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(19) **United States**(12) **Patent Application Publication****Tam et al.**(10) **Pub. No.: US 2003/0030629 A1**(43) **Pub. Date: Feb. 13, 2003**(54) **DISPLAY DEVICE, METHOD OF DRIVING A  
DISPLAY DEVICE, ELECTRONIC  
APPARATUS****Publication Classification**(76) **Inventors: Simon Tam, Cambridge (GB); Richard  
Friend, Cambridge (GB)**(51) **Int. Cl.<sup>7</sup> ..... G09G 5/00**(52) **U.S. Cl. .... 345/204**

Correspondence Address:

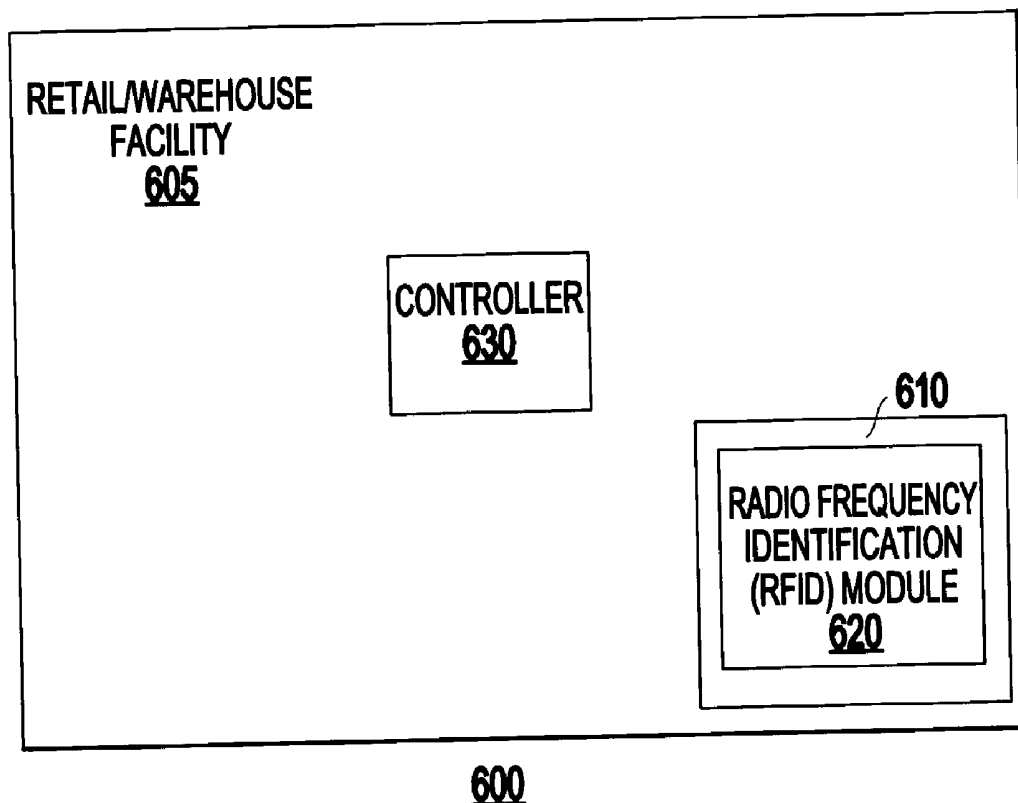
**Oliff & Berridge****P O Box 19928****Alexandria, VA 22320 (US)**(21) **Appl. No.: 10/148,136**(22) **PCT Filed: Sep. 28, 2001**(86) **PCT No.: PCT/GB01/04376**(30) **Foreign Application Priority Data**

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**ABSTRACT**

A display device comprising a driver circuit which modulates the duty cycle of the on-state of a pixel during a frame period. Preferably the driver circuit comprises a comparator and more preferably the comparator is formed of thin film transistors constituting a differential pair and an inverter. Also provided is a method of driving a display device comprising the step of modulating the duty cycle of the on-state of a pixel during a frame period. Beneficially the display device is an organic electroluminescent active matrix display device.



