

"LIQUID CRYSTAL DISPLAY DEVICE"

This invention relates to liquid crystal display devices.

Conventionally it has not been possible to provide a liquid crystal display device with a multi-colour display for the following reasons. Firstly, it is not possible to increase the number of dots or lines in a conventional liquid crystal display device because the conventional liquid crystal display device has at most a 1/16 duty ratio and thus only 16 lines can be driven using a conventional multiplex driving system.

A liquid crystal display device which has a multi-colour display needs at least 100 lines, and thus a 1/100 duty ratio must be possible.

Secondly, it is extremely difficult to obtain a multi-colour display on a single substrate especially in the case where colouring materials are included in the liquid crystal material such as in a guest-host liquid crystal display device. To superimpose panels having different colour compositions increases cost and the resultant liquid crystal display device cannot produce a clear multi-colour display.

According to one aspect of the present invention there is provided a liquid crystal display device having a plurality of picture elements arranged in a matrix of columns and rows, comprising first and second transparent substrates, each substrate having an internal surface, the internal surfaces facing each other and being spaced apart to define a space

therebetween, a plurality of parallel and spaced apart data lines and a plurality of parallel and spaced apart orthogonal signal lines, insulated from each other, a drive circuit for each picture element including, at each data and signal line intersection, a first driving electrode and an associated intermediate component means for coupling the data line to the corresponding first driving electrode, the data lines, signal lines, first electrodes and intermediate component means being formed on the internal surface of the first substrate, a plurality of colour filters formed on the internal surface of the second substrate and arranged in strips or mosaics corresponding to the intersections, a second common electrode formed on the surface of the colour filters between the colour filters and the first electrodes, and a liquid crystal material retained in and filling the space between the electrodes.

Each drive circuit may include a thin film transistor or a non-linear resistive element.

Preferably, each column or row of picture elements is shifted or displaced relative to each adjacent column or row.

Advantageously, the area of the first driving electrode of each picture element is less than the area of the corresponding colour filter.

The liquid crystal display device may include selecting means for selecting three primary colour video signals sequentially in synchronism by respective clock signals having the same frequency which is one-third the frequency of a selecting signal for selecting rows or columns of picture elements, and means for applying the video signal from the selecting means to the first or second electrodes of the picture elements.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

Figure 1 is a schematic cross-section of one embodiment of a liquid crystal display device according to the present invention;

Figures 2 and 3 illustrate the construction of colour filters of a liquid crystal display device according to the present invention;

Figure 4 consists of Figure 4(a) which is a plan view of an

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active matrix element of a liquid crystal display device according to the present invention, Figure 4(b) which is an equivalent circuit diagram of the active matrix element of Figure 4(a) and Figure 4(c) which is a section taken on the line A-B of Figure 4(a);

5 Figure 5 consists of Figures 5(a) which is a plan view of another active matrix element of a liquid crystal display device according to the present invention and Figure 5(b) which is a section of the active matrix element of Figure 5(a) taken on the line A-B;

10 Figure 6 consists of Figures 6(a) which is a plan view of a further active matrix element of a liquid display device according to the present invention and Figure 6(b) which is a section of the active matrix element of Figure 6(a) taken on the line A-B;

Figure 7 : shows the voltage-current characteristics of a non-linear element;

15 Figure 8 is an equivalent circuit diagram to illustrate the driving of a liquid crystal display device according to the present invention having non-linear active matrix elements;

Figures 9(a), 9(b) and 9(c) show, in detail, the construction of a liquid crystal display device according to the present invention;

20 Figures 10, 11 and 12 are circuit diagrams of various embodiments of driving circuit for a liquid crystal display device according to the present invention;

Figure 13 is a timing chart illustrating the operation of the driving circuit of Figure 12;

25 Figure 14 is a block diagram of a circuit for generating clock

signals for the driving circuit of Figure 12;

Figure 15 is a timing chart illustrating the operation of the circuit of Figure 14;

Figure 16 is a circuit diagram of another embodiment of a driving circuit of a liquid crystal display device according to the present invention;

Figure 17, consisting of Figures 17(a) and 17(b), shows graphically the relation between contrast of display produced by liquid crystal material and applied voltage and sample-hold operation of a video signal in a liquid crystal display device according to the present invention;

Figure 18 is a block diagram of another embodiment of a driving circuit for a liquid crystal display device according to the present invention;

