(19) Europäisches Patentamt
European Patent Office
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(11) EP 0 821 337 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
28.01.1998 Bulletin 1998/05

(51) Int. Cl.[6]: **G09G 3/36**, G09G 3/30

(21) Application number: **97112162.9**

(22) Date of filing: **16.07.1997**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE

(30) Priority: **22.07.1996 US 681045**

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(54) Active matrix pixel drive circuit with switching device and symmetrical follower circuit

(57) A two transistor pixel drive circuit is presented for use with active matrix displays. A first transistor (T1) transfers video information from a video line to a storage capacitor (C_{s2}) when strobed. The stored charge modulates an alternating current (56, 60) flowing through a second transistor (T2). A light-modulating element (44), in series with an AC power supply (56) in one leg of the second transistor (T2), is activated by the modulated current for the duration of a frame time. A second AC power supply (60), in series with an additional capacitance (C_a) in the other leg of the second transistor (T2), generates a waveform of equal magnitude and opposite polarity to the first supply (56). The additional capacitance (C_a) provides an impedance that is about equal to that of the light-modulating element (44) at the activation frequency provided by the AC supplies (56, 60). With equal impedances in each leg of the second transistor (T2), a symmetrical circuit is created that holds the input to the second transistor (T2) at a fairly constant DC level independent of the relative phase between the strobe and AC power supply waveforms. This feature prevents the appearance of moving bands across the display.

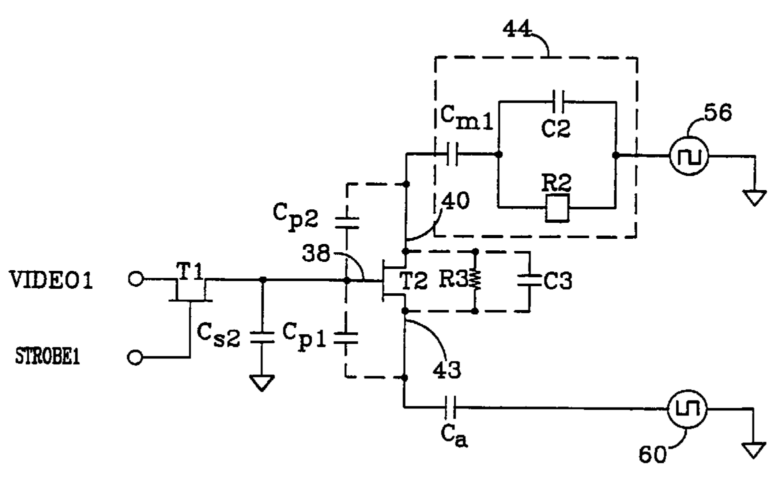

FIG.4

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to the field of pixel drive circuits, particularly those used to drive active matrix LCD displays.

Description of the Related Art

A pixel is the smallest resolvable and addressable segment of a display screen. A pixel comprises a light-modulating element, such as a liquid crystal device (LCD) or an electro-luminescent device, and a drive circuit to control the element in response to a video signal. A number of pixels are arranged in rows and columns to form a display. When the drive circuit employs a transistor to modulate current through the light-modulating element, the display is called an "active matrix."

A conventional active matrix is shown in FIG. 1. Each pixel in a given column is connected to a video signal (VIDEO1-VIDEO3), and each row is connected to a strobe line (STROBE1-STROBE3). Each pixel 10 includes a drive circuit, typically a FET transistor 12, and a light-modulating element 14. All the pixels in the matrix are essentially identical. An image is formed on the display by placing video information on the video lines (VIDEO1-VIDEO3), and sequentially activating the strobe lines (STROBE1-STROBE3) to "address" each row. When a row is addressed, the transistor 12 is switched on and the information on the video line is transferred to the light-modulating element; when not addressed, all transistors in a row are switched off, and conduct no current. The amount of time used to address one row is the "line time," and the time needed to address all rows of the matrix is called the "frame time." A display must be updated about 30 times a second to avoid the appearance of flickering, necessitating a frame time of 32 ms or less. Displays of this type are discussed in L. Tannas, Jr., Flat-Panel Displays and CRTs, Von Nostrand Reinhold Company Inc. (1985), pp. 113-116.

A conventional drive circuit and the equivalent circuit of an LCD light-modulating element as might be used in the active matrix of FIG. 1 are shown in FIG. 2. The gate 20 of the FET transistor 12 is connected to STROBE1, and the transistor's drain 22 is connected to VIDEO1. When STROBE1 is activated, the transistor 12 is switched on and conducts current from its drain 22 to its source 24. The light-modulating element 14 is connected to the source 24 and modulates light in response to the current received through transistor 12. The equivalent circuit for light-modulating element 14 includes an inherent resistance R1 and an inherent capacitance C1.

