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Lee

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(45) **Date of Patent: Dec. 4, 2007**

(54) **LIQUID CRYSTAL DISPLAY APPARATUS AND METHOD FOR DRIVING THE SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 703 days.

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(30) **Foreign Application Priority Data**

Jul. 4, 2003 (KR) 10-2003-0045449

(51) **Int. Cl.**
G09G 3/36 (2006.01)

(52) **U.S. Cl.** **345/89**

(58) **Field of Classification Search** 345/87–92
See application file for complete search history.

(56) **References Cited**

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* cited by examiner

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(57) **ABSTRACT**

A liquid crystal display apparatus capable of improving response time as well as display quality is provided. The apparatus includes a timing controller to generate a plurality of compensated grayscale data, a memory to store grayscale data or the compensated grayscale data, a column driver to apply the compensated grayscale data to a plurality of data lines, a gate driver to apply a gate signal to a plurality of gate lines, and a liquid crystal panel including the gate lines, the data lines and a plurality of switching element disposed between the data lines and the gate lines.

22 Claims, 18 Drawing Sheets

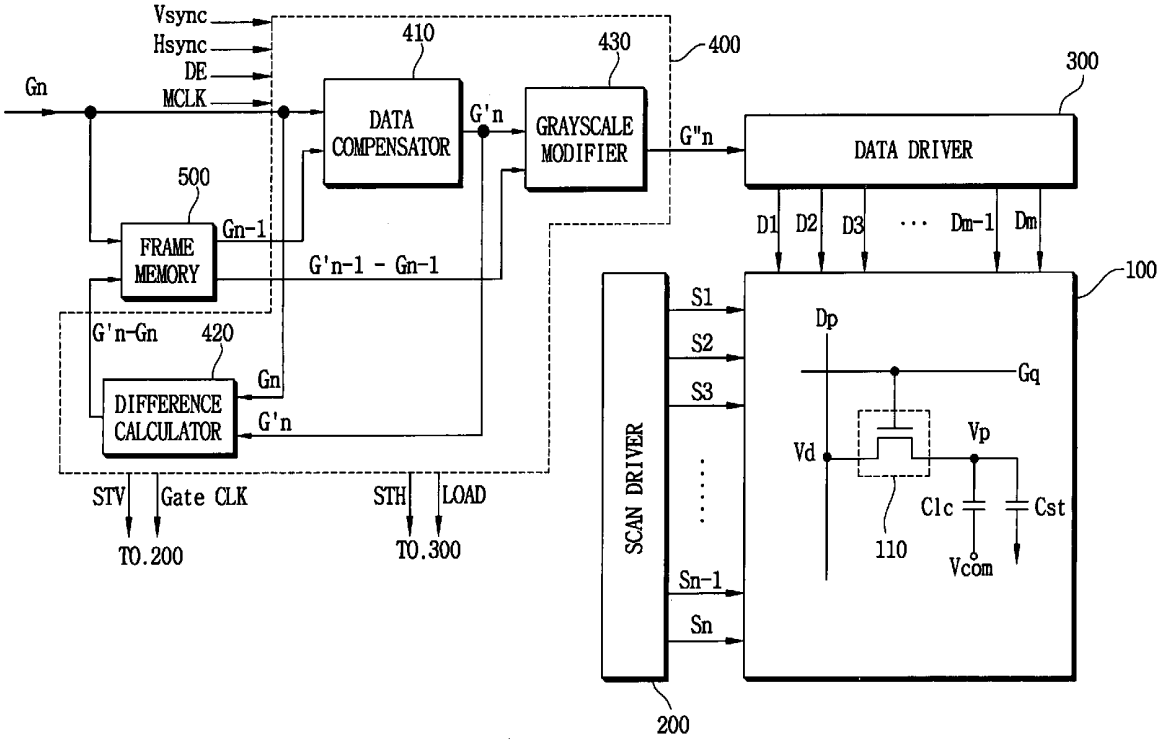


FIG. 1
(PRIOR ART)

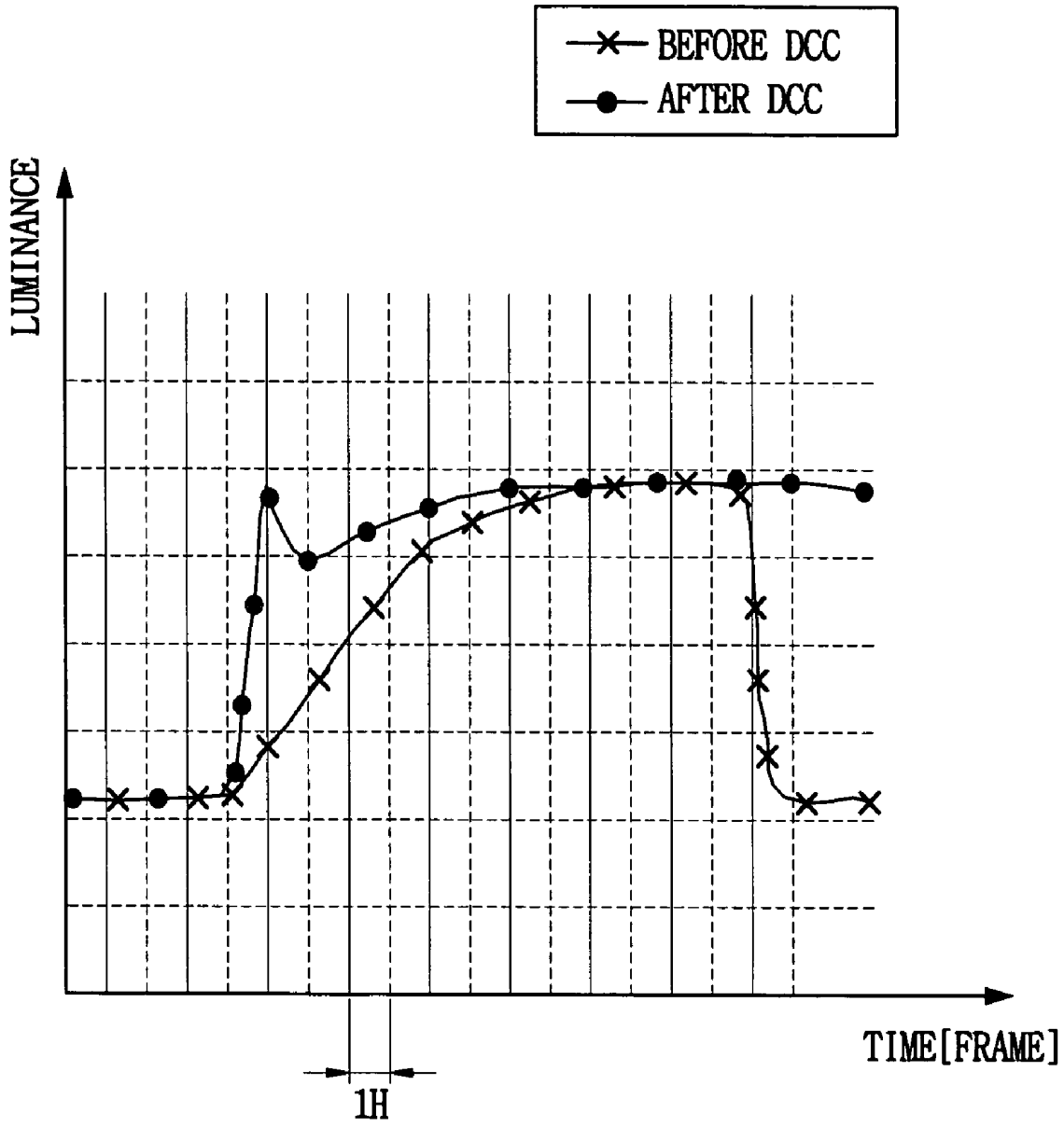


FIG. 2A
(PRIOR ART)

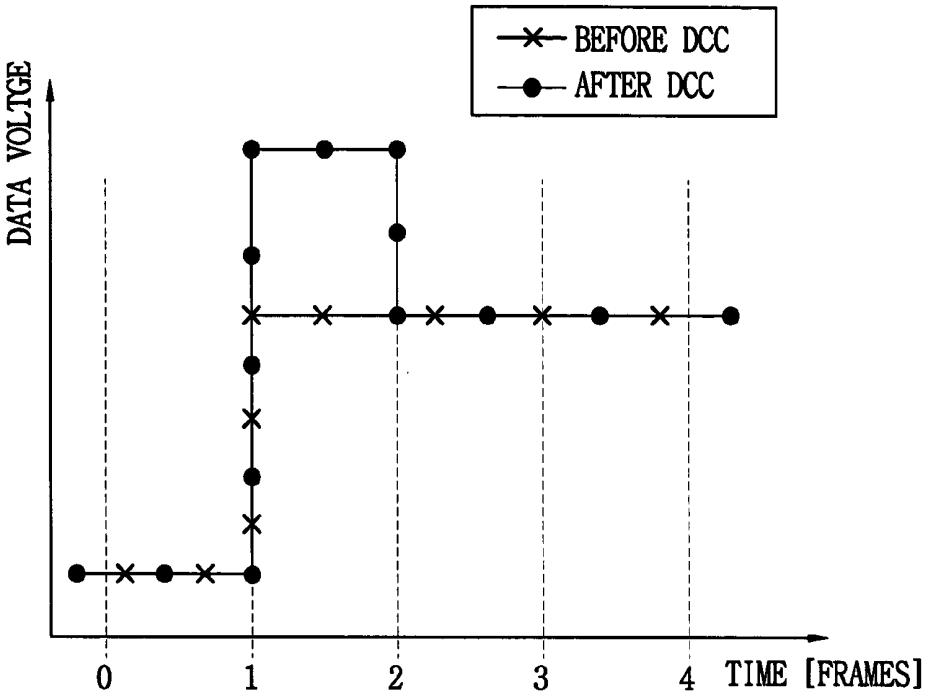


FIG. 2B
(PRIOR ART)

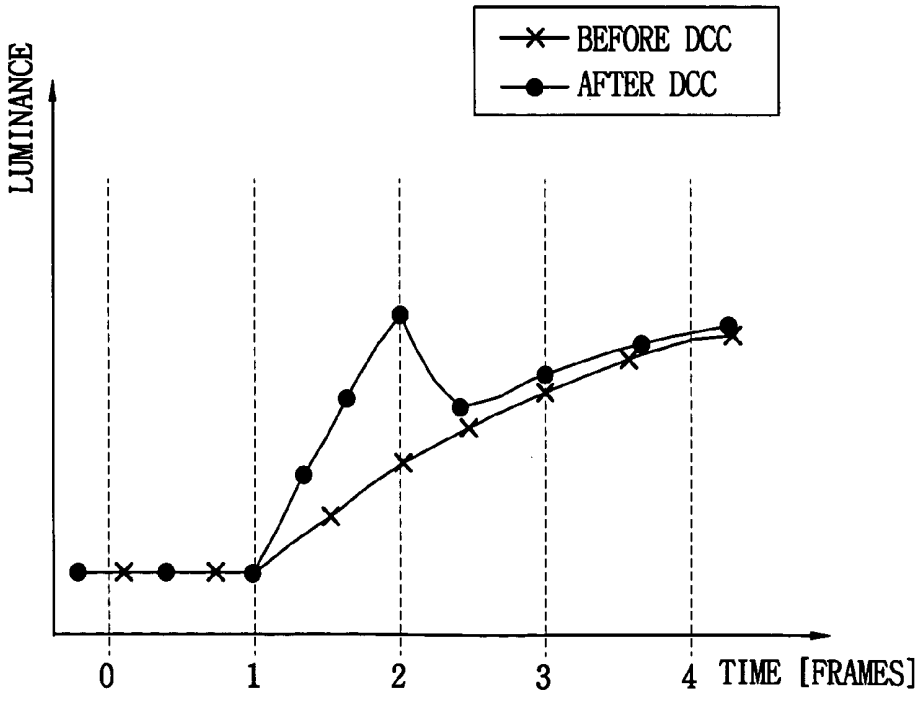


FIG. 3

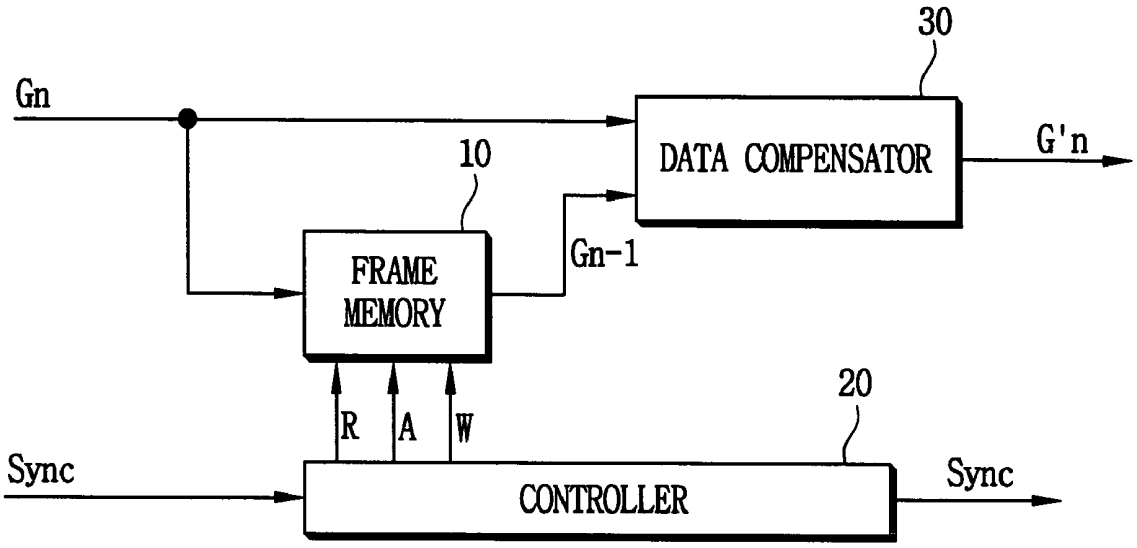

30
Gn
DATA COMPENSATOR
G'n
10
FRAME MEMORY
Gn-1
R
A
W
20
Sync
CONTROLLER
Sync

FIG. 4

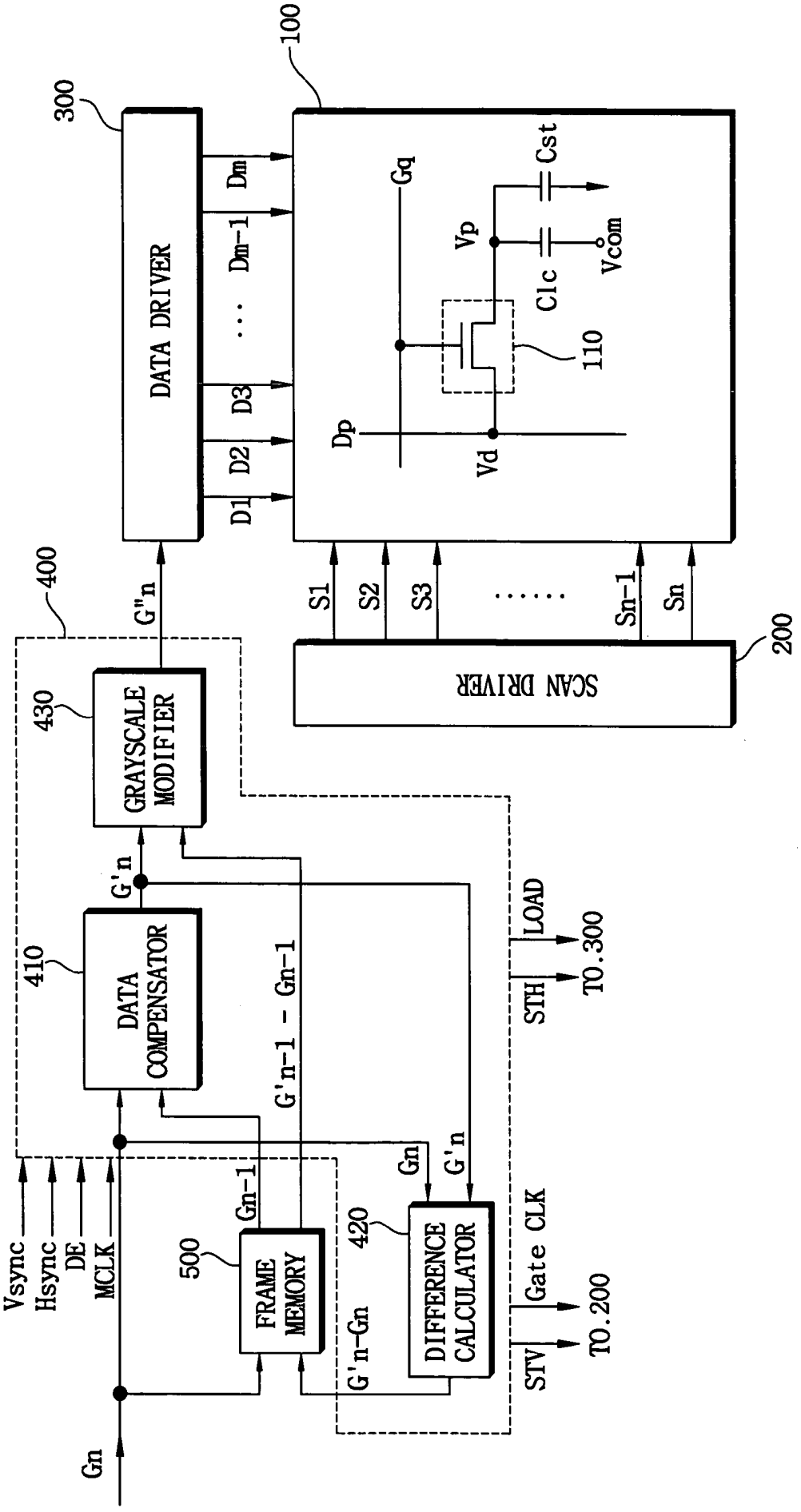

100
300
DATA DRIVER
Dm
Dm-1
D3
D2
D1
Gq
Vp
Cst
Vcom
Clc
110
Dp
Vd
S1
S2
S3
Sn-1
Sn
200
SCAN DRIVER
400
G"n
430
GRAYSCALE MODIFIER
G'n
410
DATA COMPENSATOR
G'n-1 - Gn-1
LOAD
STH
TO 300
Vsync
Hsync
DE
MCLK
Gn-1
500
FRAME MEMORY
Gn
G'n
420
DIFFERENCE CALCULATOR
Gate CLK
STV
TO 200
G'n-Gn
Gn