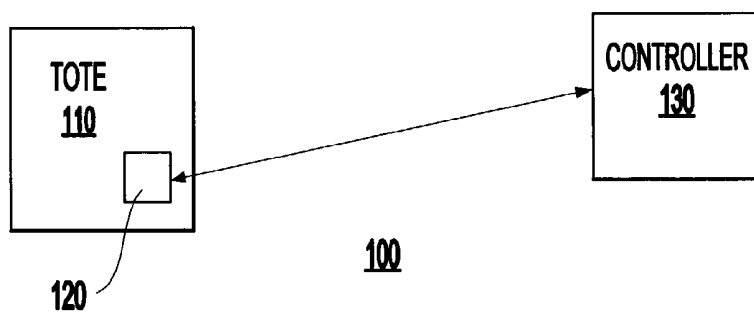


FIG.1

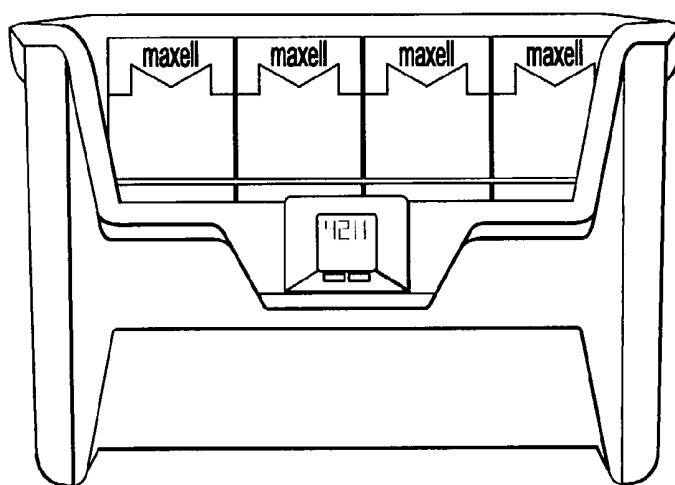


FIG.2A

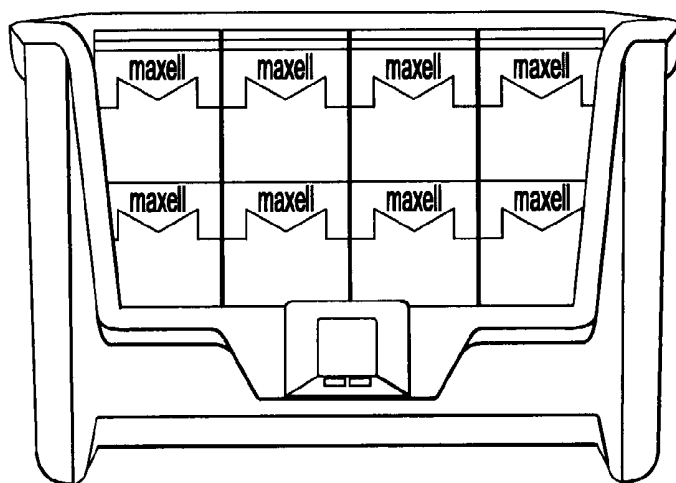


FIG.2B

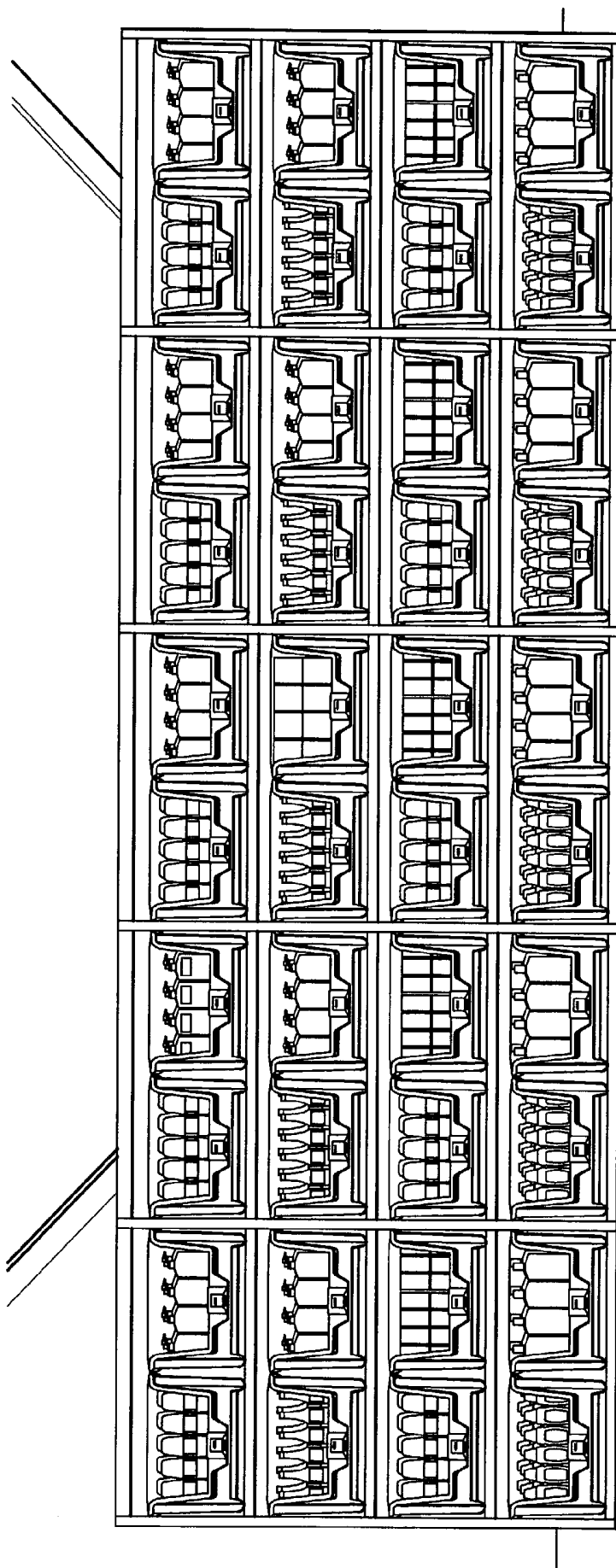


FIG. 2C