FIG. 1 shows an example of an active matrix with only three rows, but a practical modern display typically has hundreds of rows. To maintain a 30 frame per second update rate for a 1000 row display, each row can be addressed for only 32 μs. During this short time, a relatively large charge representing the video signal must be transferred by transistor 12 to the light-modulating element 14, where it is stored on inherent capacitor C1. With a duty cycle of 1/1000, it is difficult if not impossible to keep the element activated throughout the frame.

To minimize the decay of the voltage on the light-modulating element 14 within a frame time, and with it the light on the display, a large storage capacitance C_{s1} is usually added to the drive circuit. The resistance R1 of the element is also maximized so that a time constant is created by C1, C_{s1} and R1 that will keep the light-modulating element 14 essentially fully activated for the whole duration of a frame time.

There are quite a few disadvantages to this circuit, which is manufactured using integrated circuit fabrication techniques:

1) Since a large storage capacitance is needed, C_{s1} is fabricated with a thin dielectric layer having a large area. Pinholes through the thin layer are common, which results in a defective pixel.

2) The light-modulating element 14 is often an organic material, as is the case with an LCD. The inherent resistance of such a material will decrease over time, reducing the time constant obtained with R1, C1 and C_{s1}, and thus the display's brightness.

3) During the short time in which transistor 12 is switched on (32 μs for a 1000 row display), enough current must be conducted through the transistor to maintain the brightness of the light-modulating element for one entire frame time (32 ms). The need to conduct this large burst of current requires a large transistor, which takes up a considerable amount of area on an I.C. layout and leaves. less room for light transmission.

4) The organic materials from which an LCD is made, such as MLC-9500-000 from Merck of Darmstadt , Germany, must be activated with an AC signal. If a DC signal is used, the material's ions can be pulled apart and the element destroyed. Also, many light-modulating elements, including LCDs and some electro-luminescent devices, consist of a number of layers on either side of a light-modulating layer, some of which are made of a dielectric material. A reflective mode LCD, for example, uses a dielectric layer to form a dielectric mirror. These dielectric layers will not conduct a DC signal to the modulating layer, so an AC signal must be used. To accomplish this, the polarity of the video signal connected to transistor 12 must be inverted with each frame, producing a quasi-AC signal across element 14. With a frame rate of about 30 frames per second, the AC frequency is about 15 Hz. This low frequency, referred to as the "activation frequency," does not transfer well through the dielectric layers

mentioned above.

SUMMARY OF THE INVENTION

A two transistor pixel drive circuit is presented that solves the problems listed above, requires no more area than past designs, and may provide higher fabrication yields.

A switching device, preferably a transistor, is connected to a video signal and a strobe line, as before. When the strobe line is pulsed, the transistor conducts and charges a capacitance with current from the video signal, with the charge stored on the capacitance after the strobe signal ends. However, instead of using this charge to directly activate a light-modulating element, the stored charge is connected to the gate of a second transistor which modulates the flow of current from a separate current source to the light-modulating element, providing a current sufficient to activate the element for the duration of a frame time. Since the first transistor need only control the second transistor, and the current to the light-modulating element can be supplied continuously rather than in a short burst, both transistors can be small. In fact, both transistors, which are preferably FETs, can be accommodated in the same area that a single large transistor previously required. This feature also allows the use of a much smaller storage capacitance, reducing the possibility of pixel defects due to pinholes, and increasing fabrication yields.

The current source is AC, which provides the alternating polarity needed to transfer video information through the dielectric layers of some types of light-modulating elements, eliminating the need to alternate the polarity of the video signal. Use of an AC current also allows the activation frequency to be much higher than the 15 Hz of prior designs, which permits the inherent resistance of the light-modulating element to be lower than before, and reduces the problems associated with an inherent resistance that lessens over time.

The preferred embodiment of the pixel drive circuit connects in series a first AC power supply, the light-modulating element, the drain-source circuit of the second transistor, an additional capacitance and a second AC power supply. The pixel's activation frequency is established by the first and second AC power supplies, which generate waveforms that are about equal in magnitude and 180 degrees out-of-phase with each other, so that current flows through the transistor in one direction during one-half cycle of the activation frequency, and in the other direction during the other half cycle. The additional capacitance provides an impedance that is about equal to that of the light-modulating element at the activation frequency. The matched impedances in the legs of the second transistor create a symmetrical circuit, which holds the gate input to the second transistor at a fairly constant DC level independant of the relative phase of the strobe and the power supplies. Without the matched impedances, the gate input to the second transistor may drift due to a relative phase difference between the AC power supplies and the strobe signal, resulting in moving bands on the display screen.

Further features and advantages of the invention will be apparent to those skilled in the art from the following detailed description, taken together with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a prior active matrix.

FIG. 2 is a schematic diagram of a prior pixel drive circuit.