FIG. 5A

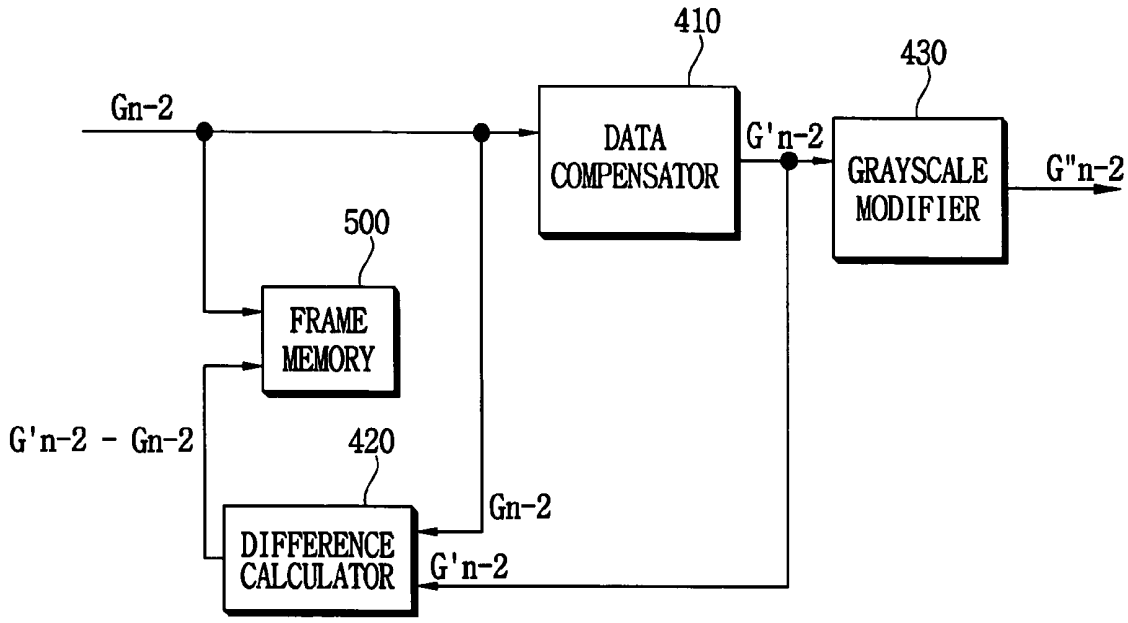

410
430
Gn-2
DATA COMPENSATOR
G'n-2
GRAYSCALE MODIFIER
G"n-2
500
FRAME MEMORY
G'n-2 - Gn-2
420
Gn-2
DIFFERENCE CALCULATOR
G'n-2

FIG. 5B

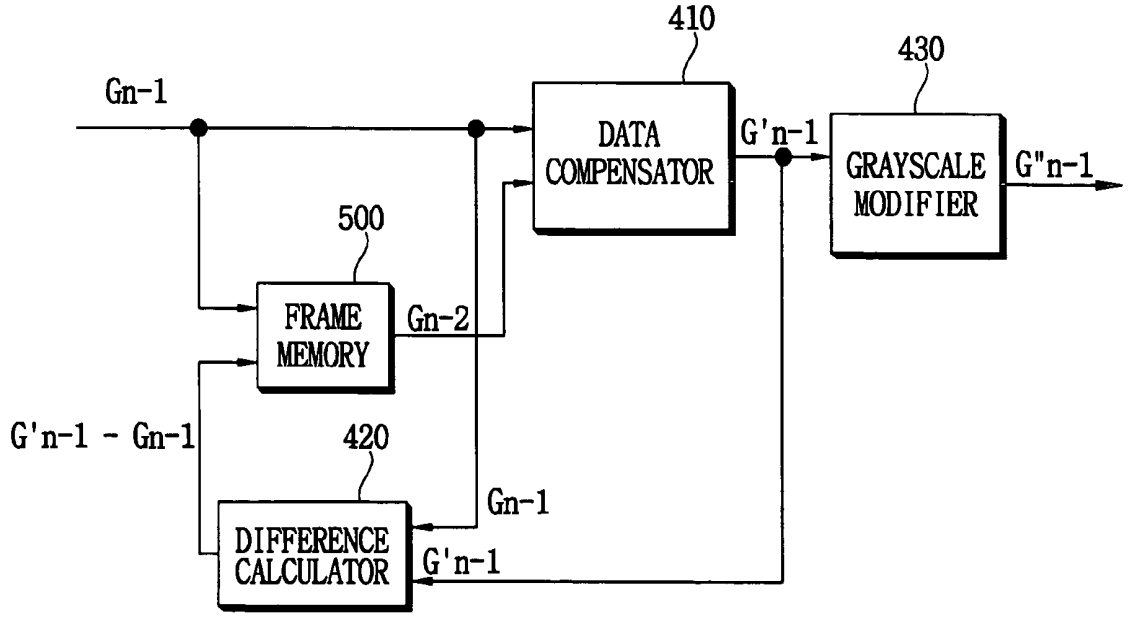

410
430
Gn-1
DATA COMPENSATOR
G'n-1
GRAYSCALE MODIFIER
G"n-1
500
FRAME MEMORY
Gn-2
G'n-1 - Gn-1
420
Gn-1
DIFFERENCE CALCULATOR
G'n-1

FIG. 5C

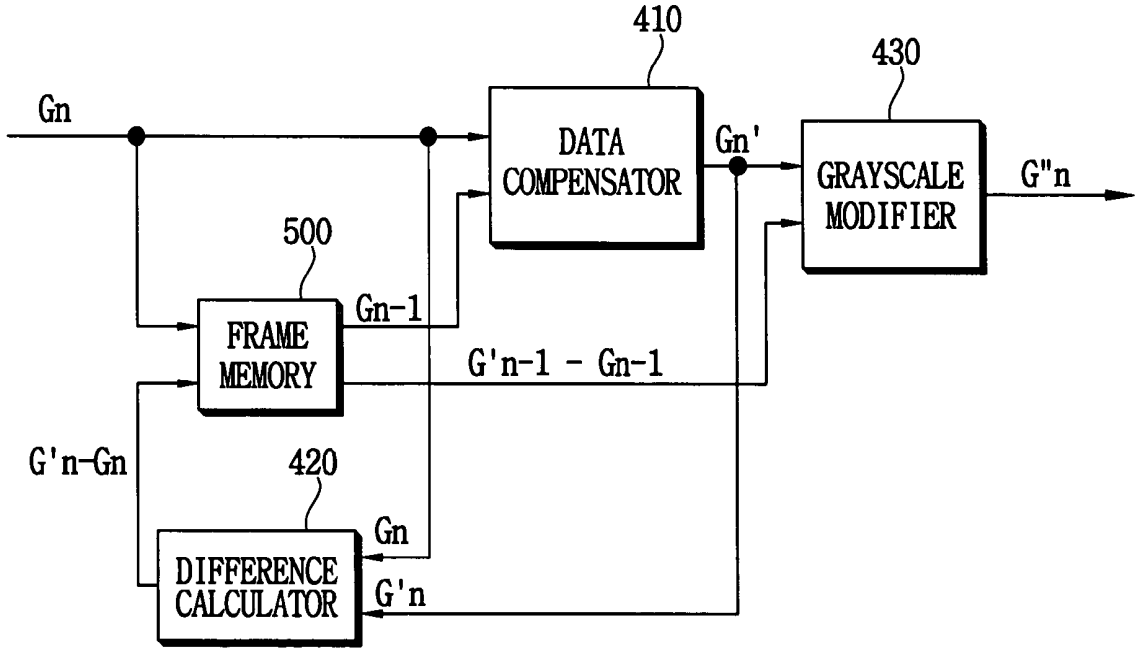

410
430
Gn
DATA COMPENSATOR
Gn'
GRAYSCALE MODIFIER
G"n
500
Gn-1
FRAME MEMORY
G'n-1 - Gn-1
G'n-Gn
420
Gn
DIFFERENCE CALCULATOR
G'n

FIG. 6

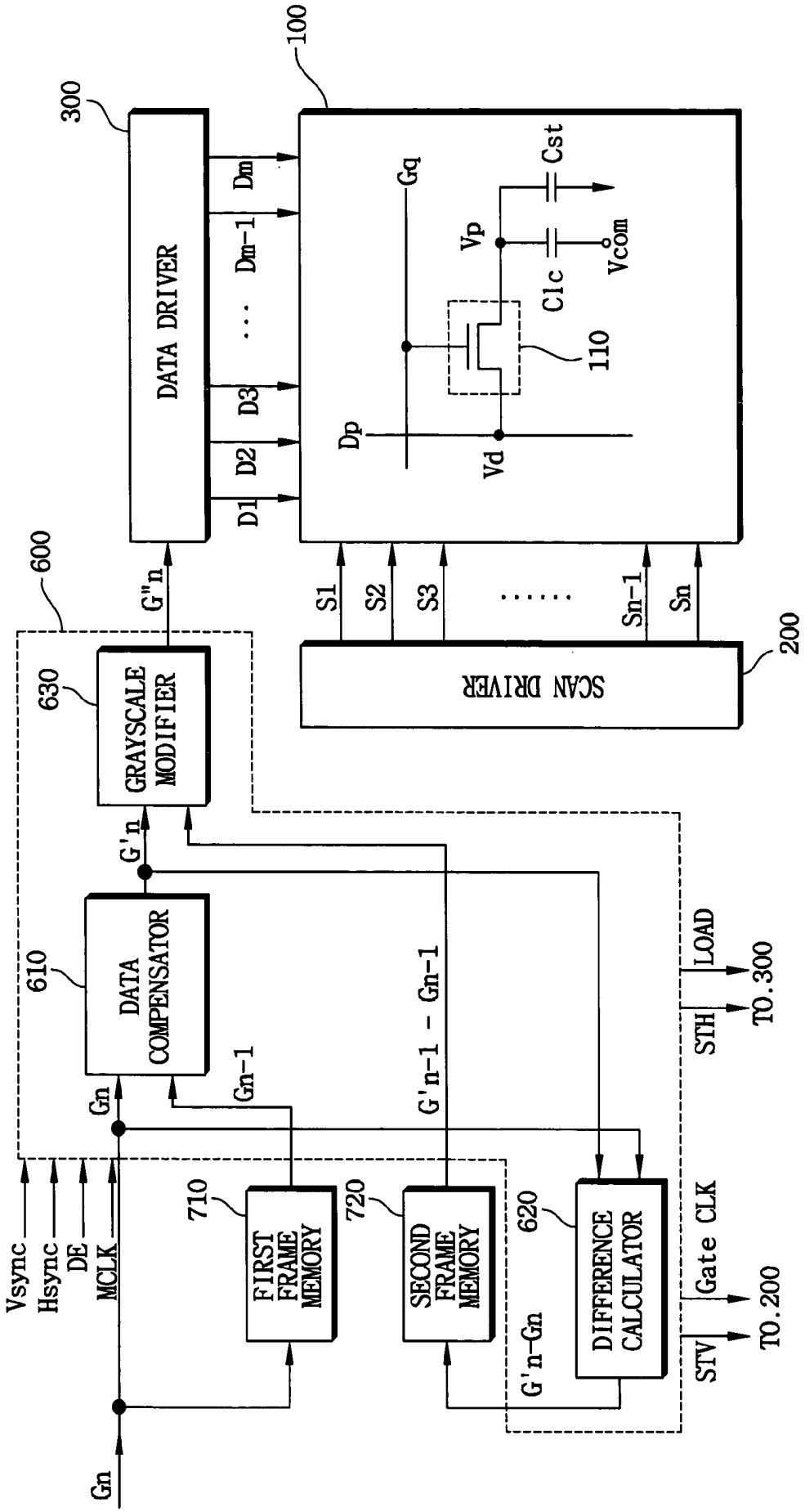

100
300
DATA DRIVER
Dm
Dm-1
D3
D2
D1
Gq
Cst
Vp
Vcom
Clc
110
Dp
Vd
600
G"n
S1
S2
S3
Sn-1
Sn
SCAN DRIVER
200
630
GRAYSCALE MODIFIER
G'n
610
DATA COMPENSATOR
Gn-1
G'n-1 - Gn-1
LOAD
TO.300
STH
Gn
710
FIRST FRAME MEMORY
720
SECOND FRAME MEMORY
620
DIFFERENCE CALCULATOR
Gate CLK
TO.200
STV
G'n-Gn
Vsync
Hsync
DE
MCLK
Gn

FIG. 7A

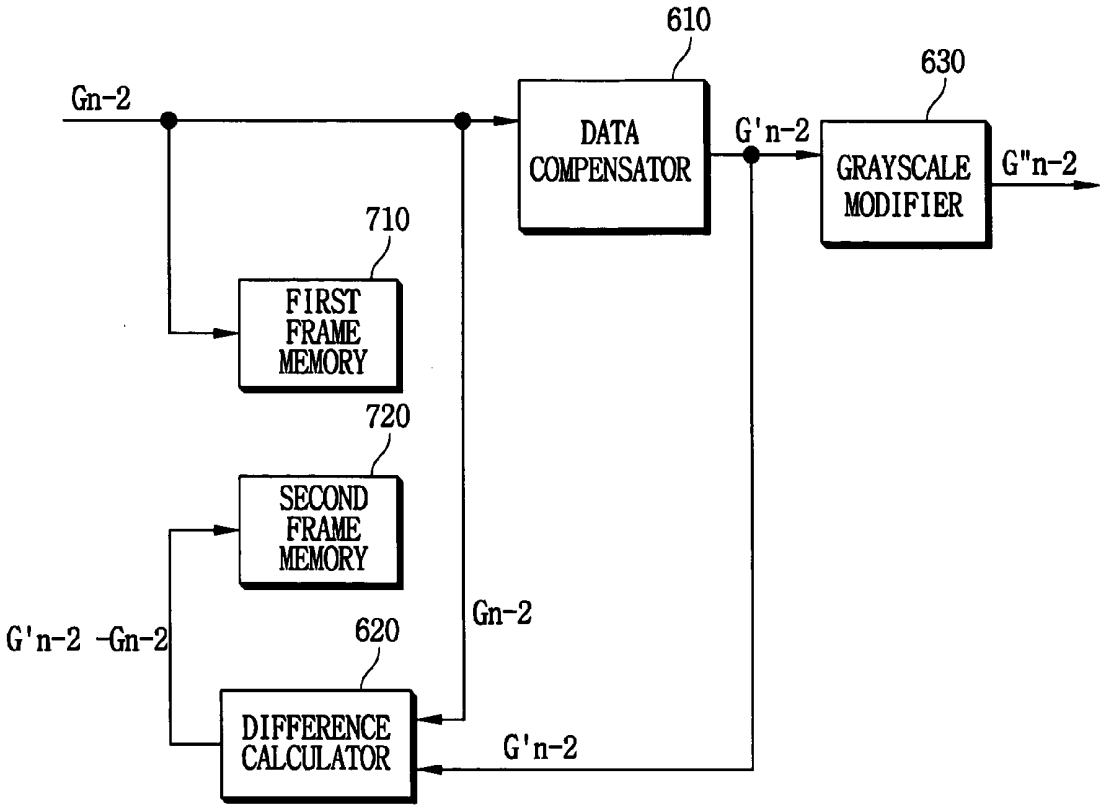

610
630
Gn-2
DATA COMPENSATOR
G'n-2
GRAYSCALE MODIFIER
G"n-2
710
FIRST FRAME MEMORY
720
SECOND FRAME MEMORY
G'n-2 -Gn-2
620
Gn-2
DIFFERENCE CALCULATOR
G'n-2

