

PATENT SPECIFICATION

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(54) A LIQUID CRYSTAL DISPLAY SYSTEM

(71) We, HITACHI LIMITED of 1-5-1 Marunouchi, Chiyoda-ku, Tokyo, Japan, a body corporate organized according to the laws of Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a liquid crystal display system of the type wherein the liquid crystal exhibits the mechanical properties of a liquid and the optical properties of a solid (crystal).

By virtue of their low power consumption, liquid crystal display devices have been used extensively in electronic wrist watches, small-sized electronic desk calculators and the like battery driven apparatus.

Two of the known modes of physical operation of liquid crystal display devices are the dynamic scattering mode (DSM) and the field effect mode (FEM). Known optical operational modes for liquid crystal display devices result in reflection type devices, transmission type devices or absorption type devices.

The present invention can be applied to all the various types of liquid crystal display devices.

The following explanation will be made with reference to the DSM reflection type liquid crystal display.

A DSM reflection type liquid crystal display device exploits the phenomena of dynamic scattering wherein when a liquid crystal is placed between two electrodes and a voltage is applied across the electrodes the molecules of the liquid crystal which were previously oriented in one given direction are then irregularly oriented, and hence incident light is scattered and the liquid crystal is changed from its transparent state to a semi-transparent (whitish) state. The construction and behaviour of such liquid crystal display devices are described in, for example, the following papers, "Electronics", July 6, 1970, pp. 64-70; and "Transistor Gijutsu" (a Japanese publication), August 1971, pp. 104-109.

When designing, a driver circuit for a

liquid crystal display device, the problem detailed herebelow must be considered.

In a liquid crystal display device including, for example, several segment electrodes for all of which is provided one common electrode (termed the digit electrode), the segments being arranged in a shape capable of representing predetermined numerals, liquid crystal material adjacent to a non-selected segment electrode exhibits scattering on account of a voltage arising between the non-selected electrode and one or more selected electrodes by the applied voltage to the selected segment electrodes. Due to such scattering, the numeral being indicated is blurred.

It is an object of the present invention to provide a liquid crystal display system which produces a clear display.

According to the present invention, there is provided a liquid crystal display system including: a driver circuit; and a liquid crystal display device, the display device having a first common electrode, a plurality of second electrodes and between said first and second electrodes liquid crystal regions of a type whereof the optical properties change on the application of a voltage in excess of a predetermined threshold voltage; said driver circuit having means for applying between said first and a selected one or more of said plurality of second electrodes a potential difference in excess of said threshold voltage, and means for applying to the non-selected electrodes of said plurality of electrodes a potential such that the potential difference between said common electrode and said non-selected electrodes is below said threshold voltage, the potential difference between selected and non-selected electrodes being less than said threshold voltage.

The present invention will now be described in greater detail, by way of example, with reference to the accompanying drawings, wherein:—

Figure 1 is a graph showing the response characteristic of a liquid crystal;

Figure 2a is a circuit diagram of a first embodiment of a driver circuit incorporated in a liquid crystal display system;

Figure 2b shows the three voltage levels used in the driver circuit;

Figure 3a shows a second embodiment of a driver circuit incorporated in a liquid crystal display system;

Figure 3b is a waveform timing chart for the circuit of Figure 3a; and

Figure 4a shows a third embodiment in the form of a dynamic driver circuit for a plurality of liquid crystal display devices; and

Figure 4b is a waveform timing chart for the circuit of Figure 4a.

Liquid crystal display devices utilized in the following embodiments exhibit a visual threshold voltage V_{th} so the aforementioned problem may be overcome by exploiting the threshold voltage characteristic.

The characteristic of the liquid crystal utilized in the following embodiments is illustrated in Figure 1 from which it can be seen that the visual state of the display changes rapidly at a boundary corresponding to a certain predetermined applied voltage, in other words, the liquid crystal has a visual threshold voltage. Liquid crystal display devices of this type are described in, for example, "Applied Physics Letters", Vol. 19, No. 10, pp. 391-393; and the Japanese publication "Transistor Gijutsu" previously mentioned.

In all the embodiments described below three predetermined voltage levels are utilized, a high voltage level V_H , a low voltage level V_L and a medium voltage level V_M . A potential difference $|V_H - V_L|$ is applied between a selected segment electrode and the common or digit electrode, the medium voltage level V_M having a value lying between the voltage level V_H and the voltage level V_L ($V_H > V_M > V_L$) being applied to the non-selected segment electrodes.

