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(54) **MULTIPLE-TONE DISPLAY SYSTEM**

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(52) **U.S. Cl.** **345/211**

(57) **ABSTRACT**

A dot matrix display system for multiple-tone displays, comprising a display device in which pixels are arrayed in a matrix shape, an LC (liquid-crystal) drive signal generator which converts color display data into LC display data, an 8-level data driver which selects one of 8-level voltages in accordance with the LC display data and then delivers the selected voltage, and an 8-level applied LC voltage generator by which the 8-level voltages to be applied to the pixels are produced so as to substantially uniformalize color differences between the respectively adjacent tones of the multiple-tone displays. Owing to the substantially uniform color differences between the respectively adjacent tones, the multiple-tone displays which are uniformly seen by the human eye can be realized.

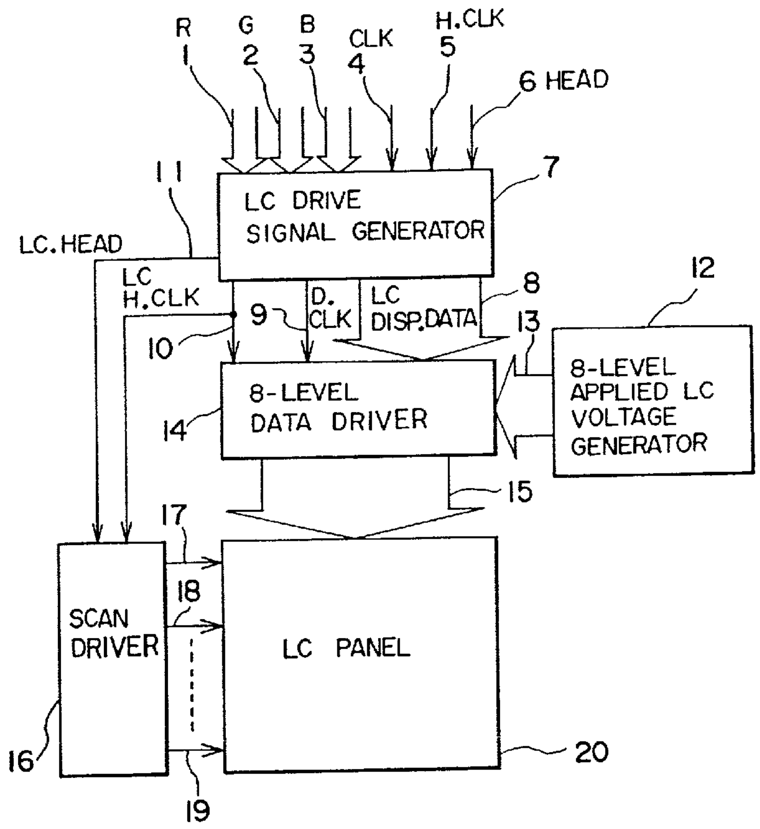


FIG. 1

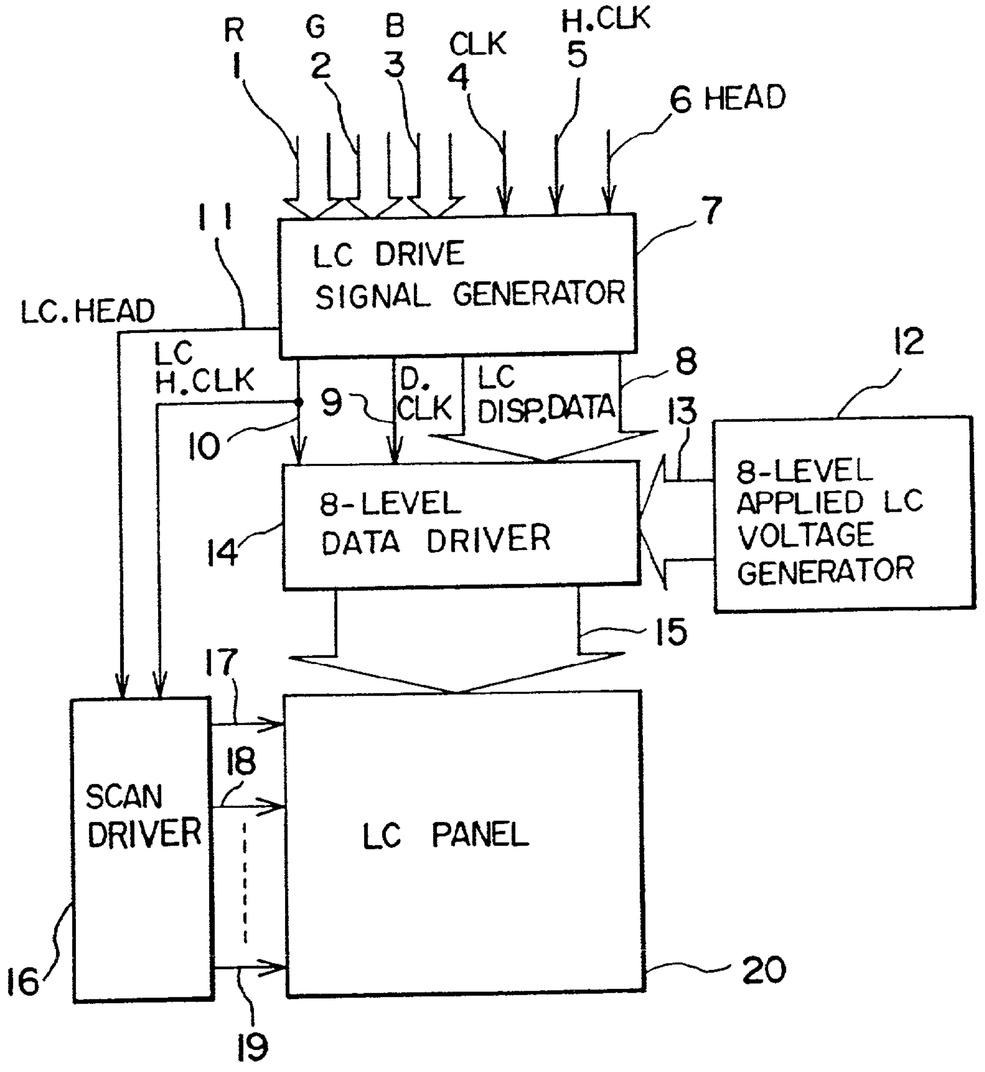
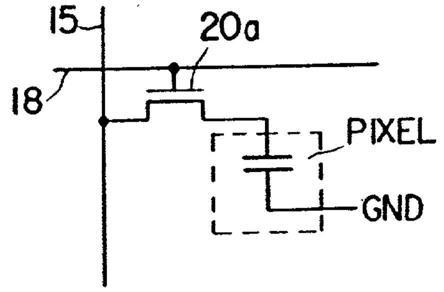
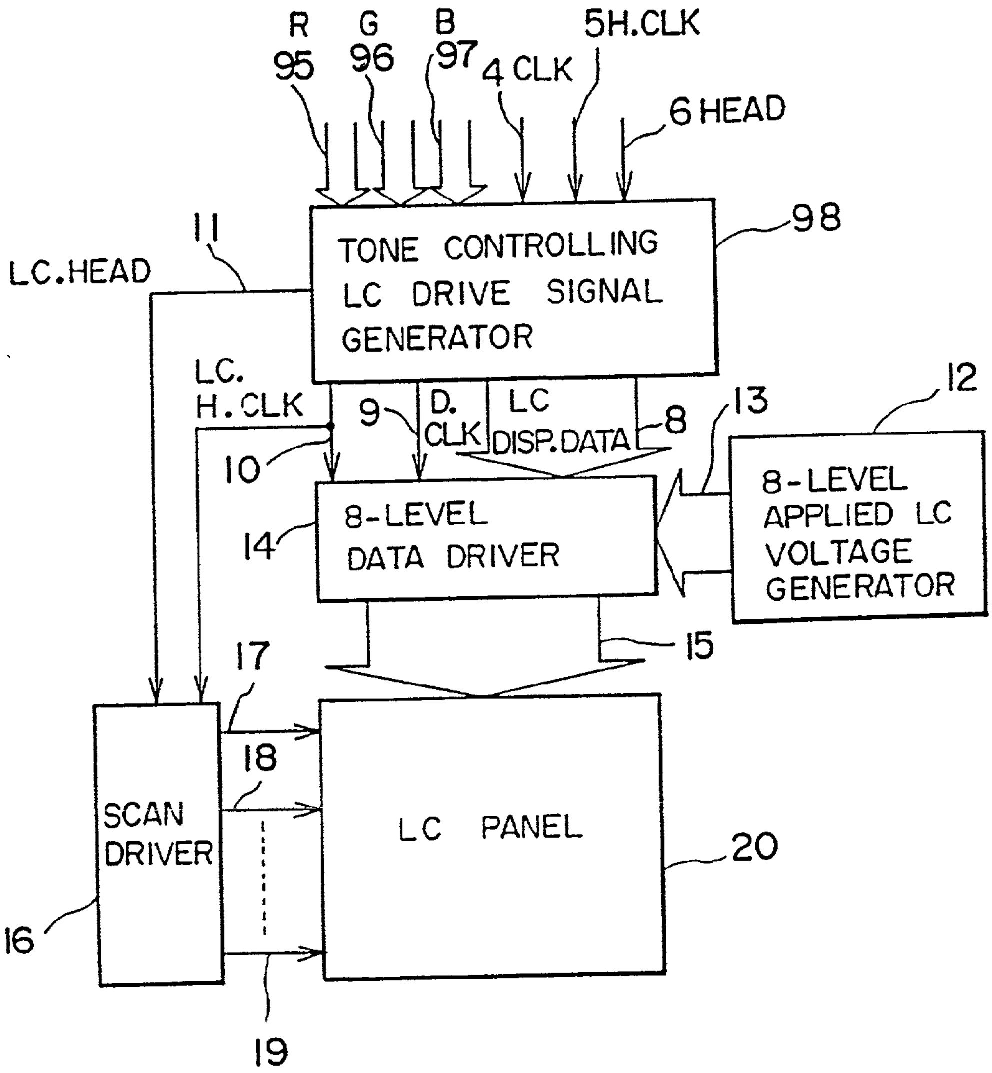

R
1
G
2
B
3
CLK
4
H.CLK
5
6 HEAD
7
11
LC DRIVE
SIGNAL GENERATOR
LC.HEAD
LC
H.CLK
D.
CLK
LC
DISP.DATA
8
12
9
10
13
8-LEVEL
DATA DRIVER
14
8-LEVEL
APPLIED LC
VOLTAGE
GENERATOR
15
17
18
SCAN
DRIVER
LC PANEL
16
19
20