FIG. 7B

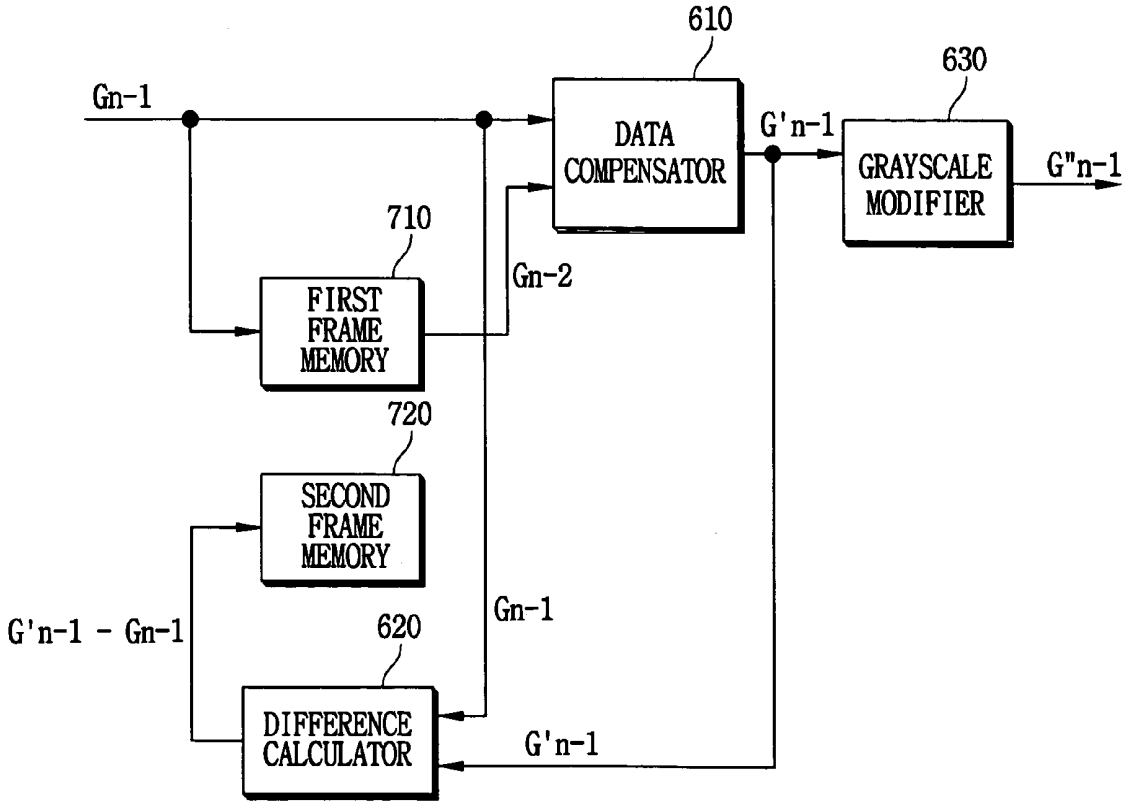

610
630
Gn-1
DATA COMPENSATOR
G'n-1
GRAYSCALE MODIFIER
G"n-1
710
Gn-2
FIRST FRAME MEMORY
720
SECOND FRAME MEMORY
G'n-1 - Gn-1
620
Gn-1
DIFFERENCE CALCULATOR
G'n-1

FIG. 7C

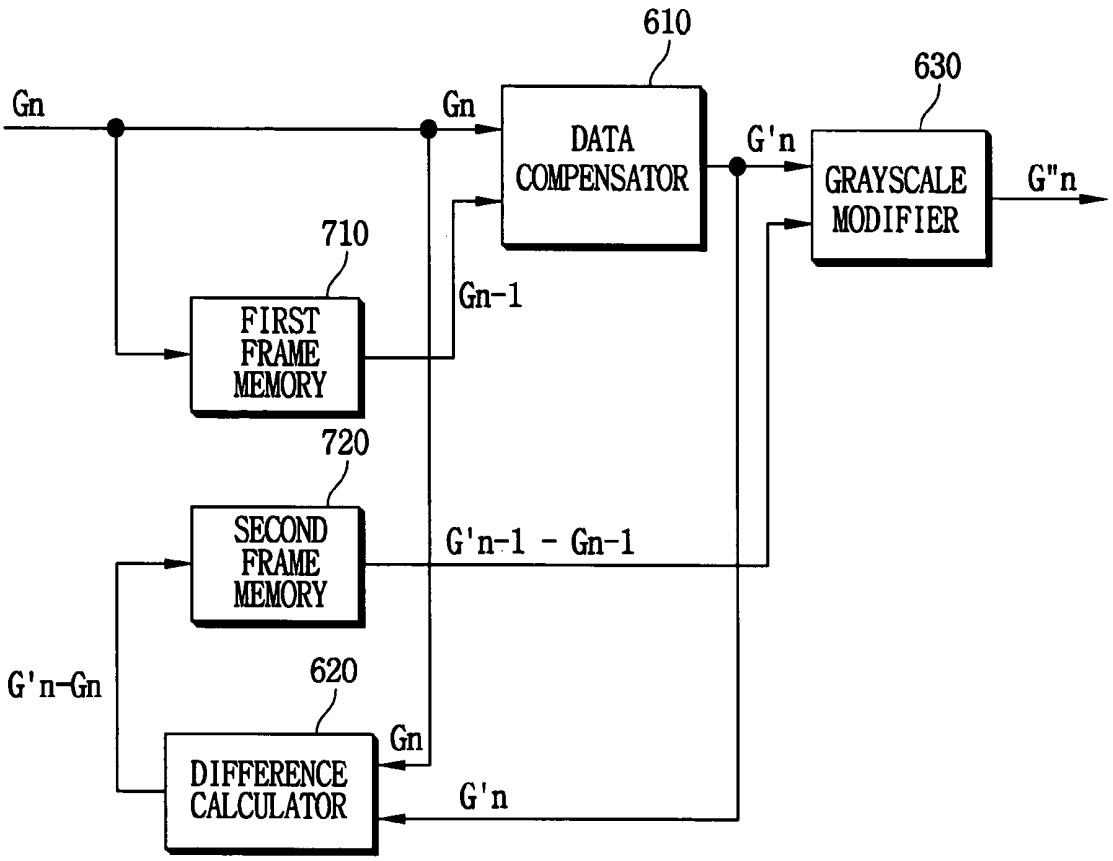

610
630
Gn
Gn
DATA COMPENSATOR
G'n
GRAYSCALE MODIFIER
G"n
710
Gn-1
FIRST FRAME MEMORY
720
SECOND FRAME MEMORY
G'n-1 - Gn-1
G'n-Gn
620
Gn
DIFFERENCE CALCULATOR
G'n

FIG. 8A

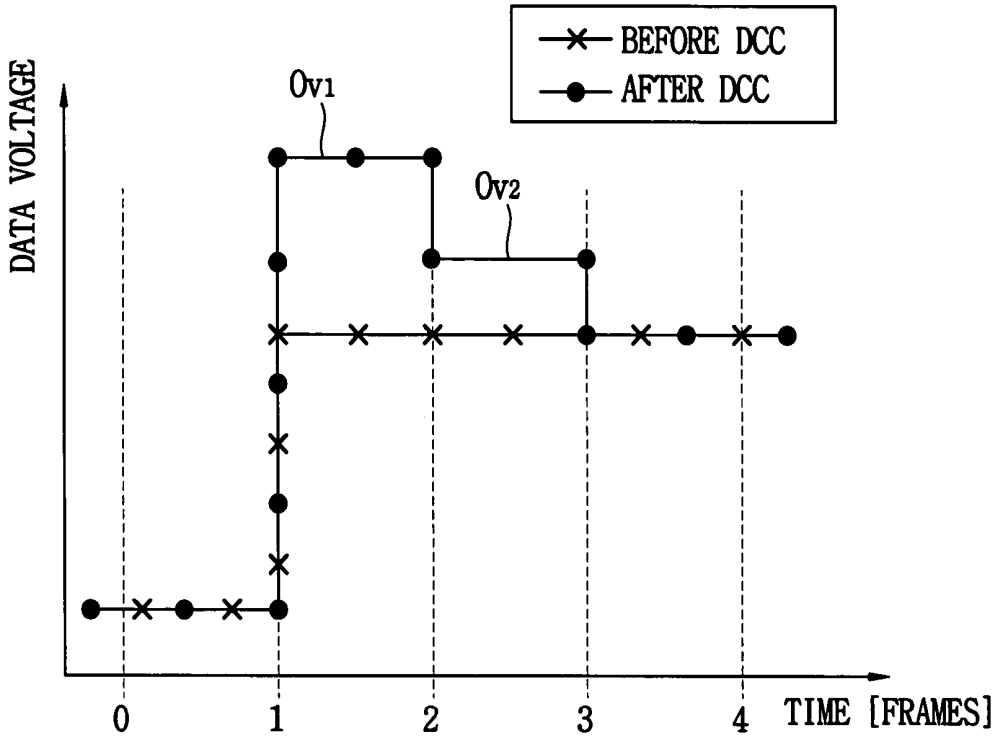

BEFORE DCC
AFTER DCC
DATA VOLTAGE
Ov1
Ov2
0
1
2
3
4
TIME [FRAMES]

FIG. 8B

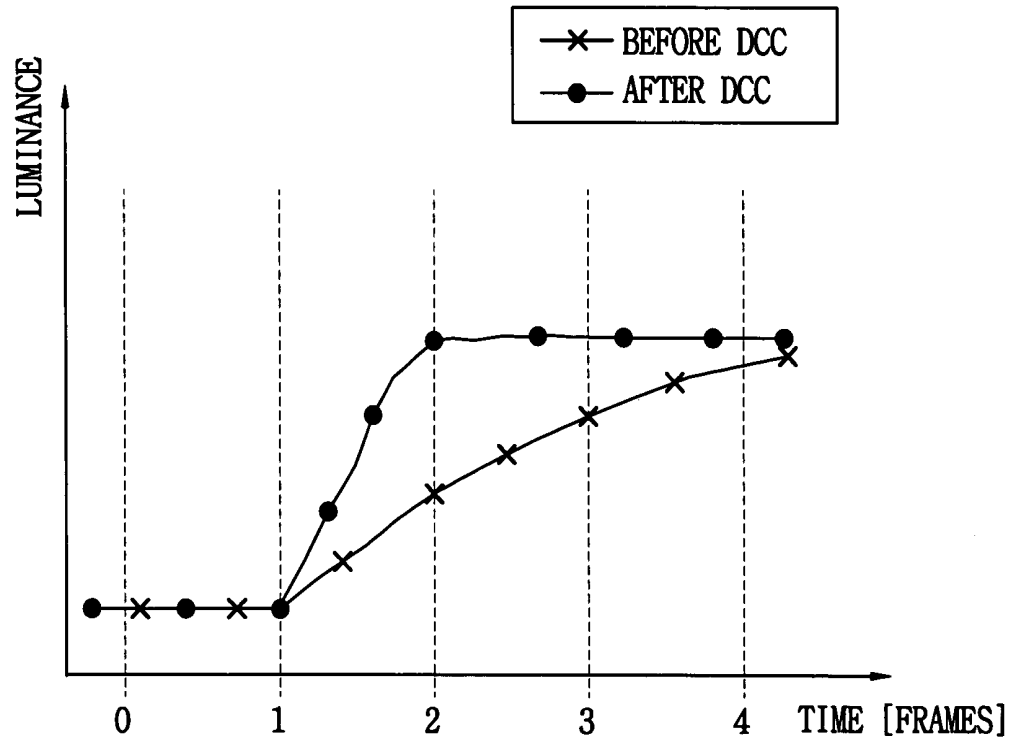

BEFORE DCC
AFTER DCC
LUMINANCE
0
1
2
3
4
TIME [FRAMES]

FIG. 9

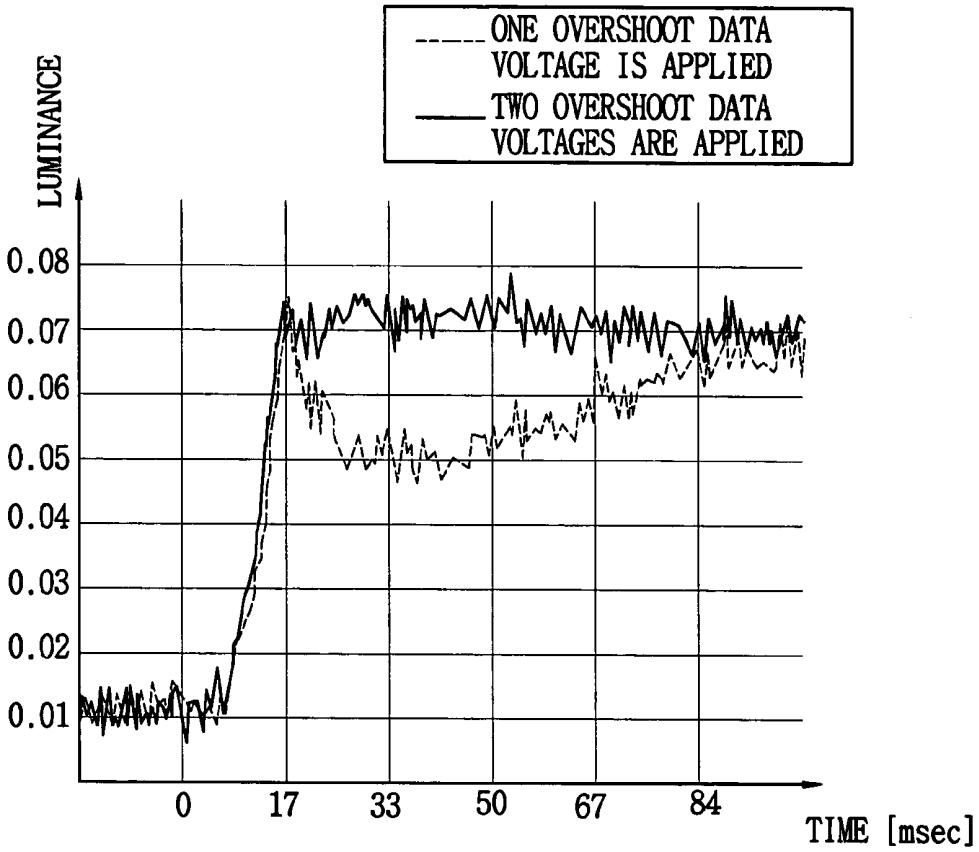

ONE OVERSHOOT DATA VOLTAGE IS APPLIED
TWO OVERSHOOT DATA VOLTAGES ARE APPLIED
LUMINANCE
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
17
33
50
67
84
TIME [msec]