FIG. 3 is a schematic diagram of a two transistor pixel drive circuit in accordance with the invention.

FIG. 4 is a schematic diagram of the preferred embodiment of the invention.

FIG. 5 is a schematic diagram of an active matrix display using pixel drive circuits as shown in FIG. 4.

DETAILED DESCRIPTION OF THE INVENTION

A two transistor pixel drive circuit which provides significant performance improvements over past designs is shown in FIG. 3. A switching device, preferably a FET transistor T1, has its gate 30 connected to a strobe signal STROBE1 and its drain connected to a video signal VIDEO1. T1 is used as a switch, and when STROBE1 is pulsed T1 conducts current between its drain 32 and source 34. Video information present at the drain 32 when T1 is "strobed," i.e., switched on by a pulse on the strobe line, is stored on a storage capacitor C_{s2} which is connected to T1's source 34. The common node 36 formed by T1's source and one side of C_{s2} is connected to the gate 38 of a second transistor T2, and the stored voltage on C_{s2} modulates the conductance of T2. T2's drain 40 is preferably connected to an AC power supply 42 and its source 43 is connected to a light-modulating element 44. Current derived from AC power supply 42 flows through and is modulated by T2 in accordance with the stored voltage on C_{s2}, to activate the light-modulating element 44.

This circuit configuration offers several advantages over previous designs. T1 is switched on and conducts current just once per frame time, for about 32 μs. With the prior circuit of FIG. 2, storage capacitor C_{s1} needs to receive enough current in 32 μs to activate the light-modulating element for an entire frame time, without losing a significant fraction of its charge. With the invention, however, C_{s2} need only store enough charge to modulate T2. Therefore, C_{s2} is very small, on the order of 1 pF, and in some cases could be just the parasitic capacitance of T2's gate-source junction. This lower charge requirement also means that T1 can be much smaller than before. Additionally, since the current needed to activate the light-modulating element 44 can be supplied continuously throughout the frame time, T2 can also be small.

Another major advantage is that the activation frequency, which was previously only 15 Hz and required the video signal to alternate its polarity for each frame time, is now derived from the AC power supply 42. The video signal need only be of one polarity, and the alternating polarity necessary to activate an organic light-modulating element 44 formed from dielectric layers is provided by the AC supply, which can have a very high activation frequency, preferably between 100 Hz and 10 MHz. Light-modulating element 44 has an inherent resistance R2 and capacitance C2; a higher activation frequency permits R2 to be small and to degrade over time, because a long time constant is no longer needed to maintain the element's brightness essentially constant over a full frame time. Also, dielectric layers, such as a dielectric mirror (represented by C_m) that might be found in a reflective LCD, are not a problem at higher activation frequencies since the AC is easily transmitted through these layers.

The circuit of FIG. 3, while providing many advantages over existing designs, has one important disadvantage. Parasitic capacitances C_{p1} and C_{p2} exist between the gate 38 and source 43 and the gate and drain 40, respectively, of T2. These capacitances are charged by the instantaneous voltages existing between T2's gate and source and gate and drain, which depend on the relative phase between the strobe signal STROBE1 and the AC power supply 42 waveform. The charges stored by the parasitic capacitances causes the voltage on the gate 38 of T2 to vary from the value that accurately represents the video signal after T1 is switched off. Thus the conductance of T2, and therefore the light modulation provided by the light-modulating element, are partly dependent upon this relative phase.

The same situation occurs in the other rows of an active matrix display, except that the relative phase between the strobe signal and the AC power supply waveform will be different for each row, and will thus affect the conductance of respective T2's differently. The net result is that a moving band is seen on the display due to the variation in relative phase from row to row.

The present invention, the preferred embodiment of which is shown in FIG. 4, offers a pixel drive circuit that solves the relative phase problem of the FIG. 3 circuit, while retaining that circuit's advantages. As before, transistor T1 is connected to a strobe line (STROBE1) and a video signal (VIDEO1). When the strobe line is pulsed, T1 is briefly switched on and conducts current to charge a storage capacitance C_{s2}. The DC voltage on C_{s2} is proportional to the voltage of VIDEO1 at the time of the strobe pulse. This DC voltage is applied to the gate 38 of second transistor T2 to modulate T2's conductance. Connected in series with the drain 40 of T2 is a light-modulating element 44 and a first AC power supply 56. Connected in series with the source 43 of T2 is a capacitor C_a and a second AC power supply 60. The light-modulating element 44 is activated by the current that flows through T2, which is modulated in accordance with the DC voltage at its gate 38, which in turn reflects the level of the VIDEO1 signal strobed into the pixel.

