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(54) DISPLAY DEVICE AND DISPLAY SYSTEM

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(73) Assignee: **Japan Display Inc.**, Minato-ku (JP)

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G09G 3/34 (2006.01)
G09G 3/36 (2006.01)

(52) **U.S. Cl.**
CPC ***G09G 3/3413*** (2013.01); ***G09G 3/36*** (2013.01); ***G09G 3/3614*** (2013.01); ***G09G 3/3655*** (2013.01); *G09G 2310/0235* (2013.01); *G09G 2320/064* (2013.01); *G09G 2320/0633* (2013.01); *G09G 2320/0666* (2013.01); *G09G 2360/144* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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(57) ABSTRACT

A display device includes: a liquid crystal display panel including a liquid crystal between two substrates; and first, second, and third light sources emitting light in different colors. A light emission period includes a first light emission period in which luminance of the first light source is higher than luminance of the second and third light sources, and at least one of the second and third light sources emits light, a second light emission period in which the luminance of the second light source is higher than the luminance of the first and the third light sources, and at least one of the first and third light sources emits light, and a third light emission period in which the luminance of the third light source is higher than the luminance of the first and second light sources, and at least one of the first and second light sources emits light.

8 Claims, 7 Drawing Sheets

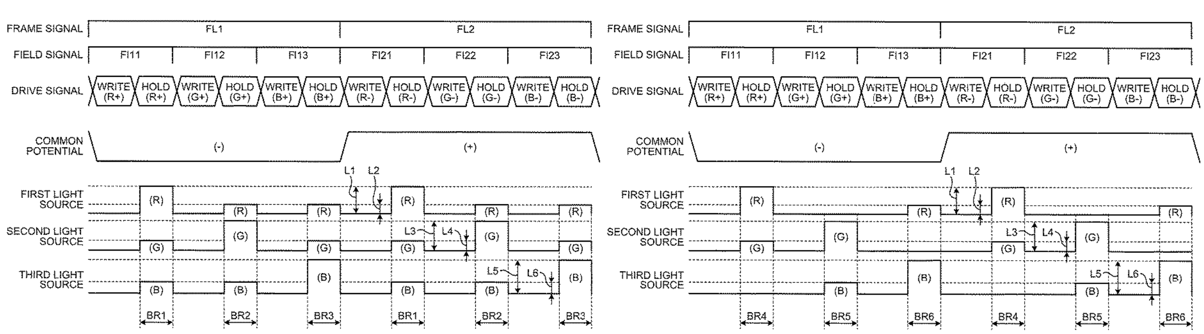


FIG.1

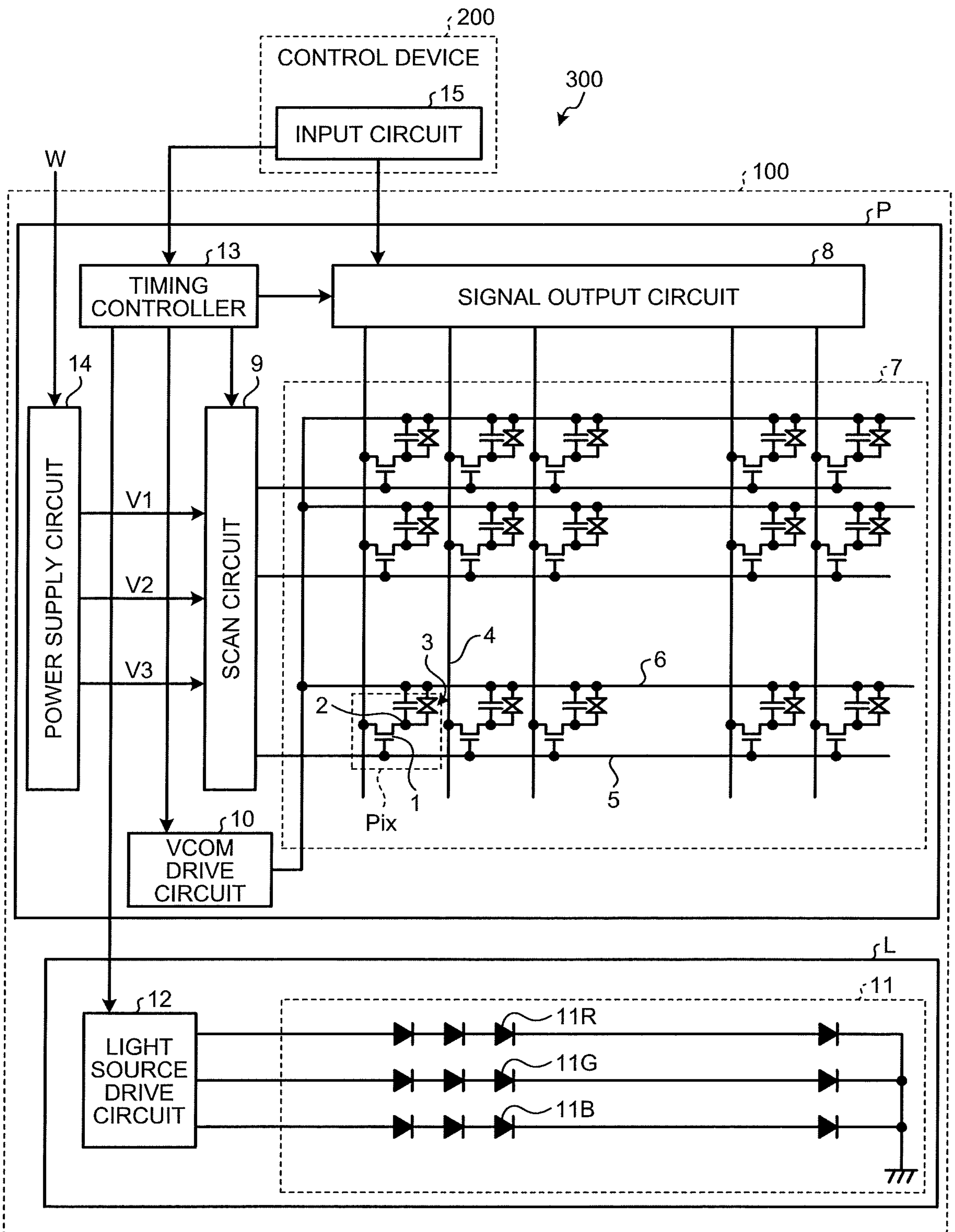

200
CONTROL DEVICE
15
INPUT CIRCUIT
300
W
100
P
13
TIMING CONTROLLER
8
SIGNAL OUTPUT CIRCUIT
14
9
7
POWER SUPPLY CIRCUIT
V1
V2
V3
SCAN CIRCUIT
3
4
6
2
1
5
Pix
10
VCOM DRIVE CIRCUIT
L
12
11
LIGHT SOURCE DRIVE CIRCUIT
11R
11G
11B

