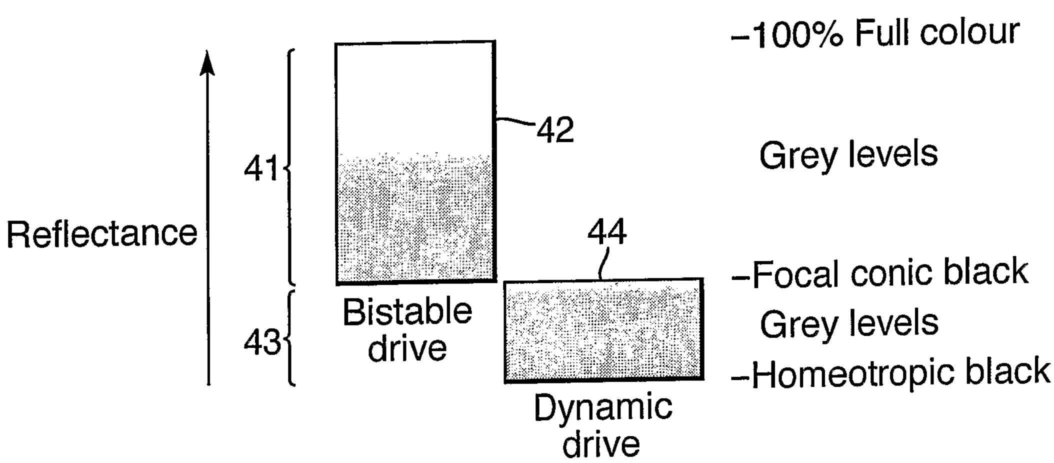

-100% Full colour
42
Grey levels
41
Reflectance
44
-Focal conic black
Bistable drive
Grey levels
43
-Homeotropic black
Dynamic drive

Fig.7.

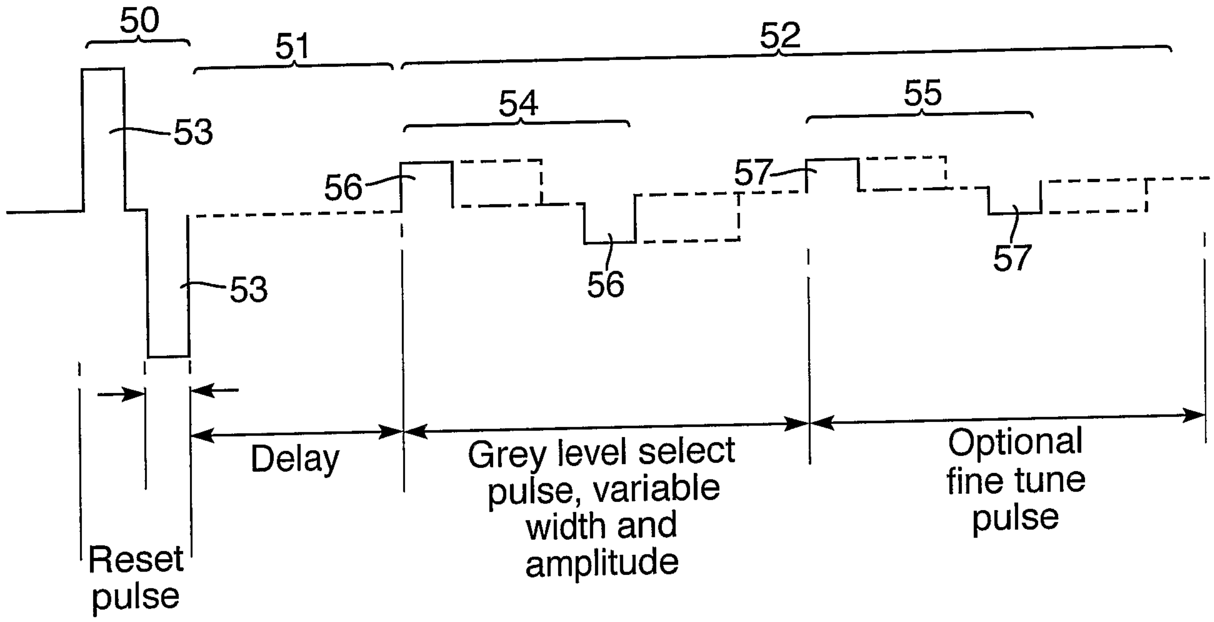

50
51
52
54
55
53
56
57
53
56
57
Delay
Grey level select pulse, variable width and amplitude
Optional fine tune pulse
Reset pulse

Fig.8.