The voltage difference $|V_H - V_L|$ is set to be in excess of the threshold voltage V_{th} , while the voltage differences $|V_H - V_M|$ and $|V_M - V_L|$ are set to be smaller than the threshold voltage V_{th} .

The driving system for the liquid crystal display device applies either the voltage difference $|V_M - V_L|$ or the voltage difference $|V_H - V_M|$ between a selected segment electrode and the other segment electrodes, whereas the greater voltage difference, i.e. $|V_H - V_L|$ is not applied between any pair of segment electrodes. Therefore, it is possible to prevent any change in the visual state of a liquid crystal due to a voltage arising between the segment electrodes and the cross-talk which arises in prior-art driver circuits for this type liquid crystal display device is prevented.

Referring to Figure 2a the circuit is designed to drive a liquid crystal display device LCD. The liquid crystal of the display device LCD is shown by oblique line shading, the crystal being connected in the display device

to an upper electrode which is common to all segments and to a plurality (m) of lower segment electrodes corresponding to the segments which are arranged to represent predetermined letters, numerals or the like symbols.

The circuit includes a p-channel insulated gate field-effect transistor M1 and an n-channel insulated gate field-effect transistor M2, hereinafter referred to as "transistors". The transistors M1 and M2 constitute a complementary circuit. The source electrodes of the transistors M1 and M2 are connected to voltage sources V_M and V_L , whilst the respective gate electrodes of the transistors M1 and M2 are driven by a segment selecting signal S1.

A high potential of level V_H is applied to the common electrode of the liquid crystal display device LCD. The output from the complementary circuit driven by the segment signal S1 is applied to one of the segment electrodes.

The relative levels of the voltages V_H , V_M and V_L are shown in Figure 2b, these voltages being set so as to satisfy the following inequalities:

$$|V_H - V_L| \geq V_{th}, \quad |V_H - V_M| < V_{th}$$

The operation of the circuit described above will now be explained.

When the segment selecting signal S1 goes to a logical "1" level (a positive potential) thus selecting the leftmost segment electrode (as shown in Figure 2a), the transistor M2 is rendered conductive to apply the low level potential V_L to the leftmost segment electrode. Thus, the corresponding liquid crystal segment is controlled to exhibit scattering.

On the other hand, considering the leftmost segment, when the segment electrode is not selected, the segment selecting signal takes a logical "0" level (earth potential), and the transistor M1 is rendered conductive. Hence, to the segment electrode is applied the medium potential V_M , and the corresponding liquid crystal segment does not exhibit scattering.

In a similar manner, the other segment electrodes are also driven with the low potential V_L when selected, and with the medium potential V_M when not selected. Consequently, a potential difference which is equal to $|V_M - V_L|$ is applied between a selected segment electrode and a non-selected segment electrode, and the driving circuit avoids the application of a potential difference equal to $|V_H - V_L|$ such as is applied between a selected segment electrode and the common electrode, between any two segment electrodes.

Referring now to Figure 3a, the essential difference between the circuit of this embodiment and the circuit shown in Figure 2a is that, in order to ensure a long lifetime for

the liquid crystal, it is driven bidirectionally, i.e., by A.C. This method is adopted in this embodiment because if a D.C. component is impressed on a liquid crystal, the liquid crystal is polarized and its lifetime is shortened.

A bidirectional drive pulse train BD is input to the circuit of Figure 3a to provide the bidirectional drive. This pulse train is directly applied to the gate electrodes of transistors M3 and M4. The pulse train BD is also applied via an inverter circuit IN1 and an AND gate AG or an OR gate OG to the gate electrodes of transistors M5 and M6 respectively. The segment signal S1 is applied to another input terminal of the AND circuit AG, while the inverse of the segment signal S1 is applied to the other input terminals of the OR circuit OG.

The output voltage from an upper complementary circuit constituted by the transistors M3 and M4 is applied to the common electrode of the liquid crystal display. The output voltage of the lower complementary circuit constituted by the transistors M5 and M6 is applied to one of the segment electrodes of the liquid crystal display.

Operation of the circuit described above will now be explained.

When the leftmost segment electrode is to be selected, the segment signal S1 goes to a logical "1" level to enable the AND gate AG and the OR gate OG, and to the gate electrodes of the transistors M5 and M6 is applied the inverse of the bidirectional drive pulse train BD. On the other hand, to both the gate electrode of the transistor M3 and that of M4 is applied to the bidirectional drive pulse train BD. Consequently, A.C. pulses having a potential difference of $|V_H - V_L|$ are applied between this segment electrode and the common electrode, in synchronism with the bidirectional drive pulse train BD. That is, as shown in the waveform timing chart of Figure 3b, for a predetermined period of time, the voltage V_c applied to the common electrode is at the level V_H , and the voltage V_{s1} applied to the leftmost segment electrode is at the level V_L (earth potential). In the next time period, the relative voltage levels are reversed (i.e., their polarities are inverted), and V_c goes to the voltage level V_L and V_{s1} to the voltage level V_H . Under these conditions that segment of the liquid crystal lying between the common and selected electrodes exhibits scattering

(because $|V_H - V_L| \geq V_{th}$).