FIG. 1A


15
20a
18
PIXEL
GND

F I G . 2



R
G
B
95
96
97
4 CLK
5H.CLK
6 HEAD
98
TONE CONTROLLING LC DRIVE SIGNAL GENERATOR
LC.HEAD
11
LC. H.CLK
9
D. CLK
LC DISP.DATA
8
10
12
13
8-LEVEL APPLIED LC VOLTAGE GENERATOR
14
8-LEVEL DATA DRIVER
15
17
18
SCAN DRIVER
LC PANEL
20
16
19

FIG. 3

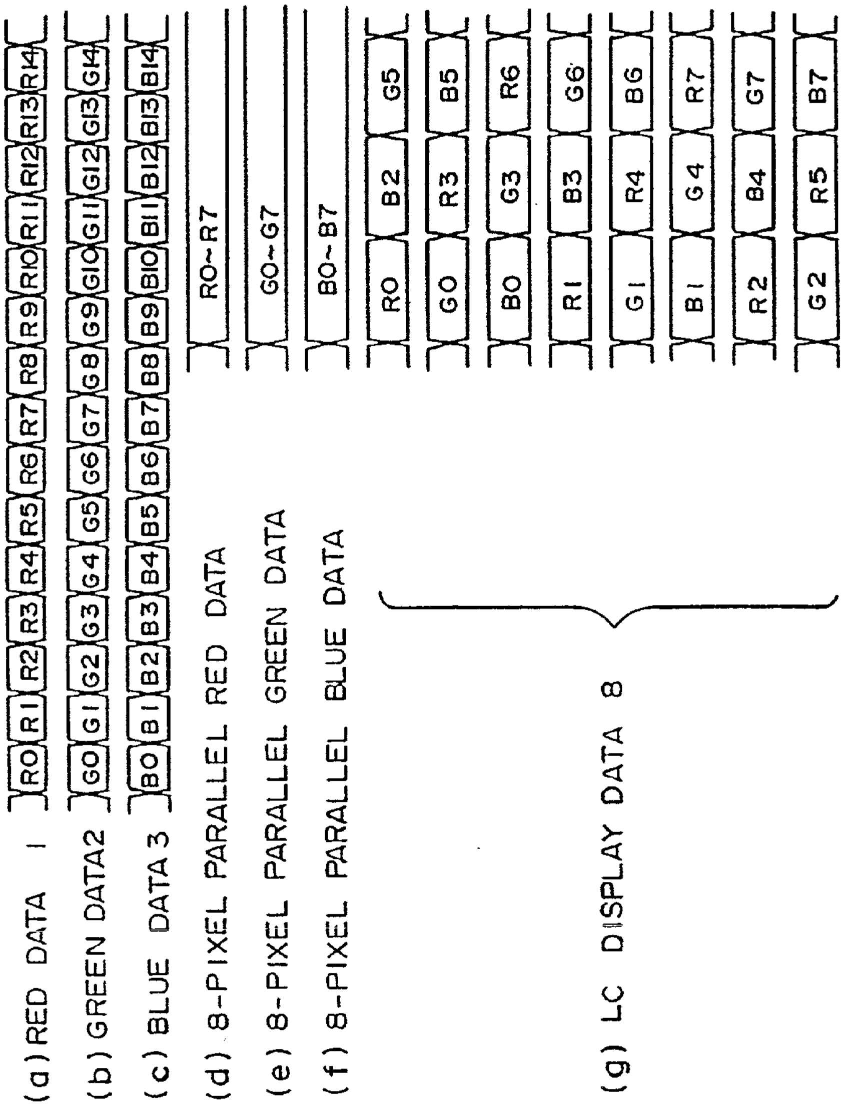

(a) RED DATA 1
(b) GREEN DATA 2
(c) BLUE DATA 3
(d) 8-PIXEL PARALLEL RED DATA
(e) 8-PIXEL PARALLEL GREEN DATA
(f) 8-PIXEL PARALLEL BLUE DATA
(g) LC DISPLAY DATA 8
R0 R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14
G0 G1 G2 G3 G4 G5 G6 G7 G8 G9 G10 G11 G12 G13 G14
B0 B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14
R0~R7
G0~G7
B0~B7
R0 B2 G5
G0 R3 B5
B0 G3 R6
R1 B3 G6
G1 R4 B6
B1 G4 R7
R2 B4 G7
G2 R5 B7