C_a is selected to provide an impedance that is about equal to the impedance of the light-modulating element 44. T2 is designed to be highly symmetrical, so that the parasitic capacitance C_{p1} that may exist between T2's gate 38 and source 43 is about equal to a parasitic capacitance C_{p2} between T2's gate and drain 40. Finally, AC power supplies 56 and 60 provide voltage waveforms that are about equal in magnitude and about 180 degrees out-of-phase. Under these conditions, via the mechanism described below, the voltage at the gate 38 of T2 will remain about constant while T1 is switched off, regardless of the phase relationship between either AC power supply and the strobe pulse. With a constant voltage at gate 38, no moving bands are seen on the display.

The relative phase problem is solved by making the circuits on either side of transistor T2 symmetrical. T2 itself is built so that its gate-drain and gate-source resistance and capacitance characteristics are nearly equal, and the impedance of the light-modulating element 44 and C_a are also closely matched. This symmetry is the key feature that makes the circuit independant of the relative phase between the strobe signal and the AC supplies. A strobe signal that comes when AC power supply 56 is high and AC supply 60 is low will have the same effect on T2's gate voltage as when a strobe comes and the supply polarities are the opposite way. The impedances in each leg of T2 create a source follower circuit with T2, with each acting as a feedback impedance for one-half of a cycle of the activation frequency generated by the the AC supplies. Charge that does arise from the relative phases between the AC supplies and strobe signal is stored on the parasitic capacitances C_{p1} and C_{p2} during one-half of a cycle. When the waveforms from the AC power supplies invert, C_{p1} simply exchanges its charge with C_{p2}, making the voltage at gate 38, and the circuit, independent of the relative phase difference. The frequency of the AC power supplies is the activation frequency, which is preferably about 2 kHz or more. The circuit will work as described as long as the waveforms from the AC supplies are periodical, including square waves and sinusoidal waveforms, have equal magnitudes, and are 180 degrees out-of-phase.

Most transistors, including the transistor T2 shown in FIG. 4, have an inherent resistance R3 and capacitance C3 between their drain and source which create leakage paths through the transistor when the transistor is switched off. A light-modulating element such as a liquid crystal typically has a characteristic threshold or "pedestal" voltage which a modulating signal must exceed before the element exhibits an electro-optical effect. When there is zero video signal to a pixel, T2's off-state leakage current must be low enough to keep the light-modulating element 44 below its threshold voltage. This is accomplished by keeping the physical dimensions of T2 small, which is made possible by the reduced current carrying requirements of the circuit.

To determine an appropriate value for C_a, the impedance of the light-modulating element must be determined. The equivalent circuit of an LCD is shown in FIG. 4, which includes an inherent resistance R2 and capacitance C2 in parallel, in series with capacitance C_{m2} introduced by a dielectric mirror if the display operates in a reflective mode. The impedance at a particular activation frequency is calculated in a conventional manner, as is described for example in Hayt and Kemmerly, Engineering Circuit Analysis, McGraw-Hill, Inc. (1971), pp. 261-263. For activation frequencies above about 1 kHz, the resistive component of the light-modulating element's impedance becomes negligible, and a simple capacitor having about the same impedance will be a good match for the light-modulating element. A good match is obtained if the two impedances are within about 3% of each other.

The AC waveforms used to control the light-modulating elements must have a magnitude and frequency sufficient to properly activate and control the elements for the full duration of a frame time, and must be able to produce complementary outputs. The magnitude and frequency values needed depend on the type of light-modulating element used. For most LCDs, a magnitude of 10-30 volts peak-to-peak and an activation frequency of about 2 kHz is sufficient.

Only a small amount of charge is needed to control the conductance of T2, and the capacitance provided by parasitic capacitances C_{p1} and C_{p2} may store enough charge to provide this function. Therefore, storage capacitance C_{s2} may not be needed.

An active matrix incorporating the two transistor pixel drive circuit of FIG. 4 is shown in FIG. 5. All pixels in the matrix are essentially identical. Each pixel location includes a second transistor (T2) and an additional capacitor (C_a), and the matrix receives the complementary AC waveforms produced by AC power supplies 56 and 60.

The active matrix shown in FIG. 5 is fabricated using conventional techniques. Since the two transistors of this design can be considerably smaller than the large single transistor of the prior art, this design requires no additional area per pixel. Also, using two smaller transistors and a smaller storage capacitor is likely to result in a higher fabrication yield than is realized by previous single transistor designs. Fabrication of active matrix displays is discussed in L. Tannas, Jr., Flat-Panel Displays and CRTs, Von Nostrand Reinhold Company Inc. (1985), pp. 130-136. The present invention imposes no limits on the size of an active matrix that can be formed from pixels as described herein.

Switching device T1 is preferably a FET, due to the ease with which a FET is integrated with the other pixel components. Other devices that connect one terminal to another on command will work, however, including bipolar transistors, and mechanical switches and relays; these devices are likely to be more difficult or impossible to integrate with the other pixel components.