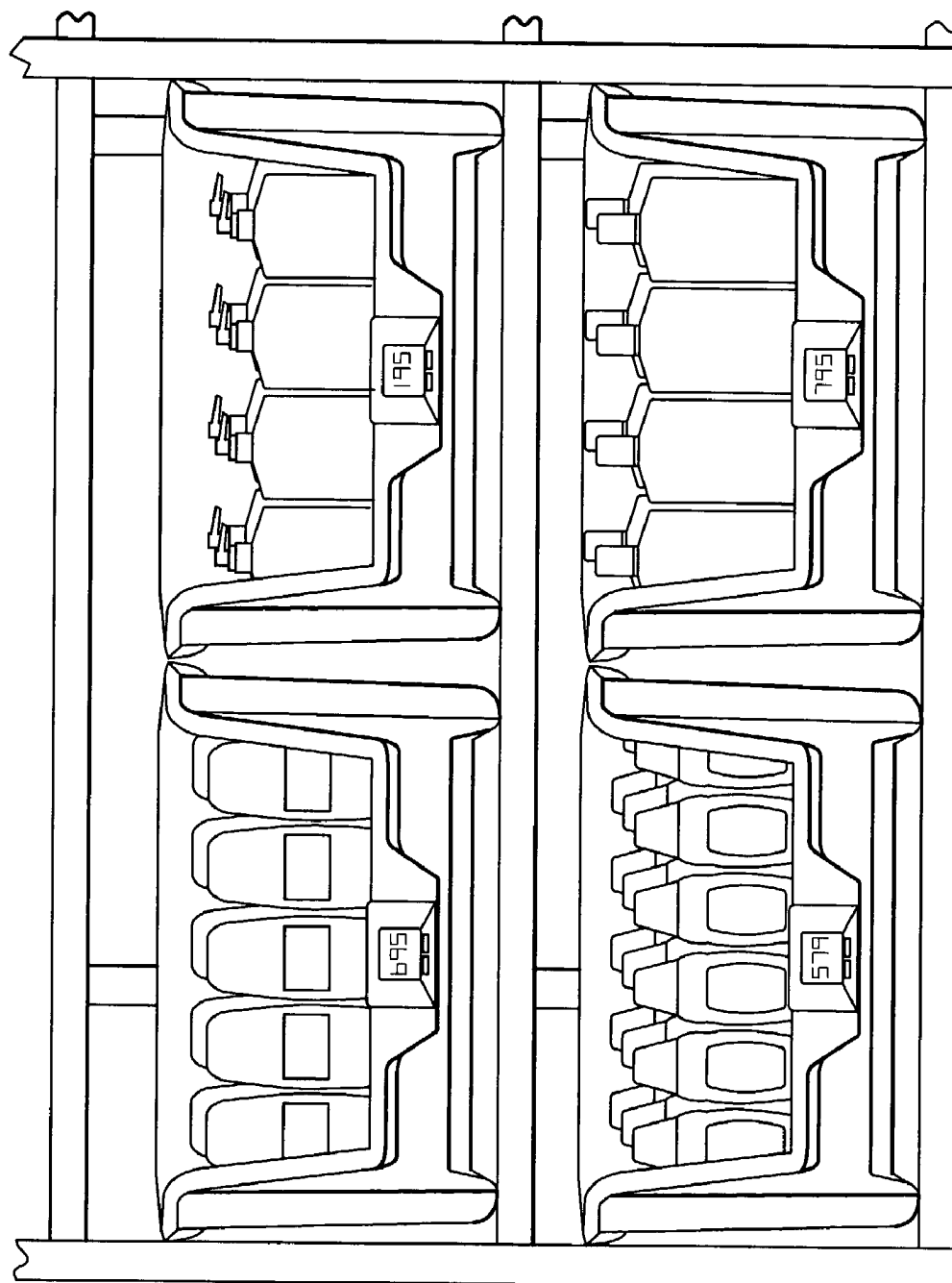


FIG. 2D

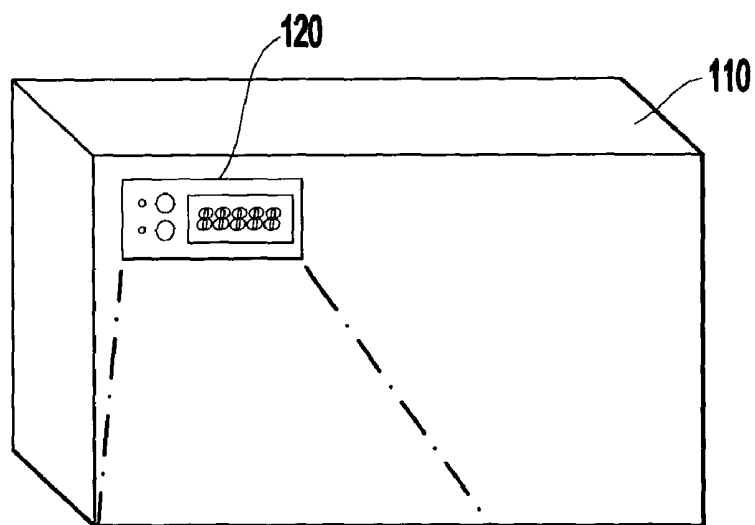


FIG. 3A

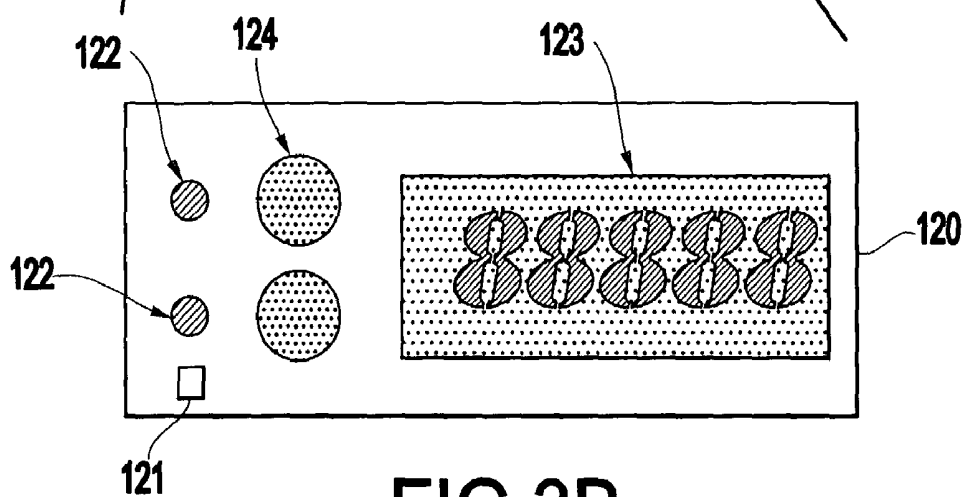
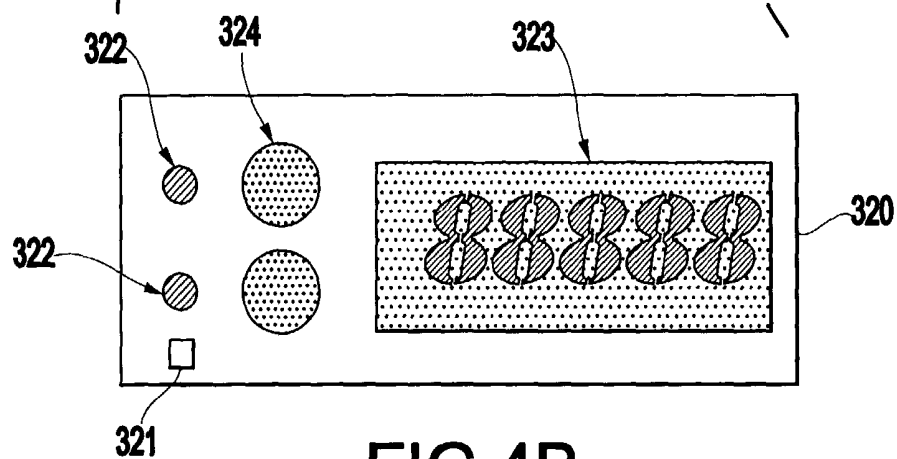
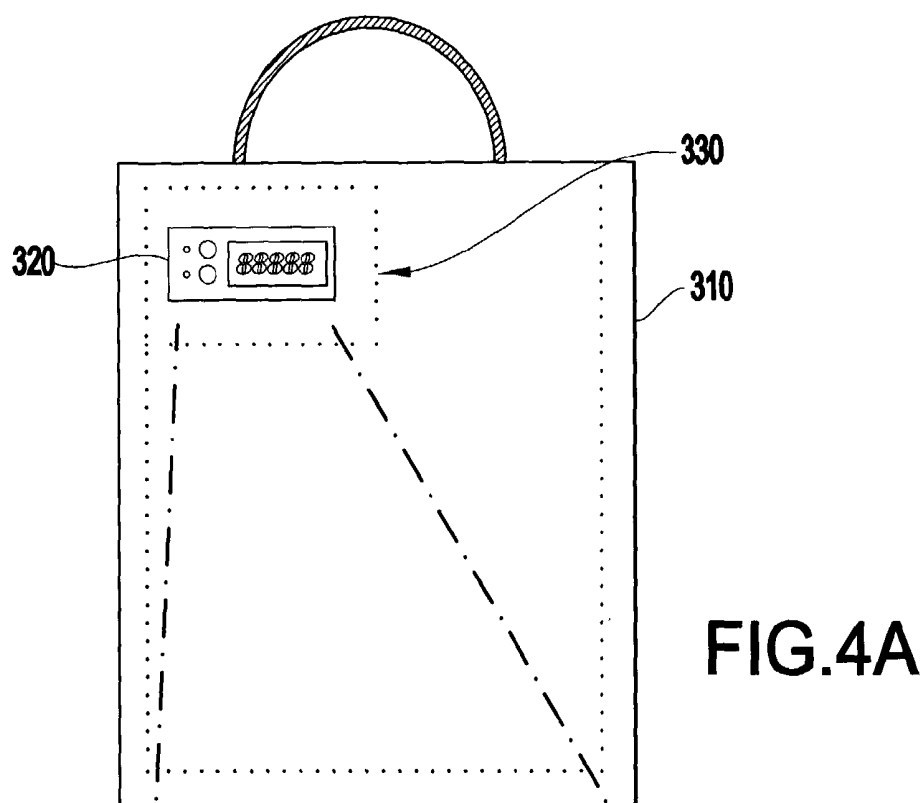