FIG. 4

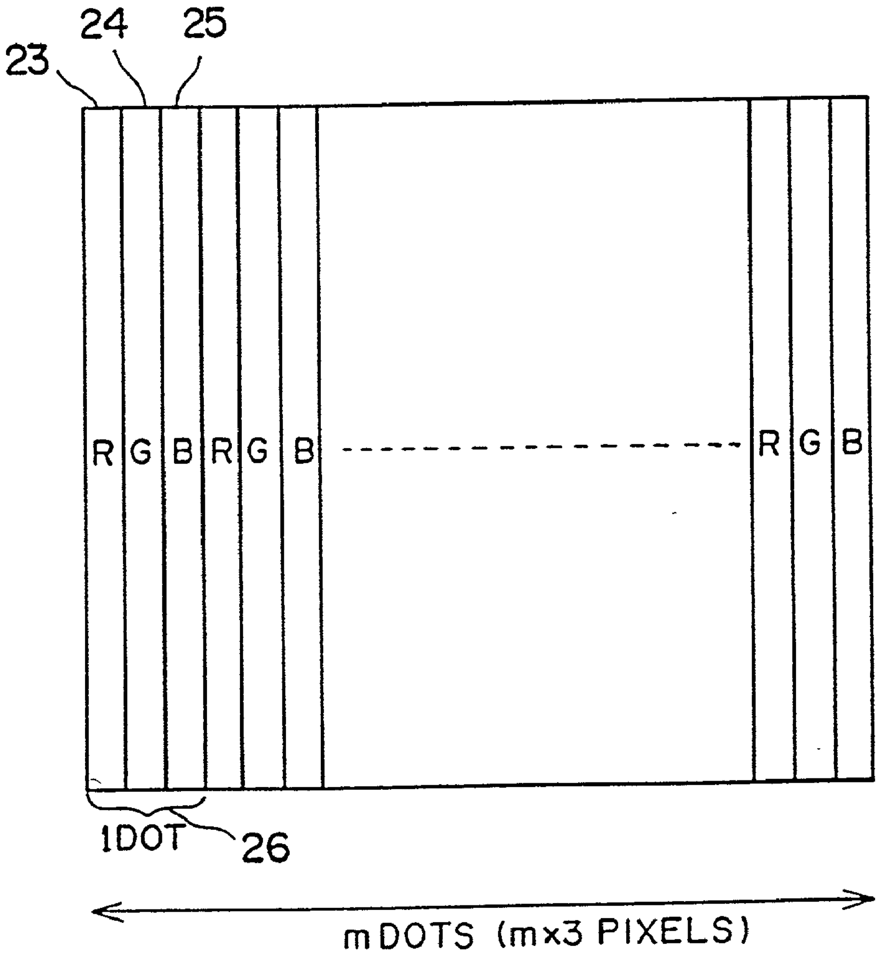


FIG.5 PRIOR ART

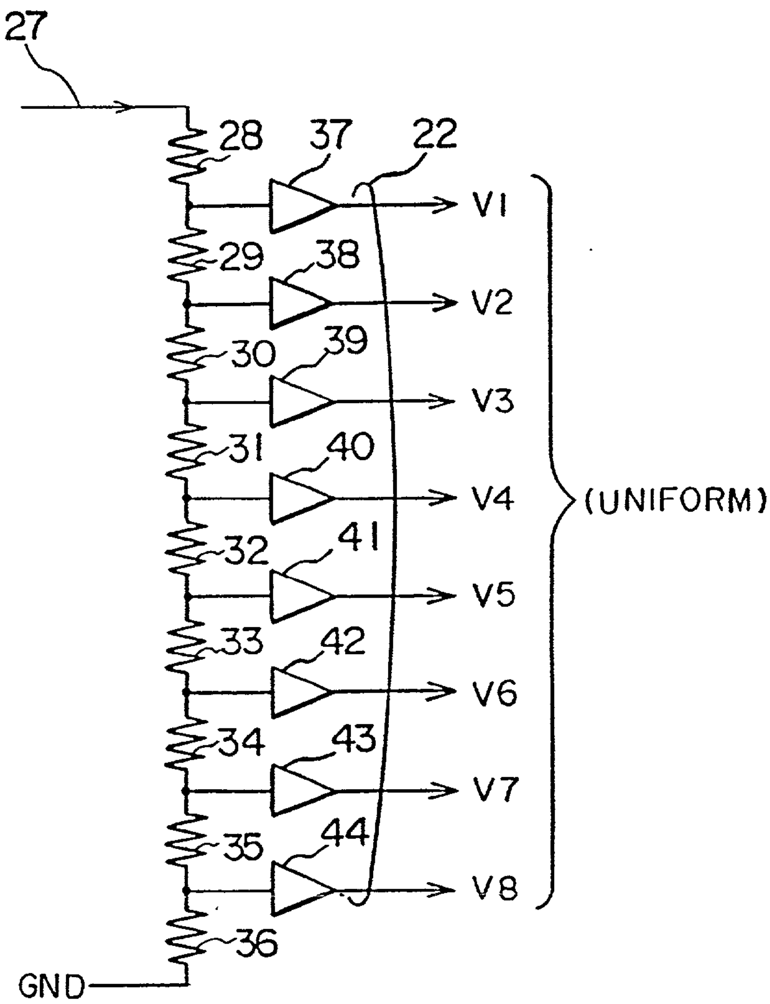


FIG. 6

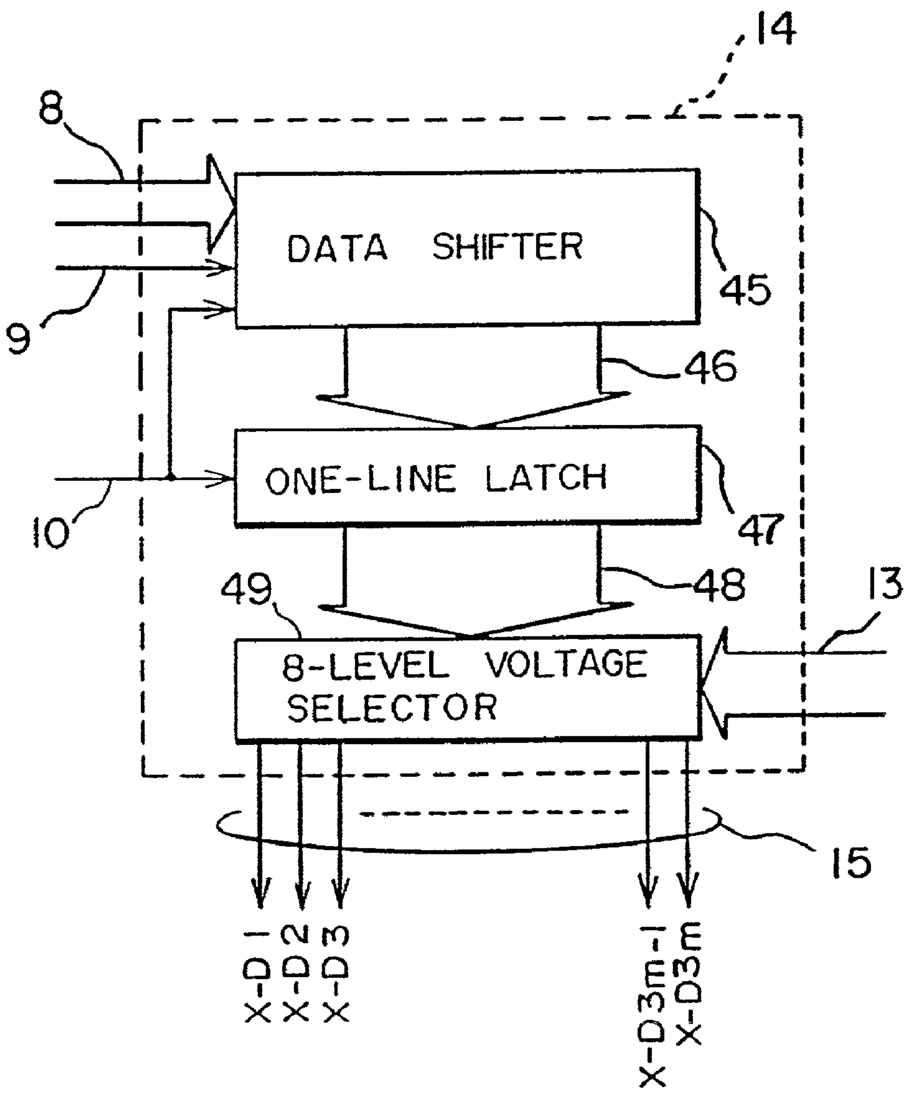
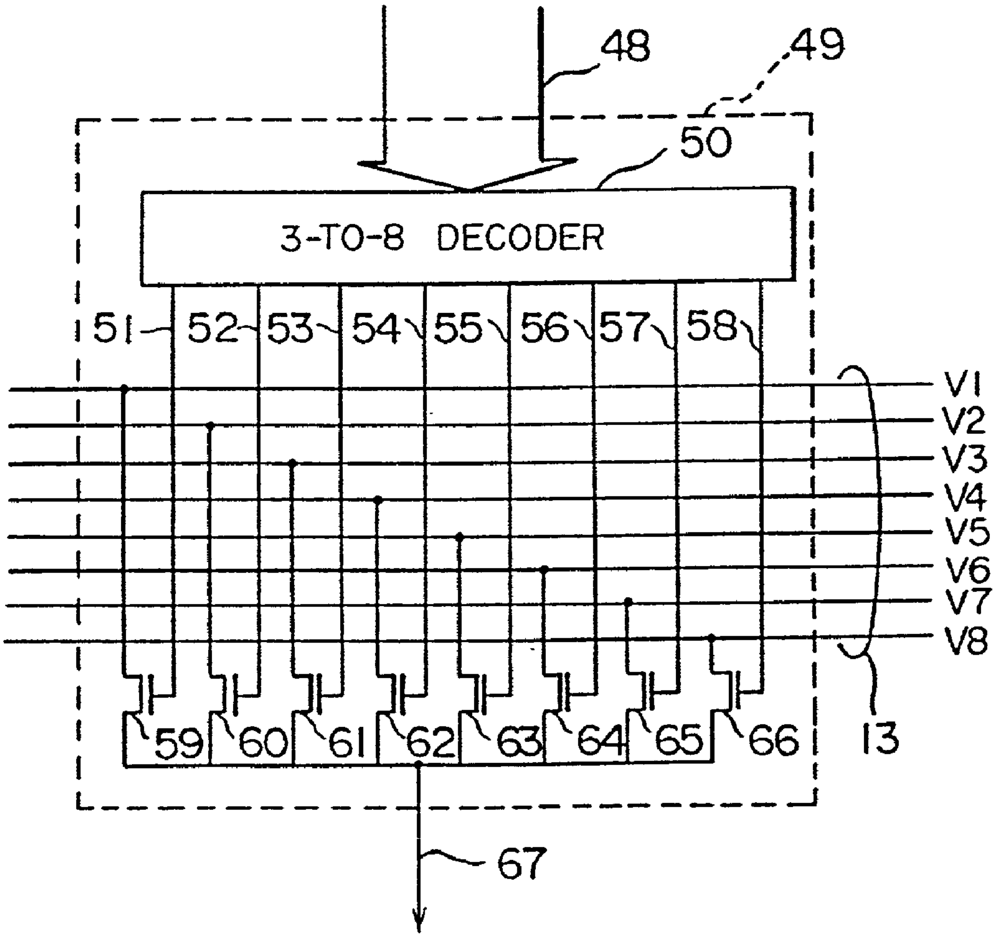