Transistor T2 is preferably a MOSFET: a MOSFET's very high input impedance helps the storage capacitance maintain its charge, and a MOSFET is easily integrated with the other drive circuit components. A thin-film type of FET (TFT) is preferred in this application. Other current modulating devices may be used as well, however, including bipolar transistors. It is important that the device used be capable of symmetrical operation for either direction of current flow, i.e., symmetrical parasitic capacitance, breakdown voltage, for example, and that the device have a high input impedance, for the reason stated above.

Light-modulating element 44 is preferably an LCD, and will work equally with in either reflective or transmissive modes. However, other types of light-modulating elements having a structure that requires an AC signal to activate the element may benefit from the pixel drive circuit. For example, electro-luminescent displays, which typically require an AC voltage to excite their phosphors, may be able to use the pixel drive circuit. Electro-luminescent devices typically require a activation higher voltage than does an LCD however. The construction of LCDs and electro-luminescent devices is discussed in L. Tannas, Jr., Flat-Panel Displays and CRTs, Von Nostrand Reinhold Company Inc. (1985), pp. 247-250 and 426-432.

In summary, a two transistor pixel drive circuit is presented for use with active matrix displays. A first transistor T1 transfers video information from a video line to a storage capacitor C_{s2} when strobed. The stored charge modulates an alternating current 56, 60 flowing through a second transistor T2. A light-modulating element 44, in series with an AC power supply 56 in one leg of the second transistor T2, is activated by the modulated current for the duration of a frame time. A second AC power supply 60, in series with an additional capacitance C_a in the other leg of the second transistor T2, generates a waveform of equal magnitude and opposite polarity to the first supply 56. The additional capacitance C_a provides an impedance that is about equal to that of the light-modulating element 44 at the activation frequency provided by the AC supplies 56, 60. With equal impedances in each leg of the second transistor T2, a symmetrical circuit is created that holds the input to the second transistor T2 at a fairly constant DC level independent of the relative phase between the strobe and AC power supply waveforms. This feature prevents the appearance of moving bands across the display.

While particular embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

Claims

1. A pixel drive circuit, comprising:

   a switching device (T1) that, when switched on, transfers a voltage from an input (VIDEO) to an output (36), and
   a light-modulating element (44),
   characterized by

   a transistor (T2) having a control input (38) and a current circuit controlled by its control input (38), said control input (38) connected to receive said voltage from said output (36) and to modulate an AC current receivable at a current terminal (40, 43) in accordance with said voltage,
   said light-modulating element (44) connected to receive said modulated AC current, said element (44) providing an impedance to said transistor (T2) when current flows through said transistor (T2) in a first direction, and
   a capacitance (C_a) providing an impedance to said transistor (T2) when current flows through said transistor (T2) in a second direction, said impedance provided by said capacitance (C_a) about equal to said impedance provided by said light-modulating element (44),
   said impedances forming symmetrical follower circuits with said transistor (T2), said symmetrical follower circuits tending to maintain said voltage received by said transistor (T2) substantially constant when said switching device (T1) is switched off.

2. An active matrix display, comprising:

   a plurality of pixels (10) arranged in rows and columns to form a matrix, each column of pixels (10) connected to a respective video signal (VIDEO) and each row of pixels (10) connected to a respective strobe signal (STROBE), each pixel (10) comprising a pixel drive circuit of claim 1,
   said switching device (T1) connected to transfer said video signal (VIDEO) from said input to said output, when switched on by said strobe signal (STROBE),
   said transistor (T2) connected to receive said video signal (VIDEO) from said switching device (T1) output and to modulate said AC current receivable at said current terminal (40, 43) in accordance with said video signal (VIDEO), and
   said follower circuits tending to maintain said voltage received by said transistor (T2) substantially independent of the relative phase between said strobe (STROBE) and AC current signals.

3. The active matrix display of claim 2, characterized in that said video signal (VIDEO) is of one polarity.

4. The apparatus of any of claims 1 - 3, characterized in that said current modulating transistor (T2) is highly symmetrical, such that parasitic capacitances (C_{p1}, C_{p2}) between the current modulating transistor's control input (38) and either side of its current circuit are approximately equal.

5. The apparatus of any of claims 1 - 4, characterized by a storage capacitor (C_{s2}) connected to the control input (38) of said current modulating transistor (T2), said capacitor (C_{s2}) being charged by the signal (VIDEO) presented to said control input (38).

6. The apparatus of any of claims 1 - 5, characterized in that said current modulating transistor (T2) is a MOSFET with an off-state current leakage below an operating threshold for said light-modulating element (44).

7. The apparatus of any of claims 1 - 6, characterized in that said light-modulating element (44) is an LCD.

8. The apparatus of any of claims 1 - 6, characterized in that said light-modulating element (44) is an electro-luminescent device.