If the leftmost segment electrode is not selected, the associated segment selecting signal S1 goes to a logical "0" level to disable the AND gate AG and the OR gate OG. The gate electrode voltage levels of the transistors M5 and M6 go to logical "0" and "1" levels respectively irrespective

of the instantaneous voltage level of the bidirectional drive pulse train BD, and both the transistors M5 and M6 are rendered conductive. At this time, the complementary circuit constituted by the transistors M5 and M6 operates as a voltage divider, and the divided voltage V_M is applied to the segment electrode (see V_{s1} in Figure 3b). If the divided voltage level V_M is chosen to satisfy the conditions

$$|V_H - V_M| < V_{th} \text{ and } |V_M - V_L| < V_{th},$$

then that segment of the liquid crystal display which corresponds to the non-selected segment electrode does not exhibit scattering. In this case, the common electrode is still driven to the voltage levels V_H and V_L in synchronism with the bidirectional drive pulse train BD. Therefore, in order to avoid applying a D.C. component to the liquid crystal, it is preferable to set the medium potential level V_M at a value which satisfies the condition:

$$V_H - V_M = V_M - V_L : V_M = \frac{V_H + V_L}{2}$$

Operation of the circuit as described above is summarized in Table 1 below:

TABLE 1

S1	BD	V_{s1}	V_c
"1"	"1"	V_H	V_L
"1"	"0"	V_L	V_H
"0"	"1"	V_M	V_L
"0"	"0"	V_M	V_H

Referring now to Figure 4a showing a third embodiment of a dynamic driving circuit for liquid crystal display devices, this circuit has the advantage of lower power consumption over the circuit of the second embodiment shown in Figure 3a. The system is claimed and described in more detail in our co-pending Application No. 54,197/73 (Serial No. 1447640).

To provide the medium potential level V_M , instead of a voltage divider comprised by switching elements, as employed in the circuit of Figure 3a, a separate power source is used. In order to prevent a current path being established at switching between the power source V_M and either of the power sources V_H or V_L , transistors M26 and M29 and transistors M16 and M19 are rendered non-conductive at switching by a blanking signal BL (see Figure 4b). The pulse width of the

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blanking signal BL must be longer than the switching time of the complementary circuits. If, however, this pulse width is made longer than is necessary, the potentials of the electrodes of the liquid crystal are held in a float-

ing state for a comparatively long time, and hence, the problem of crosstalk arises.

The relationship between the electrode potential levels Vc1 and Vs1 and the binary signals DT1, S1, BD and BL are shown in Figure 4b and table 2 below.

TABLE 2

DT1	BD	BL	Vc1
"0"	"0"	"0"	VM
"0"	"0"	"1"	VM
"0"	"1"	"0"	VM
"0"	"1"	"1"	VM
"1"	"0"	"0"	VH
"1"	"0"	"1"	FL
"1"	"1"	"0"	VL
"1"	"1"	"1"	FL

S1	BD	BL	Vs1
"0"	"0"	"0"	VM
"0"	"0"	"1"	VM
"0"	"1"	"0"	VM
"0"	"1"	"1"	VM
"1"	"0"	"0"	VL
"1"	"0"	"1"	FL
"1"	"1"	"0"	VH
"1"	"1"	"1"	FL

where FL denotes the floating state (floating potential).

In accordance with the above described embodiment, only the small potential differences $|VH-VM|$ and $|VM-VL|$ are applied between any two segment electrodes, so that no change may occur in the optical state of the liquid crystal due to a large potential difference arising between segment electrodes, thus the lifetime of the liquid crystal is increased.

Although the principle of the present invention has been expounded with reference to the preferred embodiments, various modifications of these embodiments are possible within the scope of the invention. To provide the medium voltage level VM, a pulse whose potential varies with time may be utilized and the previously-mentioned conditions can still be met. To constitute the driver circuit, single channel type transistors, bipolar transistors, passive elements, etc., can alternatively be employed.