Figure 19 is a timing chart illustrating the operation of the driving circuit of Figure 18;

Figure 20, consisting of Figures 20(a) and 20(b) shows the fundamental construction of high resolving power picture elements of a liquid crystal display device according to the present invention;

Figure 21 shows the construction of driving electrodes of a liquid crystal display device according to the present invention driven by a multiplex driving system;

Figure 22, consists of Figures 22(a) and 22(b) and shows part of a liquid crystal display device according to the present invention employing thin film transistors;

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Figures 23 and 24 show arrangements of liquid crystal display devices according to the present invention where electrodes are staggered;

Figure 25 shows another embodiment of a liquid crystal display device according to the present invention; and

Figure 26 shows a modification of the construction shown in Figure 20(a).

Figure 1 illustrates one embodiment of a liquid crystal display device according to the present invention. A red filter 8, a green filter 9 and a blue filter 10 are formed as a mosaic or in strips on a substrate 1. A passive layer 6, for example of silicon dioxide, is formed over the filters. A transparent electrode 5, acting as a liquid crystal driving electrode, is formed on the passive layer 6. In some instances the passive layer can be omitted. A layer 3 of active matrix elements, for example, switching elements or non-linear elements, is formed on a glass substrate 2. Transparent electrodes 4 corresponding to the active matrix elements are formed on the layer 3. Liquid crystal material 7 is encapsulated between the substrates 1, 2 in contact with the electrodes 4, 5 and the periphery of the glass substrates is sealed. In operation light passes through a polariser (not shown) and the light polarised thereby passes through the glass substrate 1. Light having fixed wavelength corresponding to a predetermined colour emerges from each of the filters 8, 9, 10 and passes through the liquid crystal material 7. If a voltage is applied to one or more of the electrodes 4 the coloured light in the region

of that electrode or electrodes will pass therethrough. If no voltage is applied to one or more of the electrodes 5 light in the region of that electrode or electrodes will be blocked. Thus by selectively applying a voltage to the electrodes 4, a multi-colour display can be produced, the combination of the three primary colours red, green and blue giving the seven colours of the visible spectrum.

Various brightness levels of the colours can be achieved by using the gray scale resulting from the semi-transparent states of the liquid crystal material.

Figure 2 illustrates the construction of colour filters of a liquid crystal display device according to the present invention. A water soluble organic resin layer of, for example, polyvinyl chloride or gelatine is formed on a transparent glass substrate 20, the water soluble organic layer then being coloured with red, blue and green colouring materials by printing. The colouring materials are arranged in predetermined patterns to form red, blue and green coloured filters 22, 23, 24. A black border or frame 21 is provided by colouring the boundary of each colour filter with black pigment. This is to avoid blurring of colour at the boundary of each colour filter. However, the frame 21 is not required in the case where the resin layer is of, for example, gelatine which can be etched away. In the case of a negative type liquid crystal display device, a colour inhibitor must be included in the frame 21 in addition to the black pigment since the colouring power of the colouring materials along the lateral direction is relatively strong.

Next, a transparent passive film 25 is formed on the colour filters and a transparent conductive electrode 26 is formed on the passive film 25 and photo-etched to give the necessary pattern.

5 The transparent conductive electrode 26 may be formed directly on to the colour filter without the passive film 25. In this case, the transparent conductive electrode 26 may function also as the passive film.

The colour materials of the colour filters may deteriorate or be damaged when the transparent conductive electrode is formed. This disadvantage can be avoided (as shown in Figure 3) by forming
10 a passive layer 34 on colour filters 31 on a transparent glass substrate 30 and by forming a transparent conductive electrode 33 on a thin glass or plastics film 32 and then adhering it to the glass substrate 30.

Figure 4 shows an active matrix element 41 of a liquid crystal
15 display device constructed on a transparent substrate. This type of active matrix element has the advantage that a driving duty ratio of more than 1/100 can be attained and a gray scale display can easily be achieved. The active matrix element of Figure 4 includes a silicon thin film transistor 49 on a transparent glass substrate of, for
20 example, pyrex (Trade Mark) or quartz having a comparatively high melting point. Thin film transistors can be more easily constructed on a transparent glass substrate compared with forming conventional active matrix elements on a single crystal wafer of silicon.