9. The apparatus of any of claims 1 - 8, characterized in that said AC current is provided by two AC power supplies (56, 60), with one supply (56) connected to said light-modulating element (44) and one supply (60) connected to said capacitance (C_a), said supplies (56, 60) generating respective waveforms that are about equal in frequency and magnitude and 180 degrees out-of-phase.

10. The apparatus of claim 9, characterized in that said frequency is substantially higher than 15 Hz.

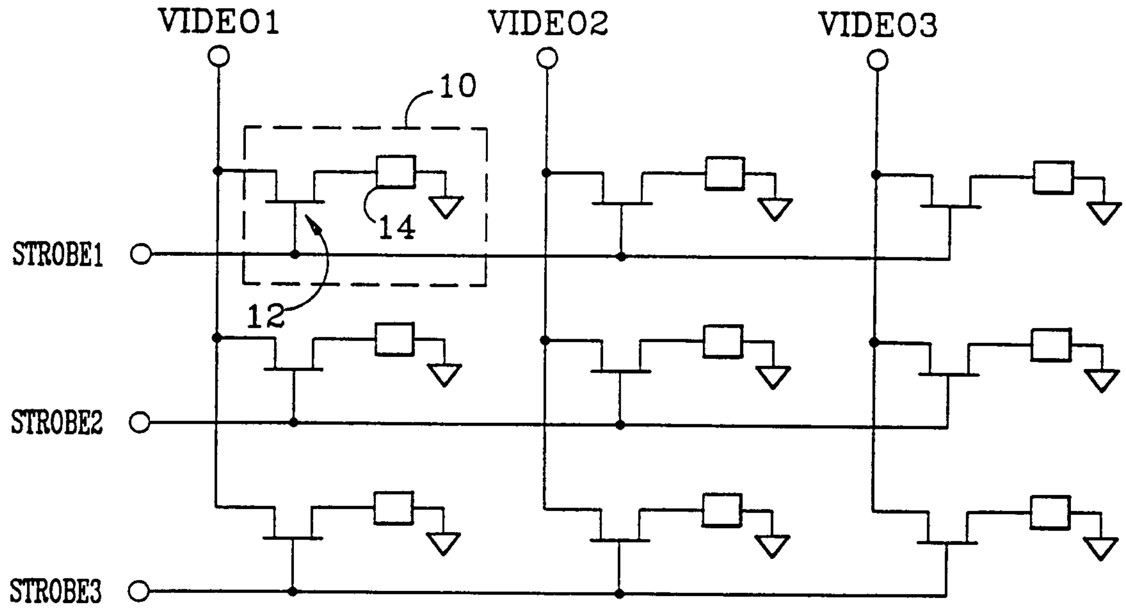

FIG. 1
(Prior Art)

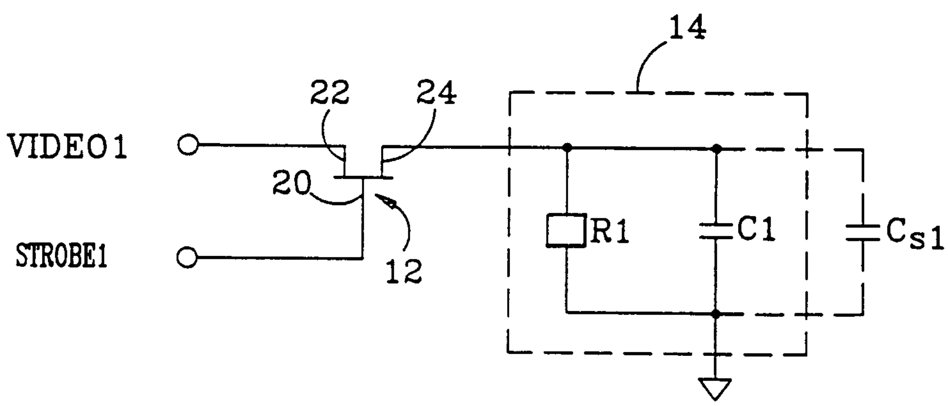

FIG. 2
(Prior Art)