14
8
9
10
DATA SHIFTER
45
46
ONE-LINE LATCH
47
48
49
13
8-LEVEL VOLTAGE SELECTOR
15
X-D1
X-D2
X-D3
X-D3m-1
X-D3m

FIG. 7



48
49
50
3-TO-8 DECODER
51
52
53
54
55
56
57
58
V1
V2
V3
V4
V5
V6
V7
V8
59
60
61
62
63
64
65
66
13
67

FIG. 8 PRIOR ART

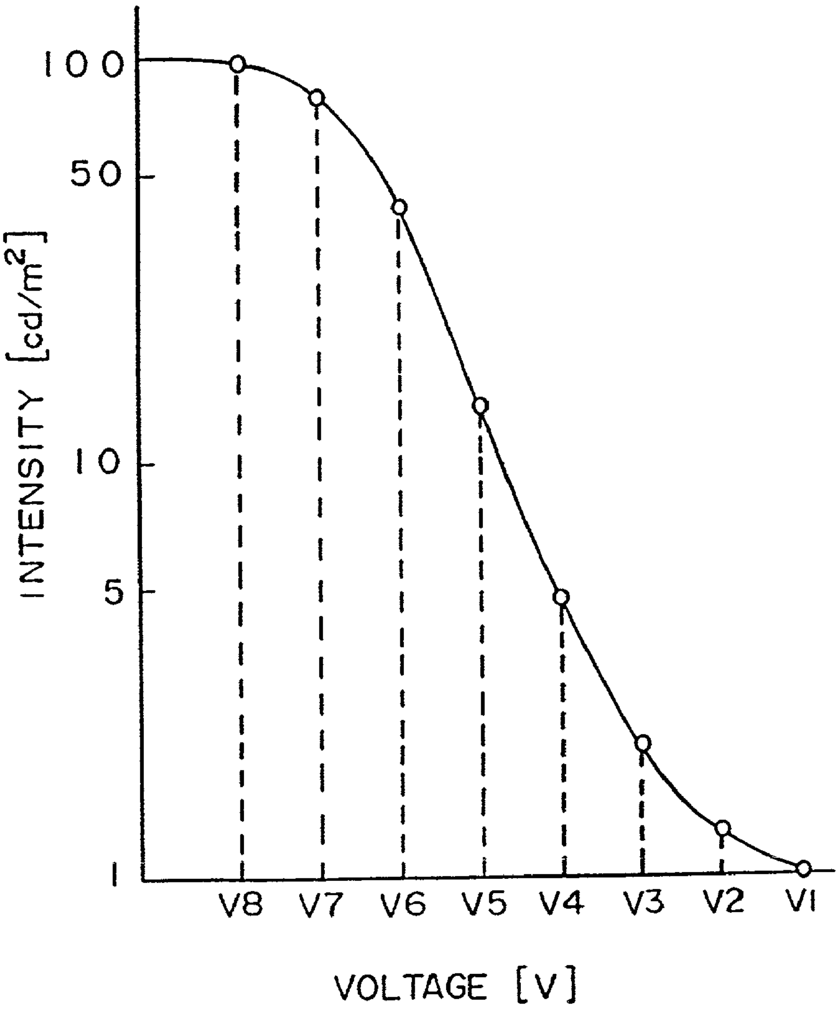


FIG.9

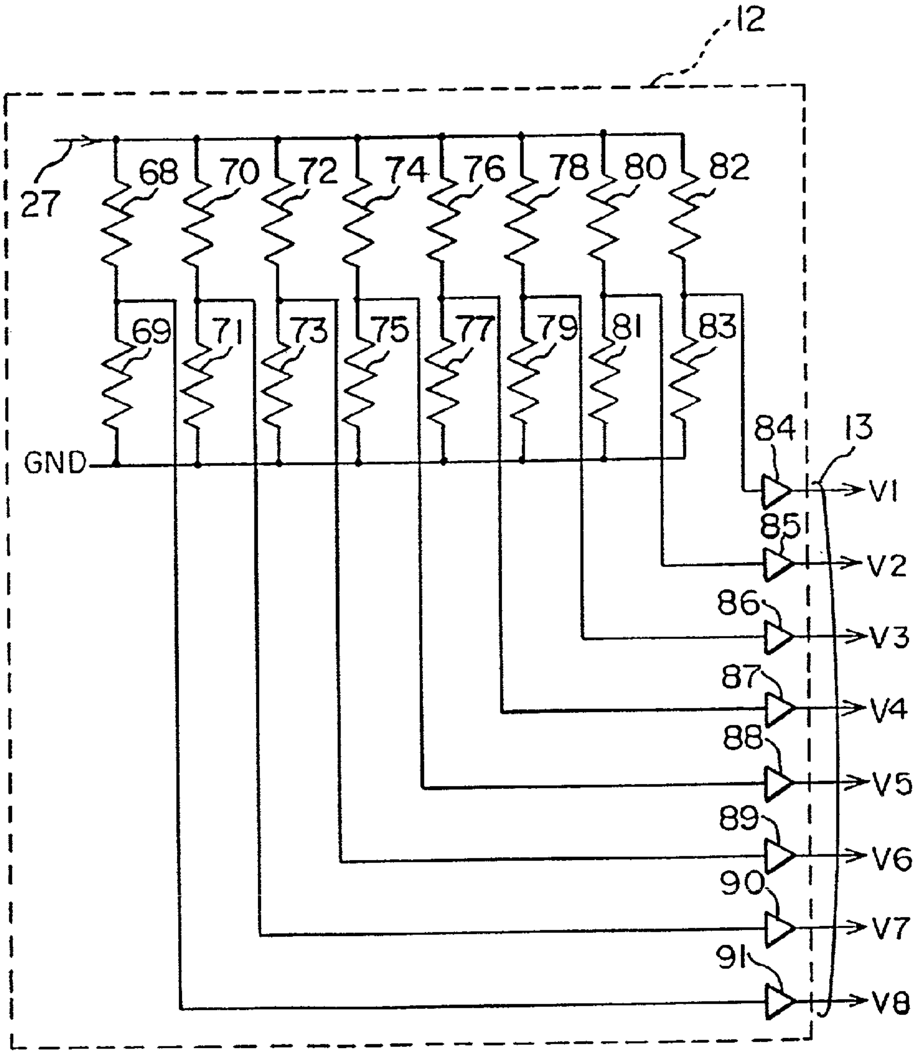

12
27
68
70
72
74
76
78
80
82
69
71
73
75
77
79
81
83
GND
84
13
V1
85
V2
86
V3
87
V4
88
V5
89
V6
90
V7
91
V8

FIG. 10

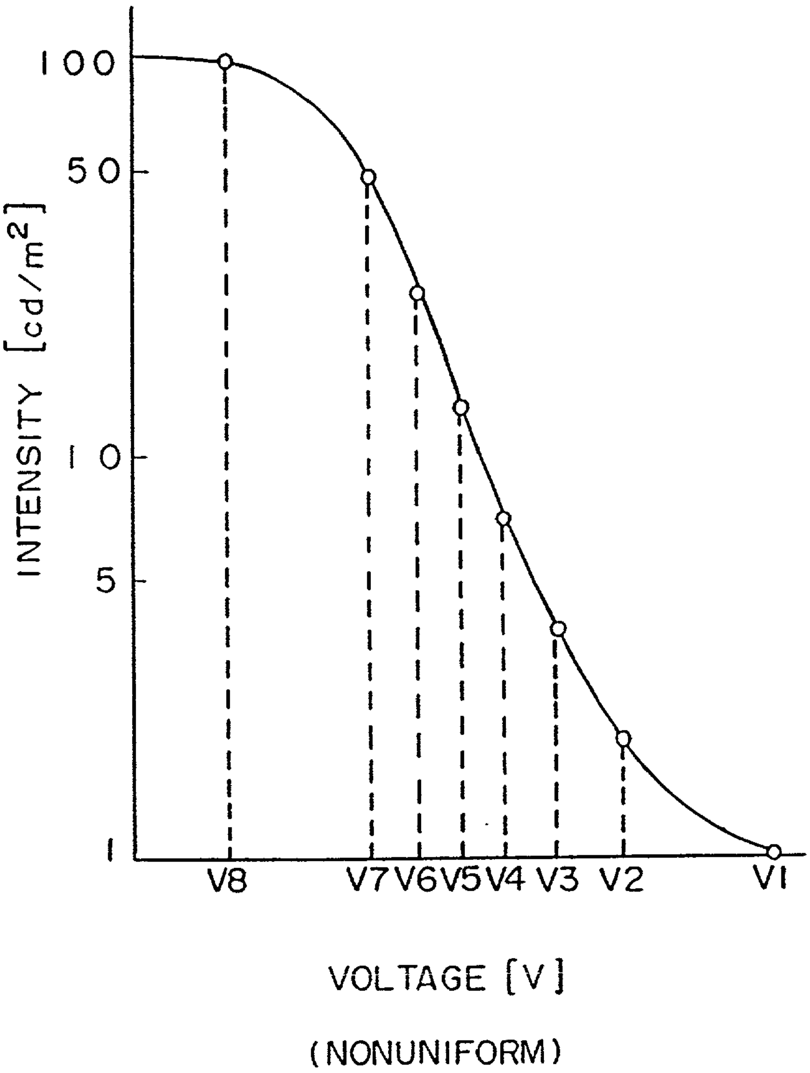
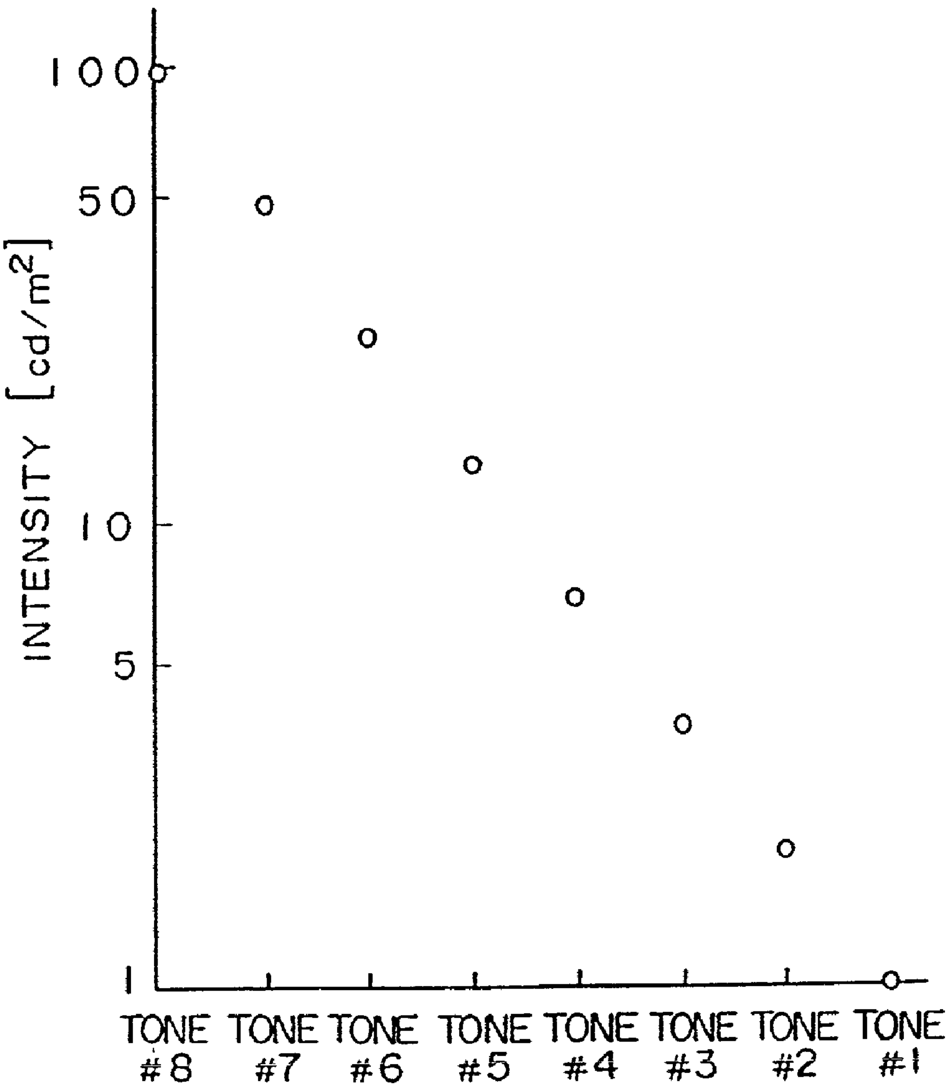

100
50
10
5
1
INTENSITY [cd/m2]
V8
V7
V6
V5
V4
V3
V2
V1
VOLTAGE [V]
(NONUNIFORM)