FIG. 10

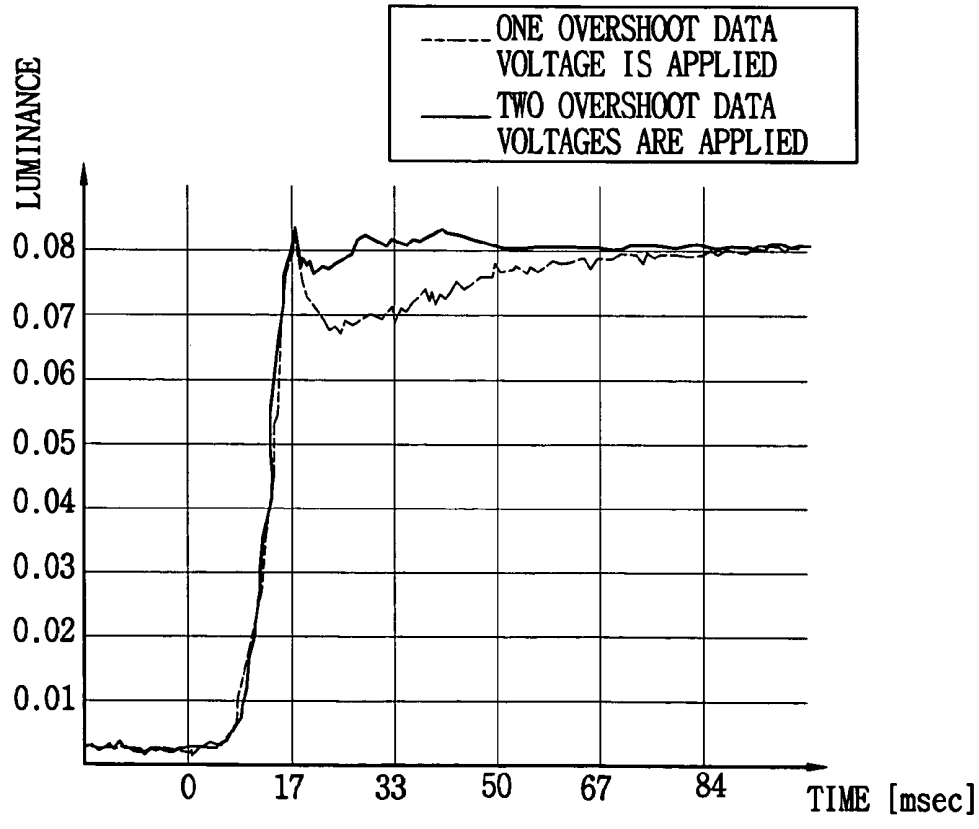

ONE OVERSHOOT DATA VOLTAGE IS APPLIED
TWO OVERSHOOT DATA VOLTAGES ARE APPLIED
LUMINANCE
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
17
33
50
67
84
TIME [msec]

FIG. 11

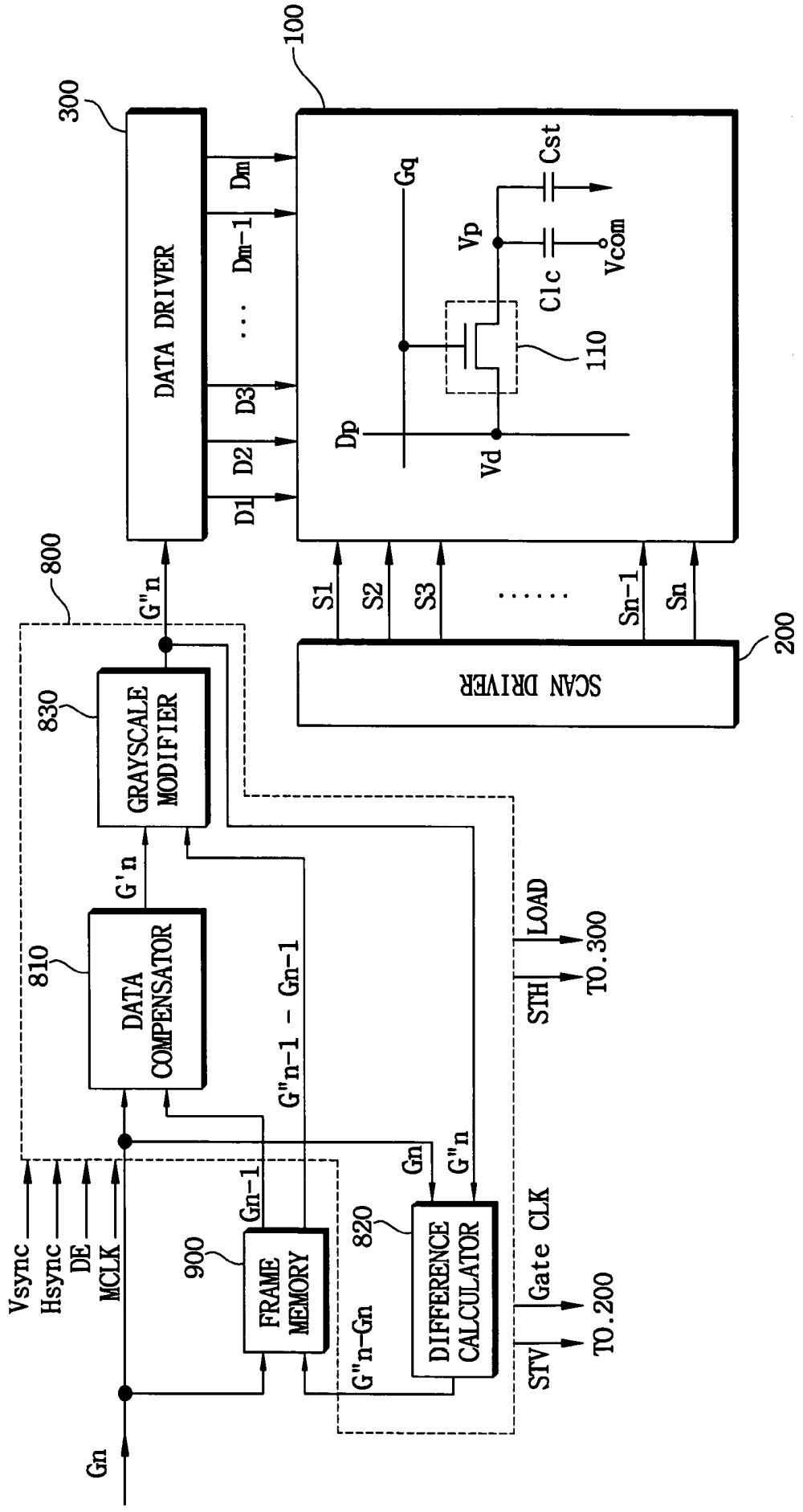

100
300
DATA DRIVER
Dm
Dm-1
D3
D2
D1
Gq
Cst
Vp
Vcom
Clc
110
Dp
Vd
S1
S2
S3
Sn-1
Sn
SCAN DRIVER
200
800
G"n
830
GRAYSCALE MODIFIER
G'n
810
DATA COMPENSATOR
G"n-1 - Gn-1
LOAD
TO 300
STH
Vsync
Hsync
DE
MCLK
Gn-1
900
FRAME MEMORY
Gn
G"n
820
DIFFERENCE CALCULATOR
G"n-Gn
Gate CLK
TO 200
STV
Gn

FIG. 12A

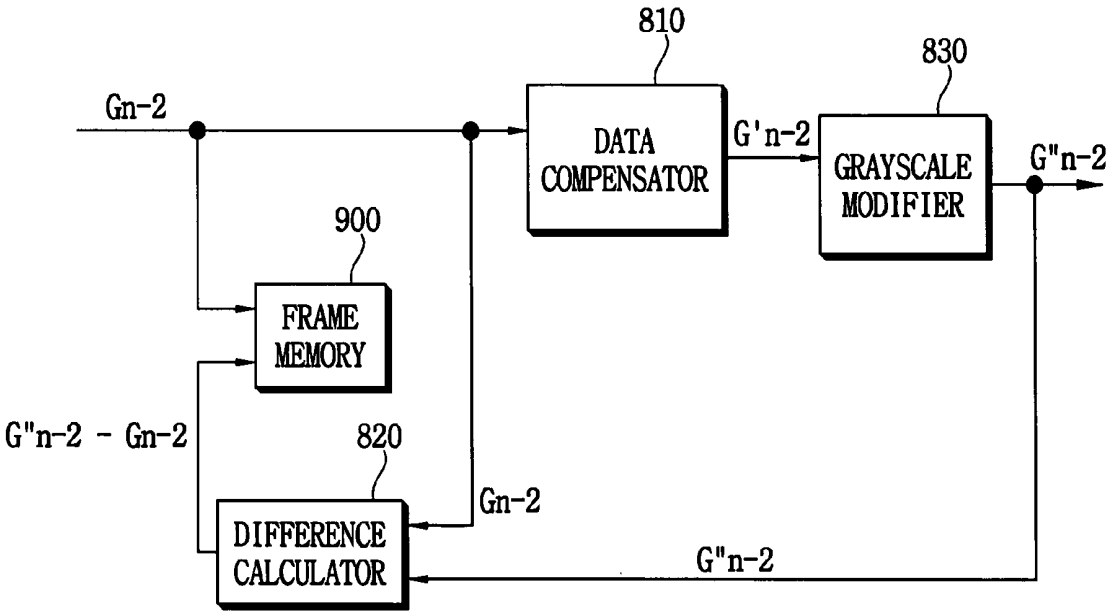


FIG. 12B

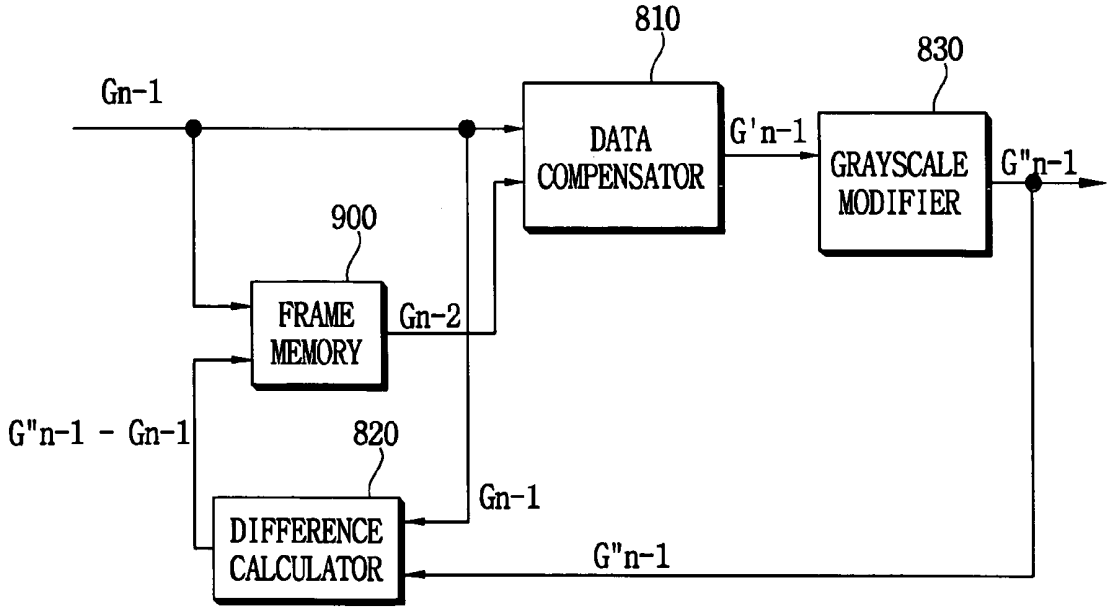


FIG. 12C

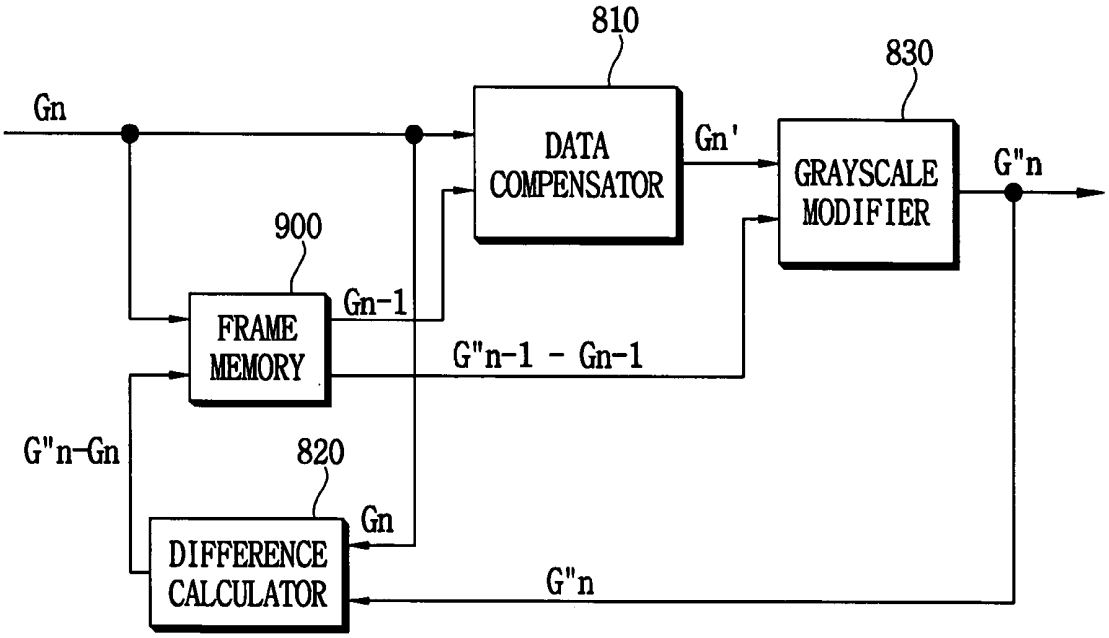

810
830
Gn
DATA COMPENSATOR
Gn'
GRAYSCALE MODIFIER
G"n
900
Gn-1
FRAME MEMORY
G"n-1 - Gn-1
G"n-Gn
820
Gn
DIFFERENCE CALCULATOR
G"n

FIG. 13

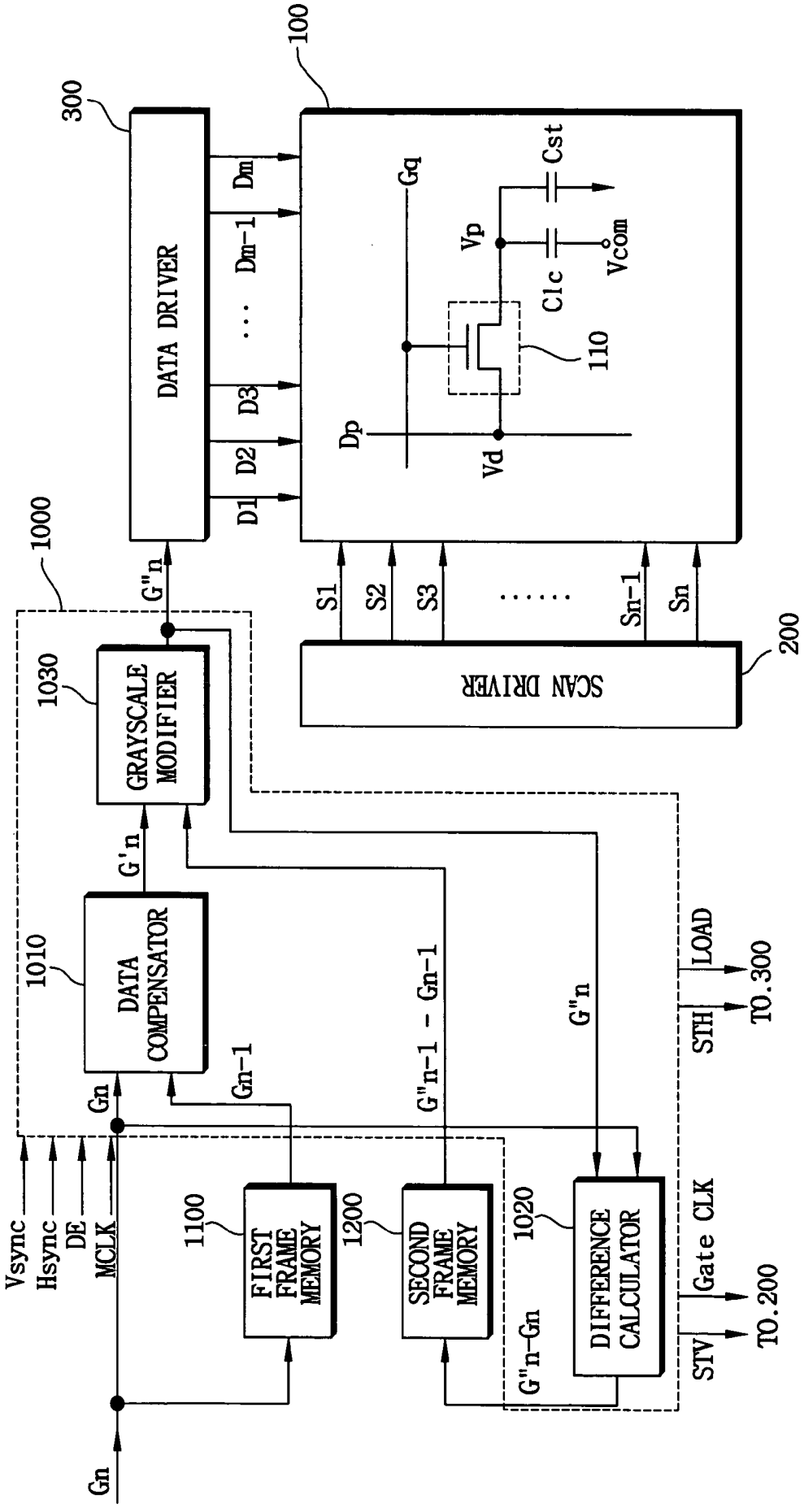

100
300
DATA DRIVER
Dm
Dm-1
D3
D2
D1
Gq
Cst
Vp
Vcom
Clc
110
Dp
Vd
1000
G"n
S1
S2
S3
Sn-1
Sn
200
SCAN DRIVER
1030
GRAYSCALE MODIFIER
G'n
1010
DATA COMPENSATOR
Gn-1
G"n-1 - Gn-1
G"n
LOAD
TO.300
STH
Gn
Vsync
Hsync
DE
MCLK
1100
FIRST FRAME MEMORY
1200
SECOND FRAME MEMORY
1020
DIFFERENCE CALCULATOR
G"n-Gn
Gate CLK
TO.200
STV
Gn