FIG. 3B



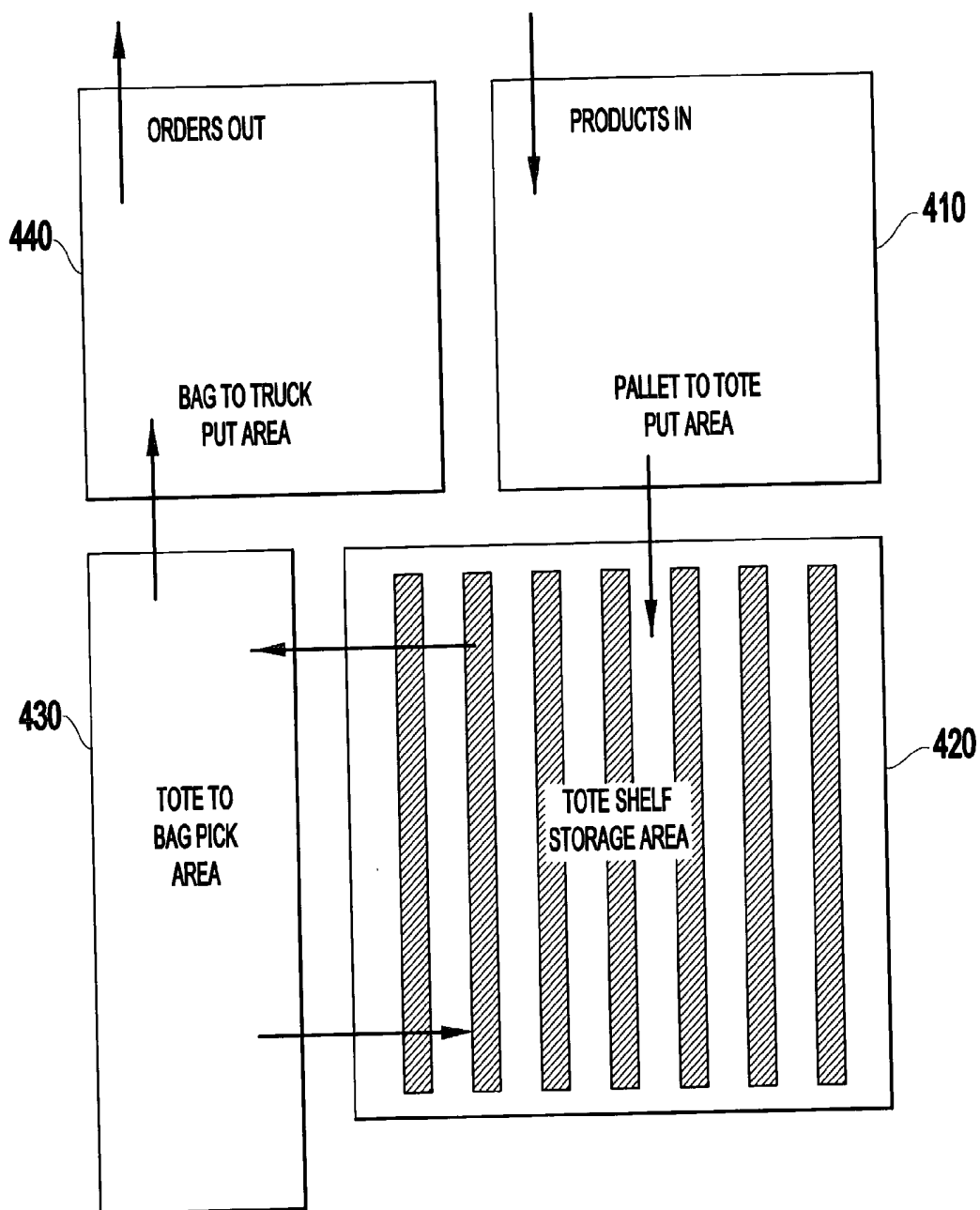


FIG.5A

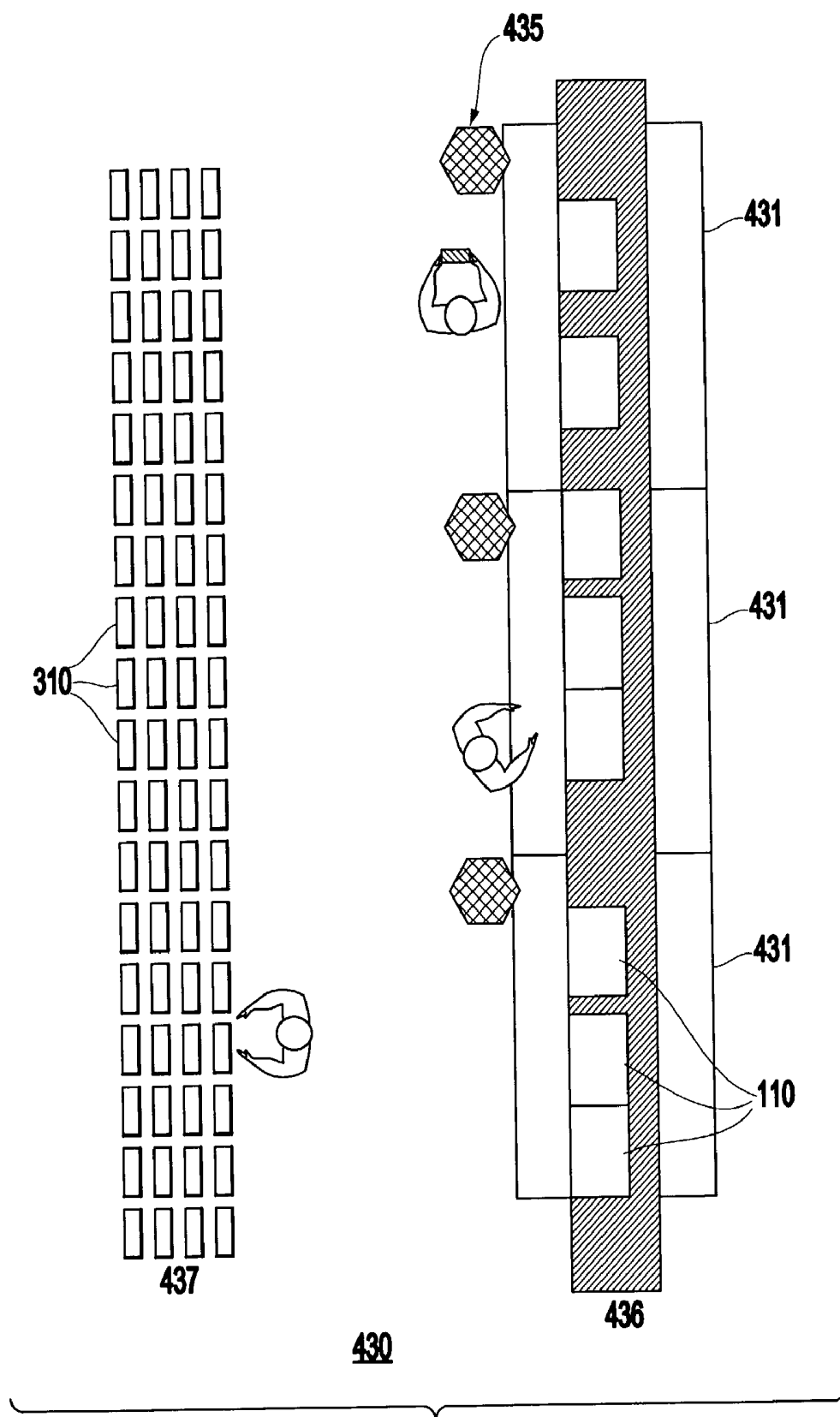