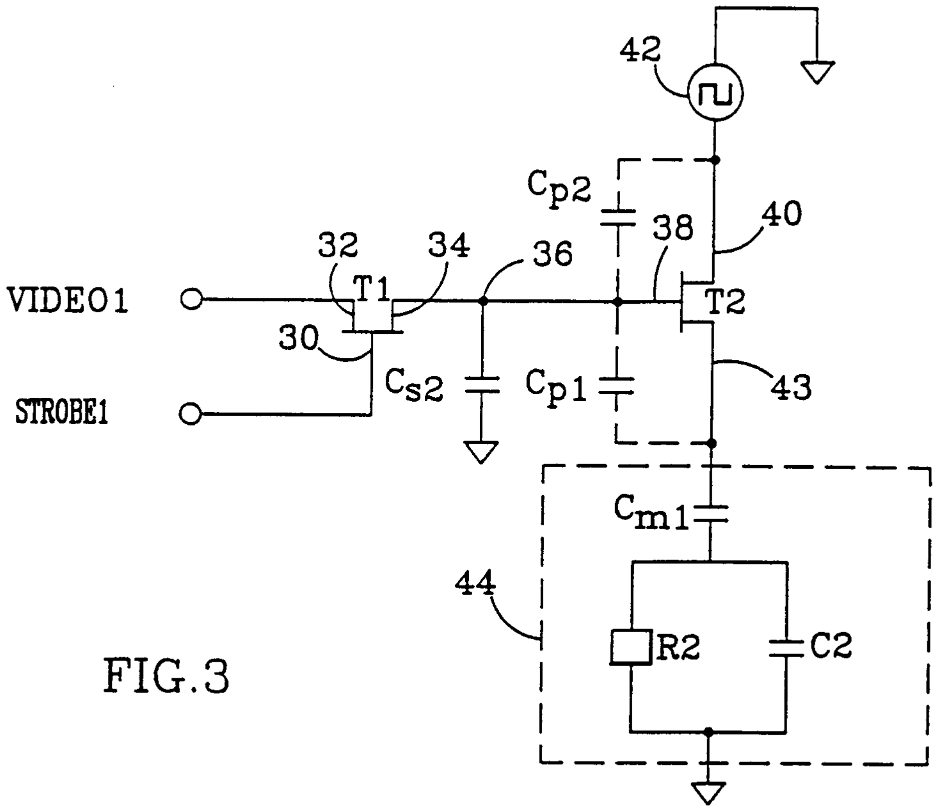
42
Cp2
38
40
32
34
36
VIDEO1
T1
T2
30
STROBE1
Cs2
Cp1
43
Cm1
44
R2
C2

FIG.3

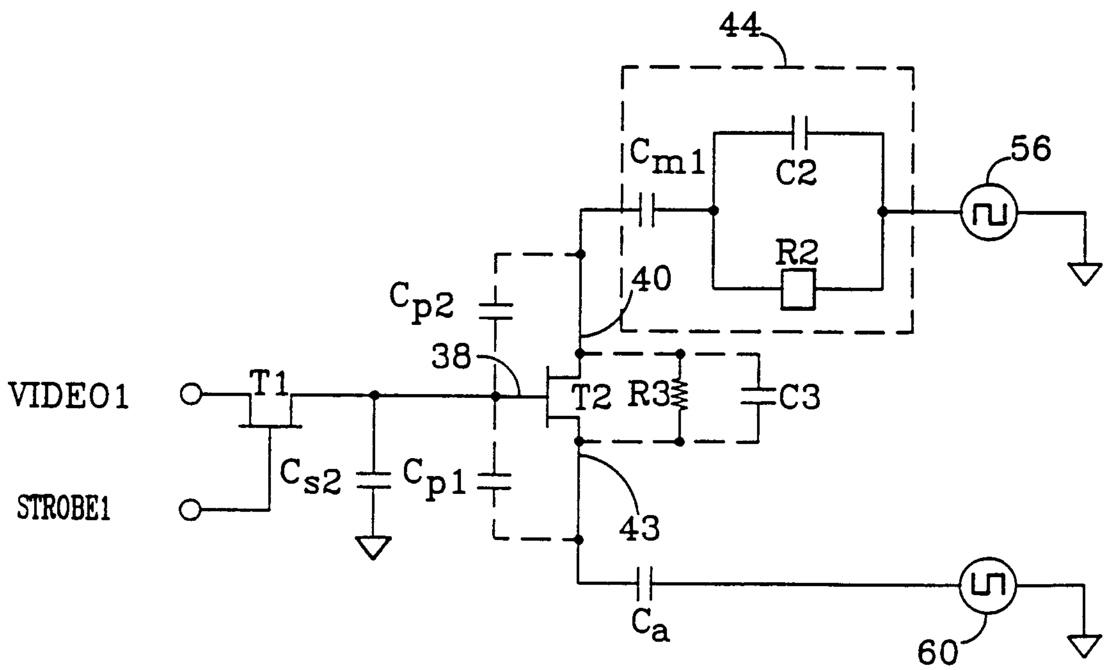
44
Cm1
C2
56
R2
Cp2
40
38
VIDEO1
T1
T2
R3
C3
Cs2
Cp1
STROBE1
43
Ca
60