FIG.2

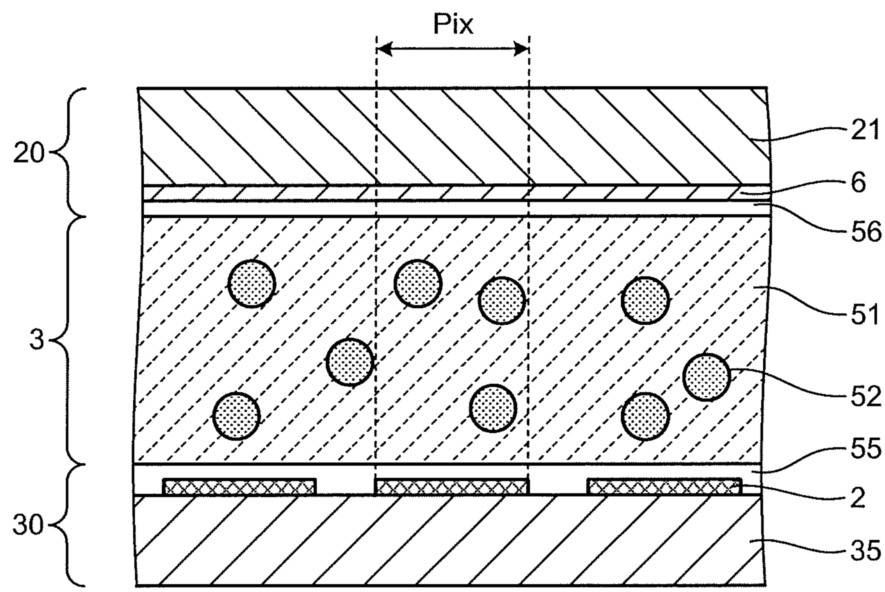


FIG.3

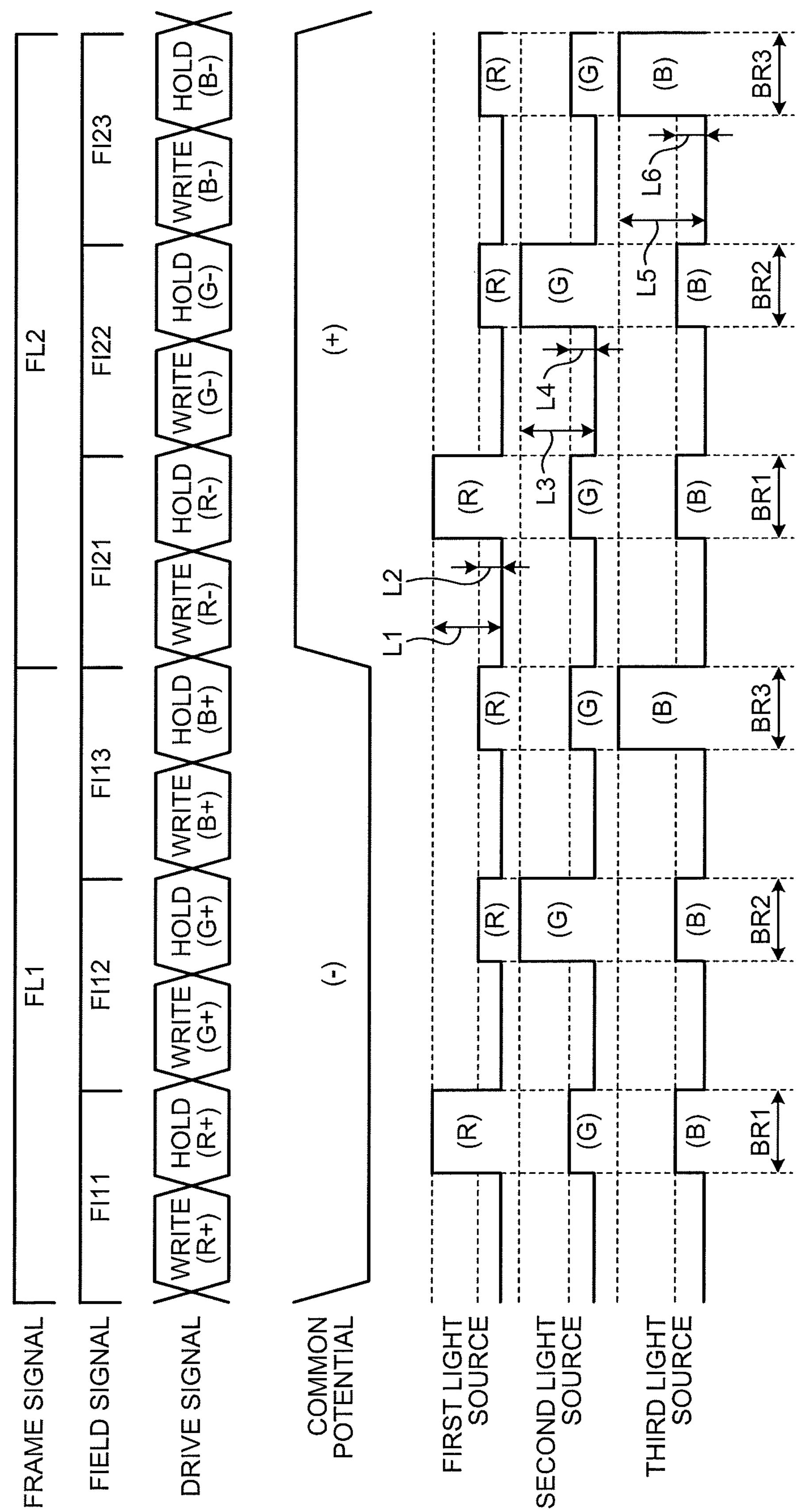
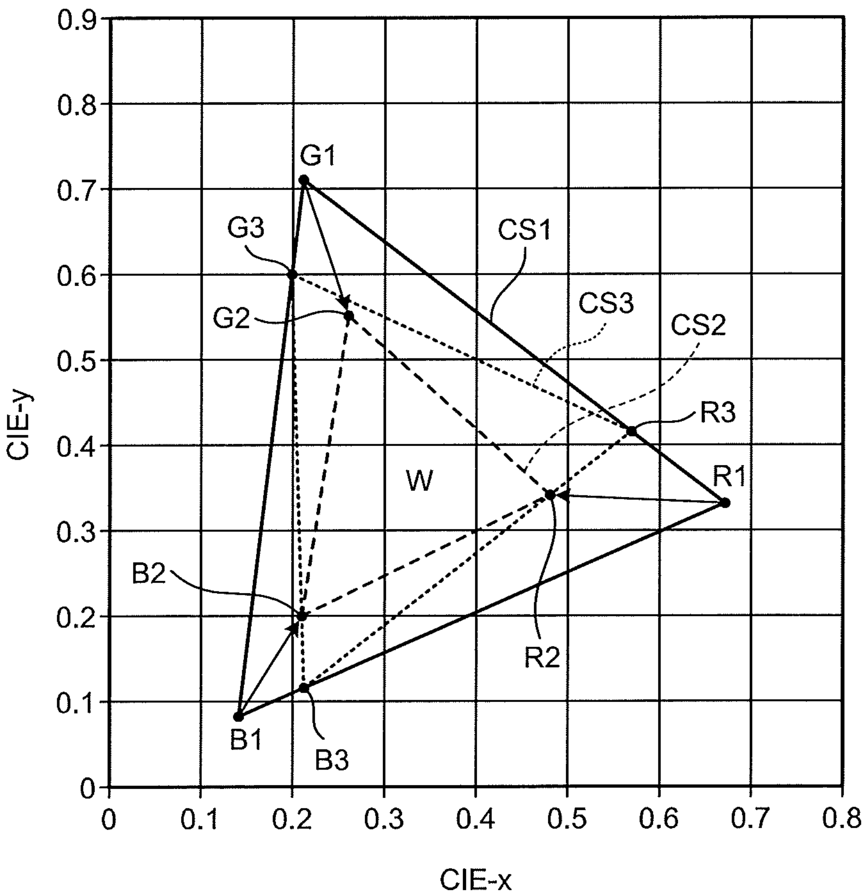

FRAME SIGNAL
FIELD SIGNAL
DRIVE SIGNAL
COMMON POTENTIAL
FIRST LIGHT SOURCE
SECOND LIGHT SOURCE
THIRD LIGHT SOURCE
FL1
FL2
FI11
FI12
FI13
FI21
FI22
FI23
WRITE (R+)
HOLD (R+)
WRITE (G+)
HOLD (G+)
WRITE (B+)
HOLD (B+)
WRITE (R-)
HOLD (R-)
WRITE (G-)
HOLD (G-)
WRITE (B-)
HOLD (B-)
(-)
(+)
(R)
(G)
(B)
BR1
BR2
BR3
L1
L2
L3
L4
L5
L6

FIG.4



0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CIE-y
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
CIE-x
G1
G3
G2
CS1
CS3
CS2
R3
R1
W
B2
R2
B1
B3