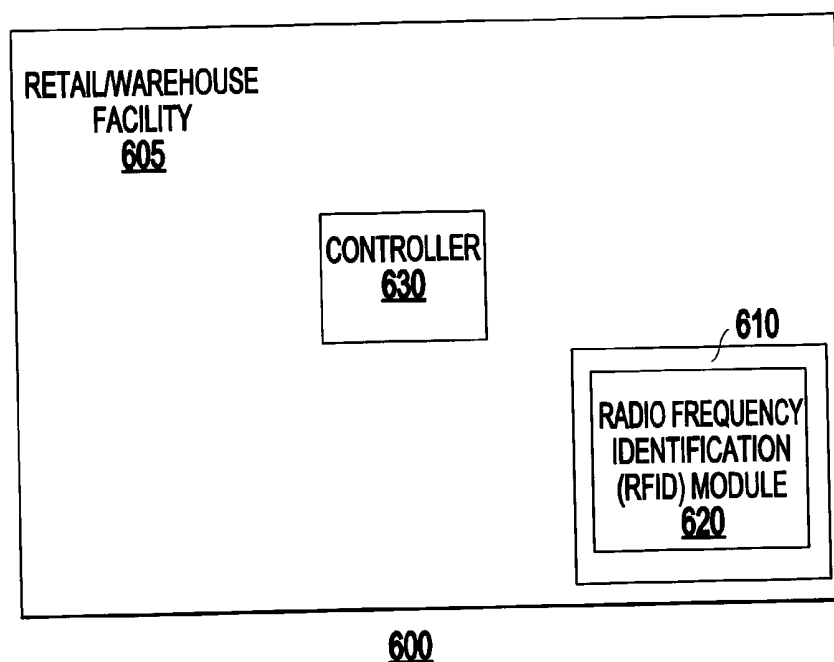
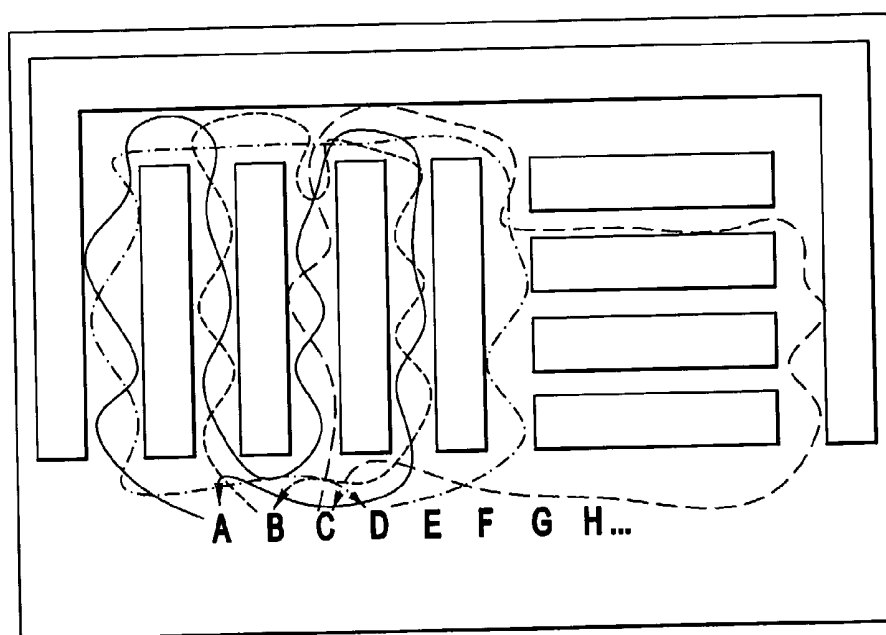