FIG.4

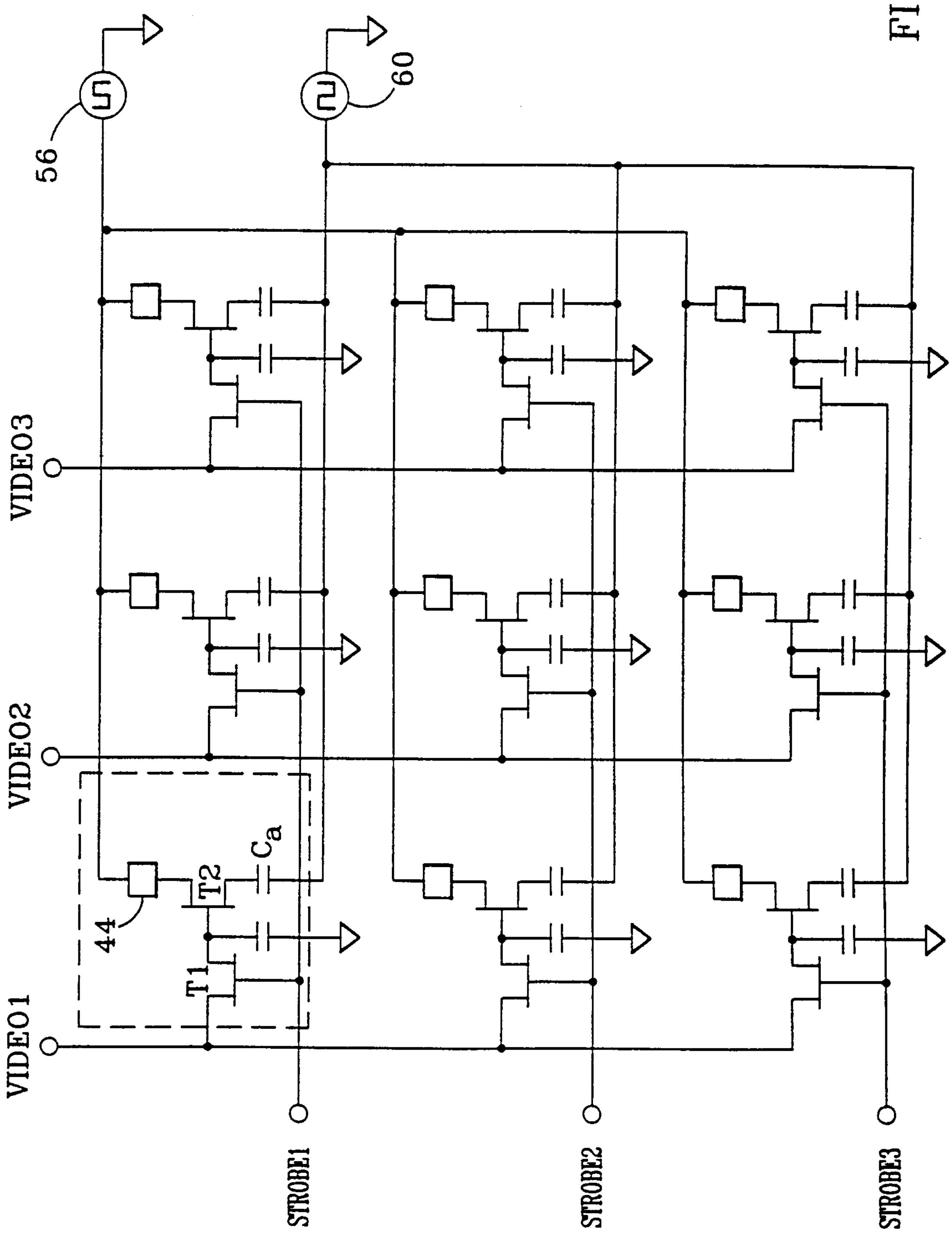
56
60
VIDEO3
VIDEO2
VIDEO1
44
T1
T2
C_a
STROBE1
STROBE2
STROBE3

FIG.5

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 11 2162

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	EP 0 414 478 A (SHARP K.K.) * Abstract * * column 2, line 7 - line 27; figures 1,6-8 * * column 3, line 26 - column 4, line 8 * * column 6, line 54 - column 7, line 32 * * column 8, line 27 - column 9, line 2 * * column 10, line 53 - column 11, line 24 * ---	1,2,5-7,9 3,8	G09G3/36 G09G3/30
Y	WO 85 02931 A (HUGHES AIRCRAFT CO.) * Abstract * * page 2, line 1 - page 3, line 11; figures 2,4 * * page 6, line 19 - page 10, line 7 * * page 12, line 5 - line 17 * ---	3	
Y	S. TRIEBWASSER: "Circuitry to address Field Effect Electroluminescent Panel" IBM TECHNICAL DISCLOSURE BULLETIN., vol. 13, no. 4, September 1970, NEW YORK US, pages 967-968, XP002044047 * Whole article * -----	8	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G09G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20 October 1997	Corsi, F

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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