FIG.5

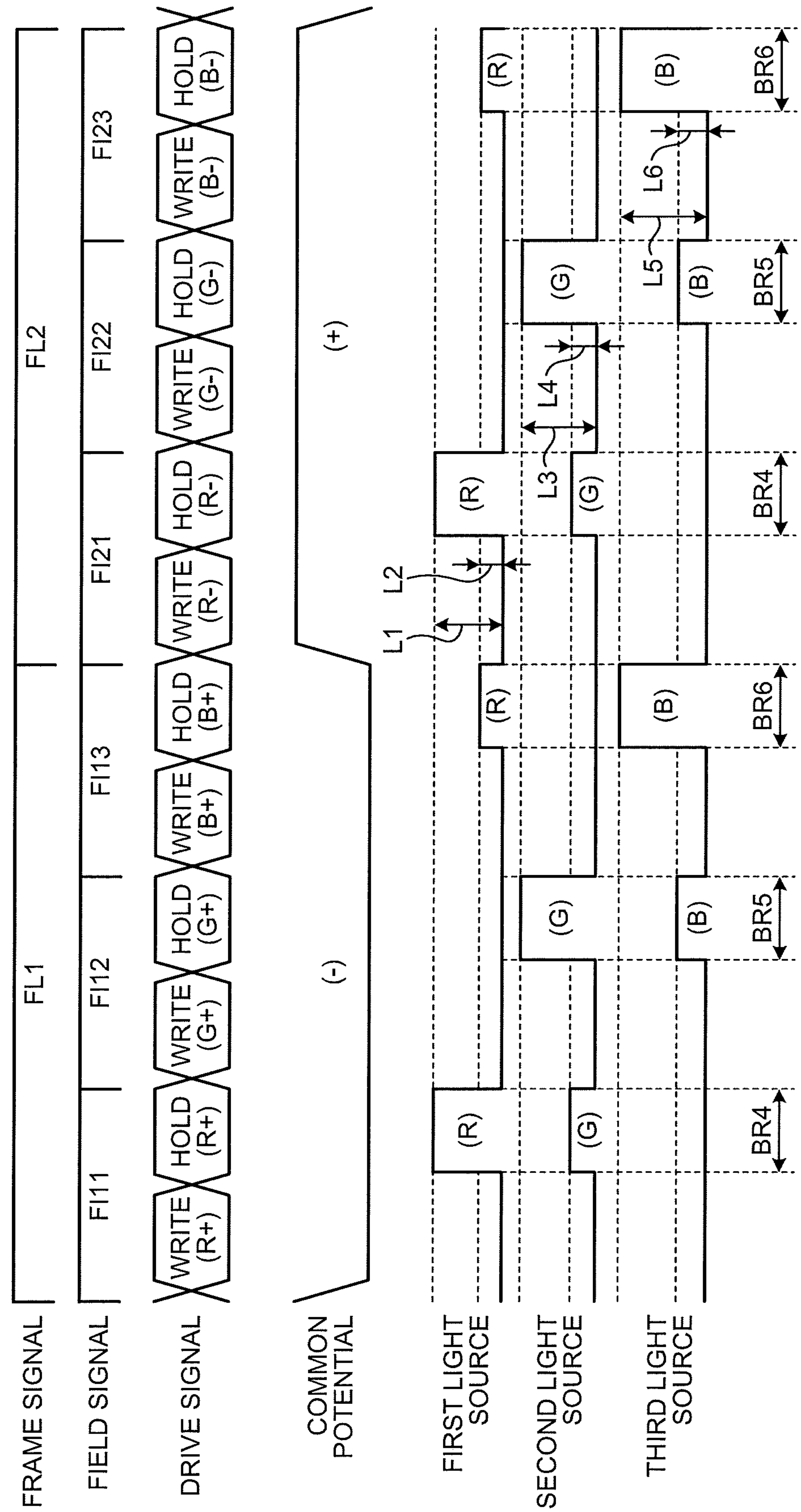

FRAME SIGNAL
FIELD SIGNAL
DRIVE SIGNAL
COMMON POTENTIAL
FIRST LIGHT SOURCE
SECOND LIGHT SOURCE
THIRD LIGHT SOURCE
FL1
FL2
FI11
FI12
FI13
FI21
FI22
FI23
WRITE (R+)
HOLD (R+)
WRITE (G+)
HOLD (G+)
WRITE (B+)
HOLD (B+)
WRITE (R-)
HOLD (R-)
WRITE (G-)
HOLD (G-)
WRITE (B-)
HOLD (B-)
(-)
(+)
(R)
(G)
(B)
L1
L2
L3
L4
L5
L6
BR4
BR5
BR6

FIG.6

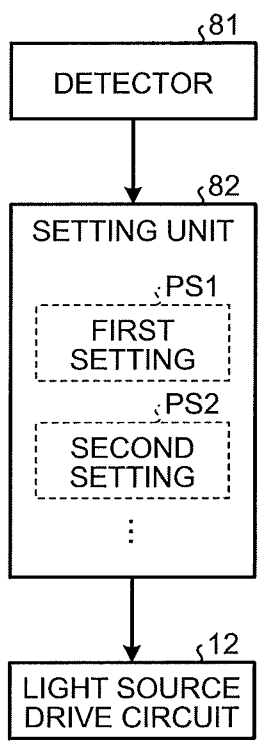

81
DETECTOR
82
SETTING UNIT
PS1
FIRST SETTING
PS2
SECOND SETTING
⋮
12
LIGHT SOURCE DRIVE CIRCUIT

FIG.7A

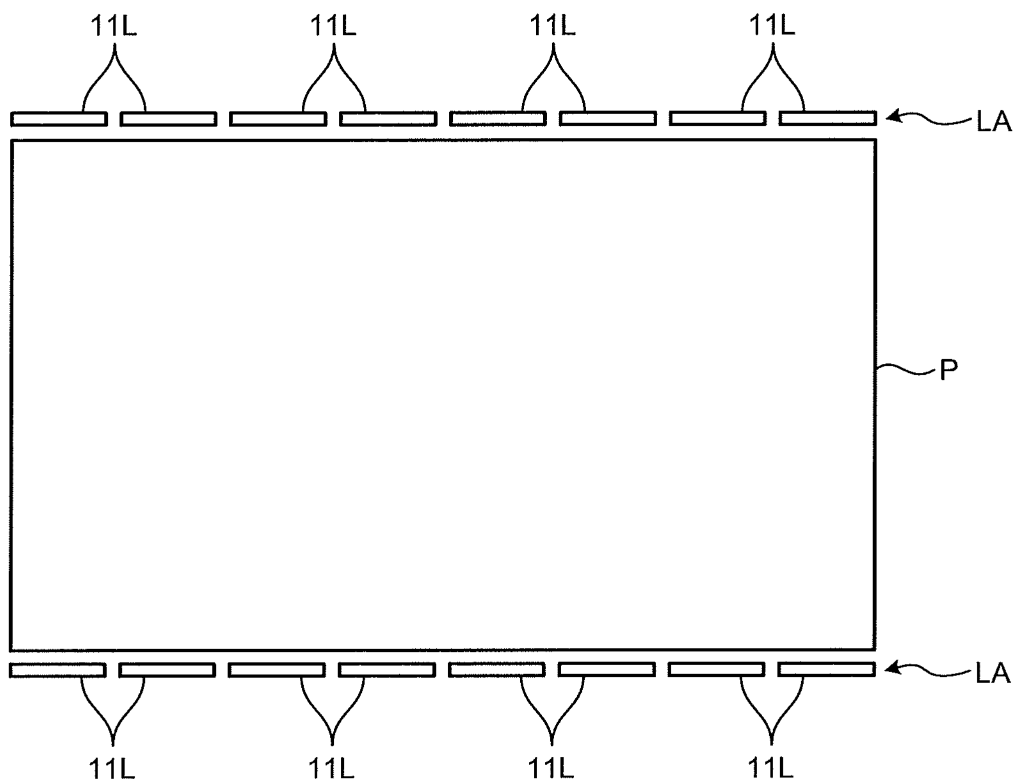
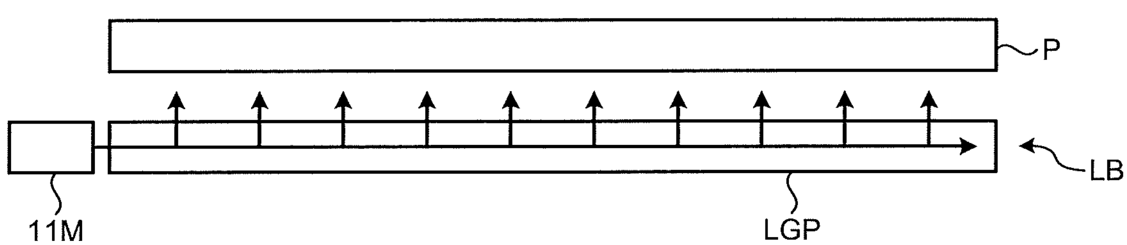


FIG.7B



DISPLAY DEVICE AND DISPLAY SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from Japanese Application No. 2019-016479, filed on Jan. 31, 2019, the contents of which are incorporated by reference herein in its entirety.

BACKGROUND

1. Technical Field

The present disclosure relates to a display device and a display system.

2. Description of the Related Art

Liquid crystal display devices are known that control each pixel so as to transmit light beams in a plurality of colors from the same pixel at different times from each other (for example, Japanese Patent Application Laid-open Publication No. 2010-097420 (JP-A-2010-097420)).

A liquid crystal display device of, for example, JP-A-2010-097420 assigns, to a light source in each color, a light emission time obtained by dividing one frame time by the number of colors of light. As a result, the light emission time of each color is shorter than that of a monochromatic light source. Thereby luminance is difficult to increase.

For the foregoing reasons, there is a need for a display device and a display system capable of more easily increasing the luminance.