FIG. 14A

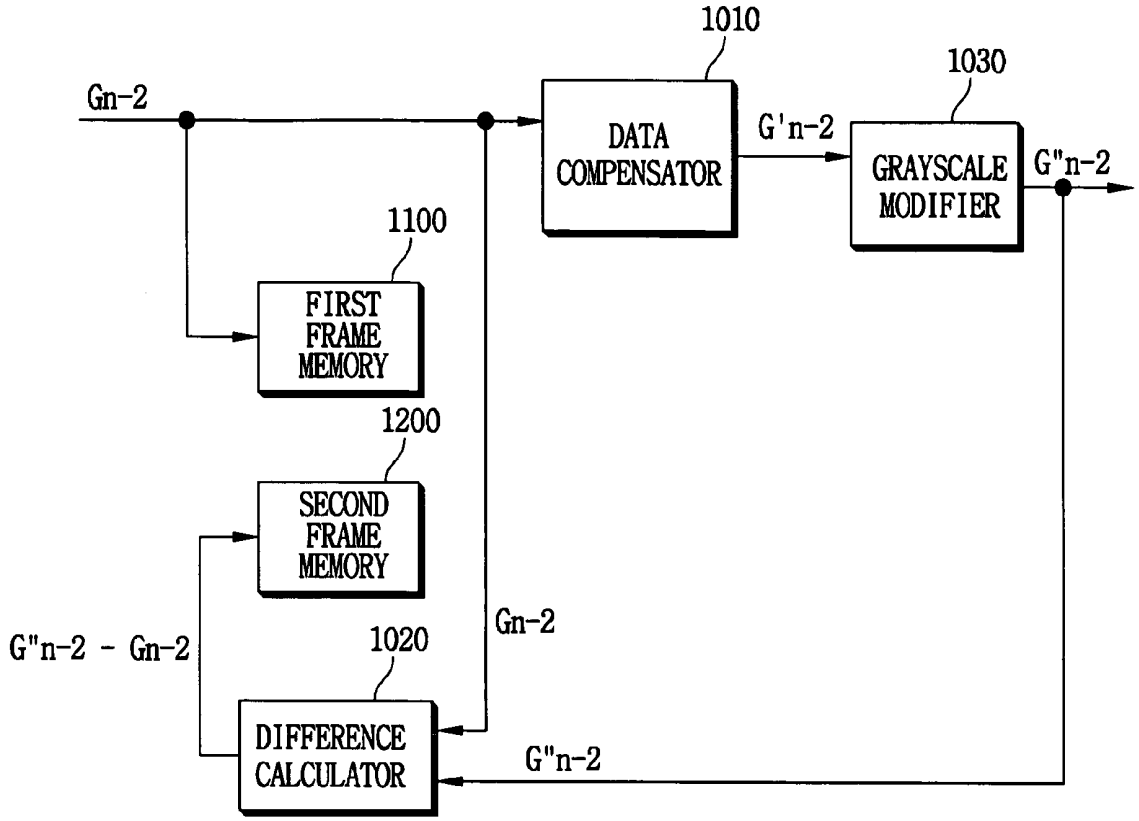


FIG. 14B

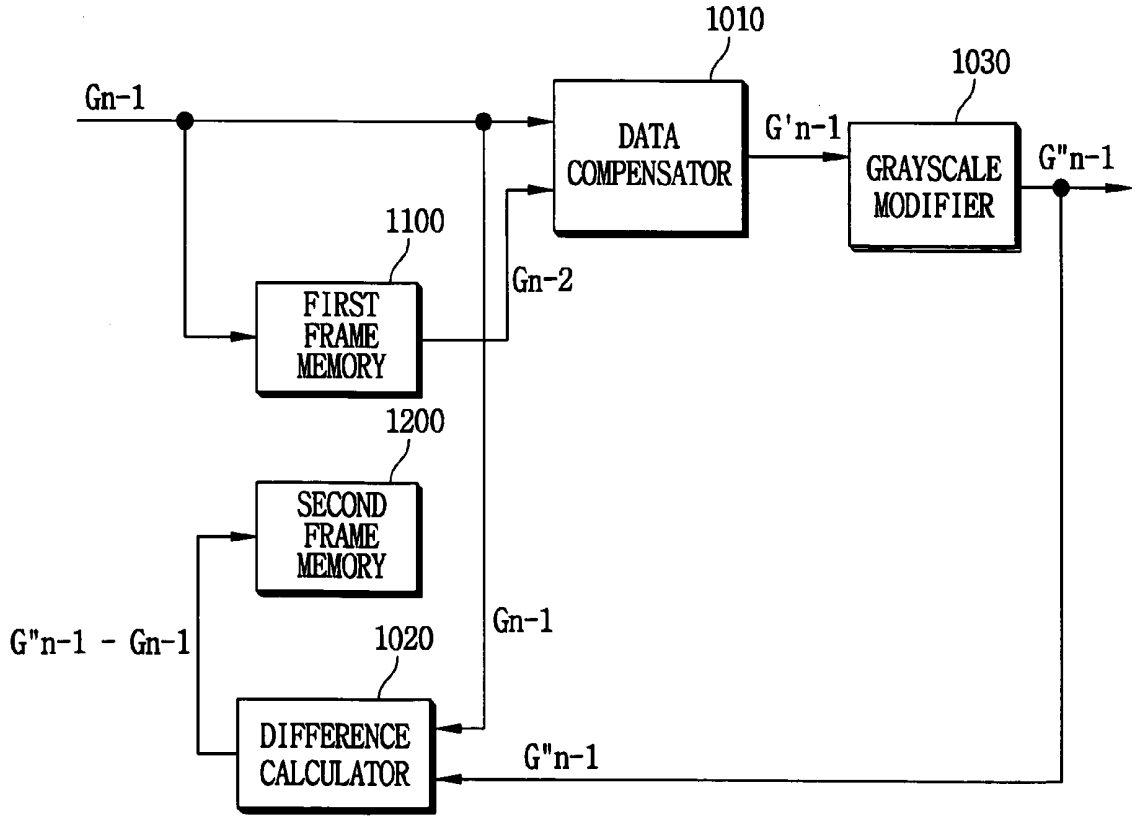


FIG. 14C

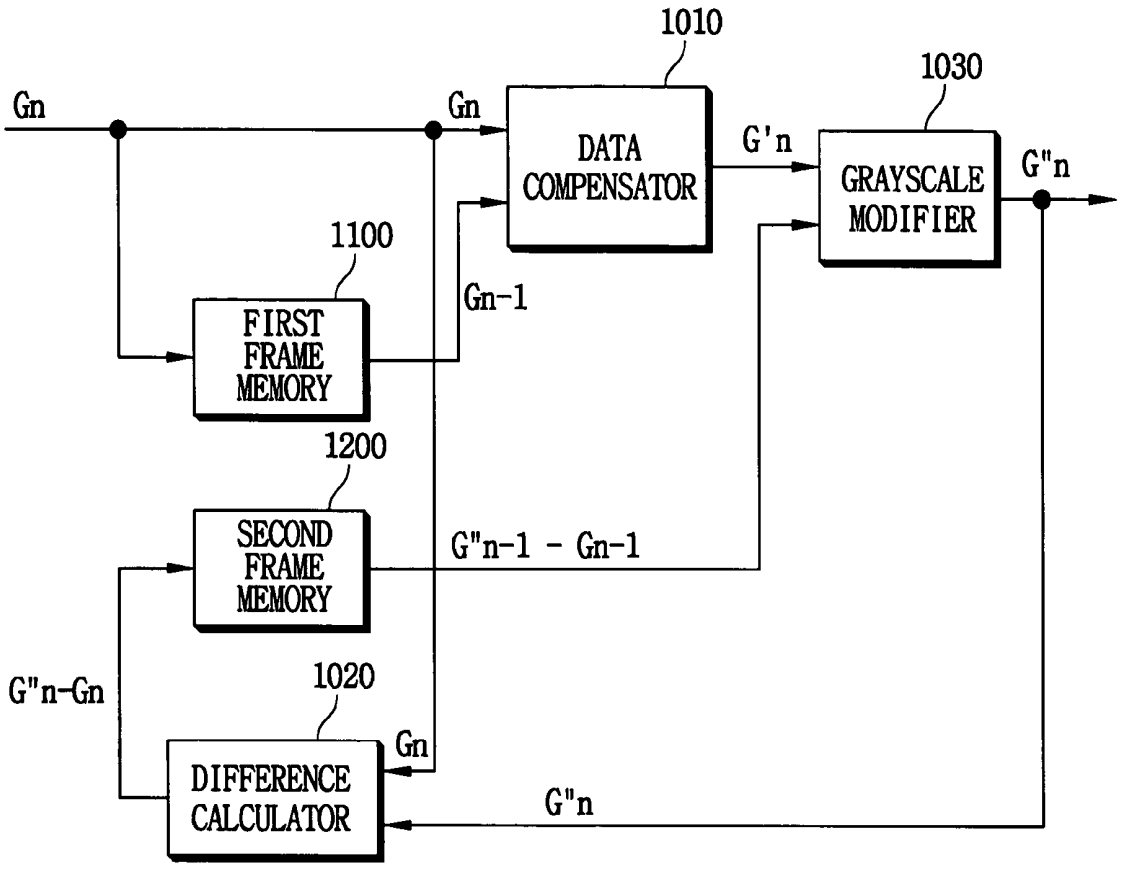
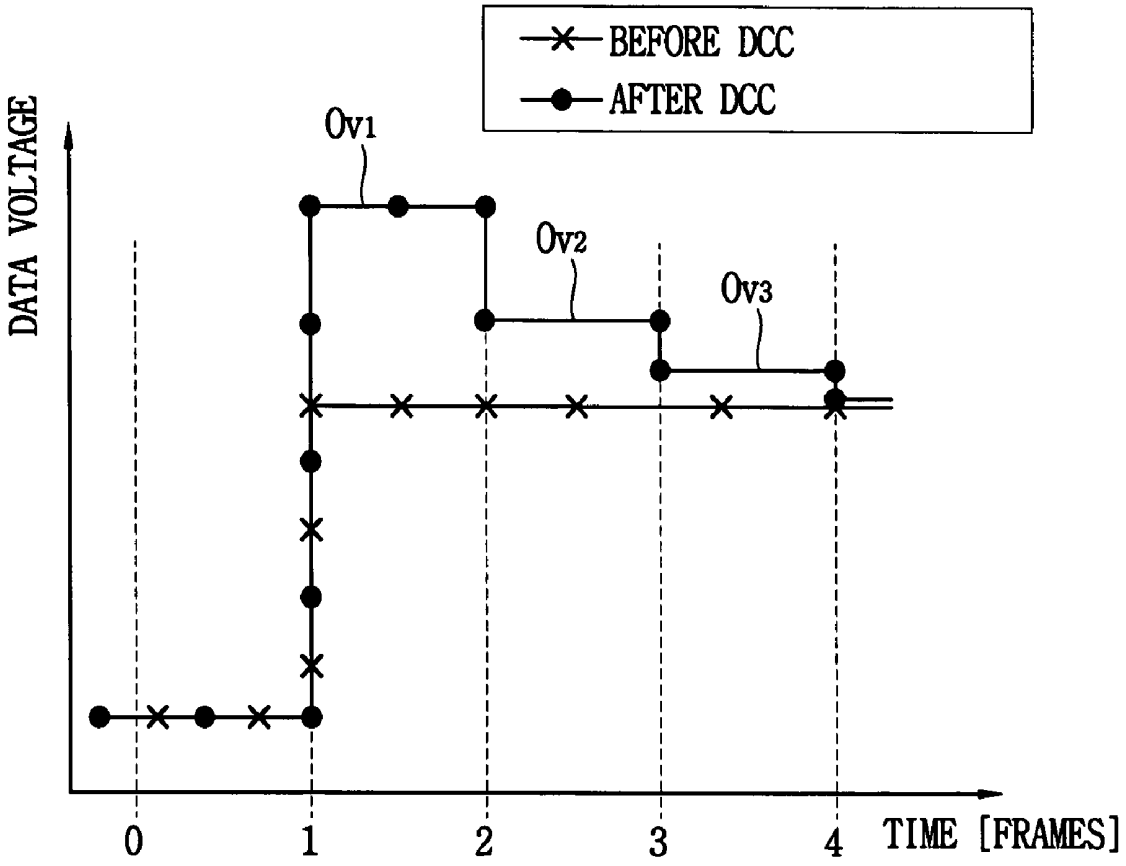

1010
1030
Gn
Gn
DATA COMPENSATOR
G'n
GRAYSCALE MODIFIER
G"n
1100
Gn-1
FIRST FRAME MEMORY
1200
SECOND FRAME MEMORY
G"n-1 - Gn-1
G"n-Gn
1020
Gn
DIFFERENCE CALCULATOR
G"n

FIG. 15


BEFORE DCC
AFTER DCC
DATA VOLTAGE
Ov1
Ov2
Ov3
0
1
2
3
4
TIME [FRAMES]

LIQUID CRYSTAL DISPLAY APPARATUS AND METHOD FOR DRIVING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid crystal display (LCD) apparatus and a method for driving the same, and more particularly, to an LCD apparatus in which at least two overshoot voltages are applied to a pixel electrode in response to a change of grayscale data of a frame to improve a response time as well as display quality and a method for driving the LCD apparatus.

2. Description of the Related Art

LCD apparatuses are thinner and lighter and draw much less power than cathode ray tubes. They are used in laptop computers, mobile phones and many other electronic devices.

Recently, new technologies have been developed to improve the display quality of LCD apparatuses. One of them is a DCC (Dynamic Capacitance Compensation) technology. The DCC technology improves a response speed of LC (Liquid Crystal) molecules by compensating a grayscale voltage of a current frame with a previous grayscale voltage and a current target grayscale voltage.

Another new technology is Patterned Vertical Alignment (PVA). PVA mode LCD apparatuses control the switching behavior of LC (Liquid Crystal) molecules by forming an opening pattern in a pixel electrode (or transparent electrode) or a common electrode or by creating fringe fields, thereby providing a wide view angle.

Although the DCC and PVA technologies improve the display quality of LCD apparatuses, LCD apparatuses still have pattern blinking problems. As LCD apparatuses become larger, the pattern blinking appears more.