Figure 4(a) shows the active matrix element 41 of a picture matrix.
25 A gate line 44 (selecting Y-line) is connected to the gate of a

transistor 49, a data line 43 (X-line) is connected to the source of the transistor 49 through a contact hole 47 and a liquid crystal driving electrode 42 is connected to the drain of the transistor 49 through a contact hole 46. A capacitor 48 for maintaining electrical charge is formed between a ground line 45 and the electrode 42.

Figure 4(b) is an equivalent circuit diagram of the active matrix element 41. When the transistor 49 goes to the ON state, a voltage through the data line 43 is applied to the capacitor 48 and the electrode 42. Electrical charge is thus stored by the capacitor 48 between the ground line 45 and the electrode 42. Thus electrical charge can be maintained for a long period of time since current leakage through the transistor and the liquid crystal material is negligibly small. The principal duty ratio is determined by the period of time the electric charge is maintained/the time necessary for inputting a data signal, and this value can be more than 10,000. However, the capacitor 48 does not need to be of as large an area as the liquid crystal driving electrode.

Figure 4(c) is a sectional view of the active matrix element taken on the line A-B of Figure 4(a). A first thin film layer silicon channel region is formed on a transparent substrate 40 by a low pressure chemical vapour deposition technique or a plasma chemical vapour deposition technique and is then patterned. An oxidation layer is formed by oxidising the surface of the first thin film layer and after that a second thin film layer of silicon is formed. The gate line and the ground line are formed by patterning

the second thin film layer. The oxidation layer is then etched using the second thin film layer as an etching mask. Thus a gate insulating film 51 and a gate electrode 50 are formed. An N-type layer is formed by implanting positive ions into the first thin film layer utilizing the gate electrode 50 as a mask. Thus, a source 53, a channel 55 and a drain 54 of the transistor 49 are formed. Next an oxidation layer 52 is deposited, a contact hole is formed and the data line 43 and electrode 42 are formed by depositing a transparent conductive film with subsequent patterning.

10 In this construction the electrode 42 plays the role of a light shutter so that coloured light coming from the colour filter corresponding in position to the active matrix element 41 is transmitted or blocked by this shutter. Furthermore, gray scale display can be achieved by varying light transmittance of the liquid

15 crystal material continuously by controlling the level of the voltage applied to the data line 43. A liquid crystal display device constructed of active matrix elements as shown in Figure 4 has the advantage that a full colour display can be produced by mixing the primary colours and varying the intensity of each colour using the gray

20 scale levels. Further a display composed of a 500 x 500 matrix of picture elements can be formed because of the extremely high duty ratio using a point or dot at-a-time system.

Additional means for improving driving duty of a liquid crystal display device according to the present invention is to use non-linear

25 elements as part of the active matrix elements. Figures 5 and 6

show the construction of active matrix elements employing non-linear elements.

An active matrix element 61 shown in Figure 5 consists of a driving electrode 57, a MIM (metal-insulator-metal) element 62 and a X-line 58. The electrode 57 is driven by applying a data signal to it via the MIM element 62 from the X-line 58. Figure 5(b) illustrates the construction of the active matrix element of Figure 5(a). A tantalum film is formed on a substrate 56 by sputtering and is then patterned to form the X-line 58. An oxidation layer 59 300 Å to 500 Å in thickness is formed on the tantalum film by anodizing it. After that, a tantalum layer 60 is formed by sputtering and then patterned to form an upper electrode. Next the electrode 57 is formed.

An active matrix element 64 shown in Figure 6 has two diodes connected in series. An X-line 66 is connected to an electrode 65 through a N- or P-type area 67, a P- or N-type area 68 and an N- or P-type area 69. Figure 6(b) illustrates the construction of the active matrix element of Figure 6(a). After forming an island of silicon on a transparent substrate 61, the N- or P-type areas 67, 69 and the P- or N-type area 68 are formed by ion implantation. A transparent conductive film is then formed and the X-line 66 and the electrode 65 are formed.

A non-linear element has characteristics as shown in Figure 7, current sharply increasing when the voltage is at a given level.

The equivalent circuit shown in Figure 8 illustrates driving

of a picture element consisting of a liquid crystal cell 81 and a non-linear element 80. The non-linear element 80 is shown as a non-linear resistance RM and a capacitor CM and the liquid crystal cell 81 is shown as an equivalent resistance RL and a capacitor CL.