SUMMARY

According to an aspect, a display device includes: a liquid crystal display panel in which a liquid crystal is sealed between two substrates facing each other; and a first light source, a second light source, and a third light source configured to emit light in colors different from one another. A light emission period in which the first light source, the second light source, and the third light source emit light includes a first light emission period in which luminance of the first light source is higher than luminance of the second light source and luminance of the third light source, and at least one of the second light source or the third light source emits light, a second light emission period in which the luminance of the second light source is higher than the luminance of the first light source and the luminance of the third light source, and at least one of the first light source or the third light source emits light, and a third light emission period in which the luminance of the third light source is higher than the luminance of the first light source and the luminance of the second light source, and at least one of the first light source or the second light source emits light.

According to another aspect, a display system includes: a display device that includes a liquid crystal display panel in which a liquid crystal is sealed between two substrates facing each other, and a first light source, a second light source, and a third light source configured to emit light in colors different from one another; and a control device configured to output signals related to control of light emission of the first light source, the second light source, and the third light source. A light emission period in which at least one of the first light source, the second light source, or the third light source emits light includes a first light emission period in which at least the first light source emits light, a second light emission period in which at least the second light source emits light, and a third light emission period in which at least the third light source emits light. The second light source and the third light source are capable of emitting light during the first light emission period. The first light source and the third light source are capable of emitting light during the second light emission period. The first light source and the second light source are capable of emitting light during the third light emission period.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic circuit diagram illustrating a main configuration of a display system;

FIG. **2** is a schematic sectional view of a liquid crystal display panel;

FIG. **3** is a timing diagram illustrating an example of a flow of field sequential control according to a first embodiment;

FIG. **4** is a diagram schematically illustrating color gamuts employable by the display system using a CIExy chromaticity diagram;

FIG. **5** is a timing diagram illustrating an example of the flow of the field sequential control according to a second embodiment;

FIG. **6** is a block diagram illustrating a relation between a detector, a setting unit, and a light source drive circuit provided in a modification;

FIG. **7A** is a schematic diagram illustrating a configuration example of a light source device; and

FIG. **7B** is a schematic diagram illustrating a configuration example of another light source device.

DETAILED DESCRIPTION

The following describes embodiments of the present invention with reference to the drawings. The disclosure is merely an example, and the present invention naturally encompasses appropriate modifications easily conceivable by those skilled in the art while maintaining the gist of the invention. To further clarify the description, widths, thicknesses, shapes, and the like of various parts are schematically illustrated in the drawings as compared with actual aspects thereof, in some cases. However, they are merely examples, and interpretation of the present invention is not limited thereto. The same element as that illustrated in a drawing that has already been discussed is denoted by the same reference numeral through the description and the drawings, and detailed description thereof will not be repeated in some cases where appropriate.

In this disclosure, when an element is described as being "on" another element, the element can be directly on the other element, or there can be one or more elements between the element and the other element.

First Embodiment

FIG. **1** is a schematic circuit diagram illustrating a main configuration of a display system **300**. The display system **300** includes a display device **100** and a control device **200**. The display device **100** includes a liquid crystal display panel P and a light source device L. The liquid crystal display panel P includes a display area **7**, a signal output circuit **8**, a scan circuit **9**, a VCOM drive circuit **10**, a timing controller **13**, and a power supply circuit **14**. Hereinafter, a display surface denotes one surface of the liquid crystal display panel P faced by the display area **7**, and a back surface denotes the other surface of the liquid crystal display panel P.

A plurality of pixels Pix are arranged in a matrix (in a row-column configuration) in the display area **7**. Each of the pixels Pix includes a switching element **1** and two electrodes. FIG. **1** and FIG. **2** (to be discussed later) illustrate a pixel electrode **2** and a common electrode **6** as the two electrodes.

FIG. **2** is a schematic sectional view of the liquid crystal display panel P. The liquid crystal display panel P includes two substrates facing each other and a liquid crystal **3** sealed between the two substrates. Hereinafter, a first substrate **30** denotes one of the two substrates, and a second substrate **20** denotes the other thereof.

The first substrate **30** includes a light-transmitting glass substrate **35**, the pixel electrodes **2** stacked on the second substrate **20** side of the glass substrate **35**, and an insulating layer **55** stacked on the second substrate **20** side thereof so as to cover the pixel electrodes **2**. The pixel electrode **2** is individually provided for each of the pixels Pix. The second substrate **20** includes a light-transmitting glass substrate **21**, the common electrode **6** stacked on the first substrate **30** side of the glass substrate **21**, and an insulating layer **56** stacked on the first substrate **30** side thereof so as to cover the common electrode **6**. The common electrode **6** has a plate-like or film-like shape shared among the pixels Pix.

The liquid crystal **3** of the first embodiment is a polymer dispersed liquid crystal. Specifically, the liquid crystal **3** includes a bulk **51** and fine particles **52**. The fine particles **52** change in orientation in the bulk **51** in accordance with potential differences between the pixel electrodes **2** and the common electrode **6**. The pixel electrode **2** is individually controlled in potential for each of the pixels Pix, and thus, the degree of at least either of optical transmission and dispersion is controlled for each of the pixels Pix. When the polymer dispersed liquid crystal is in a light-transmitting state, light incident from side surfaces of the display panel is substantially totally reflected by the first substrate **30** and the second substrate **20**, and is not emitted from the display device **100**. When the polymer dispersed liquid crystal is in a light-dispersing state, light is emitted from the surface to make display visible. The liquid crystal **3** may be a liquid crystal having positive dielectric constant anisotropy (positive liquid crystal) or a liquid crystal having negative dielectric constant anisotropy (negative liquid crystal).

In the first embodiment described with reference to FIG. **2**, the pixel electrodes **2** face the common electrode **6** so as to interpose the liquid crystal **3** therebetween. However, the liquid crystal display panel P may have a configuration in which one substrate is provided with both the pixel electrodes **2** and the common electrode **6**, and an electric field generated by the pixel electrodes **2** and the common electrode **6** controls the orientation of the liquid crystal **3**. The liquid crystal **3** may be a liquid crystal other than the polymer dispersed liquid crystal. When the liquid crystal **3** is a liquid crystal other than the polymer dispersed liquid crystal, the light source device L is provided, for example, as a backlight on the back surface side of the liquid crystal display panel P.

The following describes a mechanism for controlling the potentials of the pixel electrodes **2** and the common electrode **6**. As illustrated in FIG. **1**, the switching element **1** is a switching element using, for example, a semiconductor, such as a thin-film transistor (TFT). One of the source and the drain of the switching element **1** is coupled to one of the two electrodes (pixel electrode **2**). The other of the source and the drain of the switching element **1** is coupled to a signal line **4**. The gate of the switching element **1** is coupled to a scan line **5**. The scan line **5** applies a potential for opening and closing a circuit between the source and the drain of the switching element **1** under the control by the scan circuit **9**. The scan circuit **9** controls the potential. The control of the potential by the scan circuit **9** will be described later in detail.

In the example illustrated in FIG. **1**, a plurality of the signal lines **4** are arranged along one of the arrangement directions of the pixels Pix (along the row direction). The signal lines **4** extend along the other of the arrangement directions of the pixels Pix (along the column direction). Each of the signal lines **4** is shared by corresponding ones of the switching elements **1** of the pixels Pix arranged in the column direction. A plurality of the scan lines **5** are arranged along the column direction. The scan lines **5** extend along the row direction. Each of the scan lines **5** is shared by corresponding ones of the switching elements **1** of the pixels Pix arranged in the row direction.

The common electrode **6** is coupled to the VCOM drive circuit **10**. The VCOM drive circuit **10** applies a reference potential to the common electrode **6**. The signal output circuit **8** outputs a pixel signal to the signal line **4** at a time when the scan circuit **9** applies a potential (first potential) serving as a drive signal to the scan line **5**, so as to charge the liquid crystal (fine particles **52**) serving as a storage capacitor and a capacitive load formed between the pixel electrodes **2** and the common electrode **6**. This operation sets a voltage of the pixel Pix to a voltage corresponding to the pixel signal. After the application of the first potential is completed, the liquid crystal (fine particles **52**) serving as the storage capacitor and the capacitive load hold the pixel signal. The orientation of the liquid crystal (fine particles **52**) is controlled in accordance with the electric field generated by the voltage of each of the pixels Pix and the voltage of the common electrode **6**.

The light source device L provided with a light source **11** is disposed at a side surface of the display device **100** according to the present embodiment. The light source **11** includes a first light source **11**R that emits red light, a second light source **11**G that emits green light, and a third light source **11**B that emits blue light. Each of the first light source **11**R, the second light source **11**G, and the third light source **11**B emits light under the control of a light source drive circuit **12**. Each of the first light source **11**R, the second light source **11**G, and the third light source **11**B of the first embodiment is a light source using, for example, a light-emitting element such as a light-emitting diode (LED), but is not limited thereto, and only needs to be a light source controllable in light emission timing. The light source drive circuit **12** controls the light emission timing of the first light source **11**R, the second light source **11**G, and the third light source **11**B under the control of the timing controller **13**.