FIG. **1** is a graph showing the response time of a PVA mode LCD apparatus before and after performing a DCC method. As shown in an "x" marked line, a rising time is slow at a middle level of grayscale, i.e., until seven or eight frames are passed, when the DCC is not performed. The slow rising time can be improved by performing the DCC, as shown in a "•" marked line. However, there are still problems such as luminance deterioration or appearance of residual images. For example, when PVA mode LCD apparatuses display a motion picture, the motion picture blinks due to the change of luminance.

FIG. **2**A is a graph showing the data voltages of a PVA mode LCD apparatus before and after performing a DCC method. FIG. **2**B is a graph showing the luminance of a PVA mode LCD apparatus before and after performing a DCC method.

When the DCC method is not performed in PVA mode LCD apparatuses, an arrangement of LC molecules is gradually changed even when a level of grayscale is abruptly changed from a low level to a high level. That is, as shown the "x" marked lines of FIG. **2**A and **2**B, the arrangement of LC molecules corresponding to the high level of grayscale is completed after two or three frames have passed and a luminance is gradually increased. Although, as shown in the "•" marked lines of FIGS. **2**A and **2**B, the LC molecules are arranged rapidly, that is, the response time is reduced, by performing the DCC method, the luminance of PVA mode LCD apparatus drops again after temporarily increasing, because the LC molecules tends to return to an original arrangement. Thus, LCD apparatuses have pattern blinking, resulting in deteriorating display quality.

SUMMARY OF THE INVENTION

The present invention provides a liquid crystal display apparatus capable of reducing response time as well as improving display quality.

The present invention provides a driving device of a liquid crystal display apparatus capable of improving display quality.

The present invention further provides a method for driving a liquid crystal display apparatus in which pattern blinking is prevented and response time is reduced.

According to one aspect of the present invention, a liquid crystal display apparatus, comprises a timing controller to generate a plurality of compensated grayscale data; a memory to store grayscale data or the compensated grayscale data; a column driver to apply the compensated grayscale data to a plurality of data lines; a gate driver to apply a gate signal to a plurality of gate lines; and a liquid crystal panel including the gate lines, the data lines and a plurality of switching element disposed between the data lines and the gate lines.

According to another aspect of the present invention, a method for driving a liquid crystal display apparatus, comprises generating first compensated grayscale data in response to grayscale data for a current frame and previously stored grayscale data for a previous frame; generating second compensated grayscale data in response to the first compensated grayscale data and the grayscale data for the current frame; generating third compensated grayscale data in response to the first compensated grayscale data and previously stored compensated grayscale data; storing the grayscale data for the current frame and the second compensated grayscale data; applying a gate signal to gate lines; and applying a data voltage corresponding to the third compensated grayscale data to data lines.

According to further aspect of the present invention, A method for driving a liquid crystal display apparatus, comprises generating first compensated grayscale data in response to grayscale data for a current frame and previously stored grayscale data for a previous frame; generating second compensated grayscale data in response to the first compensated grayscale data and previously stored compensated grayscale data; generating third compensated grayscale data in response to the second compensated grayscale data and the grayscale data for the current frame; storing the grayscale data for the current frame and the third compensated grayscale data; applying a gate signal to gate lines; and applying a data voltage corresponding to the second compensated grayscale data to data lines.

This application claims a priority upon Korean Patent Application No.2003-45449 filed on Jul. 4, 2003, the contents of which are herein incorporated by reference in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will become more apparent by describing in detail the preferred embodiments thereof with reference to the accompanying drawings, in which:

FIG. **1** is a graph showing the response time of a PVA mode LCD apparatus before and after performing DCC;

FIGS. **2**A and **2**B are graphs showing the data voltage and luminance of a PVA mode LCD apparatus before and after performing DCC, respectively;

FIG. **3** is a block diagram for illustrating a DCC method;

FIG. **4** is a block diagram of an LCD apparatus according to an exemplary embodiment of the present invention;

FIGS. **5**A through **5**C are block diagrams showing an operation of the timing controller of FIG. **4**;

FIG. **6** is a block diagram of an LCD apparatus according to another exemplary embodiment of the present invention;

FIGS. **7**A through **7**C are block diagrams showing an operation of the timing controller of FIG. **6**.

FIG. **8**A is a graph showing the data voltage of an LCD apparatus before and after performing DCC, according to an exemplary embodiment of the present invention;

FIG. **8**B is a graph showing the luminance of an LCD apparatus before and after performing DCC, according to an exemplary embodiment of the present invention;

FIG. **9** is an experimental graph showing the luminance of an LCD apparatus having 64 levels of grayscale, according to an exemplary embodiment of the present invention;

FIG. **10** is an experimental graph showing the luminance of an LCD apparatus having 128 levels of grayscale, according to an exemplary embodiment of the present invention;

FIG. **11** is a block diagram of an LCD apparatus according to another exemplary embodiment of the present invention;

FIGS. **12**A through **12**C are block diagrams showing an operation of the timing controller of FIG. **11**;

FIG. **13** is a block diagram of an LCD apparatus according to a further exemplary embodiment of the present invention;

FIGS. **14**A through **14**C are block diagrams showing an operation of the timing controller of FIG. **13**; and

FIG. **15** is a graph showing the data voltage of an LCD before and after performing DCC, according to another exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, the exemplary embodiments of the present invention will be described in detail with reference to the accompanying drawings.

FIG. **3** is a block diagram for illustrating a DCC method. The grayscale data for one frame is stored in a frame memory **10**. A controller **20** applies a read instruction 'R', a write instruction 'W' and an address instruction 'A' to the frame memory **10** so as to control the frame memory **10**. A data compensator **30** generates the compensated grayscale data (or a compensated data voltage) G'n of a current frame by using the grayscale data (or a grayscale voltage) Gn of the current frame and the grayscale data Gn-1 of a previous frame, which is previously stored in the frame memory **10**.

When a target pixel voltage of the current frame is higher than the pixel voltage of the previous frame, the pixel voltage of the current frame is compensated to be higher than the target pixel voltage. The target pixel voltage of the current frame is applied to the pixels of a next frame. A value of the compensated voltage depends on the capacitance determined by the pixel voltage of the previous frame.

FIG. **4** is a block diagram of an LCD apparatus according to an exemplary embodiment of the present invention. Referring to FIG. **4**, an LCD apparatus includes a LC panel **100**, a scan driver **200**, a data driver **300**, a timing controller **400** and a frame memory **500**. The timing controller **400** receives grayscale data from an external device such as a graphic controller (not shown), and generates and applies the compensated grayscale data of the grayscale data to the data driver **300**. The timing controller **400** receives first signals Vsync, Hsync, DE and MCLK, and applies second signals STV and Gate CLK and third signals STH and LOAD to the scan driver **200** and the data driver **300**, respectively. The scan and data drivers **200** and **300** drive the LC panel **100** to display images.

The timing controller **400** includes a data compensator **410**, a difference calculator **420** and a grayscale modifier **430**. The timing controller **400** generates the second compensated grayscale data G"n of a current frame by using the difference between the grayscale data Gn-1 of a previous frame and the grayscale data Gn of the current frame and the difference between the grayscale data Gn-1 of the previous frame and the compensated grayscale data G'n-1 of the previous frame. The difference between the grayscale data Gn-1 of the previous frame and the grayscale data Gn of the current frame is the first compensated grayscale data Gn' of the current frame. The compensated grayscale data G'n-1 of the previous frame is generated by using the grayscale data Gn-1 of the previous frame and the grayscale data Gn-2 of a previous frame. The second compensated grayscale data G'n of the current frame is applied to the data driver **300**.

The frame memory **500** receives and stores the grayscale data of one frame from an external device (not shown) and the data difference of one frame from the difference calculator **420**. For example, the frame memory **500** receives and stores the grayscale data Gn of a current frame from the external device and provides the data compensator **410** with the previously stored grayscale data Gn-1 of a previous frame, in response to a control signal of a controller (not shown). Further, the frame memory **500** receives and stores the data difference G'n−Gn from the difference calculator **420** and provides the grayscale modifier **430** with the previously stored data difference G'n-1−Gn-1. The frame memory **500**, for example, includes a synchronous dynamic random access memory (SDRAM) which outputs stored data in response to the input of data or Double Data Rate (DDR) memory.

The data compensator **410** receives the grayscale data Gn of the current frame from the external device and the stored grayscale data Gn-1 of the previous frame from the frame memory **500** to generate the first compensated grayscale data G'n of the current frame. The first compensated grayscale data G'n includes overshoot data or undershoot data. The first compensated grayscale data G'n of the current frame is transferred to the grayscale modifier **430** and the difference calculator **420**. The data compensator **410**, for example, includes a LUT (look-up table).

The difference calculator **420** generates the data difference G'n−Gn by using the first compensated grayscale data G'n of the current frame and the grayscale data Gn of the current frame. The difference calculator **420** provides the frame memory **500** with the data difference G'n−Gn.

The grayscale modifier **430** generates the second compensated grayscale data G"n by using the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1) of the previous frame. The second compensated grayscale data G"n is applied to the data driver **300** so that a data voltage is greater or less than a target pixel voltage during the variation of grayscale. Thus, the response time of LC molecules is optimized.

For example, when the grayscale data Gn-1 of the previous frame is the substantially same as the grayscale data Gn of the current frame, the grayscale data Gn of the current frame is not compensated. When the grayscale data Gn-1 of the previous frame has a lower level than that of the grayscale data Gn of the current frame, for example, the grayscale data Gn-1 of the previous frame is a black color and the grayscale data Gn of the current frame is a white color, the timing controller **400** outputs the second compen-

sated grayscale data G"n that is higher than the grayscale data Gn of the current frame. Thus, the timing controller **400** outputs the second compensated grayscale data G"n as overshoot waveform using the grayscale data Gn-1 of the previous frame and the grayscale data Gn of the current frame.

The timing controller **400** minimizes the number of frame memories as well as optimizes the response time of LC molecules. Assume that each grayscale of red color, green color and blue color is 8-bit data (that is, the total bits of grayscale is 24 bits) and the frame memory **500** has a 32-bit data bus. In this case, the frame memory **500** has 8-bit as a surplus, and stores the data difference G'n−Gn as an 8-bit. Thus, a process time is reduced.

For example, when each grayscale data of red color, green color and blue color is x-bit data, the data difference G'n−Gn of each color is y-bit data (wherein y is an integer smaller than x). If the data difference G'n−Gn of the RGB is 8-bit data, the combination of the data difference G'n−Gn of the RGB includes, for example, 8-bit of (3, 3, 2), (3, 2, 3) or (2, 3, 3). The data difference G'n−Gn of the current frame corresponds to a most significant bit (MSB). Therefore, the timing controller **400** generates the second compensated grayscale data G"n by using one frame memory **500**, which stores the grayscale data in one portion and stores the data difference in a remaining portion. Thus, the response time of the LC molecules is enhanced with the minimized number of the frame memories.

The timing controller **400** is implemented in a single unit or is integrally formed with an external (not shown) or the data driver **300**. The data driver **300** applies the data voltage, which is adjusted according to the compensated grayscale data G"n, to the pixel of the LC panel **100**. Thus, the response time of LC molecules is improved without modifying the LC panel **100** or the physical property of LC molecules, resulting in improving of the display quality of an LCD apparatus.

The LC panel **100** includes a plurality of gate lines (or scan lines) Gq for receiving gate-on signals from the scan driver **200**, a plurality of data lines (or source lines) Dp for receiving compensated data voltages from the data driver **300** and the pixels defined by the gate lines Gq and the data lines Dp. Each of the pixels includes a thin film transistor **110** having gate and source electrodes respectively connected to the gate line Gq and the data line Dp, a liquid crystal capacitor Clc connected to the drain electrode of the thin film transistor **110** and a storage capacitor Cst. The LC panel **100** includes TN (Twist Nematic) mode LC molecules or PVA (Patterned Vertical Alignment) mode LC molecules.

The scan driver section **200** applies the gate-on signals S**1**, S**2**, S**3**, . . . , Sn to the gate lines Gq in sequence so as to turn on the thin film transistor **110** that is electrically connected to the gate lines Gq. The scan driver section **200** is, for example, formed with a printed circuit board or a flexible printed circuit (FPC). Alternatively, the scan driver section **200** may include a shift register having plurality of stages, each output terminal being electrically connected to the gate line Gq, formed on the same substrate on which the thin film transistor **110** is formed.

The data driver **300** receives the second compensated grayscale data Gn" from the timing controller **400**, and transforms the second compensated grayscale data Gn" into data signals D**1**, D**2**, . . . , Dm. The data signals D**1**, D**2**, . . . , Dm are applied to each of the data lines Dp.

FIGS. **5**A to **5**C are block diagrams showing an operation of the timing controller of FIG. **4**. Referring to FIG. **5**A, when the grayscale data Gn-2 of a (n-2)-th frame is applied to a frame memory **500** and a data compensator **410**, the data compensator **410** generates first compensated grayscale data G'n-2 of the (n-2)-th frame. The data compensator **410** provides the grayscale modifier **430** and a difference calculator **420** with the first compensated grayscale data G'n-2. The first compensated grayscale data G'n-2 is not compensated or is the same as the grayscale data Gn-2.

The difference calculator **420** receives the grayscale data Gn-2 of the (n-2)-th frame and the first compensated grayscale data G'n-2 of the (n-2)-th frame. The difference calculator **420** calculates the data difference (G'n-2)−(Gn-2). The difference calculator **420** provides the frame memory **500** with the data difference (G'n-2)−(Gn-2). The frame memory **500** stores the data difference (G'n-2)−(Gn-2).

The grayscale modifier **430** receives the first compensated grayscale data G'n-2 and generates second compensated grayscale data G"n-2. The second compensated grayscale data G"n-2 is the same as the grayscale data Gn-2. Thus, the grayscale data Gn-2 is not compensated at the (n-2)-th frame.

Referring to FIG. **5**B, when the grayscale data Gn-1 of a (n-1)-th frame is applied to the frame memory **500** and the data compensator **410**, the frame memory **500** provides the data compensator **410** with the stored grayscale data Gn'-2 of the (n-2)-th frame. The data compensator **410** generates the first compensated grayscale data G'n-1 of the (n-1)-th frame using the grayscale data Gn-1 and the grayscale data Gn-2. The data compensator **410** provides the grayscale modifier **430** and the difference calculator **420** with the first compensated grayscale data G'n-1.

The difference calculator **420** receives the grayscale data Gn-1 of the (n-1)-th frame and the first compensated grayscale data G'n-1 of the (n-1)-th frame. The difference calculator **420** calculates the data difference (G'n-1)−(Gn-1). The difference calculator **420** provides the frame memory **500** with the data difference (G'n-1)−(Gn-1). The frame memory **500** stores the data difference (G'n-1)−(Gn-1).

The grayscale modifier **430** receives the first compensated grayscale data G'n-1 and generates second compensated grayscale data G"n-1. The second compensated grayscale data G"n-1 is the same as the first compensated grayscale data Gn'-1.

Referring to FIG. **5**C, when the grayscale data Gn of an n-th frame is applied to the frame memory **500** and the data compensator **410**, the frame memory **500** provides the data compensator **410** with the stored grayscale data Gn-1 of the (n-1)-th frame. The data compensator **410** generates the first compensated grayscale data G'n of the n-th frame using the grayscale data Gn and the grayscale data Gn-1. The data compensator **410** provides the grayscale modifier **430** and the difference calculator **420** with the first compensated grayscale data G'n.

The difference calculator **420** receives the grayscale data Gn of the n-th frame and the first compensated grayscale data G'n of the n-th frame. The difference calculator **420** calculates the data difference G'n−Gn. The difference calculator **420** provides the frame memory **500** with the data difference G'n−Gn. The frame memory **500** stores the data difference G'n−Gn and provides the grayscale modifier **430** with the stored data difference (G'n-1)−(Gn-1).

The grayscale modifier **430** receives the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1). The grayscale modifier **430** generates the second compensated grayscale data G"n using the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1). The second compensated grayscale data G"n is provided to the data driver **300**.

FIG. **6** shows a block diagram of an LCD apparatus including two frame memories. The same reference numerals are used to refer the same or like parts those described in FIG. **6** and any further explanation is omitted.

Referring to FIG. **6**, an LCD apparatus includes an LC panel **100**, a scan driver **200**, a data driver **300**, a timing controller **600**, a first frame memory **710**, and a second frame memory **720**. The timing controller **600** receives first timing signals 'Vsync', 'Hsync', 'DE' and 'MCLK', and it provides the scan driver **200** with second timing signals 'Gate CLK' and 'STV' and the data driver **300** with third timing signals 'LOAD' and 'STH'. The timing controller **600** includes a data compensator **510**, a difference calculator **620** and a grayscale modifier **630**.