5 An operating voltage VD higher than the threshold level is applied to the non-linear element 80 when the liquid crystal cell 81 is to produce a display, a voltage VM almost equal to an applied voltage VD being applied to the liquid crystal cell because of the low resistance of the resistor RM. Thus, in effect, a voltage VM almost
10 equal to the voltage VD is applied to the liquid crystal cell. The resistance RM becomes extremely high as the operating voltage VD falls below the threshold level. The voltage VM gradually decreases due to discharge of the capacitor CL, the time constant of the discharge being determined by the resistance of the resistor RL and
15 the capacitance of the capacitor CL but the voltage causing the liquid crystal cell to produce a display can be maintained for a relatively long time. While the liquid cell is not producing a display, the voltage VM is nearly 0 volts. Therefore, the voltage VM for causing the liquid crystal cell to produce a display is held on the capacitor
20 CL so that the duty ratio of the liquid crystal display device as a whole can be increased. This is a similar effect to that achieved by the active matrix element shown in Figure 4. The electrodes 57, 65 of the active matrix elements of Figures 5 and 6 also play the role of a light shutter.

25 The advantage of using non-linear elements in active matrix

elements of a liquid crystal display device according to the present invention is their simple construction enabling conventional simple multiplex driving systems whose duty ratio is either $1/8$ or $1/16$ to be employed. Non-linear elements can be used to produce gray scale display. There are two ways of driving a liquid crystal display device to produce a gray scale display. One method is to drive active matrix elements such as shown in Figure 4 with voltages corresponding to the contrast level or gray scale thus producing a continuous gray scale display. The voltages corresponding to the gray scale display can be obtained by sampling and holding an image signal, that is, a dot at-a-time system. Another method of driving a liquid crystal display device to produce a gray scale display is to drive the active matrix elements by varying the pulse width of a driving signal. For instance sixteen levels of the gray scale display can be obtained by dividing a selecting frame into 16 terms wherein one term means one level of the gray scale display. The above-mentioned pulse width modulation system is a line at-a-time system.

In the case of driving liquid crystal display devices with active matrix elements including non-linear elements both a line at-a-time driving system and a dot at-a-time driving system can be used.

In the embodiments according to the present invention described so far the colour filters are formed on one substrate and the active matrix elements on the other substrate with the liquid crystal material therebetween. If the active matrix elements are

formed directly on the colour filters the characteristics of the colour filters may deteriorate and there is a tendency to decrease manufacturing yield.

5 Figure 9 shows in detail an embodiment of a liquid crystal display device according to the present invention. Figure 9(a) shows a glass substrate 99 with active matrix elements 90 thereon and respective driving electrodes 97. Red (R), blue (B) and green (G) colour filters 92, 93, 94 are formed on a glass substrate 91. A passive layer 95 covers the colour filters and a driving electrode 96 is formed thereon. A liquid crystal layer 98 is disposed between the glass substrates 90, 91. A polarizing plate (not shown) is attached to either glass substrate and light is applied through the polarizer into the liquid crystal display device.

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There is a problem of light shielding because of the existence of gaps between the colour filters or between the electrodes 97, light entering these gaps causing deterioration of the colour display. For instance, when light is passed through the glass substrate 91 some light leaks through the gaps between the colour filters and between the electrodes 97 even if the active matrix elements are not energised.

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There are two possible measures to counter this problem.

One measure is to use negative-type liquid crystal material where light is not transmitted without a voltage being applied. Thus the transmittance of light is always shielded through the gaps between the electrodes 97. Another measure is to form a black frame between the colour filters as shown in Figure 2. The use of these two measures together brings about an even more effective result.

The appearance of light passing through the liquid crystal material may be blurred upon energising the active matrix elements.

For example when only the active matrix elements above the filter 92 is energised some light at the edges adjacent the filter 94 and the filter 93 may leak through the active matrix element corresponding to the filter 92. This light leakage causes the colour display to deteriorate. To avoid this problem the colour filters should have a large area compared to that of the corresponding active matrix elements. For example, the driving electrodes 97 of the active matrix elements are made smaller than the corresponding colour filters as shown in Figure 9(b) and Figure 9(c).