FIG.5B





**FIG.6**



**FIG.7A**

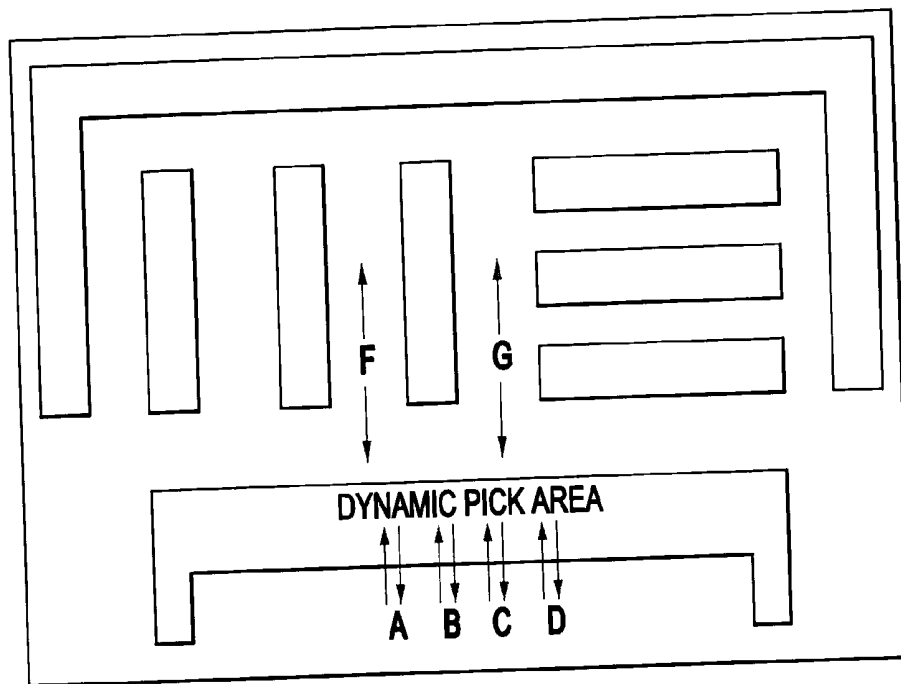


FIG. 7B

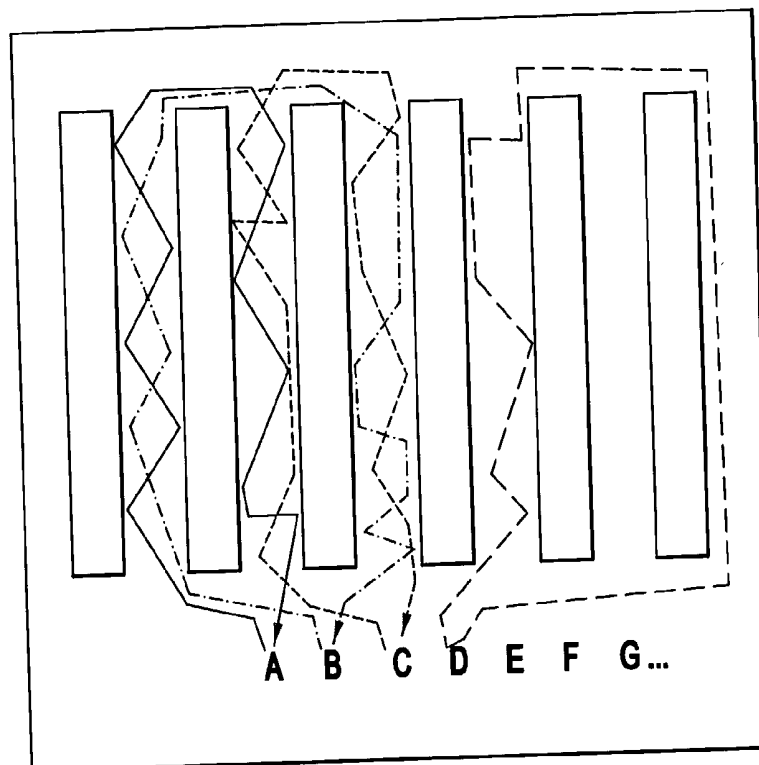


FIG. 7C

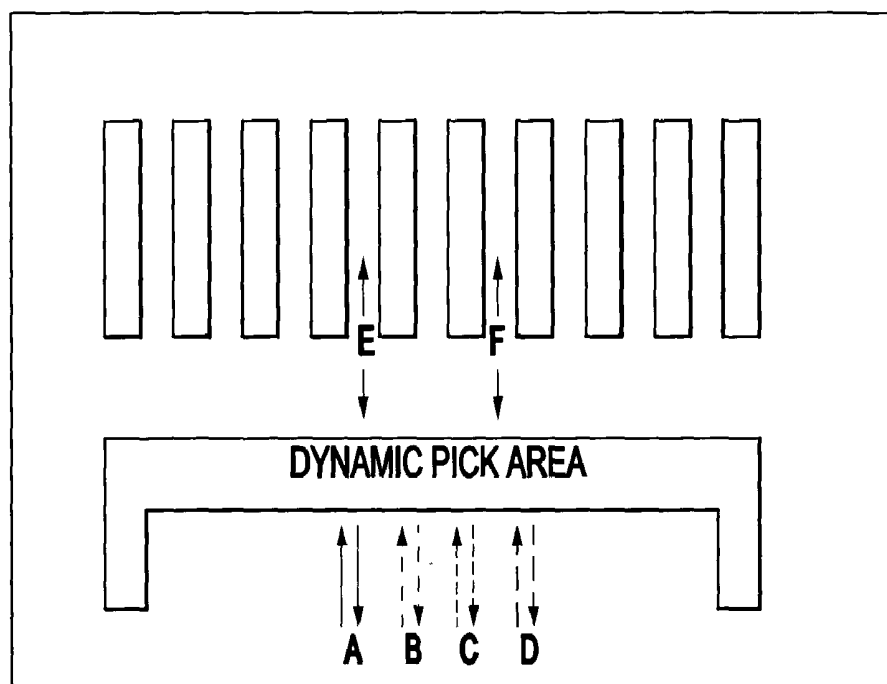


FIG.7D

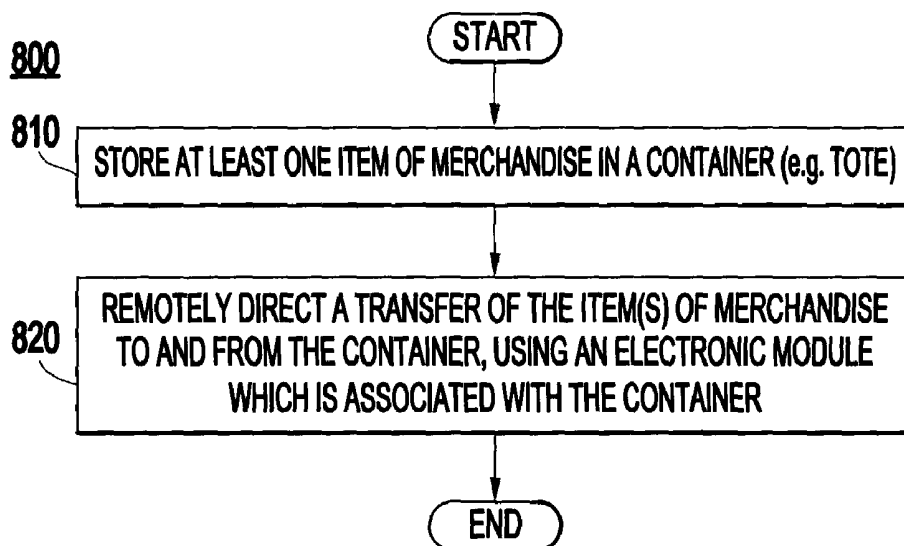
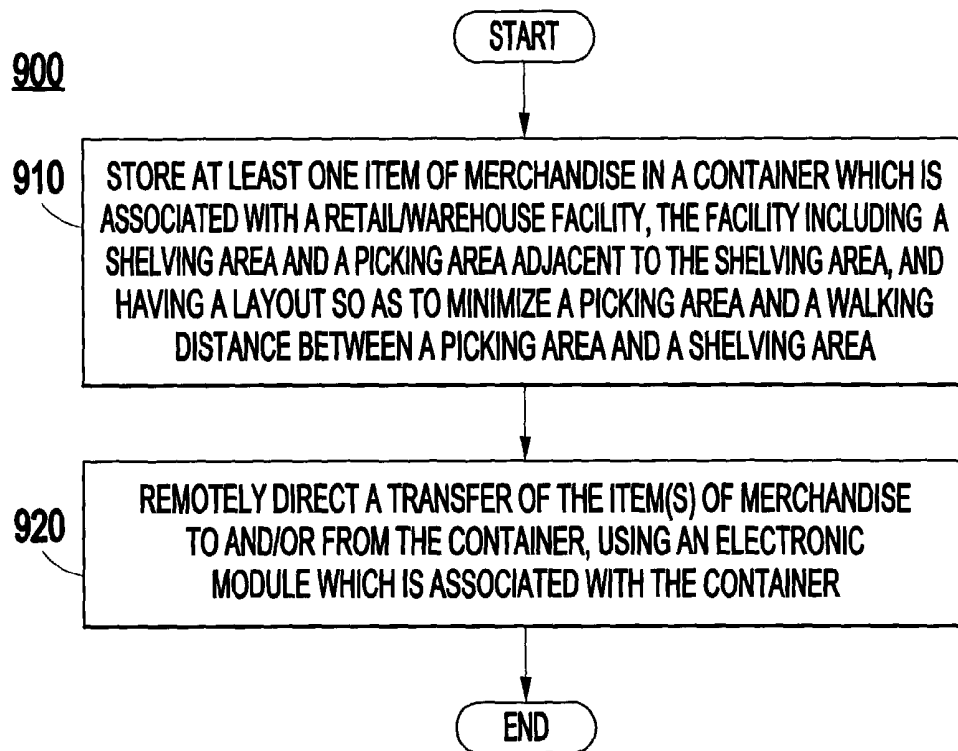