In response to the grayscale data Gn of a current frame, the timing controller **600** generates the first compensated grayscale data Gn' of the current frame by using the difference between the grayscale data Gn of the current frame and the grayscale data Gn-1 of a previous frame. The first compensated grayscale data Gn' is used to generate data difference G'n−Gn. The timing controller **600** generates the second compensated grayscale data G"n of the current frame using the first compensated grays scale data G'n and the difference between the grayscale data Gn-1 of the previous frame and the compensated grayscale data G'n-1 of the previous frame. The compensated grayscale data G'n-1 of the previous frame is generated by using the grayscale data Gn-1 of the previous frame and the grayscale data Gn-2 of a previous frame. The second compensated grayscale data G"n is transferred to the data driver **300**.

When the grayscale data Gn-1 of the previous frame is the substantially same as the grayscale data Gn of the current frame, the grayscale data Gn is not compensated. When the grayscale data Gn-1 of the previous frame has a lower level (for example, a black color) than the level (for example, a white color) of the grayscale data Gn of the current frame, the grayscale data Gn is compensated to be greater than the grayscale data Gn-1.

The first frame memory **710** receives and stores the grayscale data Gn of the current frame. The first frame memory **710** provides the data compensator **610** with the previously stored grayscale data Gn-1 of the previous frame in response to a control signal of a controller (not shown). The first frame memory **710** includes, for example, a synchronous dynamic random access memory (SDRAM), which outputs the stored grayscale data Gn-1 of the previous frame in response to the input of the grayscale data Gn of the current frame or DDR memory.

The second frame memory **720** receives and stores the data difference G'n−Gn from the difference calculator **620**. The second frame memory **720** provides the grayscale modifier **630** with the previously stored data difference (G'n-1)−(Gn-1) of the previous frame. The second frame memory **720** includes, for example, a SDRAM, which outputs the data difference (G'n-1)−(Gn-1) in response to the input of the data difference G'n−Gn.

The data compensator **610** receives the grayscale data Gn of the current frame and the grayscale data Gn-1 of the previous frame. The data compensator **610** generates the first compensated grayscale data G'n by using the grayscale data Gn and the grayscale data Gn-1. The first compensated grayscale data G'n is transferred to the difference calculator **620** and the grayscale modifier **630**.

The difference calculator **620** receives the first compensated grayscale data G'n and the grayscale data Gn. The difference calculator **620** generates the data difference G'n−Gn between the first compensated grayscale data G'n and the grayscale data Gn. The data difference G'n−Gn is transferred to the second frame memory **720**. The second frame memory **720** stores the data difference G'n−Gn and provides the grayscale modifier **630** with the data difference (G'n-1)−(Gn-1).

The grayscale modifier **630** receives the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1). The grayscale modifier **630** generates the second compensated grayscale data G"n by using the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1). The second compensated grayscale data G"n is transferred to the data driver **300**.

FIGS. **7**A to **7**C are block diagrams showing an operation of a timing controller of FIG. **6**. Referring to FIG. **7**A, the grayscale data Gn-2 of a (n-2)-th frame is applied to a first frame memory **710** and a data compensator **610** from an external device. The data compensator **610** generates and provides the first compensated grayscale data G'n-2 of the (n-2)-th frame to the grayscale modifier **630** and a difference calculator **620**. The first compensated grayscale data G'n-2 is the same as the grayscale data Gn-2.

The difference calculator **620** receives the grayscale data Gn-2 of the (n-2)-th frame from the external device and the first compensated grayscale data G'n-2 of the (n-2)-th frame from the data compensator **610**. The difference calculator **620** calculates the data difference (G'n-2)−(Gn-2), which is provided to a second frame memory **720**. The second frame memory **720** stores the data difference (G'n-2)−(Gn-2).

The grayscale modifier **630** receives the first compensated grayscale data G'n-2 and generates second compensated grayscale data G"n-2. The second compensated grayscale data G"n-2 is the same as the grayscale data Gn-2. The grayscale data Gn-2 is not compensated at the (n-2)-th frame.

Referring to FIG. **7**B, the grayscale data Gn-1 of a (n-1)-th frame is applied to the first frame memory **710** and the data compensator **610** from the external device. The first frame memory **710** provides the data compensator **610** with the stored grayscale data Gn-2 of the (n-2)-th frame. The data compensator **610** generates the first compensated grayscale data G'n-1 of the (n-1)-th frame by using the grayscale data Gn-1 and the grayscale data Gn-2. The data compensator **610** provides the grayscale modifier **630** and the difference calculator **620** with the first compensated grayscale data G'n-1.

The difference calculator **620** receives the grayscale data Gn-1 of the (n-1)-th frame from the external device and the first compensated grayscale data G'n-1 of the (n-1)-th frame from the data compensator **610**. The difference calculator **620** calculates the data difference (G'n-1)−(Gn-1), which is provided to a second frame memory **720**. The second frame memory **720** stores the data difference (G'n-1)−(Gn-1).

The grayscale modifier **630** receives the first compensated grayscale data G'n-1 and generates second compensated grayscale data G"n-1. The compensated grayscale data G"n-1 is the same as the first compensated grayscale data Gn'-1.

Referring to FIG. **7**C, the grayscale data Gn of an n-th frame is applied to the first frame memory **710** and the data compensator **610** from the external device. The first frame memory **710** provides the data compensator **610** with the stored grayscale data Gn-1 of the (n-1)-th frame. The data compensator **610** generates the first compensated grayscale data G'n of the n-th frame by using the grayscale data Gn and the grayscale data Gn-1. The data compensator **610** provides the grayscale modifier **630** and the difference calculator **620** with the first compensated grayscale data G'n.

The difference calculator **620** receives the grayscale data Gn of n-th frame from the external device and the first compensated grayscale data G'n of n-th frame from the data compensator **610**. The difference calculator **620** calculates the data difference G'n−Gn. The difference calculator **620** provides the second frame memory **720** with the data difference G'n−Gn. The second frame memory **720** stores the data difference G'n−Gn, and provides the grayscale modifier **630** with the stored data difference (G'n-1)−(Gn-1).

The grayscale modifier **630** receives the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1). The grayscale modifier **630** generates the second compensated grayscale data G"n by using the first compensated grayscale data G'n and the data difference (G'n-1)−(Gn-1). The second compensated grayscale data G"n is provided to the data driver **300**.

Since the data voltage compensated according to the second compensated grayscale data G"n is applied to the pixel electrode of the LC panel **100**, a response time of LC molecules is enhanced. Further, since the LCD apparatus employs the separate frame memory for storing complete data difference, for example, the second frame memory **720**, the LCD apparatus may use a larger amount of the data difference G'n−Gn in compensating the grayscale data, thereby more minutely compensating the grayscale data.

FIG. **8**A is a graph showing the data voltages of an LCD apparatus before and after performing DCC, according to an exemplary embodiment of the present invention. FIG. **8**B is a graph showing the luminance of an LCD apparatus before and after performing DCC, according to an exemplary embodiment of the present invention. The "x" marked lines in FIGS. **8**A and **8**B illustrate the data voltage and luminance of the LCD apparatus performing no DCC, and the "•" marked lines in FIGS. **8**A and **8**B illustrate the data voltage and luminance of the LCD apparatus performing DCC according to the present invention.

When the grayscale data of pixel frames is changed from a low level to a high level in the LCD apparatus performing no DCC, as shown in the "x" marked lines, the data voltage arrives at the desired level after two or three frames have passed and the luminance gradually increases. Thus, a response time is slow and residual image appears in the LCD apparatus.

However, when the level of the grayscale data is changed in the LCD performing DCC according to the present invention, as shown in the "•" marked lines, the luminance does not drop because two overshoot voltages Ov**1** and Ov**2** are continuously applied to at least two frames. Particularly, the first overshoot data voltage Ov**1**, which is the difference between the grayscale data of the first and second frames, is applied to a pixel electrode during a second frame. Then the second overshoot data voltage Ov**2**, which is the difference between the first overshoot data voltage Ov**1** and the grayscale data of the second frame, is applied to a pixel electrode during a third frame. Thus, the first overshoot data voltage Ov**1** rearranges LC molecules rapidly and the second overshoot data voltage Ov**2** prevents the LC molecules from returning to an original arrangement. As a result, a luminance arrives at a desired level at the first frame.

FIG. **9** is an experimental graph showing the luminance of an LCD apparatus at a middle level of 64-level grayscale according to the present invention. In FIG. **9**, a dotted line illustrates the luminance of an LCD apparatus in which only one overshoot data voltage is applied to pixel electrodes in response to the change of the grayscale data, and a solid line illustrates the luminance of an LCD apparatus in which two overshoot data voltage are applied to the pixel electrodes in response to the change of the grayscale data.

When a level of grayscale data is changed from 10th level to 60th level, the luminance of the LCD apparatus of the dotted line drops after rapidly increasing. However, the luminance of the LCD apparatus of the solid line does not drop after rapidly increasing due to the consecutive applying of two overshoot data voltages. Thus, the image blinking is not appeared in the LCD apparatus.

FIG. **10** is an experimental graph showing the luminance of an LCD at a middle level of 128-level grayscale according to the present invention. In FIG. **10**, a dotted line illustrates the luminance of an LCD apparatus in which only one overshoot data voltage is applied to pixel electrodes in response to the change of the grayscale data, and a solid line illustrates the luminance of an LCD apparatus in which two overshoot data voltage are applied to the pixel electrodes during the change of the grayscale data.

When a level of grayscale data is changed from 10th level to 120th level, the luminance of the LCD apparatus of the dotted line drops after rapidly increasing, as shown in a dotted line. However, the luminance of the LCD apparatus of the solid line does not drop due to the consecutive applying of two overshoot data voltages. Thus, the image blinking does not appear in the LCD apparatus, resulting in improving the display quality.

FIG. **11** is a block diagram of an LCD apparatus according another exemplary embodiment of the present invention. The same reference numerals are used to refer the same or like parts those described in FIG. **11** and any further explanation is omitted.

Referring to FIG. **11**, an LCD apparatus includes an LC panel **100**, a scan driver section **200**, a data driver section **300**, a timing controller **800**, and a frame memory **900**. The scan driver section **200**, the data driver section **300** and the timing controller **800** modify and apply the grayscale data received from an external device, for example, a graphic controller, to the LC panel **100**. The timing controller **800** may be embodied in a single unit or the timing controller **800** may be integrally formed with an external graphic card (not shown) or a data driver section **300**.

The timing controller **800** includes a data compensator **810**, a difference calculator **820** and a grayscale modifier **830**. When the timing controller **800** receives the grayscale data Gn of a current frame, the timing controller **800** generates first compensated grayscale data G'n by using the grayscale data Gn-1 of a previous frame and the grayscale data Gn of the current frame. The timing controller **800** generates the data difference G"n−Gn between the grayscale data Gn of the current frame and the second compensated grayscale data G"n of the current frame. The timing controller **800** generates the second compensated grayscale data G"n by using the first compensated grayscale data G'n and data difference (G"n-1)−(Gn-1). The timing controller **800** provides the data driver **300** with the second compensated grayscale data G"n. The compensated grayscale data G"n optimizes a response time of LC molecules.

For example, when the grayscale data Gn-1 of the previous frame is the substantially same as the grayscale data Gn of the current frame, the grayscale data Gn of the current frame is not compensated. When the grayscale data Gn-1 of the previous frame has a lower level (for example, a black color) than the level (for example, a white color) of the grayscale data Gn of the current frame, the timing controller **800** outputs the second compensated grayscale data G"n that is higher than the grayscale data Gn of the current frame.

That is, the timing controller **800** outputs the second compensated grayscale data G"n as overshoot waveform.

The frame memory **900** stores the grayscale data Gn of the current frame and the data difference G"n−Gn between the grayscale data Gn of the current frame and the second compensated grayscale data G"n of the current frame. The grayscale data Gn is x-bit data provided from an external device. The data difference G"n−Gn is y-bit data generated from the difference calculator **820**. The frame memory **900** provides the data compensator **810** with the previously stored grayscale data Gn-1 of the previous frame in response to a control signal of a controller (not shown). The frame memory **900** includes, for example, a SDRAM, which outputs the grayscale data Gn-1 of the previous frame in response to the input of the grayscale data Gn of the current frame.

The data compensator **810** generates the first compensated grayscale data G'n by using the grayscale data Gn-1 of the previous frame that is stored in the frame memory **900** and the grayscale data Gn of the current frame received from the external device. The data compensator **810** provides the grayscale modifier **830** with the first compensated grayscale data G'n. The data compensator **810** includes, for example, a look-up table for storing the compensated grayscale data corresponding to the difference of grayscale data between frames.

The difference calculator **820** generates the data difference G"n−Gn between the second compensated grayscale data G"n of the current frame and the grayscale data Gn of the current frame. The difference calculator **820** provides the frame memory **900** with the data difference G"n−Gn, which is stored in the frame memory **900**.

The grayscale modifier **830** generates the second compensated grayscale data G"n by using the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1). The grayscale modifier **640** provides the data driver **300** and the difference calculator **820** with the second compensated grayscale data G"n.

The timing controller **800** minimizes the number of frame memories as well as optimizes the response time of LC molecules. Assume that each grayscale data of red color, green color and blue color is 8-bit data (that is, the total bits of grayscale is 24 bits) and the frame memory **900** has a 32-bit data bus. In this case, the frame memory **900** has 8-bit as a surplus, and stores the data difference G'n−Gn as an 8-bit so as to enhance a process time.

For example, when each grayscale of red color, green color and blue color is x-bit data, the data difference G"n−Gn of each color is y-bit data (wherein y is an integer smaller than x). If the data difference G"n−Gn of the RGB is 8-bit data, the combination of the data difference G"n−Gn of the RGB includes, for example, 8-bit of (3, 3, 2), (3, 2, 3) or (2, 3, 3). The data difference G"n−Gn of the current frame corresponds to a most significant bit (MSB). Therefore, the timing controller **800** generates the second compensated grayscale data G"n by using one frame memory **900**, which stores the grayscale data in one portion and stores the data difference in a remaining portion. Thus, the response time of the LC molecules is enhanced with a minimized number of the frame memories.

FIGS. **12**A to **12**C are block diagrams of an operation of the timing controller of FIG. **11**. Referring to FIG. **12**A, the grayscale data Gn-2 of a (n-2)-th frame is provided to a frame memory **900** and a data compensator **810** from an external device. The data compensator **810** generates and provides the first compensated grayscale data G'n-2 of the (n-2)-th frame to the grayscale modifier **830**. The grayscale modifier **640** generates second compensated grayscale data G"n-2 in response to the first compensated grayscale data G'n-2. The first and second compensated grayscale data G'n-2 and G"n-2 is the same as the grayscale data of the (n-2)-th frame. That is, the grayscale data Gn-2 is not compensated at the (n-2)-th frame.

A difference calculator **820** receives the grayscale data Gn-2 of the (n-2)-th frame from the external device and the second compensated grayscale data G"n-2 of the (n-2)-th frame from the grayscale modifier **830**. The difference calculator **820** calculates the data difference (G"n-2)−(Gn-2). The difference calculator **820** provides the frame memory **900** with the data difference (G"n-2)−(Gn-2), which is stored in the frame memory **900**.

Referring to FIG. **12**B, the grayscale data Gn-1 of a (n-1)-th frame is provided to the frame memory **900** and the data compensator **810**. The frame memory **610** provides the data compensator **810** with the stored grayscale data Gn-2 of the (n-2)-th frame. The data compensator **810** generates the first compensated grayscale data G'n-1 of the (n-1)-th frame by using the grayscale data Gn-1 and the grayscale data Gn-2. The data compensator **810** provides the grayscale modifier **830** with the first compensated grayscale data G'n-1. The grayscale modifier **830** generates the second compensated grayscale data G"n-1 in response to the first compensated grayscale data G'n-1. The second compensated grayscale data G"n-1 is the same as the first compensated grayscale data G'n-1.

The difference calculator **820** receives the grayscale data Gn-1 of the (n-1)-th frame and the second compensated grayscale data G"n-1 of the (n-1)-th frame. The difference calculator **820** calculates the data difference (G"n-1)−(Gn-1). The difference calculator **820** provides the frame memory **900** with the data difference (G"n-1)−(Gn-1), which is stored in the frame memory **900**.