The timing controller **13** controls timing of the signal output circuit **8**, the scan circuit **9**, the VCOM drive circuit **10**, and the light source drive circuit **12**. In the first embodiment, field sequential control is performed.

FIG. **3** is a timing diagram illustrating an example of a flow of the field sequential control according to the first embodiment. FIG. **3** illustrates the schematic timing diagram of two frame periods. The timing diagram of FIG. **3** includes information on output timing of a frame signal, output timing of a field signal, switching timing of the drive signal, switching timing of the common potential, and lighting timing of the first light source **11**R, the second light source **11**G, and the third light source **11**B. The switching timing of the drive signal represents switching timing of the potential of the scan line **5**. The switching timing of the common potential represents switching timing of the potential of the common electrode **6**.

The frame signal is a signal representing start timing of each frame period. FIG. **3** illustrates that the frame signal is output when a first frame period FL**1** starts, when a second frame period FL**2** starts, and when the next frame (third frame) period starts after the end of the second frame period.

The field signal is a signal representing start timing of field periods included in each frame period. Each frame period includes a number of the field periods corresponding to the number of colors of the light emitted from the light source **11**. FIG. **3** illustrates that the field signal is output when a first field period FI**11**, a second field period FI**12**, and a third field period FI**13** included in the first frame period FL**1** start, when a first field period FI**21**, a second field period FI**22**, and a third field period FI**23** included in the second frame period FL**2** start, and when a first field period of the next frame (third frame) period starts after the end of the second frame period.

Each of the field periods includes a writing period of the pixel signal and a holding period of the pixel signal held by the storage capacitor. In FIG. **3**, WRITE (R+) represents the writing period of the first field period FI**11**; HOLD (R+) represents the holding period of the first field period FI**11**; WRITE (G+) represents the writing period of the second field period FI**12**; HOLD (G+) represents the holding period of the second field period FI**12**; WRITE (B+) represents the writing period of the third field period FI**13**; HOLD (B+) represents the holding period of the third field period FI**13**; WRITE (R−) represents the writing period of the first field period FI**21**; HOLD (R−) represents the holding period of the first field period FI**21**; WRITE (G−) represents the writing period of the second field period FI**22**; HOLD (G−) represents the holding period of the second field period FI**22**; WRITE (B−) represents the writing period of the third field period FI**23**; and HOLD (B−) represents the holding period of the third field period FI**23**. The writing period is a period in which the TFTs are sequentially turned on to write the pixel signals for each row. The holding period is a period in which all the TFTs are turned off to hold the voltages written in the writing period.

The writing period included in each of the field periods in one frame period is a period for writing the pixel signal corresponding to a gradation value of a corresponding one of the different colors. For example, the pixel signals of the first frame are assumed to be represented by red-green-blue (RGB) gradation values as (R,G,B)=(r1, g1, b1). The value r1 represents the gradation value of red (R) in an input signal including the information representing the RGB gradation values. The value g1 represents the gradation value of green (G) in the input signal including the information representing the RGB gradation values. The value b1 represents the gradation value of blue (B) in the input signal including the information representing the RGB gradation values. In this case, the pixel signal corresponding to the gradation value r1 is written in the writing period of the first field period FI**11**. The pixel signal corresponding to the gradation value g1 is written in the writing period of the second field period FI**12**. The pixel signal corresponding to the gradation value b1 is written in the writing period of the third field period FI**13**. The holding periods included in the field periods in one frame period are periods for holding the pixel signals corresponding to the gradation values of the different colors. The writings of the pixel signals as described above are individually performed for each of the pixels Pix in each of the field periods. The RGB gradation values in the pixel signal for each of the pixels Pix correspond to an image output to be displayed.

Each of the light sources (for example, the first light source **11**R, the second light source **11**G, and the third light source **11**B) for a plurality of colors included in the light source **11** is controlled so as to be lit at least during the holding period of the corresponding field period. For example, the first light source **11**R is a red light source, the second light source **11**G is a green light source, and the third light source **11**B is a blue light source. For example, in the first frame period FL**1**, the first light source **11**R is lit during a first light emission period BR**1** corresponding to the holding period of the first field period FI**11**. In this way, each of the pixels Pix can perform color display by lighting the light sources of different colors for each of the field periods.

In the first embodiment, the second light source **11**G and the third light source **11**B are also lit in addition to the first light source **11**R during the first light emission period BR**1**. The luminance of the first light source **11**R during the first light emission period BR**1** is higher than the luminance of the second light source **11**G during the first light emission period BR**1** and the luminance of the third light source **11**B during the first light emission period BR**1**. In the example illustrated in FIG. **3**, the luminance of the first light source **11**R during the first light emission period BR**1** is luminance L**1**. The luminance of the second light source **11**G during the first light emission period BR**1** is luminance L**4**. The luminance of the third light source **11**B during the first light emission period BR**1** is luminance L**6**. The luminance L**1** is higher than the luminance L**4** and the luminance L**6**. As a result, scattered light looking red is emitted corresponding to the gradation value (r1) of red (R) written during the writing period of the first field period FI**11**. In the example illustrated in FIG. **3**, the luminance L**4** is equal to the luminance L**6**, but may differ from luminance L**6**. However, the luminance L**1** remains to be higher than the luminance L**4** and the luminance L**6** even if the luminance L**4** differs from the luminance L**6**.

In the first frame period FL**1**, the second light source **11**G is lit during a second light emission period BR**2** corresponding to the holding period of the second field period FI**12**. In the first embodiment, the first light source **11**R and the third light source **11**B are also lit in addition to the second light source **11**G during the second light emission period BR**2**. The luminance of the second light source **11**G during the second light emission period BR**2** is higher than the luminance of the first light source **11**R during the second light emission period BR**2** and the luminance of the third light source **11**B during the second light emission period BR**2**. In the example illustrated in FIG. **3**, the luminance of the second light source **11**G during the second light emission period BR**2** is luminance L**3**. The luminance of the first light source **11**R during the second light emission period BR**2** is luminance L**2**. The luminance of the third light source **11**B during the second light emission period BR**2** is the luminance L**6**. The luminance L**3** is higher than the luminance L**2** and the luminance L**6**. As a result, scattered light looking green is emitted corresponding to the gradation value (g1) of green (G) written during the writing period of the second field period FI**12**. In the example illustrated in FIG. **3**, the luminance L**2** is equal to the luminance L**6**, but may differ from the luminance L**6**. However, the luminance L**3** remains to be higher than the luminance L**2** and the luminance L**6** even if the luminance L**2** differs from the luminance L**6**.

In the first frame period FL**1**, the third light source **11**B is lit during a third light emission period BR**3** corresponding to the holding period of the third field period FI**13**. In the first embodiment, the first light source **11**R and the second light source **11**G are also lit in addition to the third light source **11**B during the third light emission period BR**3**. The luminance of the third light source **11**B during the third light emission period BR**3** is higher than the luminance of the first light source **11**R during the third light emission period BR**3** and the luminance of the second light source **11**G during the third light emission period BR**3**. In the example illustrated in FIG. **3**, the luminance of the third light source **11**B during the third light emission period BR**3** is luminance L**5**. The luminance of the first light source **11**R during the third light emission period BR**3** is luminance L**2**. The luminance of the second light source **11**G during the third light emission period BR**3** is luminance L**4**. The luminance L**5** is higher than the luminance L**2** and the luminance L**4**. As a result, scattered light looking blue is emitted corresponding to the gradation value (b1) of blue (B) written during the writing period of the third field period FI**13**. In the example illustrated in FIG. **3**, the luminance L**2** is equal to the luminance L**4**, but may differ from the luminance L**4**. However, the luminance L**5** remains to be higher than the luminance L**2** and the luminance L**4** even if the luminance L**2** differs from the luminance L**4**.

The luminance L**1** of the main light source (first light source **11**R) during the first light emission period BR**1**, the luminance L**3** of the main light source (second light source **11**G) during the second light emission period BR**2**, and the luminance L**5** of the main light source (third light source **11**B) during the third light emission period BR**3** need not be the same luminance, and are set as appropriate.