FIG.8



**FIG.9**

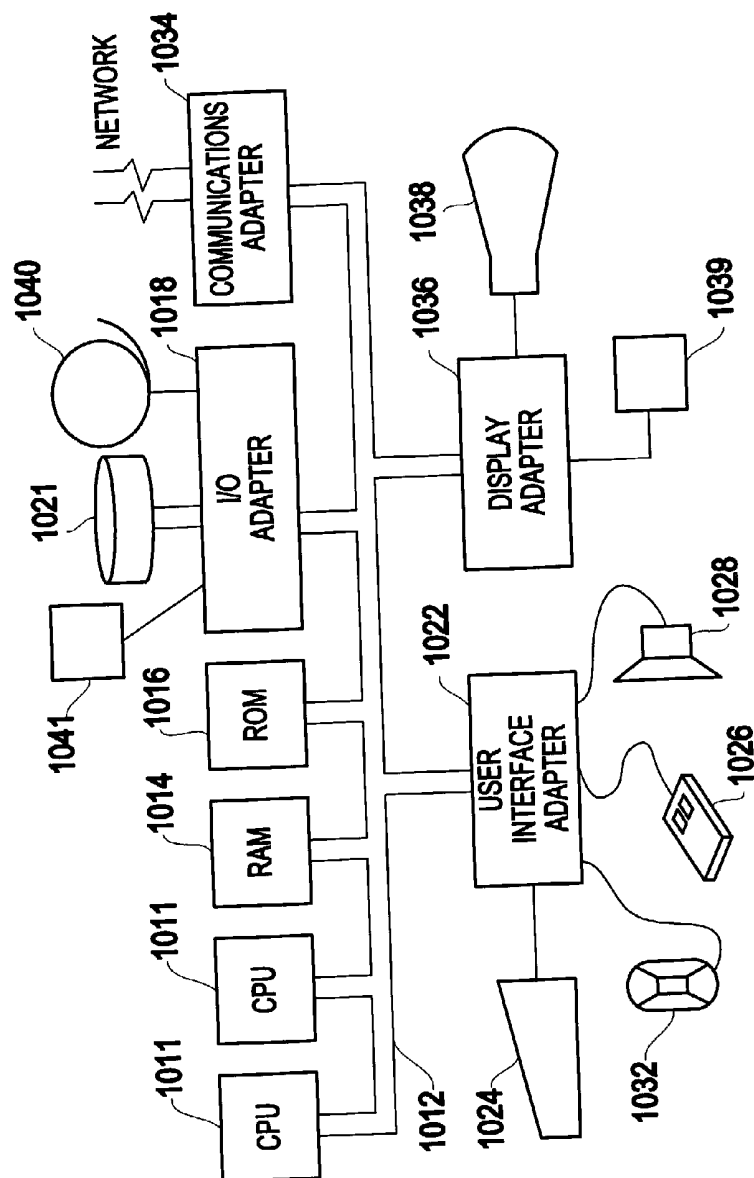


FIG. 10

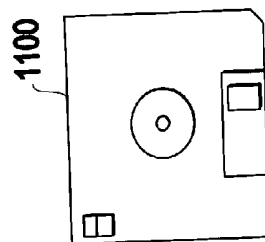


FIG. 11

# DISPLAY DEVICE, METHOD OF DRIVING A DISPLAY DEVICE, ELECTRONIC APPARATUS

[0001] The present invention relates to display devices and in particular to improving the display quality thereof. The invention also relates to a method and an electronic apparatus.

[0002] One example of a display device to which the present invention relates is an organic electroluminescent display device. Organic electroluminescent devices (OLEDs) comprise a layer (active layer) of organic light emitting material, often a light emitting polymer, sandwiched between two electrodes which are used to pass a current through the active material. The device essentially behaves like a diode and the intensity of light emission is a function of the forward bias current which is applied. The devices are good candidates for the fabrication of display panels.

[0003] A basic requirement for a display panel is an ability to display good quality graphical images. This is dependent upon the ability of the individual pixels to generate a range of brightness intensity. The image quality improves as the number of gray scales increases. The conventionally used standard is 3x8 bit colour, equivalent to 256 gray scales per colour. This standard is used in many current day applications.

[0004] Various methods of generating gray scales with an analog driving circuit have been proposed for OLED displays. The conventional technique is to drive the OLED with a voltage dependent current and this has allowed the implementation of active matrix OLED displays. A typical arrangement is illustrated in FIG. 1 hereof.

[0005] As shown in FIG. 1, when transistor  $T_1$  is selected (by voltage  $V_{sel}$ ) it turns on and the data voltage ( $V_{dat}$ ) is transferred to the gate of transistor  $T_2$ . Assuming  $T_2$  is biased in the saturation region, the data voltage  $V_{dat}$  is converted into current, which drives the OLED to the required brightness intensity.

[0006] The variation of threshold voltages of the transistors is, however, a very significant problem in the practical implementation of the above described display panels. Another significant problem is the high power consumption of these circuits.

[0007] An alternative method of providing gray scaling is to use an area dithering technique in which each pixel is divided into a number of sub-pixels, preferably with binary weighted areas. Each sub-pixel is driven either fully on or fully off. Thus a digital driver can be used and power consumption reduced. However, this technique has the disadvantage that the panel size is increased (because each pixel is replaced by a number of sub-pixels and, in the limit, each sub-pixel is the same size as a conventional pixel) and also there is a large increase in the number of signal lines required (because of the need to address each sub-pixel).