Liquid crystal display devices which produce a multi-colour display require that the difference in the transmission of light between an opened state of liquid crystal shutter and closed state must be relatively large. When the liquid crystal display device is of the normal positive twisted nematic type two polarizers are used, one being disposed on each side of the liquid crystal display device. In this case the light transmittance ratio is determined by the

arrangement of polarizers, the ratio being taken in directions parallel and vertical to the polarisers. Practically this ratio is from 10 to 50.

In the case of a guest-host liquid crystal display device, the brightness is twice that of a twisted nematic liquid crystal display device and the transmittance ratio, which is relatively large, is solely determined by the liquid crystal material since only one polarizer is needed. For instance, in most cases a guest-host liquid crystal display device includes a black colouring material which completely blocks light until a voltage is applied when it becomes transparent so that the light transmittance is over 50.

Moreover, a positive-type guesthost liquid crystal display device shows excellent characteristics compared with the negative-type, especially stability, reliability, lower driving voltage and large transmittance ratio. Further positive-type guest-host liquid crystal display devices are advantageous from the point of view of avoiding leakage and blurring of light. Thus ideally a liquid crystal display device according to the present invention is of the guest-host type and black colouring material in the liquid crystal material enables an excellent multi-colour display to be produced using three primary colours.

Figure 10 is a circuit diagram of a driving circuit for a liquid crystal display device according to the present invention using a point or dot at-a-time system. Filters 106 of three primary colours are arranged in strips in the Y-direction, a common electrode is formed all over the surface of the filters, and driving

electrodes aligned with the filters are arranged as strips extending in the same direction as the filters. Upper electrodes 105 are arranged in strips in the X-

direction. Thus a matrix of picture elements is formed. A shift

5 register 101 supplies signals S_1 S_n to respective transistors

104 in synchronism with a clock signal ϕ_5 , and a video signal VS

from an amplifier 103 is supplied to the electrodes X_1 to X_n

successively by rendering the transistors 104 conductive in a point

or dot at-a-time system. A shift register 102 selects Y-lines Y_1 ...

10 Y_m successively in synchronism with a clock signal ϕ_4 . Three colour

signals VSR, VSB, VSG are selected for every Y line in synchronism

with clock signals ϕ_1 , ϕ_2 , ϕ_3 . The clock signals ϕ_1 , ϕ_2 , ϕ_3 have the

same pulse width as the clock signal ϕ_4 but a period which is three

times as long as that of the clock signal ϕ_4 . In this method, the

15 filters are arranged as strips in the Y direction and the frequency

for changing over each individual colour signal can be reduced. Thus the

number of lines in the Y-direction can be increased so that a superior

resolving power can be obtained and a good quality display can be

produced.

20 Figure 11 illustrates another embodiment of a driving circuit for a liquid crystal display device according to the present invention

where colour filters 116 are arranged in strips extending in the X

direction and using the same point or dot at-a-time system as

Figure 10. Therefore the number of lines in the transverse direction

25 can be increased and the picture elements are in the form of square

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dots. Thus a natural display can be produced. In Figure 11, the output from a shift register 112 selects driving electrodes 115 successively in synchronism producing signals for Y lines Y_1 to Y_m . While one of the driving electrodes 115 is selected, a shift register 111 selects successively a unit group consisting of red, green and blue (R, G, B) filters. In addition clock signals ϕ_1 , ϕ_2 , or ϕ_3 produced by dividing a clock signal ϕ_5 into three phases select successively in synchronism colour video signals VSR, VSG, VSB which are transmitted to the X lines. In this method, the video signal lines are in parallel with each other according to every colour video signal and connected to sample hold switches 113. This is advantageous from the point of view of reduction of power consumption of the shift register 111 which can be used within the range of its operating speed, since the frequency of the clock signal ϕ_5 can be one-third of the number of dots.

Figure 12 illustrates a further embodiment of a driving circuit for a liquid crystal display device according to the present invention where the colours R, G, B of the colour filters are arranged in a mosaic. A colour R, G, B is allocated to each picture element, the colours being shifted by one pitch to the left in each X line. For example, each picture element shown in Figure 12 is driven by signals from X- and Y-lines constructed on the glass plate as shown in Figures 4 to 8. A shift register 122 receives a clock signal YCL and selects gate or Y lines Y_1 to Y_m successively in synchronism. On the other hand, during the period of selecting one of the Y lines,

a shift register 121 supplies signals S_1 to S_n successively to the gate of transistors 123 for data or X-lines X_1 to X_n . A video signal V_s from an amplifier 124 is sampled successively by the transistor 123 and held on the X-lines X_1 to X_n by actuating the gates of transistors 123. Thereby, the video signal is transmitted to respective picture elements and a display can be produced.