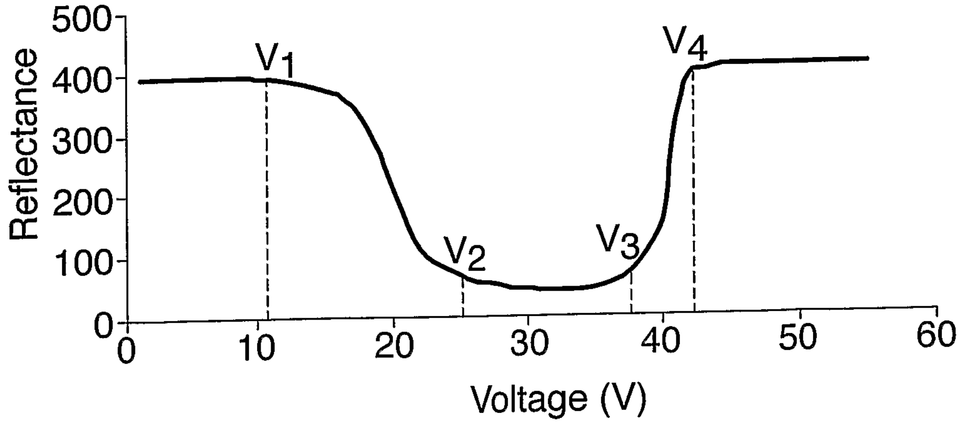
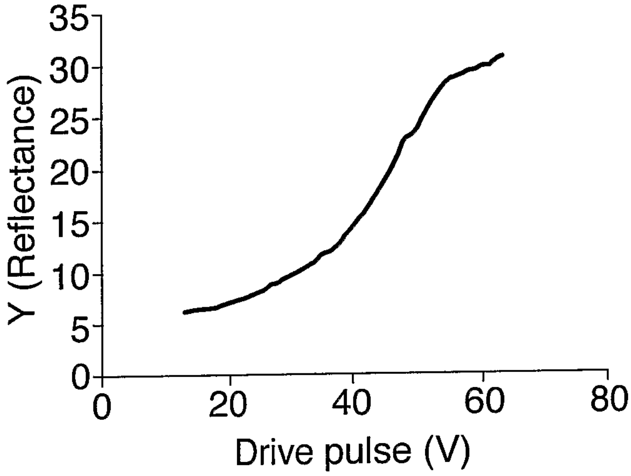

500
400
300
200
100
0
Reflectance
V1
V2
V3
V4
0
10
20
30
40
50
60
Voltage (V)

Fig.9.


35
30
25
20
15
10
5
0
Y (Reflectance)
0
20
40
60
80
Drive pulse (V)