WHAT WE CLAIM IS:—

1. A liquid crystal display system including: a driver circuit; and a liquid crystal display device, the display device having a first common electrode, a plurality of second electrodes and between said first and second electrodes liquid crystal regions of a type whereof the optical properties change on the application of a voltage in excess of a predetermined threshold voltage; said driver circuit having means for applying between said first and a selected one or more of said

plurality of second electrodes a potential difference in excess of said threshold voltage, and means for applying to the non-selected electrodes of said plurality of electrodes a potential such that the potential difference between said common electrode and said non-selected electrodes is below said threshold voltage, the potential difference between selected and non-selected electrodes being less than said threshold voltage.

2. A display system according to claim 1, wherein said means for applying between said first and a selected one or more of said second electrodes a potential difference in excess of said threshold voltage includes, a high voltage source connected to said common electrode and associated with each second electrode a low voltage source connected via a respective controllable switching means to a respective second electrode, those controllable switching means associated with selected second electrodes being controlled to conduct.

3. A display system according to claim 2, additionally including, associated with each second electrode a medium level voltage source connected via a second controllable switching means to the respective second electrodes, those second controllable switching means associated with non-selected electrodes being controlled to conduct.

4. A display system according to claim 1, additionally including, associated with each second electrode a high level voltage source connected via a second controllable switching

blanking signal BL must be longer than the switching time of the complementary circuits. If, however, this pulse width is made longer than is necessary, the potentials of the electrodes of the liquid crystal are held in a float-

ing state for a comparatively long time, and hence, the problem of crosstalk arises.

The relationship between the electrode potential levels Vc1 and Vs1 and the binary signals DT1, S1, BD and BL are shown in Figure 4b and table 2 below.

TABLE 2

DT1	BD	BL	Vc1
"0"	"0"	"0"	VM
"0"	"0"	"1"	VM
"0"	"1"	"0"	VM
"0"	"1"	"1"	VM
"1"	"0"	"0"	VH
"1"	"0"	"1"	FL
"1"	"1"	"0"	VL
"1"	"1"	"1"	FL

S1	BD	BL	Vs1
"0"	"0"	"0"	VM
"0"	"0"	"1"	VM
"0"	"1"	"0"	VM
"0"	"1"	"1"	VM
"1"	"0"	"0"	VL
"1"	"0"	"1"	FL
"1"	"1"	"0"	VH
"1"	"1"	"1"	FL

where FL denotes the floating state (floating potential).

In accordance with the above described embodiment, only the small potential differences |VH-VM| and |VM-VL| are applied between any two segment electrodes, so that no change may occur in the optical state of the liquid crystal due to a large potential difference arising between segment electrodes, thus the lifetime of the liquid crystal is increased.

Although the principle of the present invention has been expounded with reference to the preferred embodiments, various modifications of these embodiments are possible within the scope of the invention. To provide the medium voltage level VM, a pulse whose potential varies with time may be utilized and the previously-mentioned conditions can still be met. To constitute the driver circuit, single channel type transistors, bipolar transistors, passive elements, etc., can alternatively be employed.

WHAT WE CLAIM IS:—

1. A liquid crystal display system including: a driver circuit; and a liquid crystal display device, the display device having a first common electrode, a plurality of second electrodes and between said first and second electrodes liquid crystal regions of a type whereof the optical properties change on the application of a voltage in excess of a predetermined threshold voltage; said driver circuit having means for applying between said first and a selected one or more of said

plurality of second electrodes a potential difference in excess of said threshold voltage, and means for applying to the non-selected electrodes of said plurality of electrodes a potential such that the potential difference between said common electrode and said non-selected electrodes is below said threshold voltage, the potential difference between selected and non-selected electrodes being less than said threshold voltage.

2. A display system according to claim 1, wherein said means for applying between said first and a selected one or more of said second electrodes a potential difference in excess of said threshold voltage includes, a high voltage source connected to said common electrode and associated with each second electrode a low voltage source connected via a respective controllable switching means to a respective second electrode, those controllable switching means associated with selected second electrodes being controlled to conduct.

3. A display system according to claim 2, additionally including, associated with each second electrode a medium level voltage source connected via a second controllable switching means to the respective second electrodes, those second controllable switching means associated with non-selected electrodes being controlled to conduct.

4. A display system according to claim 1, additionally including, associated with each second electrode a high level voltage source connected via a second controllable switching





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5 means to the respective second electrodes, such that when both a first and the second controllable switching means associated with a second electrode are controlled to conduct a medium level voltage is applied to said second electrode.

5. A liquid crystal display system constructed and arranged substantially as herein described, with reference to and as illustrated

in Figure 2a or Figure 3a of the accompanying 10 drawings.

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