The light emission luminance (auxiliary light emission luminance), such as the luminance L**2**, L**4**, or L**6**, of a light source (auxiliary light source) other than the main light source in each of the periods can be represented as a ratio (for example, in a range from 0.01 to 0.5) to the luminance (for example, the luminance L**1**, L**3**, or L**5**) in the period in which the auxiliary light source serves as the main light source. For example, power consumption can be reduced while limiting a reduction in display quality within an allowable range by setting the light emission amount (L**4**/L**3**) of the second light source **11**G during the first light emission period BR**1** to 0.1 to 0.5, and setting the light emission amount (L**6**/L**5**) of the third light source **11**B during the first light emission period BR**1** to 0.1 to 0.4. The power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**2**/L**1**) of the first light source **11**R during the second light emission period BR**2** to 0.02 to 0.15, and setting the light emission amount (L**6**/L**5**) of the third light source **11**B during the second light emission period BR**2** to 0.1 to 0.3. The power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**2**/L**1**) of the first light source **11**R during the third light emission period BR**3** to 0.1 to 0.5, and setting the light emission amount (L**4**/L**3**) of the second light source **11**G during the third light emission period BR**3** to 0.1 to 0.5.

A light source of at least one color may emit light as an auxiliary light source when the main light source emits light. At this time, the auxiliary light emission luminance can be represented as a ratio (for example, in a range from 0.01 to 0.5) to the luminance in the period in which the auxiliary light source serves as the main light source. For example, the power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**4**/L**3**) of the second light source **11**G during the first light emission period BR**1** to 0.1 to 0.5, and setting the light emission amount (L**6**/L**5**) of the third light source **11**B during the first light emission period BR**1** to substantially 0. The power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**2**/L**1**) of the first light source **11**R during the second light emission period BR**2** to 0, and setting the light emission amount (L**6**/L**5**) of the third light source **11**B during the second light emission period BR**2** to 0.05 to 0.3. The power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**2**/L**1**) of the first light source **11**R during the third light emission period BR**3** to 0.1 to 0.5, and setting the light emission amount (L**4**/L**3**) of the second light source **11**G during the third light emission period BR**3** to substantially 0.

FIG. **4** is a diagram schematically illustrating color gamuts CS**1**, CS**2**, and CS**3** employable by the display system **300** using a CIExy chromaticity diagram. For example, the color gamut CS**1** is contained in a frame obtained by connecting a first red color R**1** reproduced when only the first light source **11**R is lit during the first light emission period BR**1**, a first green color G**1** reproduced when only the second light source **11**G is lit during the second light emission period BR**2**, and a first blue color B**1** reproduced when only the third light source **11**B is lit during the third light emission period BR**3**. In other words, the color of the light of the first light source **11**R corresponds to the first red color R**1**; the color of the light of the second light source **11**G corresponds to the first green color G**1**; and the color of the light of the third light source **11**B corresponds to the first blue color B**1**. In the first embodiment, however, as described with reference to FIG. **3**, during the first light emission period BR**1**, the second light source **11**G and the third light source **11**B are lit in addition to the first light source **11**R to reproduce a second red color R**2**. The second red color R**2** has higher luminance than the first red color R**1** because the luminance of the second light source **11**G and the third light source **11**B is added. The addition of the luminance of the second light source **11**G and the third light source **11**B causes the saturation of the second red color R**2** as a red color to be lower than that of the first red color R**1**. In the first embodiment, during the second light emission period BR**2**, the first light source **11**R and the third light source **11**B are lit in addition to the second light source **11**G to reproduce a second green color G**2**. The second green color G**2** has higher luminance than the first green color G**1** because the luminance of the first light source **11**R and the third light source **11**B is added. The addition of the luminance of the first light source **11**R and the third light source **11**B causes the saturation of the second green color G**2** as a green color to be lower than that of the first green color G**1**. In the first embodiment, during the third light emission period BR**3**, the first light source **11**R and the second light source **11**G are lit in addition to the third light source **11**B to reproduce a second blue color B**2**. The second blue color B**2** has higher luminance than the first blue color B**1** because the luminance of the first light source **11**R and the second light source **11**G is added. The addition of the luminance of the first light source **11**R and the second light source **11**G causes the saturation of the second blue color B**2** as a blue color to be lower than that of the first blue color B**1**. The first embodiment employs the color gamut CS**2** in a frame obtained by connecting the second red color R**2**, the second green color G**2**, and the second blue color B**2** described above.

Employing the color gamut CS**2** causes the luminance of a display screen of the display device **100** to be higher than that in the case of employing the color gamut CS**1**.

As described above, one frame period includes the writing and holding of the pixel signal of R, G, and B as well as the illumination in which the light sources of the colors corresponding to the pixel signal of R, G, and B are lit at relatively high luminance, so that the color reproduction in the color gamut CS**2** is performed. The color reproduction is performed with the same mechanism in the second frame period FL**2** and periods after the the second frame period FL**2**.

The frequency of the field period is obtained by multiplying the frequency of the frame period by the number of colors of the light emitted by the light source **11**. In the first embodiment, the frequency of the frame period is, for example, 60 Hz. However, the frequency of the frame period is not limited thereto, and may be 120 Hz or another frequency. When the frequency of the frame period is 60 Hz, the frequency of the field period is 180 Hz in the first embodiment. However, the frequency of the field period can be changed as appropriate in accordance with the frequency of the frame period and/or the number of colors of the light emitted by the light source **11**.

FIG. **3** illustrates that the length of the writing period is apparently the same as that of the holding period. However, the holding period is actually longer than the writing period.

In the liquid crystal display panel P using the liquid crystal, inversion driving is performed to invert relative levels of potentials of two electrodes at a predetermined period. In FIG. **3**, the VCOM drive circuit **10** controls the potential of the common electrode **6** so as to set the common potential to a negative (−) potential in the first frame period FL**1**, and set the common potential to a positive (+) potential in the second frame period FL**2**. In response to this operation, the pixel signal is written so as to set the potential of the pixel electrode **2** to a positive (+) potential in the first frame period FL**1**, and the pixel signal is written so as to set the potential of the pixel electrode **2** to a negative (−) potential in the second frame period FL**2**. Symbols in a parenthesis in an explanation of the drive signal illustrated in FIG. **3** represent a combination of the colors of the RGB gradation values corresponding to the written pixel signal with the potential.

In the first embodiment, in each of the pixels Pix, the potential of the pixel electrode **2** is controlled for the inversion driving. Specifically, the signal output circuit **8** outputs the pixel signal for the inversion driving to the signal line **4**. In other words, the signal output circuit **8** outputs the pixel signal such that a voltage between the pixel electrode **2** and the common electrode **6** changes in polarity without changing its amplitude in accordance with timing at which the common electrode **6** is driven to be inverted. The VCOM drive circuit **10** switches the potential of the common electrode **6** for the inversion driving. The timing controller **13** synchronizes timing at which an inversion drive circuit switches the potential of the pixel electrode **2** with the timing at which the VCOM drive circuit **10** switches the potential of the common electrode **6**, at a cycle of a frame period. These circuits serve as an inversion driver of the first embodiment.

In the example illustrated in FIG. **3**, the inversion driving is performed at a cycle of a frame period such that the potential of the pixel electrode **2** is relatively higher than that of the common electrode **6** in the first frame period FL**1**, and the potential of the pixel electrode **2** is relatively lower than that of the common electrode **6** in the second frame period FL**2**. However, this example is merely a specific control example of the inversion driving method. The inversion driving method is not limited to this example. For example, the relative levels of potentials of the pixel electrode **2** and the common electrode **6** may be inverted at a cycle of a plurality of frame periods.

An image signal (RGB data) serving as a source of the pixel signals is supplied to the liquid crystal display panel P through an input circuit **15** included in the control device **200**. The input circuit **15** outputs, to the signal output circuit **8**, signals representing the gradation values of the colors of red (R), green (G), and blue (B) of the respective pixels Pix based on the image signal. The input circuit **15** also outputs, to the timing controller **13**, control signals including, among others, a synchronization signal synchronized with timing of the signals input to the signal output circuit **8**. The timing controller **13** controls operations of, for example, the signal output circuit **8**, the scan circuit **9**, and the VCOM drive circuit **10** based on the signals received from the input circuit **15**.

The light source drive circuit **12** operates under the timing control of the timing controller **13**. Either of the display device **100** and the control device **200** may serve as a controller of the luminance of each of the first light source **11**R, the second light source **11**G, and the third light source **11**B that are lit under the control of the light source drive circuit **12**. In other words, the light source drive circuit **12** may hold luminance control parameters for lighting the first light source **11**R, the second light source **11**G, and the third light source **11**B, for example, in the relation between the luminance values L**1**, L**2**, L**3**, L**4**, L**5**, and L**6** described with reference to FIG. **3**. Alternatively, the luminance control parameters may be output from the input circuit **15** of the control device **200** to the display device **100**. When the luminance control parameters are output from the input circuit **15** of the control device **200** to the display device **100**, the luminance control parameters may be supplied to the light source drive circuit **12** through the timing controller **13**, or may be directly supplied from the input circuit **15** to the light source drive circuit **12** without passing through the timing controller **13**.