FIG. 11



100
50
10
5
1
INTENSITY [cd/m2]
TONE #8
TONE #7
TONE #6
TONE #5
TONE #4
TONE #3
TONE #2
TONE #1

FIG. 12

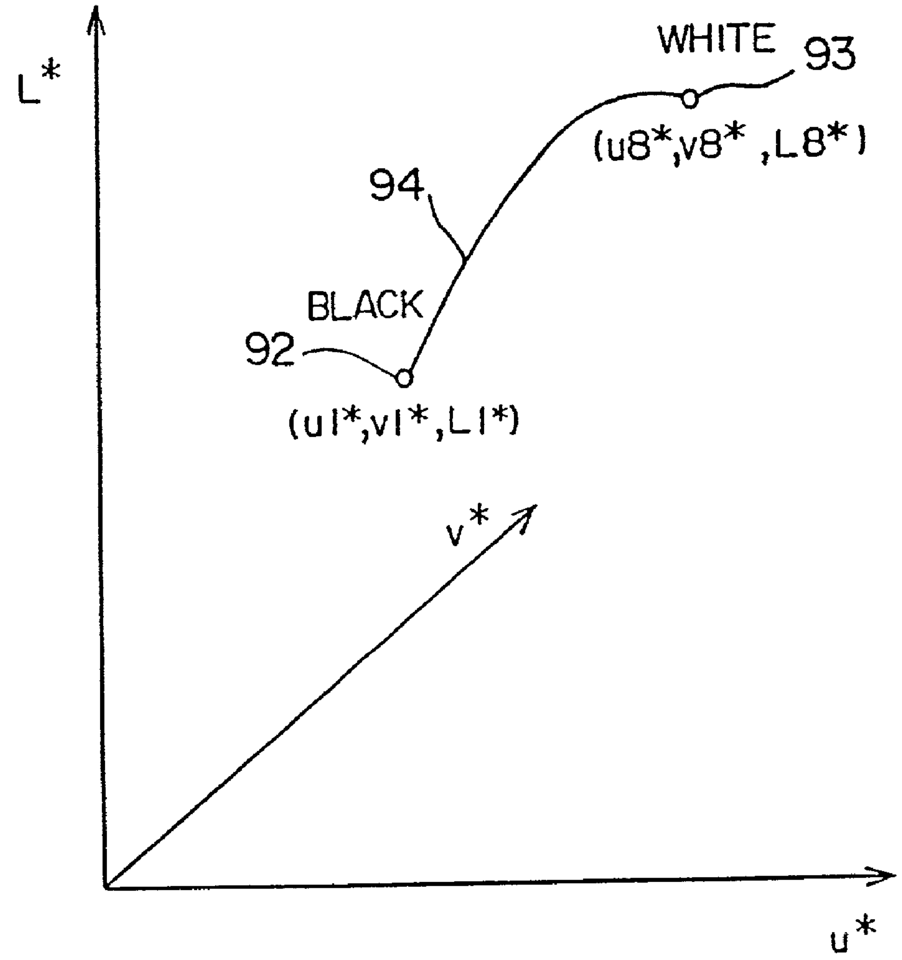


FIG. 13

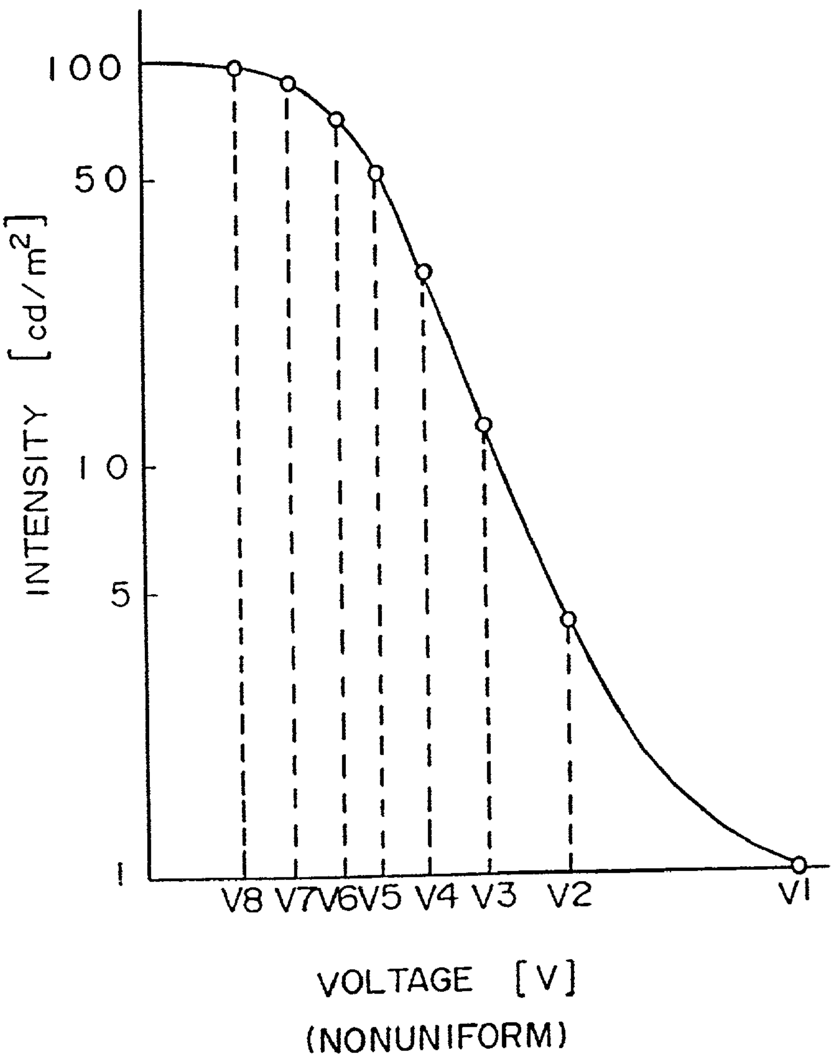

100
50
10
5
1
INTENSITY [cd/m2]
V8 V7 V6 V5 V4 V3 V2 V1
VOLTAGE [V]
(NONUNIFORM)

FIG. 14

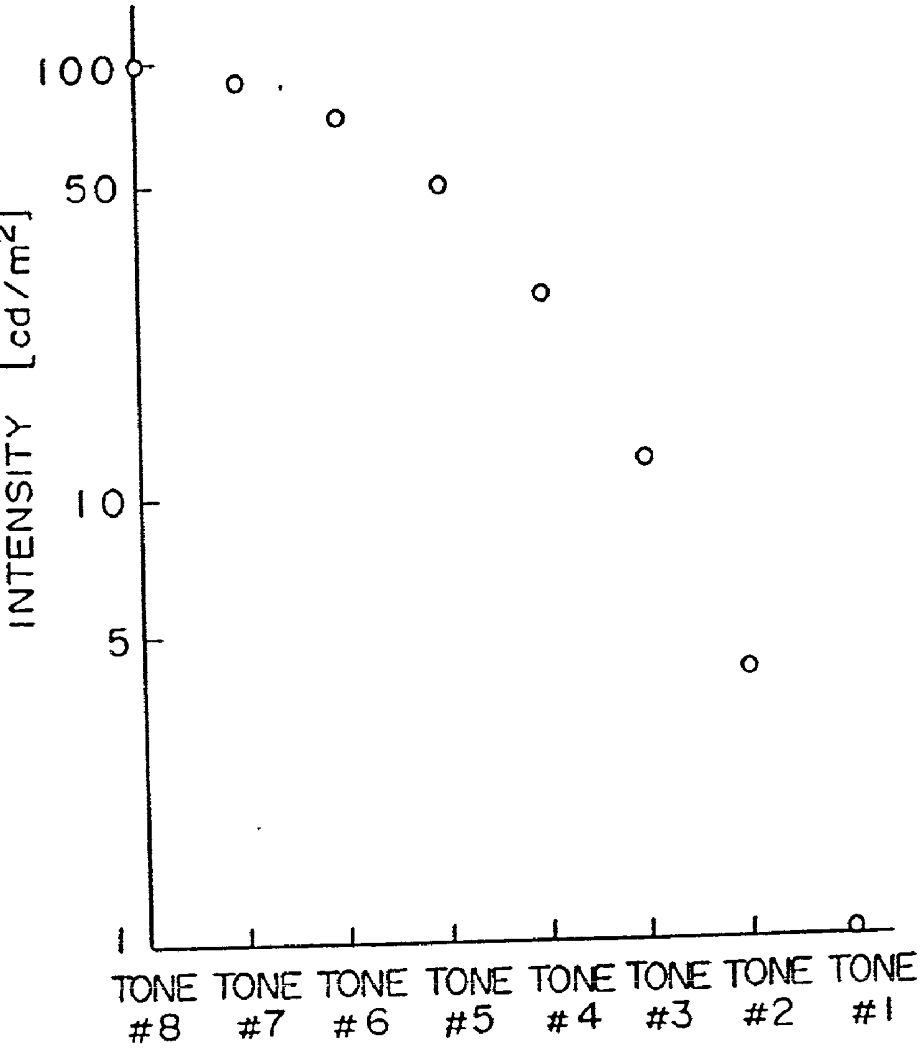
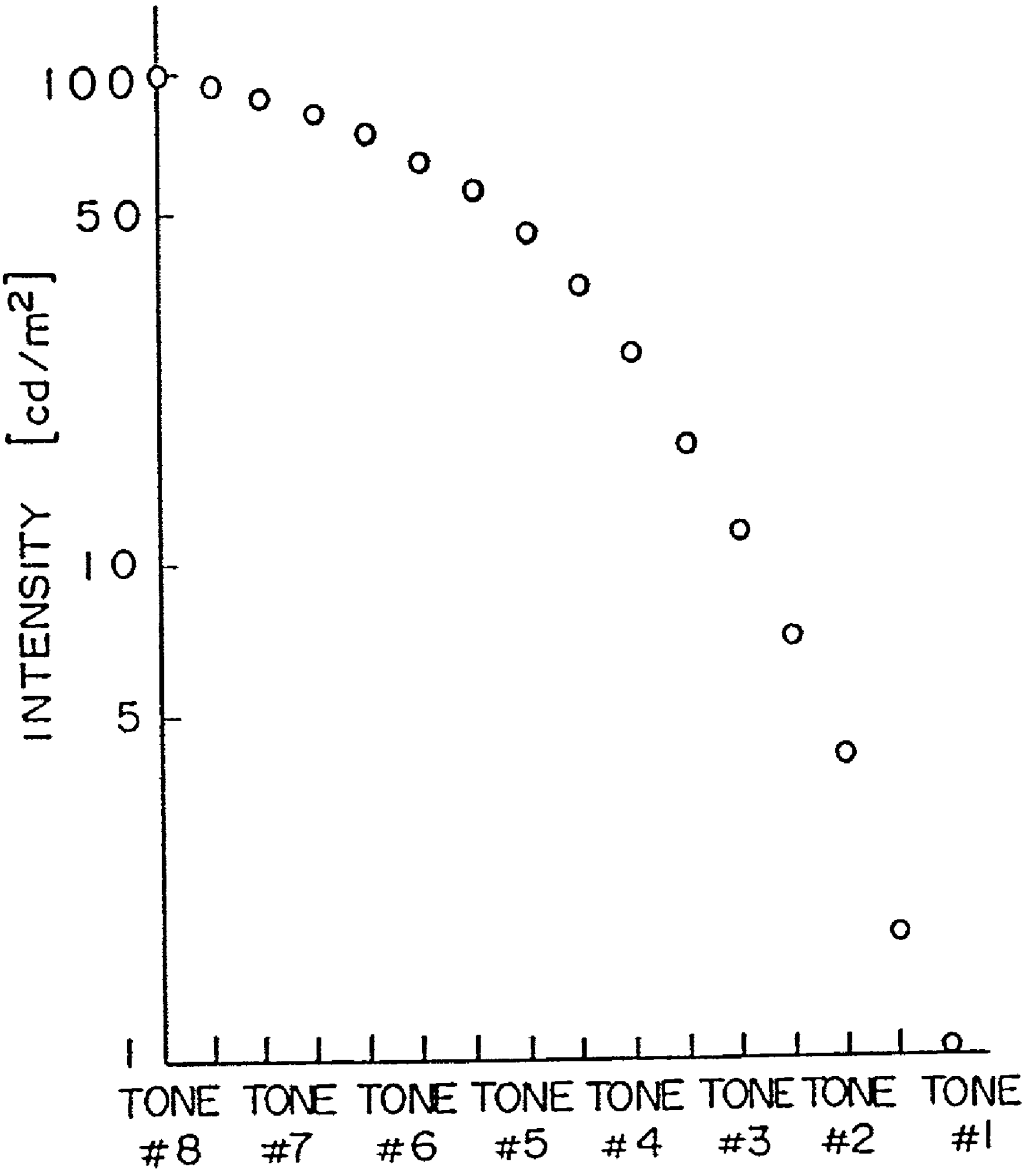

100
50
10
5
1
INTENSITY [cd/m2]
TONE #8
TONE #7
TONE #6
TONE #5
TONE #4
TONE #3
TONE #2
TONE #1

FIG. 15



100
50
10
5
1
INTENSITY [cd/m2]
TONE #8
TONE #7
TONE #6
TONE #5
TONE #4
TONE #3
TONE #2
TONE #1

MULTIPLE-TONE DISPLAY SYSTEM

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a display system of the dot matrix type, and a display method therefor. More particularly, it relates to a method of driving a display system for presenting multicolor/multiple-tone (or polytonal) displays, and a system therefor.

[0003] 2. Description of the Related Art

[0004] An LC (liquid-crystal) display system in the prior art displays an image in such a way that interface signals received as external inputs are converted into drive signals for driving the LC display system, that the drive signals are delivered to LC drive means, and that the LC drive means accepts for 8-level display data among the delivered drive signals every horizontal line of a frame and then affords the accepted data to an LC panel as 8-level LC drive voltages conforming to the display data. With this mode, 8 tones or gradations are displayed by the 8-level voltages divided uniformly or equally, as stated in "Lecturing thesis C-480", the Spring National Meeting of the Institute of Electronics, Information and Communication Engineers of Japan, 1991.