Referring to FIG. **12**C, the grayscale data Gn of an n-th frame is applied to the frame memory **900** and the data compensator **810**. The frame memory **500** provides the data compensator **810** with the stored grayscale data Gn-1 of the (n-1)-th frame. The data compensator **810** generates the first compensated grayscale data G'n of the n-th frame by using the grayscale data Gn and the grayscale data Gn-1. The data compensator **810** provides the grayscale modifier **830** with the first compensated grayscale data G'n.

The difference calculator **630** receives the grayscale data Gn of the n-th frame and the second compensated grayscale data G"n of the n-th frame. The difference calculator **820** calculates the data difference G"n−Gn. The difference calculator **820** provides the frame memory **610** with the data difference G"n−Gn. The frame memory **900** stores the data difference G"n−Gn and provides the grayscale modifier **830** with the stored data difference (G'n-1)−(Gn-1).

The grayscale modifier **830** receives the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1). The grayscale modifier **830** generates the compensated grayscale data G"n by using the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1). The second compensated grayscale data G"n is provided to the data driver **300** of FIG. **11** and the difference calculator **820**. When the data voltage corresponding to the second compensated grayscale data G"n is applied to the pixel electrode of the LC panel **100**, a response time of LC molecules is enhanced.

FIG. **13** is a block diagram of an LCD apparatus according to a further exemplary embodiment of the present

invention. The same reference numerals are used to refer the same or like parts those described in FIG. **11** and any further explanation is be omitted.

Referring to FIG. **13**, an LCD apparatus includes an LC panel **100**, a scan driver **200**, a data driver **300**, a timing controller **1000**, and a first frame memory **1100**, and a second frame memory **1200**. The timing controller **1000** receives first timing signals 'Vsync', 'Hsync', 'DE' and 'MCLK' and provides the scan driver **200** and the data driver **300** with second timing signals 'Gate CLK' and 'STV' and third timing control signals 'LOAD' and 'STH', respectively. The scan and data drivers **200** and **300** drive the LC panel **100** together.

The timing controller **1000** includes a data compensator **1010**, a difference calculator **1020** and a grayscale modifier **1030**. When the timing controller **1000** receives the grayscale data Gn of a current frame, the timing controller **1000** generates the first compensated grayscale data G'n of the current frame by using the grayscale data Gn of the current frame and the grayscale data Gn-1 of a previous frame. The timing controller **1000** further generates the data difference G"n−Gn between the second compensated grayscale data G"n of the current frame and the grayscale data Gn of the current frame. The timing controller **1000** furthermore generates the second compensated grayscale data G"n by using the data difference (G"n-1)−(Gn-1) between the second compensated grayscale data G"n-1 of the previous frame and the grayscale data Gn-1 of the previous frame, and the first compensated grayscale data G'n of the current frame. The second compensated grayscale data G"n is transferred to the data driver section **300** and used to adjust the data voltage therein.

When the grayscale data Gn-1 of the previous frame is the substantially same as the grayscale data Gn of the current frame, the grayscale data Gn is not compensated. However, when the grayscale data Gn-1 of the previous frame has a lower level (for example, a black color) than a level (for example, a white color) of the grayscale data Gn of the current frame, the grayscale data Gn is compensated to be higher and the compensated grayscale data G"n is generated.

The first frame memory **1100** receives the grayscale data Gn of the current frame and stores the grayscale data Gn. In accordance with a controller (not shown), the first frame memory **1100** provides the data compensator **1010** with the previously grayscale data Gn-1 of the previous frame. For example, the first frame memory **1100** includes a SDRAM in which the stored grayscale data Gn-1 is outputted in response to the input of the grayscale data Gn.

The second frame memory **1200** receives the data difference G"n−Gn from the difference calculator **1020**, and stores the data difference G"n−Gn therein. The second frame memory **1200** provides the grayscale modifier **1030** with the stored data difference (G"n-1)−(Gn-1) of the previous frame. The second frame memory **1200** includes, for example, a SDRAM in which the data difference (G"n-1)−(Gn-1) of the previous frame is outputted to the grayscale modifier **1030** in response to the input of the data difference G"n−Gn of the current frame.

The data compensator **1010** receives the grayscale data Gn of the current frame and the grayscale data Gn-1 of the previous frame. The data compensator **1010** generates the first compensated grayscale data G'n of the current frame using the grayscale data Gn of the current frame and the grayscale data Gn-1 of the previous frame. The first compensated grayscale data G'n is transferred to the grayscale modifier **1030**.

The difference calculator **1020** receives the second compensated grayscale data G"n and the grayscale data Gn. The difference calculator **1020** generates the data difference G"n−Gn between the second compensated grayscale data G"n and the grayscale data Gn. The data difference G"n−Gn is transferred to the second frame memory **1200**. The second frame memory **1200** stores the data difference G"n−Gn, and provides the grayscale modifier **1030** with the previous data difference (G"n-1)−(Gn-1).

The grayscale modifier **1030** receives the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1). The grayscale modifier **1030** generates the second compensated grayscale data G"n using the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1). The second compensated grayscale data G"n is transferred to the data driver **300**.

FIGS. **14**A to **14**C are block diagrams showing an operation of the timing controller of FIG. **13**. Referring to FIG. **14**A, the grayscale data Gn-2 of a (n-2)-th frame is applied to a first frame memory **1100** and a data compensator **1010** from an external device. The data compensator **1010** generates the first compensated grayscale data G'n-2 of the (n-2)-th frame and provides the grayscale modifier **1030** with the generated first compensated grayscale data G'n-2. The grayscale modifier **1030** generates the second compensated grayscale data G"n-2 in response to the first compensated grayscale data G'n-2. The first and second compensated grayscale data G'n-2 and G"n-2 is the same as the grayscale data Gn-2 at the (n-2)-th frame.

The difference calculator **1020** receives the grayscale data Gn-2 of the (n-2)-th frame from the external device and the second compensated grayscale data G"n-2 of the (n-2)-th frame from the grayscale modifier **1030**. The difference calculator **1020** calculates the data difference (G"n-2)−(Gn-2) between the received grayscale data. The difference calculator **1020** provides a second frame memory **1200** with the data difference (G"n-2)−(Gn-2), which is stored in the second frame memory **1200**.

Referring to FIG. **14**B, the grayscale data Gn-1 of a (n-1)-th frame is applied to the first frame memory **1100** and the data compensator **1010** from the external device. The data compensator **1010** generates the first compensated grayscale data G'n-1 of the (n-1)-th frame by using the grayscale data Gn-1 received from the external device and the grayscale data Gn-2 of the (n-2)-th frame received from the first frame memory **1100**. The generated first compensated grayscale data G'n-1 is provided to the grayscale modifier **1030**. In response to the first compensated grayscale data G'n-1, the grayscale modifier **1030** generates the second compensated grayscale data G"n-1, which is the same to the first compensated grayscale data G'n-1.

The difference calculator **1020** receives the grayscale data Gn-1 of the (n-1)-th frame from the external device and the second compensated grayscale data G"n-1 of the (n-1)-th frame from the grayscale modifier **1030**, and calculates the data difference (G"n-1)−(Gn-1) between the received grayscale data. The difference calculator **1020** provides the second frame memory **1200** with the data difference (G"n-1)−(Gn-1), which is stored in the second frame memory **1200**.

Referring to FIG. **14**C, the grayscale data Gn of an n-th frame is applied to the first frame memory **1100** and the data compensator **1010** from the external device. The first frame memory **1100** provides the data compensator **1010** with the stored grayscale data Gn-1 of the (n-1)-th frame, in response to the input of the grayscale data Gn. The data compensator **1010** generates the first compensated grayscale data G'n of

the n-th frame using the grayscale data Gn and the grayscale data Gn-1. The data compensator **1010** provides the grayscale modifier **1030** with the first compensated grayscale data G'n.

The difference calculator **1020** receives the grayscale data Gn of the n-th frame from the external device and the second compensated grayscale data G"n of the n-th frame from the grayscale modifier **1030**. The difference calculator **1020** calculates the data difference G"n−Gn and provides the calculated data difference G"n−Gn to the second frame memory **1200**. In response to the input of the data difference G"n−Gn, the second frame memory **1200** stores the data difference G"n−Gn and provides the grayscale modifier **1030** with the stored data difference (G"n-1)−(Gn-1).

The grayscale modifier **1030** receives the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1) and generates the second compensated grayscale data G"n, using the first compensated grayscale data G'n and the data difference (G"n-1)−(Gn-1). The compensated grayscale data G"n is provided to the data driver **300** of FIG. **13** and the difference calculator **1020**. The second compensated grayscale data G"n is used to produce compensated data voltage, which is applied to a pixel electrode. Thus, a response time of liquid crystal molecules is enhanced.

FIG. **15** is a graph showing the data voltage of an LCD apparatus before and after performing DCC according to another exemplary embodiment of the present invention. In FIG. **15**, an "x" marked line indicates the data voltage of an LCD apparatus performing no DCC and a "•" marked line indicates the data voltage of an LCD apparatus performing DCC according to another exemplary embodiment of the present invention.

When a low level of grayscale data at a first frame is changed to a high level of grayscale data at a second frame, a first overshoot data voltage Ov**1**, which is the difference between the grayscale data of the first and second frames, is applied to a pixel electrode during the second frame. A second overshoot data voltage Ov**2**, which is the difference between the first overshoot data voltage Ov**1** and the grayscale data of the second frame, is applied to the pixel electrode during a third frame. A third overshoot data voltage (Ov**3**), which is a difference of the second over shoot data voltage Ov**2** and the grayscale data of the third frame, is applied to the pixel electrode during a fourth frame. The magnitude of the overshoot data voltages is decreased as the frames are passed.

Since three overshoot data voltages are consecutively applied to the pixel. electrodes of the LC panel **100**, a luminance does not drop, resulting in improving of a display quality. Particularly, the first overshoot data voltage Ov**1** rearranges LC molecules rapidly, and the second and third overshoot data voltages Ov**2** and Ov**3** prevent the LC molecules from returning to an original arrangement. Thus, a luminance reaches to a target level even at the first frame. Further, since the complete data difference is stored and used to generate the overshoot data voltages, the display quality is further enhanced.

While the invention has been described with reference to an exemplary embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A liquid crystal display apparatus, comprising:

a timing controller to generate a plurality of compensated grayscale data;

a memory to store at least grayscale data;

a column driver to apply the compensated grayscale data to a plurality of data lines;

a gate driver to apply a gate signal to a plurality of gate lines; and

a liquid crystal panel including the gate lines, the data lines and a plurality of switching elements disposed between the data lines and the gate lines;

wherein the timing controller comprises:

a data compensator to generate current frame first compensated grayscale data in response to receiving previous frame grayscale data from the memory and current frame grayscale data from an external source;

a difference calculator to calculate a data difference between the current frame first compensated grayscale data and the current frame grayscale data, the difference calculator receiving the current frame first compensated grayscale data from the data compensator; and

a grayscale modifier to generate current frame second compensated grayscale data in response to receiving the current frame first compensated grayscale data from the data compensator and the data difference of the previous frame compensated grayscale data and the previous frame grayscale data from the frame memory.

2. The liquid crystal display apparatus according to claim **1**, wherein the memory includes at least one frame memory for receiving and storing both the current frame grayscale data and the data difference between the current frame first compensated grayscale data and the current frame grayscale data.

3. The liquid crystal display apparatus according to claim **2**, wherein the frame memory stores the data difference between the current frame first compensated grayscale data and the current frame grayscale data, the data difference having a number of bits substantially smaller than a number of bits of the current frame grayscale data.

4. The liquid crystal display apparatus according to claim **2**, wherein the at least one frame memory includes a synchronous dynamic random access memory (SDRAM) or Double Date Rate (DDR) memory.

5. The liquid crystal display apparatus according to claim **1**, wherein the memory includes a first frame memory for receiving and storing current frame the grayscale data and a second frame memory for receiving and storing the data difference between the current frame first compensated grayscale data and the current frame grayscale data.

6. The liquid crystal display apparatus according to claim **5**, wherein the first and second frame memories each include a synchronous dynamic random access memory (SDRAM) or Double Date Rate (DDR) memory.

7. The liquid crystal display apparatus according to claim **1**, wherein the data compensator includes a look-up table.

8. The liquid crystal display apparatus according to claim **1**, wherein the liquid crystal panel includes a Patterned Vertical Alignment mode liquid crystal panel.

9. The liquid crystal display apparatus according to claim **1**, wherein the current frame first compensated grayscale data includes overshoot data or undershoot data.

10. A liquid crystal display apparatus comprising:
a timing controller to generate a plurality of compensated grayscale data;
a memory to store at least grayscale data;
a column driver to apply the compensated grayscale data to a plurality of data lines;
a gate driver to apply a gate signal to a plurality of gate lines; and
a liquid crystal panel including the gate lines, the data lines and a plurality of switching elements disposed between the data lines and the gate lines;
wherein the timing controller comprises:
a data compensator to generate current frame first compensated grayscale data in response to receiving previous frame grayscale data from the memory and current frame grayscale data from an external source;
a grayscale modifier to generate current frame second compensated grayscale data in response to receiving the current frame first compensated grayscale data from the data compensator and a data difference between a previous frame second compensated grayscale data and a previous frame grayscale data, the data difference stored in the memory; and
a difference calculator to calculate a data difference between the current frame second compensated grayscale data and the current frame grayscale data, the difference calculator receiving the current frame second compensated grayscale data from the grayscale modifier.

11. The liquid crystal display apparatus according to claim 10, wherein the data compensator includes a look-up table.

12. The liquid crystal display apparatus according to claim 10, wherein the current frame first compensated grayscale data includes overshoot data or undershoot data.

13. A method for driving a liquid crystal display apparatus, comprising:
generating current frame first compensated grayscale data in response to receiving previous frame grayscale data from a memory and current frame grayscale data received from an external source;
calculating a data difference between the current frame first compensated grayscale data and the current frame grayscale data;
generating current frame second compensated grayscale data in response to the current frame first compensated grayscale data and the data difference between the previous frame compensated grayscale data and the previous frame grayscale data;
storing the current frame grayscale data and the data difference in the memory;
applying a gate signal to gate lines;
applying a data voltage corresponding to the current frame second compensated grayscale data to data lines.

14. The method according to claim 13, wherein the current frame first compensated grayscale data includes overshoot data or undershoot data.

15. The method according to claim 13, wherein storing includes storing the current frame grayscale data and the data difference in the same memory.

16. The method according to claim 15, wherein the number of bits of the data difference is less than the number of bits of the current frame grayscale data.

17. The method according to claim 13, wherein storing includes storing the current frame grayscale data in a first memory and storing the data difference in a second memory.

18. A method for driving a liquid crystal display apparatus comprising:
generating current frame first compensated grayscale data in response to receiving previous frame grayscale data from a memory and current frame grayscale data received from an external source;
generating current frame second compensated grayscale data in response to the current frame first compensated grayscale data and a data difference between a previous frame compensated grayscale data and a previous frame grayscale data;
calculating a data difference between the current frame second compensated grayscale data and the current frame grayscale data;
storing the current frame grayscale data and the data difference between the current frame second compensated grayscale data and the current frame grayscale data in the memory;
applying a gate signal to gate lines;
applying a data voltage corresponding to the current frame second compensated grayscale data to data lines.

19. The method according to claim 18, wherein the current frame first compensated grayscale data includes overshoot data or undershoot data.

20. The method according to claim 18, wherein storing includes storing the current frame grayscale data and the data difference between the current frame second compensated grayscale data and the current frame grayscale data in the same memory.

21. The method according to claim 20, wherein the number of bits of the data difference between the current frame second compensated grayscale data and the current frame grayscale data is less than the number of bits of the current frame grayscale data.

22. The method according to claim 18, wherein storing includes storing the current frame grayscale data in a first memory and storing the data difference between the current frame second compensated grayscale data and the current frame grayscale in a second memory.

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[标]申请(专利权)人(译)	李承WOO		
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摘要(译)

提供一种能够改善响应时间以及显示质量的液晶显示装置。该装置包括：时序控制器，用于产生多个补偿的灰度数据;存储器，用于存储灰度数据或补偿的灰度数据;列驱动器，用于将补偿的灰度数据应用于多个数据线;栅极驱动器，用于应用栅极信号通向多条栅极线，液晶面板包括栅极线，数据线和设置在数据线和栅极线之间的多个开关元件。