Although, in FIG. **1**, the input circuit **15** is provided in the control device **200** independent from the display device **100**, the input circuit **15** may be provided in the liquid crystal display panel P. The input circuit **15** may be provided as a function of a display driver integrated circuit (DDIC) designed so as to integrate other circuits, for example, the timing controller **13**.

According to the first embodiment, the first light source **11**R, the second light source **11**G, and the third light source **11**B emit light in each of the first light emission period BR**1**, the second light emission period BR**2**, and the third light emission period BR**3**. During the first light emission period BR**1**, the luminance of the first light source **11**R is higher than the luminance of the second light source **11**G and the luminance of the third light source **11**B. During the second light emission period BR**2**, the luminance of the second light source **11**G is higher than the luminance of the first light source **11**R and the luminance of the third light source **11**B. During the third light emission period BR**3**, the luminance of the third light source **11**B is higher than the luminance of the first light source **11**R and the luminance of the second light source **11**G. As a result, the display output can be performed using the color gamut CS**2** that enables both the color reproduction corresponding to the colors of the light of the first light source **11**R, the second light source **11**G, and the third light source **11**B and securement of the luminance.

Accordingly, the luminance can be increased more easily than in the case where only a light source of a color corresponding to the gradation value of the pixel signal supplied in each of the field periods is lit.

As illustrated in FIG. **3**, the luminance can be increased without changing a hue by setting the luminance of the second light source **11**G equal to the luminance of the third light source **11**B during the first light emission period BR**1**, setting the luminance of the first light source **11**R equal to the luminance of the third light source **11**B during the second light emission period BR**2**, and setting the luminance of the first light source **11**R equal to the luminance of the second light source **11**G during the third light emission period BR**3**.

The hue can be adjusted while simultaneously increasing the luminance by setting the luminance of the second light source **11**G different from the luminance of the third light source **11**B during the first light emission period BR**1**, setting the luminance of the first light source **11**R different from the luminance of the third light source **11**B during the second light emission period BR**2**, and setting the luminance of the first light source **11**R different from the luminance of the second light source **11**G during the third light emission period BR**3**.

Second Embodiment

The following describes the display device according to a second embodiment with reference to FIGS. **4** and **5**. The configuration of the second embodiment is the same as the configuration of the first embodiment except for specially mentioned items.

FIG. **5** is a timing diagram illustrating an example of the flow of the field sequential control according to the second embodiment. In the second embodiment, during a first light emission period BR**4**, one of the second light source **11**G and the third light source **11**B is lit in addition to the first light source **11**R, but the other thereof is not lit. The luminance of the first light source **11**R during the first light emission period BR**4** is higher than the luminance of the one of the second light source **11**G and the third light source **11**B. In the example illustrated in FIG. **5**, the first light source **11**R and the second light source **11**G are lit, but the third light source **11**B is not lit, during the first light emission period BR**4**. The luminance of the first light source **11**R during the first light emission period BR**4** is the luminance L**1**. The luminance of the second light source **11**G during the first light emission period BR**4** is the luminance L**4**. The luminance L**1** is higher than the luminance L**4**.

In the second embodiment, during a second light emission period BR**5**, one of the first light source **11**R and the third light source **11**B is lit in addition to the second light source **11**G, but the other thereof is not lit. The luminance of the second light source **11**G during the second light emission period BR**5** is higher than the luminance of the one of the first light source **11**R and the third light source **11**B. In the example illustrated in FIG. **5**, the second light source **11**G and the third light source **11**B are lit, and the first light source **11**R is not lit, during the second light emission period BR**5**. The luminance of the second light source **11**G during the second light emission period BR**5** is the luminance L**3**. The luminance of the third light source **11**B during the second light emission period BR**5** is the luminance L**6**. The luminance L**3** is higher than the luminance L**6**.

In the second embodiment, during a third light emission period BR**6**, one of the first light source **11**R and the second light source **11**G is lit in addition to the third light source **11**B, but the other thereof is not lit. The luminance of the third light source **11**B during the third light emission period BR**6** is higher than the luminance of the one of the first light source **11**R and the second light source **11**G. In the example illustrated in FIG. **5**, the third light source **11**B and the first light source **11**R are lit, and the second light source **11**G is not lit, during the third light emission period BR**6**. The luminance of the third light source **11**B during the third light emission period BR**6** is the luminance L**5**. The luminance of the first light source **11**R during the third light emission period BR**6** is the luminance L**2**. The luminance L**5** is higher than the luminance L**2**.

In the second embodiment, in the same way as in the first embodiment, the luminance L**1** of the main light source (first light source **11**R) during the first light emission period BR**4**, the luminance L**3** of the main light source (second light source **11**G) during the second light emission period BR**5**, and the luminance L**5** of the main light source (third light source **11**B) during the third light emission period BR**6** need not be the same luminance, and are set as appropriate. The light emission luminance (auxiliary light emission luminance), such as the luminance L**2**, L**4**, or L**6**, of a light source (auxiliary light source) other than the main light source in each of the periods can be represented as a ratio (for example, in a range from 0.01 to 0.5) to the luminance (for example, the luminance L**1**, L**3**, or L**5**) in the period in which the auxiliary light source serves as the main light source. For example, the power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**4**/L**3**) of the second light source **11**G during the first light emission period BR**4** to 0.1 to 0.5. The power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**6**/L**5**) of the third light source **11**B during the second light emission period BR**5** to 0.05 to 0.3. The power consumption can be reduced while limiting the reduction in display quality within the allowable range by setting the light emission amount (L**2**/L**1**) of the first light source **11**R during the third light emission period BR**6** to 0.1 to 0.5.

In the example described with reference to FIG. **5**, during the first light emission period BR**4**, the second light source **11**G is lit in addition to the first light source **11**R to reproduce a third red color R**3** that is closer to the first green color G**1** than the first red color R**1** is (refer to FIG. **4**). During the second light emission period BR**5**, the third light source **11**B is lit in addition to the second light source **11**G to reproduce a third green color G**3** that is closer to the first blue color B**1** than the first green color G**1** is (refer to FIG. **4**). During the third light emission period BR**6**, the first light source **11**R is lit in addition to the third light source **11**B to reproduce a third blue color B**3** that is closer to the first red color R**1** than the first blue color B**1** is (refer to FIG. **4**). The second embodiment employing the example described with reference to FIG. **5** employs a color gamut CS**3** in a frame obtained by connecting the third red color R**3**, the third green color G**3**, and the third blue color B**3** described above (refer to FIG. **4**), and reproduces colors in the color gamut CS**3**.

The relation between the one and the other described above with reference to FIG. **5** may be reversed. In other words, for example, the first light source **11**R and the third light source **11**B may be lit, and the second light source **11**G may be unlit, during the first light emission period BR**4**. During the second light emission period BR**5** and the third light emission period BR**6**, the relation between the one and the other may be reversed in the same way.

According to the second embodiment, the hue can be adjusted by lighting light sources of other colors in addition to a light source of a color corresponding to a color of the pixel signal. The luminance of the display screen can be higher than that in the case where only the light source of the color corresponding to the color of the pixel signal is lit.

Modification

FIG. **6** is a block diagram illustrating a relation between a detector **81**, a setting unit **82**, and the light source drive circuit **12** provided in a modification. The display system **300** may further include the detector **81** and the setting unit **82** as illustrated in FIG. **6**. The detector **81** is an optical sensor that detects brightness of ambient light at a periphery of the display system **300**. The periphery of the display system **300** corresponds to at least either one of a periphery of the display device **100** and a periphery of the control device **200**, and preferably corresponds to the periphery of the display device **100**.

The setting unit **82** includes a circuit that sets amounts of light of the light sources of other colors based on the brightness of the ambient light detected by the detector **81**. The term "the light sources of other colors" as used herein refers to the light sources of the other colors that are lit in addition to the light source of the color corresponding to the color of the pixel signal. Specifically, the setting unit **82** holds parameters corresponding to a plurality of settings, for example, a first setting PS**1** and a second setting PS**2** as illustrated in FIG. **6**. The luminance of the light sources of the other colors when being lit is different between the first setting PS**1** and the second setting PS**2**.