[0005] **FIG. 5** of the accompanying drawings illustrates the circuit arrangement of an 8-level uniform applied LC voltage generator (a generator by which the 8-level uniform voltages to be applied to the LC panel are produced) in the prior art. Numeral **27** indicates an LC driving supply voltage, which is divided into the 8-level voltages by resistors **28-36**. Operational amplifiers **37-44** are respectively connected to the nodes of the adjacent resistors **28-36**. Herein, the 8-level uniform voltages **22** to be applied to the LC panel (**8**-level voltages **V1-V8**) are produced by equalizing all the resistances of the resistors **29-35**. The values of the voltages **V1-V8** on this occasion are listed in Table 1 below. As can be understood from this table, all the voltage differences between the respectively adjacent levels are 0.7 [V].

TABLE 1

TONE	VOLTAGE VALUE [V]
#1	6.50
#2	5.80
#3	5.10
#4	4.40
#5	3.70
#6	3.00
#7	2.30
#8	1.60

[0006] **FIG. 8** is a diagram showing an example of the relationship between the applied voltage to the LC panel and the display intensity or brightness of this LC panel in the prior art. The levels of the display intensity correspond respectively to the 8-level applied LC voltages **V1-V8** obtained by uniformly dividing the supply voltage **27**. In the illustrated graph, the display intensity levels are plotted on a logarithmic scale.

[0007] In this manner, the 8-level applied LC voltages are based on the uniform voltage division in the prior-art example. The uniform LC voltages incur the problem that the displayed tones are not always seen uniformly or in a well-balanced manner by the human eye.

SUMMARY OF THE INVENTION

[0008] An object of the present invention is to provide a method of and a system for presenting multiple-tone displays in which tones or gradations are made visible to the human eye uniformly or in a well-balanced manner in consideration of the optical characteristics of the displays.

[0009] In the present invention, the object is accomplished by contriving 8-level applied LC voltage generation means so as to uniformalize or equalize the color differences between the respectively adjacent tones of a tonal display operation.

[0010] In one aspect of performance of the present invention, a multiple-tone display system wherein multiple-tone representations are presented on a display device which has a large number of pixels arrayed in a dot matrix shape consists in comprising a data converter for receiving multiple-tone display information which contain a plurality of bits per pixel, and then sequentially converting the multiple-tone display information into display data which correspond to one horizontal line of the display device; a drive voltage generator for generating a plurality of drive voltage levels which substantially uniformalize color differences between respectively adjacent ones of a plurality of tones that can be displayed by the multiple-tone display information containing the plurality of bits per pixel; a data driver connected to the drive voltage generator and data converter, for selecting one of the plurality of drive voltage levels from the drive voltage generator for every pixel on one line of the display device and then applying the selected drive voltage level to the display device in accordance with the display data delivered from the data converter; and a scan driver for selecting one of horizontal lines of the display device which is to be successively displayed, in synchronism with the operations of the data converter and data driver.

[0011] According to the above construction of the present invention, the multiple-tone or polytonal representations which can be seen uniformly or in a well-balanced manner by the human eye can be realized by uniformalizing or equalizing the color differences between the respectively adjacent tones in a tonal display operation. Such a function and effect will be clarified from the following detailed description of embodiments read with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is a block diagram of an embodiment of an 8-tone display system which adopts the present invention;

[0013] **FIG. 2** is a block diagram of an embodiment of a 16-tone display system which adopts the present invention;

[0014] **FIG. 3** is a timing chart for explaining the operation of an LC (liquid-crystal) drive signal generator depicted in **FIG. 1**;

[0015] **FIG. 4** is a diagram showing the pixel configuration of an LC panel depicted in **FIG. 1**;

[0016] **FIG. 5** is a circuit diagram showing the internal arrangement of an 8-level uniform applied LC voltage generator in the prior art;

[0017] **FIG. 6** is a block diagram of an 8-level data driver depicted in **FIG. 1**;

[0018] **FIG. 7** is a circuit diagram showing the internal arrangement of an 8-level voltage selector depicted in **FIG. 6**;

[0019] **FIG. 8** is a graph showing an example of the relationship between the applied voltage of an LC panel and the display intensity thereof in the prior art;

[0020] **FIG. 9** is a circuit diagram showing the internal arrangement of an 8-level applied LC voltage generator depicted in **FIG. 1**;

[0021] **FIG. 10** is a graph showing an example of the setting of 8-level applied LC voltages;

[0022] **FIG. 11** is a graph showing the characteristics of 8-tone display intensity levels which are attained by the voltage setting illustrated in **FIG. 10**;

[0023] **FIG. 12** is a graph showing the coordinates of a white display and a black display within the CIELUV uniform color space;

[0024] **FIG. 13** is a graph showing display intensity levels in the case of setting applied voltages so as to uniformalize color differences;

[0025] **FIG. 14** is a graph showing the characteristics of the 8-tone display intensity levels which are attained by the voltage setting illustrated in **FIG. 13**; and

[0026] **FIG. 15** is a graph showing the display intensity characteristics of a 16-tone display operation according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] First, an embodiment of the present invention will be described with reference to **FIG. 1**, **FIGS. 3 and 4**, **FIGS. 6 and 7**, FIGS. **9** thru **14**, and Table 2.

[0028] **FIG. 1** is a block diagram of the embodiment of a multiple-tone display system to which the present invention is applied. Referring to the figure, numeral **1** indicates "red" input display data, numeral **2**"green" input display data, numeral **3**"blue" input display data, and numeral **4** a clock signal. A set of input display data **1-3** correspond to one pixel, and is fed set by set in synchronism with the clock signal **4**. Each of the red input display data **1**, green input display data **2** and blue input display data **3** is composed of 3 bits, and which represents any of 8 tones. Here, the word "pixel" is intended to mean one lighting element for red, green or blue, and 3 pixels constitute one dot in the case of a color display system. The details of such pixels will be explained later. Further, numeral **5** indicates a horizontal clock signal, and numeral **6** a head signal. The display data corresponding to one horizontal line are fed in one cycle of the horizontal clock signal **5** (one horizontal period). Besides, the head signal **6** indicates the head line of the display data, and the display data corresponding to one frame are fed in one cycle of the head signal **6**. The multiple-tone display system in this embodiment comprises an LC (liquid-crystal) drive signal generator **7**, which produces LC display data **8**, a data clock signal **9**, an LC horizontal clock signal **10** and an LC head signal **11**. The LC drive signal generator **7** rearranges the input display data **1-3** into the order of R (red) pixels, G (green) pixels and B (blue) pixels for the purpose of presenting LC displays, whereupon it delivers the display data for 8 pixels in parallel. In this regard, each display data for one pixel is composed of 3 bits representing any of the 8 tones as stated before. Besides, the LC drive signal generator **7** receives the clock signal **4**, horizontal clock signal **5** and head signal **6** so as to produce the data clock signal **9**, LC horizontal clock signal **10** and LC head signal **11**, respectively.

[0029] An 8-level applied LC voltage generator **12** produces 8-level voltages **13** which are to be applied to an LC panel **20**. As will be explained later, the 8-level applied LC voltages **13** are obtained by dividing an LC driving supply voltage (**27** in **FIG. 9**) nonuniformly. An 8-level data driver **14**, a typical example of which is a product "HD66310" manufactured by Hitachi, Ltd., accepts the LC display data **8** for one horizontal line in accordance with the data clock signal **9**. Thereafter, it shifts the accepted data to its output stage in synchronism with the LC horizontal clock signal **10**. In accordance with the shifted data, one level is selected for each of the output data lines of the 8-level data driver **14** from among the 8-level applied LC voltages **13**, whereby LC horizontal data **15** are output. Accordingly, the 8-level data driver **14** delivers as the output LC horizontal data **15** the LC display data **8** of a horizontal line which is one line precedent to the line accepted by the data clock pulse **9**. The LC display data **8** are data which are conformed to the input specifications of the 8-level data driver **14**.

[0030] The inputs of the aforementioned product "HD66310" are such that the data for one pixel is composed of 3 bits, and that 4 pixels are received in parallel. In the ensuing description of the illustrated example, the inputs of the 8-level data driver **14** shall be so assumed that the data for one pixel is composed of 3 bits and that the 8 pixels (24 bits) are received in parallel. Shown at numeral **16** is a scan driver, which delivers its output to any of the first scan line **17**, the second scan line **18**, . . . and the nth scan line **19**. That is, the scan driver **16** produces its output voltage for selecting that one of the scan lines **17-19** which corresponds to the horizontal line for displaying the LC horizontal data **15** delivered from the 8-level data driver **14**. The LC panel **20** has a resolution of m horizontal dots (3·m pixels) and n vertical lines, and presents the 8-tone displays in accordance with the voltages of the LC horizontal data **15**.

[0031] **FIG. 3** is a timing chart of the various signals concerning the operation in which the LC drive signal generator **7** produces the LC display data **8** from the input display data **1-3** in the embodiment of **FIG. 1**. Symbol (a) in **FIG. 3** denotes the "red" input display data **1**, symbol (b) the "green" input display data **2**, and symbol (c) the "blue" input display data **3**. The data **1-3** are signals which are simultaneously fed pixel by pixel, and which for one pixel is 3-bit data representative of any one of 8 tones. Symbols (d)-(f) denote those parallel signals for 8 pixels into which the input display data **1-3** fed pixel by pixel as shown at (a)-(c) have been respectively converted. Symbol (g) denotes the LC display data **8**. The data **8** are those parallel data for 8 pixels into which all of the red, green and blue data have been rearranged in conformity with the pixel array of the LC panel **20**.

[0032] **FIG. 4** illustrates the pixel configuration of the color LC panel **20**. The 3 pixels of a "red" pixel **23**, a "green" pixel **24** and a "blue" pixel **25** constitute one dot **26**. The LC display data **8** are generated in conformity with the depicted pixel array.