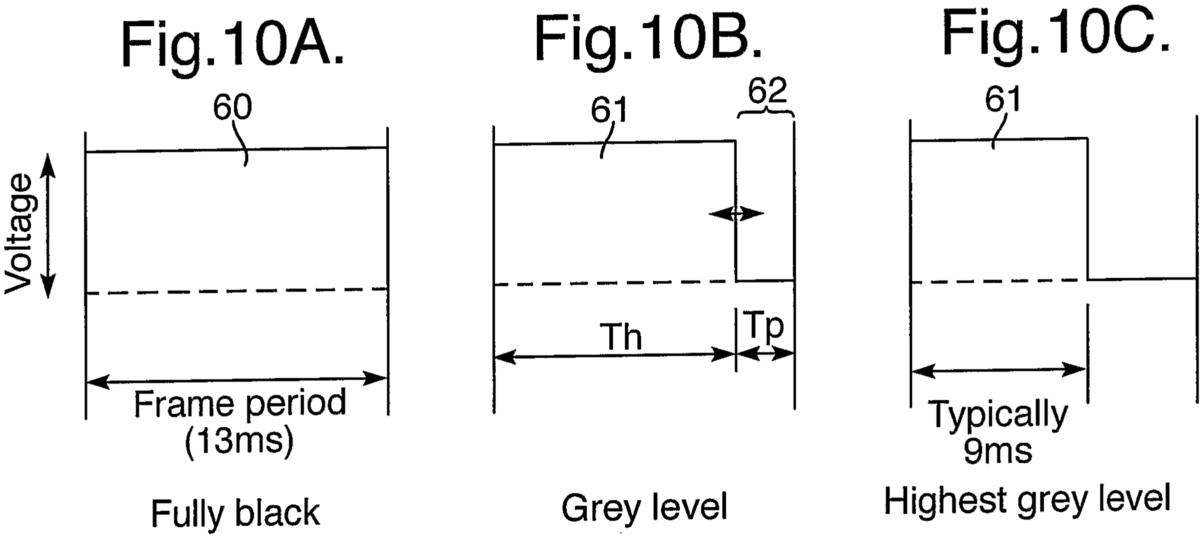


Fig.10A.
60
Voltage
Frame period
(13ms)
Fully black
Fig.10B.
61
62
Th
Tp
Grey level
Fig.10C.
61
Typically
9ms
Highest grey level

Fig.11.

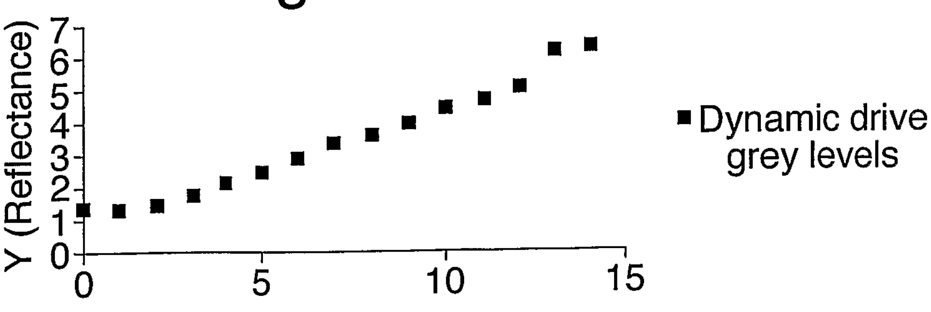

7
6
5
4
3
2
1
0
Y (Reflectance)
0
5
10
15
Dynamic drive
grey levels

Fig.12.