The following describes an exemplary case where the luminance of the light sources of the other colors when being lit with the first setting PS**1** is higher than that with the second setting PS**2**. For example, when the ambient light is bright, the display screen is difficult to be viewed if the luminance obtained by the light from the light source device L is low. Therefore, if the brightness of the ambient light detected by the detector **81** is equal to or higher than a predetermined threshold of brightness, the setting unit **82** employs the first setting PS**1** to set the luminance of the light sources of the other colors when being lit to the light source drive circuit **12**. In other words, if the brightness of the ambient light is equal to or higher than the predetermined threshold, the auxiliary light sources are lit in addition to the main light source. The light source drive circuit **12** determines the luminance L**2**, L**4**, and L**6** in accordance with the first setting PS**1**. If the ambient light is dark, the display screen looks relatively brighter than the surroundings and can be easily viewed. In this case, the saturation may be preferred to the luminance. Therefore, if the brightness of the ambient light detected by the detector **81** is lower than the predetermined threshold of brightness, the setting unit **82** employs the second setting PS**2** to set the luminance of the light sources of the other colors when being lit to the light source drive circuit **12**. The light source drive circuit **12** determines the luminance L**2**, L**4**, and L**6** in accordance with the second setting PS**2**. When the second setting PS**2** is used, the luminance L**2**, L**4**, and L**6** may be substantially 0. In other words, if the brightness of the ambient light is lower than the predetermined threshold of brightness, and the saturation may be preferred to the luminance, the above-mentioned auxiliary light sources may be unlit. The predetermined threshold is a value of brightness (for example, a value (also called brightness) of the hue-saturation-value (HSV) model) corresponding to a degree of brightness of the ambient light at which the display screen is difficult to be viewed with the second setting PS**2**. The predetermined threshold is determined based on, for example, a preliminary measurement taking into account display characteristics (such as hue characteristics) of the liquid crystal display panel P. The steps of the setting based on the brightness of the ambient light are not limited to the two steps: the first setting PS**1** and the second setting PS**2**. Divisions of three or more steps may be provided in the brightness of the ambient light, and presettings for setting the light source device L may be provided corresponding to the number of the divisions. In this case, the setting is made so as to increase the lighting rate of the auxiliary light sources with increase in the brightness of the ambient light.

The detector **81** and the setting unit **82** may be provided in the display device **100** or in the control device **200**. Alternatively, the setting unit **82** may be provided in the control device **200**, and the detector **81** may be provided in the display device **100**. In this case, the setting unit **82** may be integrated with the input circuit **15**. In other words, in a configuration in which the luminance is determined under the control of the input circuit **15**, the input circuit **15** may use parameters, for example, the first setting PS**1** and the second setting PS**2**, held in the setting unit **82** for the control. As described above, the control device **200** may control, based on the brightness of the ambient light, the luminance of the second light source **11**G and the luminance of the third light source **11**B in the first light emission period BR**1** or BR**4**, the luminance of the first light source **11**R and the luminance of the third light source **11**B in the second light emission period BR**2** or BR**5**, and the luminance of the first light source **11**R and the luminance of the second light source **11**G in the third light emission period BR**3** or BR**6**.

While FIG. **6** illustrates the first setting PS**1** and the second setting PS**2** among the parameters held in the setting unit **82**, three or more kinds of parameters may be used for setting the luminance of the light sources of the other colors when being lit. Criteria of the brightness of the ambient light for selecting which of the settings is to be employed can be set as appropriate based on, for example, preliminary measurements. The modification described above with reference to FIG. **6** is applicable to either of the first and second embodiments.

The combination of the light sources of a plurality of colors included in the light source **11** is not limited to the combination of red (R), green (G), and blue (B). The light source **11** may include, for example, light sources corresponding to respective three colors represented by a combination of cyan, magenta, and yellow.

The light source device L (or a light source device LB) only needs to be capable of illuminating the liquid crystal display panel P, and can be changed as appropriate in the specific arrangement thereof. For example, light sources of a plurality of colors, such as the first light source **11**R, the second light source **11**G, and the third light source **11**B, may be directly arranged on a light emitting surface of the light source **11** for illuminating the liquid crystal display panel P, as schematically illustrated in FIG. **1**, or the light source device may be a light source device LA such as that of FIG. **7**A or the light source device LB such as that of FIG. **7**B, which will be described below.

FIG. **7**A is a schematic diagram illustrating a configuration example of the light source device. FIG. **7**A illustrates a top view of the configuration example of the light source device. As illustrated in FIG. **7**A, the light source device LA includes a plurality of light sources **11**L provided in positions facing each other with the liquid crystal display panel

P therebetween. The light sources **11**L emit light from lateral sides of the liquid crystal display panel P to illuminate the liquid crystal display panel P. The light sources **11**L may each include the first light source **11**R, the second light source **11**G, and the third light source **11**B, or the respective light sources **11**L may be light sources of different colors. When the respective light sources **11**L are light sources of different colors, at least one or more of the light sources of a plurality of colors (for example, red, green, and blue) set as the colors of the light sources is/are provided. In FIG. **7**, the light sources **11**L are provided in the positions facing each other with the liquid crystal display panel P therebetween, the light sources **11**L may be provided on only one side surface of the liquid crystal display panel P.

FIG. **7**B is a schematic diagram illustrating a configuration example of the light source device LB. FIG. **7**B illustrates a cross-sectional view of the configuration example of the light source device. As illustrated in FIG. **7**B, the configuration may be employed in which a multicolor light source **11**M is disposed on a lateral side of a light guide plate LGP provided on the back surface of the liquid crystal display panel P. The multicolor light source **11**M includes, for example, light sources corresponding to the respective three colors represented by the above-described combination of the first light source **11**R, the second light source **11**G, and the third light source **11**B or the above-described combination of cyan, magenta, and yellow. The multicolor light source **11**M is controlled so as to emit light of colors different among the field periods in each of the frame periods.

Other operational advantages accruing from the aspects described in the embodiments herein that are obvious from the description herein, or that are appropriately conceivable by those skilled in the art will naturally be understood as accruing from the present invention.

What is claimed is:

1. A display device comprising:

a liquid crystal display panel in which a liquid crystal is sealed between two substrates facing each other; and

a first light source, a second light source, and a third light source configured to emit light in colors different from one another,

wherein a light emission period in which the first light source, the second light source, and the third light source emit light includes

a first light emission period in which luminance of the first light source is higher than luminance of the second light source and luminance of the third light source,

a second light emission period in which the luminance of the second light source is higher than the luminance of the first light source and the luminance of the third light source, and

a third light emission period in which the luminance of the third light source is higher than the luminance of the first light source and the luminance of the second light source,

wherein the first light source, the second light source, and the third light source emit light simultaneously in each of the first light emission period, the second light emission period, and the third light emission period, the first light source, the second light source, and the third light source are configured to emit light such that:

saturation of color obtained by causing the first to third light sources to emit light in the first light emission period is lower than saturation of color obtained by causing only the first light source to emit light,

saturation of color obtained by causing the first to third light sources to emit light in the second light emission period is lower than saturation of color obtained by causing only the second light source to emit light, and

saturation of color obtained by causing the first to third light sources to emit light in the third light emission period is lower than saturation of color obtained by causing only the third light source to emit light.

2. The display device according to claim **1**,

wherein the luminance of the second light source is equal to the luminance of the third light source during the first light emission period,

wherein the luminance of the first light source is equal to the luminance of the third light source during the second light emission period, and

wherein the luminance of the first light source is equal to the luminance of the second light source during the third light emission period.

3. The display device according to claim **1**,

wherein the luminance of the second light source differs from the luminance of the third light source during the first light emission period,

wherein the luminance of the first light source differs from the luminance of the third light source during the second light emission period, and

wherein the luminance of the first light source differs from the luminance of the second light source during the third light emission period.

4. The display device according to claim **1**,

wherein the first light source is configured to emit red light,

wherein the second light source is configured to emit green light, and

wherein the third light source is configured to emit blue light.

5. The display device according to claim **1**,

wherein, when the first light source emits light during at least one of the second light emission period or the third light emission period, the first light source emits light at 1% to 50% of the luminance at which the first light source emits light during the first light emission period,

wherein, when emitting light during at least one of the first light emission period or the third light emission period, the second light source emits light at 1% to 50% of the luminance at which the second light source emits light during the second light emission period, and

wherein, when emitting light during at least one of the first light emission period or the second light emission period, the third light source emits light at 1% to 50% of the luminance at which the third light source emits light during the third light emission period.

6. The display device according to claim **1**, wherein the light emission period includes only three light emission periods of:

the first light emission period, the second light emission period, and the third light emission period.

7. The display device according to claim **1**, wherein the first light source, the second light source, and the third light source are controlled to emit such that a color gamut becomes smaller.

8. The display device according to claim **1**, wherein:

luminance of the second light source and luminance of the third light source during the first light emission period are set depending on brightness of ambient light, luminance of the first light source and the luminance of the third light source during the second light emission period are set depending on the brightness of the ambient light, and

the luminance of the first light source and the luminance of the second light source during the third light emission period are set depending on the brightness of the ambient light.

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