The video signal V_s consists of respective colour signals VSR , VS_B , VSG multiplexed in synchronism with clock signals ϕ_1 to ϕ_3 . It is necessary that the timing of the clock signals ϕ_1 to ϕ_3 corresponds to the arrangement of each colour filter allocated to the picture element. For example during the period of selecting the Y-line Y_1 , the signal S_1 must be applied to the gate of the transistor in synchronism with the clock signal ϕ_1 , but during the period of selecting the Y-line Y_2 , this signal must be applied to the gate of the transistor in synchronism with the clock signal ϕ_2 because the video signal VSR must be supplied to the picture element with the colour R and the video signal VSG must be supplied to the picture element with the colour G.

Figure 13 is a timing chart illustrating the operation of the driving circuit of Figure 12. In the case of selecting the Y-line Y_1 , firstly the video signal VSR is supplied to the X-line X_1 in synchronism with the clock signal ϕ_1 whilst the signal S_1 is applied to the gate of the transistor 123 of the X-line X_1 . The video signal VSG is applied to the X-line X_2 in synchronism with the clock signal ϕ_2 whilst the signal S_2 is applied. The video signal VS_B is supplied

to the X-line X_3 whilst the signal S_3 is applied.

While in the case of selecting the Y-line Y_2 , firstly the video signal VSG, secondly the video signal VSB and thirdly the video signal VSR are supplied to the X-lines X_1 , X_2 , X_3 respectively in dependence upon the signal S_1 , S_2 , S_3 applied to the gates of the transistors 123 for the X-lines X_1 , X_2 , X_3 . Thus it is necessary to shift the clock signals ϕ_1 , ϕ_2 , ϕ_3 for each of the Y-lines in order to supply the requisite video signals VSG, VSB, VSR to the respective colour filters.

The circuit shown in Figure 14 is an example of a circuit for shifting the phases of the clock signals ϕ_1 to ϕ_3 , its operation being illustrated by the waveforms of Figure 15. A 1/3 frequency divider 143 is reset by a vertical synchronising signal V to supply signals Q_1 , Q_2 to a 1/3 frequency divider 142 in synchronism with a Y clock signal YCL. The 1/3 frequency divider 142 divides the signals Q_1 , Q_2 by 1/3 in synchronism with a X clock signal XCL and loads or presets the values of the signals Q_1 , Q_2 every time a horizontal synchronizing signal H is inputted. Therefore the phases of signals Q_3 , Q_4 from the 1/3 divider are shifted every pulse of the clock signal YCL and the respective video signals can be properly applied to the respective picture elements in the driving circuit shown in Figure 12.

Figure 16 is another embodiment of a driving circuit of a liquid crystal display device according to the present invention. A red filter 161, a green filter 162, a blue filter 163 and a white filter 164 are formed in a block and a plurality of such blocks are

arranged in a matrix. In the case of low level transmission of light through the colour filters, it is a problem to get good reproduction of a white colour. In order to solve this problem, this embodiment provides a transparent portion as the white filter
5 164 this being controlled by an ~~illuminance~~ ^{illuminance} video signal VSW. Thus the whole brightness can be improved and white colour produced fairly well. In this driving circuit with respect to the X direction a shift register (not shown) controls picture elements in the same manner as Figure 11. In addition, with respect to the Y direction,
10 the Y-line Y_i or the Y-line Y_{i+1} is selected in synchronism with a clock signal ϕ_3 and video signals VSR and VSB or video signals VSG and VSW are alternately supplied to the corresponding filters in synchronism with the clock signals ϕ_1 , ϕ_2 , the frequency of which is one-half that of the clock signal ϕ_3 .

15 Figure 17 shows how to control voltage amplitude to produce gray scale display. A video signal VS shown in Figure 17(a) is sampled and held in synchronism with a clock signal ϕ_5 and supplied to an X-line. The characteristic curve of applied voltage V relative to contrast C is as shown in Figure 17(b). A gray scale display can be produced
20 with the voltage in the range of ΔV . A more superior gray scale can be achieved by implementing γ correction or video signal correction according to the characteristics of the liquid crystal material.