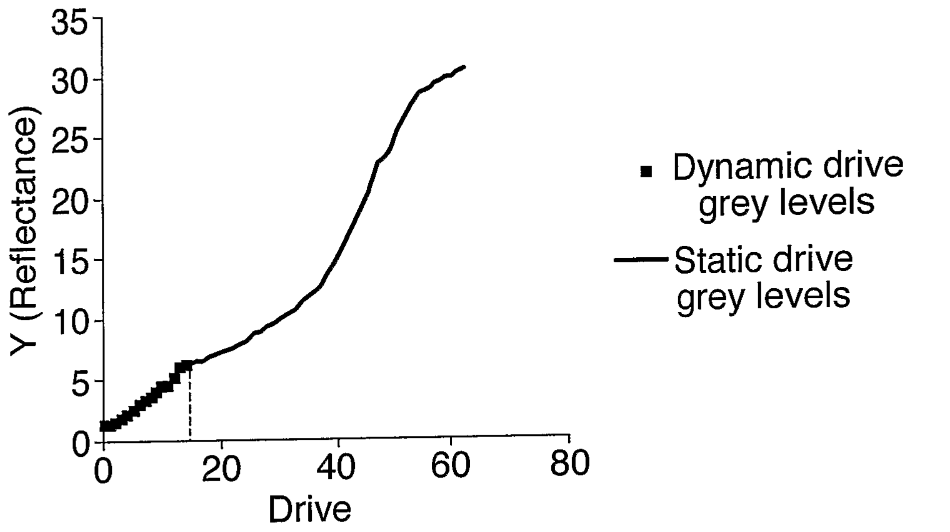
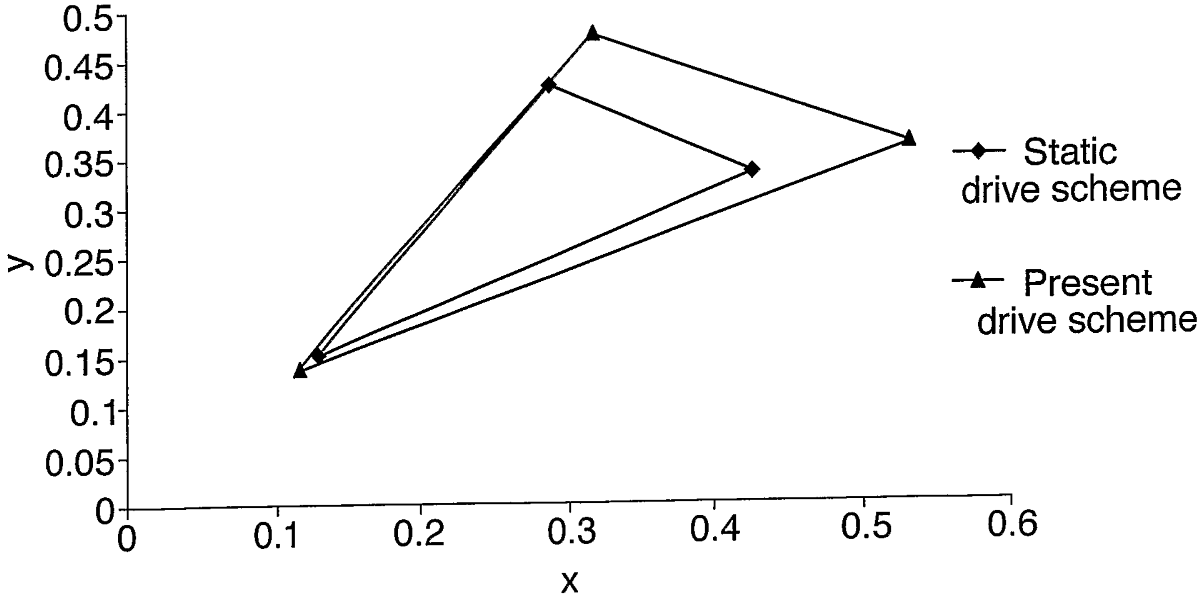

Y (Reflectance)
0
5
10
15
20
25
30
35
0
20
40
60
80
Drive
Dynamic drive grey levels
Static drive grey levels

Fig.13.


y
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
x
Static drive scheme
Present drive scheme

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2005/004278

A. CLASSIFICATION OF SUBJECT MATTER
G09G3/36 G02F1/137

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G09G G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2004/030335 A (MAGINK DISPLAY TECHNOLOGIES LTD; BEN-SHALOM, AMIR; COATES, DAVID) 8 April 2004 (2004-04-08) cited in the application page 6, line 24 - page 7, line 15 figures 1,21-24 page 2, line 22 - page 3, line 9; tables on,page,7 page 6, line 13 - line 14 page 11, last line - page 12, line 1 page 15, line 4 - line 9 page 15, line 14 - line 17 page 15, line 27 - line 28 page 16, line 19 - line 20 tables on,page,14 ----- -/--	1-20

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 February 2006	02/03/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Gundlach, H

INTERNATIONAL SEARCH REPORT

Inte nal application No
PCT/GB2005/004278

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 283 435 A (EASTMAN KODAK COMPANY) 12 February 2003 (2003-02-12) paragraphs '0026!, '0027!; figures 4a,4b,4c column 7, line 41 - line 43; figure 3 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte ıal application No
PCT/GB2005/004278

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			EP	1563341 A2	17-08-2005
			JP	2006501500 T	12-01-2006
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			US	2003034945 A1	20-02-2003