[0033] **FIG. 9** illustrates an example of the internal circuit arrangement of the 8-level applied LC voltage generator **12** shown in **FIG. 1**. Numeral **27** indicates an LC driving supply voltage. The voltage generator **12** includes resistors **68-83**, and operational amplifiers **84-91**. Pairs of resistors **68** and **69**, **70** and **71**, **72** and **73**, **74** and **75**, **76** and **77**, **78** and **79**, **80** and **81**, and **82** and **83** divide the LC driving supply voltage **27** so as to deliver the 8-level applied LC voltages **13** (**V8**-**V1**) through the corresponding operational amplifiers **91-84**, respectively. In this embodiment, the voltages **13** to be applied to the LC panel **20** are set at a relationship of V1>V2>. . . >V7>V8. It is also assumed that the tone or gradation #1 (black display: lowest intensity or brightness level) of each pixel is attained by the voltage **V1**, that the tone #8 (white display: highest intensity level) thereof is attained by the voltage **V8**, and that the tones #2-#7 (half-tones: intermediate intensity levels) thereof are respectively attained by the other voltages V2-V7.

[0034] **FIG. 6** is a block diagram showing the details of the 8-level data driver **14**. Numeral **45** indicates a data shifter, and numeral **46** shifted data. The data shifter **45** accepts the LC display data **8** for one line within one horizontal period, and delivers them as the shifted data **46** in accordance with the data clock signal **9**. Besides, numeral **47** indicates a one-line latch, and numeral **48** display data. The one-line latch **47** latches the shifted data **46** corresponding to one line, and delivers them as the display data **48** in synchronism with the LC horizontal clock **10**. An 8-level voltage selector **49** selects one of the 8-level applied LC voltages **13** for each of the output lines thereof in accordance with the display data **48**, and delivers the selected voltage levels as the LC horizontal data **15** (X-D**1** to X-D**3**m) to the output lines. The symbols X-D**1** to X-D**3**m signify that the horizontal lines of the LC horizontal data **15** are in the number of (3×m) because the LC panel **20** has the resolution of the m horizontal dots each of which is composed of 3 pixels.

[0035] **FIG. 7** is a circuit diagram showing the internal arrangement of the 8-level voltage selector **49** of the 8-level data driver **14**. The voltage selector **49** includes a 3-to-8 decoder **50**, decoder output lines **51-58** and switching elements **59-66**. Numeral **67** indicates an LC horizontal data line, which is one of the output lines for the LC horizontal data (X-D1 to X-D3m). The 3-to-8 decoder **50** brings one of the decoder output lines **51-58** to "1" in accordance with the display data **48** each being composed of 3 bits per pixel, thereby turning "on" one of the switching elements **59-66**. Thus, one level of the 8-level applied LC voltages **13** is selected and is delivered to the LC horizontal data line **67**.

[0036] Now, the operation of this embodiment will be described.

[0037] Referring to **FIG. 1**, the LC drive signal generator **7** produces the LC display data **8** synchronous with the data clock signal **9** for the LC displays from the "red" input display data **1**, "green" input display data **2**, "blue" input display data **3** and clock signal **4**. Also, it produces the data clock signal **9**, LC horizontal clock signal **10** and LC head signal **11** which are LC driving signals, from the horizontal clock signal **5** and head signal **6**.

[0038] The 8-level applied LC voltage generator **12** produces the applied LC voltages (the voltages to be applied to the LC panel **20**) **13** of 8 levels whose voltage differences are set as desired as will be detailed later.

[0039] The 8-level data driver **14** produces the LC horizontal data **15** from the LC display data **8**, data clock signal **9**, LC horizontal clock signal **10** and 8-level nonuniform applied LC voltages **13**. The scan driver **16** accepts the "1" level of the LC head signal **11** in accordance with the LC horizontal clock signal **10**, and supplies the first scan line **17** with the selecting voltage (the output voltage of the scan driver **16** for selecting the horizontal line of the LC panel **20**). Thereafter, the selecting voltage of the scan driver **16** is successively shifted to the second scan line **18**, . . . and the nth scan line **19** in accordance with the LC horizontal clock signal **10**. Thus, one frame of the LC panel **20** is scanned. On this occasion, the displays conforming to the voltages of the LC horizontal data **15** fed from the 8-level data driver **14** are presented on that line of the LC panel **20** to which the selecting voltage has been delivered from the scan driver **16**. Incidentally, the color display operation is effected with 8^3 (512) colors on the basis of the combination of the 8 tones of the respective primary colors (red, green and blue).

[0040] A method of setting the 8-level applied LC voltages **13** adjusted to the visual characteristics of the human eye will be explained in detail.

[0041] The display intensity or brightness in the case of setting the voltages **V1**-**V8** nonuniformly is illustrated in **FIG. 10**. The display intensity characteristics of the 8 tones in this case become as shown in **FIG. 11**. Herein, the tones or gradations **#1**-**#8** are set so as to uniformalize the levels of the display intensity on a logarithmic scale.

[0042] **FIG. 12** illustrates the CIELUV uniform color space stipulated by the CIE (Commission International de l'Eclairage). The distance between coordinate points within this space expresses that difference of colors which is visible to the human eye. Marks * are affixed to the coordinate values of the coordinate point **92** of the black display based on the level V1 among the 8-level applied LC voltages **13** and the coordinate point **93** of the white display based on the level V8. These marks * indicate that psychological factors are considered in addition to coordinates (Y, u', v') obtained by an optical measurement. Shown at numeral **94** is the locus of coordinates obtained by changing the 8-level applied LC voltages **13** from the level V1 to the level V8 for each of the R, G and B pixels. Incidentally, the coordinates are obtained irrespective of the properties (LC material, color filter characteristics, etc.) of the LC panel **20** by conducting the optical measurement after the voltage setting. The method of the optical measurement in this embodiment will be stated below.

[0043] An optical measuring apparatus employed in this embodiment is a product "1980B" fabricated by PHOTO RESEARCH INC. The coordinate (Y) expressive of the intensity and the coordinates (u', v') expressive of the colors can be obtained by measuring light on the front surface of the LC panel **20** in SPECTRARADIOMETER MODE among the measurement modes of the apparatus "1980B". The range of the measurement is within a circle having a diameter of about 5 [mm] at the central part of the LC panel **20**. The same voltage is applied to all of the R, G and B pixels on each occasion. The coordinates (Y, u', v') obtained by the optical measurement for any desired voltage setting are computed in accordance with Eqs. (1), whereby they can be reduced to the coordinates within the CIELUV uniform color space:

$$L^* = 116\left(\frac{Y}{Y0}\right)^{1/3} - 16\left(\text{where } \frac{Y}{Y0} > 0.008856\right), \quad u^* = 13\,L^*(u' - u0'),\ v^* = 13\,L^*(v' - v0') \tag{1}$$

[0044] The distances between the coordinates contained in the CIELUV uniform color space are called "color differences" which are the differences of the colors seen by the human eye. Incidentally, coordinate values (**Y0**, u**0**', v**0**') express the intensity and color coordinates of a known reference color (for example, the white of a fluorescent lamp) . By way of example, the color difference (dE*) between the black display **92** based on the 8-level applied LC voltage **V1** and the white display **93** based on the voltage **V8** as shown in **FIG. 12** is computed by Eq. (2):

$$dE=\sqrt{(L8^*-L1^*)^2+(u8^*-u1^*)^2+(v8^*-v1^*)^2} \tag{2}$$

[0045] Herein, the exemplified distance is a distance in a straight line and is different from a distance extending along the locus **94** depicted in **FIG. 12**. Accordingly, the distance of the locus **94** can be found in such a way that, while the applied voltage is changed little by little between the levels **V1** and **V8**, the color differences involved between the respective voltages are computed, and that the computed color differences are added up. Incidentally, the above equations (1) and (2) are respectively contained on page 143 and page 149 in "Mitsuo Ikeda: Shikisai-kōgaku no Kiso (Fundamentals of Color Engineering)" (issued by Asakura Book Store in 1980).

[0046] In this embodiment, while the applied voltage is changed little by little (for example, every 0.1 or 0.2 [V]) between the levels **V1** and **V8**, the color differences involved between the respective voltages are calculated, and the calculated color differences are added up, thereby finding the distances involved between the respectively adjacent applied voltages and the distance along the locus **94**. According to the present invention, in order to uniformalize or equalize the color differences among the 8 tones or gradations of the display operation, the distance of the locus **94** is divided by (the number of tones−1), namely, by **7** in the case of the 8-tone display operation. Subsequently, a set of applied voltages (voltages to be applied to the LC panel **20**) are evaluated in order that the color differences between the respectively adjacent tones may substantially agree with a value obtained by the division.

[0047] After setting the applied voltages, the optical measurement is conducted for the individual tonal displays, and the color differences between the respectively adjacent tones are computed using Eq. (2). Herein, in a case where the computed color differences are different from the requested ones, the steps of the voltage setting, optical measurement and color difference computation are performed again. Such processing is iterated until the requested color differences are realized. Results thus obtained are listed in Table 2 below.

TABLE 2

Tone	Voltage value [V]	Color difference
#1	6.50	
#2	4.96	15.2
#3	4.92	15.4
#4	3.83	15.4
#5	3.43	15.4
#6	3.00	15.4
#7	2.51	15.3
#8	1.77	15.3

[0048] In this table, the value of each "color difference" represents the color difference with respect to the tone of the adjoining upper row. For example, the value of the color difference of the row of the tone #3 represents the color difference with respect to the tone #2. Here, the color differences are substantially uniform and are 15.3 on average.

[0049] The display intensity or brightness levels of the LC panel **20** attained by setting the 8-level applied LC voltages **13** as listed in Table 2 become as shown in **FIG. 13**, while the display intensity characteristics of the 8 tones become as shown in **FIG. 14**.

[0050] Meanwhile, an embodiment in the case of increasing the number of tones from 8 to 16 in accordance with an FRC (frame rate control) mode will be described with reference to **FIG. 2**, **FIG. 15**, and Tables 3 and 4.

[0051] The "FRC mode" is a method wherein the displays of two tones for a certain pixel are changed-over alternately in successive frames (each frame corresponding to one frame scan period), thereby attaining a tone intermediate between the two tones.

[0052] **FIG. 2** is a block diagram of the embodiment of an LC (liquid-crystal) multiple-tone display system which employs the FRC mode. Referring to the figure, numeral **95** indicates "red" input display data, numeral **96**"green" input display data, numeral **97**"blue" input display data, and numeral **4** a clock signal. In this embodiment, each of the input display data **95-97** is assumed to be 4-bit data which is fed in synchronism with the clock signal **4**. Shown at numeral **98** is a tone controlling LC drive signal generator, which delivers LC display data **8**, a data clock signal **9**, an LC horizontal clock signal **10** and an LC head signal **11**. More specifically, the tone controlling LC drive signal generator **98** converts the input display data **95-97** each being composed of 4 bits, into the LC display data **8** composed of 3 bits. Also, it produces the data clock signal **9**, LC horizontal clock signal **10** and LC head signal **11** in the same manner as in the foregoing embodiment. An 8-level applied LC voltage generator **12** produces 8-level applied LC voltages (voltages to be applied to an LC panel **20**) **13** for the FRC mode. A method of converting the 4-bit input display data **95-97** into the 3-bit LC display data **8**, and a method of setting the 8-level applied LC voltages **13** will be detailed later. An 8-level data driver **14**, a scan driver **16** and the LC panel **20** are similar to the corresponding devices in the case of the 8-tone display operation, respectively.