The above-mentioned means of producing a gray scale display by controlling voltage amplitude is mainly adopted to drive a liquid
25 crystal display device with active matrix elements composed of thin

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film transistors or non-linear elements while the production of a gray scale display by controlling or modulating pulse width is mainly adopted for a liquid crystal display device of high duty multiplex construction or composed of non-linear elements.

Figure 18 illustrates another embodiment of a driving circuit of a liquid crystal display device according to the present invention which is driven by a pulse width modulation system. The colour filters 146 are arranged in a mosaic.

Colour video signals VSR, VSG, VSB are multiplexed in synchronism with the clock signals ϕ_1 to ϕ_3 in the same manner as described with reference to Figure 12, and are outputted to a 4-bit A/D converter 187. Outputs D_0 to D_3 from the converter 187 are transmitted to a shift register 180 during the period of selecting the Y-lines Y and supplied to a latch 181 in synchronism with a pulse LP. A 4-channel multiplexer 182 forms pulses having different pulse width, where a 4-bit data signal selects one of time bases TBO to TB3. These pulses are supplied to X-lines X_1 to X_n via a driver 183.

The Y-lines are selected successively by a shift register 184, and a driver 185 supplies the selecting signal to the Y-lines.

Figure 19 illustrates the operation of the driving circuit

of Figure 18. A frame has a positive field A and a negative field B, and the width of a driving pulse X_i is selected within one selection period T_{SEL} . For instance, in the case where the gray scale is 0, the driving waveform is shown as $X_i(0)$, in the case where the gray scale is 7, the driving waveform is shown as $X_i(7)$, and in the case where the gray scale is 15 the driving waveform is shown as $X_i(15)$. These driving waveforms are formed by combining time bases T_{B0} to T_{B3} as indicated by the 4-bit data signal.

In the matrix driving system utilising thin film transistors, a Y-line is formed on the same substrate as the X-line and a transparent driving electrode film of, for example, indium-tin-oxide or other transparent conductive film is deposited all over the surface of the opposite substrate.

Thus in the liquid crystal display device shown in Figure 9, the transparent driving electrode film completely covers all the colour filters. Accordingly, this construction removes the problem that the colour filters and the liquid crystal material react with each other to reduce reliability since the transparent driving electrode film shields completely the colour filters from the liquid crystal material. Thus the transparent driving electrode film acts as a passive film in this context and this is particularly advantageous.

In a practical liquid crystal display device, sometimes there is a problem with resolving power. Arranging the colour filters in a mosaic improves the resolving power as will be explained.

Figure 20 shows the fundamental construction of high resolving power of liquid crystal display devices according to the present invention. Figure 20(a) shows colour filters shifted by $1/2$ pitch in the X direction and Figure 20(b) shows colour filters shifted by $1/2$ pitch in the Y direction. The resolving power of the above-mentioned arrangements of picture elements is increased in the oblique direction. Therefore oblique lines are not visible and resolving power can be considerably increased. The colour filters R, G, B are each arranged at the apex of a triangle consisting of colour filters R, G, B. Thus proper resolving power can be obtained even where fewer picture elements are used.

Figure 21 illustrates driving electrodes of a liquid crystal display device driven by a multiplex driving system. X electrodes are arranged and shifted by $1/2$ pitch with distributing wires in similar manner to that shown in Figure 20(a). The X and Y electrodes are normally transparent conductive electrodes, the distributing wires being of very small width and made from a deposited metallic thin film so as to lower electrical resistance.

Figure 22 shows part of a liquid crystal display device according to the present invention employing thin film transistors to improve resolving power. The liquid crystal display device has data lines 213 to 215 and gate lines 210 to 212. The transistors

and the picture element electrodes are normally arranged in odd-number gates lines as shown by a transistor 216 and a driving electrode 217. On the other hand, for even-numbered gate lines, transistors 219, 22 and driving electrodes 221, 223 are arranged in parallel with each other relative to data line 214, namely are substantially shifted by $1/2$ pitch. Figure 22 (a) shows the case where the data lines 213 to 215 and the driving electrodes 217, 220, 221, 223 are formed in or on the same layer. In the case where the data lines and the driving electrodes overlap, it is also possible to shift a driving electrode 224 itself by $1/2$ pitch with a single transistor 225 as shown in Figure 22(b).