[0053] **FIG. 15** is a graph showing the display intensity or brightness characteristics of 16-tone displays which are presented in each of colors R (red), G (green) and B (blue) by this embodiment.

[0054] In order to explain the details of the operation of this embodiment, **FIGS. 2 and 15** will be referred to again.

[0055] In the construction of **FIG. 2**, the LC drive signal generator **98** produces the LC display data **8** of 3 bits synchronous with the data clock **9** for the LC display operation, on the basis of the "red" input display data **95**, "green" input display data **96** and "blue" input display data **97** which are respectively fed in serial 4-bit units and in synchronism with the clock signal **4**. An example of the conversion of the 4-bit data into the 3-bit data is indicated in Table 3 below

[0056] That is, Table 3 exemplifies the data of 16-tone displays and the values of attained color differences in this embodiment.

TABLE 3

Tone	4-bit data	3-bit data	Voltage value [V]	Color diff.
#1	0000	000	6.50	
#2	0001	000–001	6.50–4.57	4.695
#3	0010	001	4.57	5.751
#4	0011	001–010	4.57–4.02	6.242
#5	0100	010	4.02	6.943
#6	0101	010–011	4.02–3.72	6.212
#7	0110	011	3.72	6.714
#8	0111	011–100	3.72–3.37	7.240
#9	1000	100	3.37	7.435
#10	1001	100–101	3.37–3.12	8.192
#11	1010	101	3.12	8.059
#12	1011	101–110	3.12–2.77	7.573
#13	1100	110	2.77	7.585
#14	1101	101–111	3.12–1.77	5.689
#15	1110	110–111	2.77–1.77	7.072
#16	1111	111	1.77	10.707

[0057] Each of the tones which indicates two sorts of 3-bit data, is subjected to the FRC mode. The tone controlling LC display data generator **98** changes-over the two sorts of data alternately in the successive frames.

[0058] Besides, the LC drive signal generator **98** produces the data clock signal **9**, LC horizontal clock signal **10** and LC head signal **11** which are LC driving signals, from a horizontal clock signal **5** and a head signal **6** in the same manner as in the foregoing case of the 8-tone display operation.

[0059] The 8-level applied LC voltage generator **12** produces the 8-level applied LC voltages (voltages to be applied to the LC panel **20**) **13** the differences of which are set as desired. The voltages are set so that the LC panel **20** may exhibit intensity or brightness characteristics similar to those in the case of the 8-tone display operation. The values of the voltages and the color differences between the respectively adjacent tones or gradations on that occasion are listed in Table 3. As seen from the table, the color differences have errors of ±50 [%] or so with respect to their average value of 7.1, but the errors pose no problem in vision. The 16-tone display intensity characteristics shown in **FIG. 15** are similar to the 8-tone display intensity characteristics shown in **FIG. 14**. Incidentally, the large errors of the color differences in this embodiment are ascribable to the fact that, with the FRC operation, when the voltage value of any tone not based on the FRC (for example, the tone #3) is changed, also the voltage values of the FRC-based tones adjoining the tone (the tones #2 and #4) change, so the color differences are difficult to be uniformalized.

[0060] The 8-level data driver **14** produces LC horizontal data **15** from the LC display data **8**, data clock signal **9**, LC horizontal data **10** and 8-level nonuniform applied LC voltages **13** in the same manner as in the foregoing embodiment shown in **FIG. 1**. The scan driver **16** accepts the "1" level of the LC head signal **11** in accordance with the LC horizontal clock signal **10**, and supplies the first scan line **17** with a selecting voltage. Thereafter, the selecting voltage of the scan driver **16** is successively shifted to the second scan line **18**, . . . and the nth scan line **19** in accordance with the LC horizontal clock signal **10**. Thus, one frame of the LC panel **20** is scanned. On this occasion, the LC horizontal data **15** fed from the 8-level data driver **14** are presented on that line of the LC panel **20** to which the selecting voltage has been delivered from the scan driver **16**.

[0061] Moreover, 16 tones or gradations which are seen uniformly or in a well-balanced manner in each of the colors of "red", "green" and "blue" by the human eye can be attained by modifying the embodiment of **FIG. 2** as follows: The 8-level applied LC voltage generators **12** are disposed for the colors of red, green and blue independently of one another. Also, the tone controlling LC drive signal generator **98** converts the 4-bit data into the 3-bit data for the colors of red, green and blue independently of one another.

[0062] Table 4 indicates another example of the combination between a voltage setting and the FRC mode for presenting 16-tone displays which have the intensity or brightness characteristics as shown in **FIG. 15**. Even when the combination is changed, the 16-tone displays uniformly visible to the human eye can be realized by conforming the intensity characteristics to those shown in **FIG. 15**.

TABLE 4

Tone	Voltage value [V]
#1	7.00
#2	7.00–4.60
#3	7.00–4.00
#4	4.60
#5	4.60–4.00
#6	4.00
#7	4.00–3.62
#8	3.62
#9	3.62–3.21
#10	3.21
#11	2.99
#12	2.99–2.59
#13	2.59
#14	3.21–0.01
#15	2.99–0.01
#16	0.01

[0063] Even in a case where the number of tones or gradations has been further increased, tonal displays seen to be uniform by the human eye can be presented by conforming intensity or brightness characteristics to a curve as shown in **FIG. 15**.

[0064] According to the present invention, the color differences between the respectively adjacent tones of a tonal display operation are uniformalized, whereby multiple-tone displays uniformly visible to the human eye can be realized.

What is claimed is:

1. A multiple-tone display system wherein multiple-tone representations are presented on a display device which has a large number of pixels arrayed in a dot matrix, comprising:

data conversion means for receiving multiple-tone display information which contain a plurality of bits per pixel, and then sequentially converting said multiple-tone display information into display data which correspond to one horizontal line of said display device;

drive voltage generation means for producing a plurality of drive voltage levels which substantially uniformalize color differences between respectively adjacent ones of a plurality of tones that can be displayed by said multiple-tone display information containing said plurality of bits per pixel;

data drive means connected to said drive voltage generation means and said data conversion means, for selecting one of said plurality of drive voltage levels from said drive voltage generation means for every pixel on one line of said display device and then applying the selected drive voltage level to said display device in accordance with said display data delivered from said data conversion means; and

scan drive means for selecting one of horizontal lines of said display device which is to be successively displayed, in synchronism with the operations of said data conversion means and said data drive means.

2. A multiple-tone display system as defined in claim 1, wherein said drive voltage generation means includes a group of voltage dividing resistors which divide a reference voltage by respective unequal voltage division ratios for predetermining said drive voltage levels.

3. A multiple-tone display system as defined in claim 1, wherein each of said pixels of said display device includes a switching element, and a liquid crystal which is controlled by said switching element.

4. A multiple-tone display system as defined in claim 1, wherein one-display dot is constituted by three pixels of red, green and blue in said display device, and wherein color displays in M^3 colors can be presented where letter M denotes the number of said drive voltage levels.

5. A multiple-tone display system as defined in claim 4, wherein said data conversion means includes data converters for red, green and blue which are respectively disposed independently of one another.

6. A multiple-tone display system as defined in claim 1, wherein said multiple-tone display information contain m bits (where m denotes an integer of at least 2) per pixel, and wherein said drive voltage generation means produces M drive voltage levels (where $M=2^m$).

7. A multiple-tone display system as defined in claim 6, wherein said multiple-tone display information contains one bit added to said m bits per pixel, and wherein said drive voltage generation means includes voltage change-over means for delivering two unequal drive voltage levels while changing them over alternately in successive frames of said display device, and it produces substantially N drive voltage levels (where N denotes $2^{(m+1)}$) on the basis of said M drive voltage levels by the use of said voltage change-over means.

8. A multiple-tone display system as defined in claim 7, wherein said drive voltage generation means sets errors of said color differences between the respectively adjacent tones so as to be within ±50 [%].

9. A multiple-tone display system as defined in claim 1, wherein said drive voltage generation means includes voltage change-over means for delivering two unequal drive voltage levels while changing them over alternately in successive frames of said display device, and it produces substantially N (N>M) drive voltage levels where letter M denotes the number of said drive voltage levels.

10. A multiple-tone display system as defined in claim 9, wherein said drive voltage generation means sets errors of said color differences between the respectively adjacent tones so as to be within ±50 [%].

* * * * *

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其他公开文献	US6437765		
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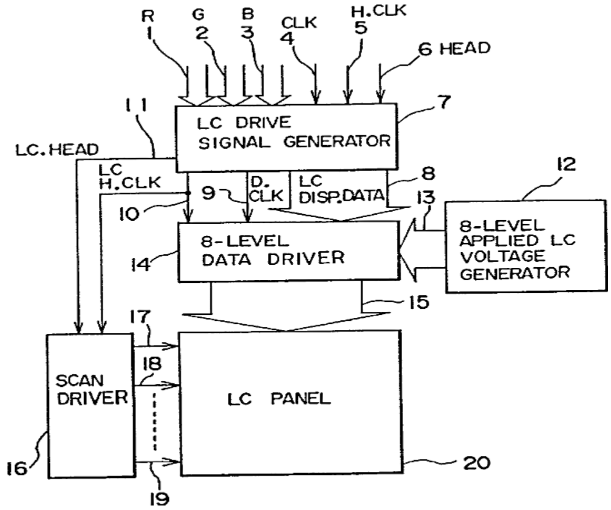
摘要(译)

一种用于多色调显示器的点阵显示系统，包括其中像素以矩阵形状排列的显示装置，将彩色显示数据转换为LC显示数据的LC（液晶）驱动信号发生器，8级数据驱动器根据LC显示数据选择8级电压中的一个，然后输出所选择的电压，并且产生8级施加的LC电压发生器，通过该发生器施加要施加到像素的8级电压，以便基本上均匀化多色调显示器的各个相邻色调之间的色差。由于各个相邻音调之间基本上均匀的色差，可以实现人眼均匀看到的多色调显示。


R
G
B
CLK
H.CLK
1
2
3
4
5
6 HEAD
LC DRIVE
SIGNAL GENERATOR
7
11
LC. HEAD
LC
H.CLK
9
D.
CLK
LC
DISP.DATA
8
10
13
12
8-LEVEL
APPLIED LC
VOLTAGE
GENERATOR
14
8-LEVEL
DATA DRIVER
15
17
18
SCAN
DRIVER
LC PANEL
16
19
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