Figure 23 shows another embodiment of a liquid crystal display device according to the present invention employing thin film transistors. Data lines 230 to 232 are shifted by $1/2$ pitch by making them zig-zag. It is advantageous that unnaturalness caused by shifting electrodes by $1/2$ pitch can be removed, since the size of picture elements is quite the same in both shifted portion and unshifted portion.

Figure 24 shows a similar arrangement where the driving electrodes are shifted by $1/2$ pitch in the Y direction by making the gate lines zig-zag.

Figure 25 shows a yet further embodiment of a liquid crystal display device according to the present invention using thin film transistors. Drivers 270 to 273 are directly connected to data lines 277, 279, 281, 283. Data lines 278, 280, 282 are alternately

connected to right or left drivers every scanning of one gate line. For example, when a thin film transistor is turned ON by a gate line 284 and switches 274 to 276 are set to the left position, the same data is supplied to both picture elements 289, 290 and picture elements 291, 292 as pairs, respectively. Then, when the thin film transistor is turned OFF by the gate line 284 and is turned ON by a gate line 285, and the switches 274 to 276 are set to the right position, the same data is respectively supplied to three pairs of picture elements 294, 295, 296, 297, and 298, 299. Thus the method shown in Figure 20(a) can be realised.

Figure 26 shows a modification of the construction of Figure 20(c) wherein data lines or X-lines 311, 312, 313 are staggered.

The liquid crystal display devices according to the present invention and described above produce a coloured display and use a large volume driving system such as a high duty ratio system, a multiplex driving system or a driving system where thin film devices, such as non-linear elements or thin film transistors are used. Light transmission type liquid crystal display devices can be constructed where some increased power consumption is allowable and light reflection type liquid crystal display devices can be constructed where the plane of reflection is deposited on the lower side can be utilised for low power consumption. In one embodiment of the present invention a full colour display composed of more than 100 x 100 lines was achieved with excellent image quality without distortion, compact size display and low power consumption for

producing graphical picture displays of quality comparable to that of cathode ray tubes.

The embodiments of the present invention and described above employ three different systems for enlarging the duty ratio.

- 5 Firstly, in the multiplex driving system superhigh duty ratio from 1/60 to 1/200 can be realised by improving the liquid crystal material and using sophisticated construction techniques for the liquid crystal display device. Secondly, the gap between the electrodes of the liquid crystal display device must be controlled
10 to be from 5 μm to 7 μm instead of the conventional 10 μm . Thirdly, active matrix elements, such as transistor switches, non-linear elements (MIM elements or diodes) are used in the driving circuit. One embodiment of a liquid crystal display device according
15 to the present invention uses negative type liquid crystal micro-shutters which open and close colour filter dots which are arranged in a mosaic or in strips in order to product a colour display. It has been found that fine and clear colour displays can be realised in such embodiments.



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C L A I M S

1. A liquid crystal display device having a plurality of picture elements arranged in a matrix of columns and rows, comprising first and second transparent substrates, each substrate having an internal surface, the internal surfaces facing each other and being spaced apart to define a space therebetween, a plurality of parallel and spaced apart data lines and a plurality of parallel and spaced apart orthogonal signal lines, insulated from each other, a drive circuit for each picture element including, at each data and signal line intersection, a first driving electrode and an associated intermediate component means for coupling the data line to the corresponding first driving electrode, the data lines, signal lines, first electrodes and intermediate component means being formed on the internal surface of the first substrate, a plurality of colour filters formed on the internal surface of the second substrate and arranged in strips or mosaics corresponding to the intersections, a second common electrode formed on the surface of the colour filters between the colour filters and the first electrodes, and a liquid crystal material retained in and filling the space between the electrodes.
2. A device according to claim 1, in which each drive circuit includes a thin film transistor or a non-linear resistive element.



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3. A device according to claim 1, in which each column or row of picture elements is shifted or displaced relative to each adjacent column or row.

5 4. A device according to any preceding claim, in which the area of the first driving electrode of each picture element is less than the area of the corresponding colour filter.

10 5. A device according to any preceding claim, including means for selecting three primary colour video signals sequentially in synchronism by respective clock signals having the same frequency which is one-third the frequency of a selecting signal for selecting rows or columns of picture elements, and means for applying the video signal from the selecting means to the first or second electrodes of the picture element.

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6. A liquid crystal display device substantially as herein described with reference to and as shown in the accompanying drawings.