[0008] Against this background, it is an object of the present invention to provide a display device with good gray scale capabilities which mitigates the above mentioned disadvantages.

[0009] According to the present invention there is provided a display device comprising a driver circuit which modulates the duty cycle of the on-state of a pixel during a frame period.

[0010] Thus, the present invention provides pulse width modulation of the on-period of a pixel and the integrating function of the human eye perceives this as modulation of the intensity of the emitted light. Modulation of the on-period is in stark contrast to the conventional control of brightness, i.e. control of the instantaneous amplitude of the current supplied.

[0011] Embodiments of the present invention will now be described in more detail by way of further example only and with reference to the accompanying drawings, in which:

[0012] FIG. 1 is a circuit diagram of a conventional pixel level driver in an OLED display panel;

[0013] FIG. 2 is a circuit diagram of a pixel level driver in an OLED display panel, according to one embodiment of the present invention;

[0014] FIG. 3 illustrates a detailed circuit diagram and operating waveforms for an implementation of the comparator shown in the circuit of FIG. 2;

[0015] FIG. 4 illustrates driving waveforms in the circuit of FIG. 2;

[0016] FIG. 5 is a circuit diagram illustrating the use of an integrated waveform generator;

[0017] FIG. 6 illustrates a generalised synchronous driving scheme;

[0018] FIG. 7 illustrates a generalised asynchronous driving scheme;

[0019] FIGS. 8A and 8B show the significance of using higher frequencies in the asynchronous driving scheme;

[0020] FIGS. 9A and 9B illustrate the incorporation of gamma correction into the driving voltage;

[0021] FIG. 10 is a detailed circuit diagram of a sawtooth wave generator;

[0022] FIG. 11 shows input waveforms for the circuit of FIG. 10;

[0023] FIGS. 12A and 12B show gray scales obtained in a specific example;

[0024] FIG. 13 is a schematic view of a mobile personal computer incorporating a display device having a pixel driver according to the present invention,

[0025] FIG. 14 is a schematic view of a mobile telephone incorporating a display device having a pixel driver according to the present invention, and

[0026] FIG. 15 is a schematic view of a digital camera incorporating a display device having a pixel driver according to the present invention,

[0027] A description will first be given of the pixel level configuration according to one embodiment of the present invention. Thus, FIG. 2 is a circuit diagram of an individual pixel 10 within an active matrix OLED display panel. The circuit is implemented using polysilicon TFT components and comprises an MOS-input comparator 12 and two pass-gates,  $SW_1$  and  $SW_2$ . The use of pass-gates avoids so-called "feed-through", i.e. coupling with other circuit voltages. The inverting input (+) of the comparator 12 is connected to a waveform source  $V_{saw}$ . The non-inverting input (-) is connected to a storage capacitor  $C_1$  and a pass-gate  $SW_1$ . The

pass-gate  $SW_1$  is controlled by a waveform  $V_{sel}$ . The output of the comparator is connected to a pass-gate  $SW_2$ . Pass-gate  $SW_2$  controls the current flowing in to the organic light emitting element **14**. By applying a time varying signal to  $V_{saw}$ , the light emitting element **14** is switched on for a period depending on the value of the data voltage  $V_{dat}$  which is applied to the other side of pass-gate  $SW_1$  compared to the capacitor  $C_1$  and the comparator **12**.

[0028] In a line-at-a-time driving scheme,  $V_{sel}$  sets the state of the pass-gate  $SW_1$  of the pixel elements on the same row. When pass-gate  $SW_1$  is closed, the data voltage  $V_{dat}$  is transferred to the inverting input of the comparator **12** and to the capacitor  $C_1$ . Then, when pass-gate  $SW_1$  is opened the data voltage is memorised by capacitor  $C_1$ . The waveform  $V_{saw}$  is then initiated. When the voltage,  $V_+$ , at the inverting input of the comparator **12** is less than the voltage,  $V_-$ , at the non-inverting input thereof, the comparator outputs a LO signal which puts the light emitting element **14** in to the on-state. When the voltage,  $V_+$ , at the inverting input of the comparator **12** is greater than the voltage,  $V_-$ , at the non-inverting input thereof, the comparator outputs a HI signal which puts the light emitting element **14** in to the off-state. As a result the data voltage stored by the capacitor  $C_1$  modulates the duration for which the light emitting element **14** remains in the on-state during a frame period.

[0029] The frame period might typically be 20 mS and with the response time of the light emitting element **14** being of the order of nano-seconds, the speed of the polysilicon TFTs and any stray capacitance become the limiting factors in operation of the driving scheme. That is, exceptionally effective switching can be obtained.

[0030] In the circuit illustrated in **FIG. 2**, a common operating voltage  $V_{OELD}$  is used for all OELD pixels of the same type. The voltage  $V_{OELD}$  is set externally and is independent of the supply voltage  $V_{DD}$  of the driving circuit. This significantly increases the flexibility of controlling the bias conditions for the OELDs.

[0031] A description will now be given of the detailed considerations which apply to the practical implementation of the comparator **12** used in the circuit of **FIG. 2**.

[0032] Since a separate comparator is provided for each pixel, the circuit area and power consumption of the comparator should be kept as low as possible. Further, in order to achieve a high number of gray scales, the comparator must be able to distinguish a small difference in input voltages. For example, if it is desired to implement 256 gray scales with a voltage swing of 0V to 5V then clearly something of the order of  $\Delta V=19.5$  mV is appropriate. Thus switching must be very fast but, from the previous discussion, it is well within the ability of the described circuit.

[0033] A detailed circuit diagram of one implementation of the comparator **12** of **FIG. 2** is illustrated in **FIG. 3**. The circuit of **FIG. 3** comprises two stages: a CMOS differential amplifier **16**, and a CMOS inverter **18**. The CMOS inverter **18** turns the pass-gate  $SW_2$  fully on or fully off very quickly. For level shifting purposes the power supply of the inverter stage **18** can be different from that of the differential stage **16**.

[0034] The differential stage **16** comprises the drain-source series connection circuit of transistors **20**, **21** and **23** connected between the  $V_{DD}$  rail and ground, together with

the similarly connected circuit of transistors **20**, **22** and **24**, wherein transistors **22** and **24** are connected in parallel with transistors **21** and **23**. The respective gates of transistors **21** and **22** provide the two input terminals (+), (-) of the comparator **12**, whereas the gate of transistor **20** receives a bias voltage  $V_{bias}$ . The output stage **18** comprises two transistors, **25** and **26**, which are source-drain series connected between the  $V_{DD}$  rail and ground. The output  $V_{out}$  of the comparator is taken from the connection between the transistors **25** and **26** and the gates thereof receive there input from the junction between transistors **21** and **23**.

[0035] The circuit illustrated in **FIG. 3** uses seven TFTs. Using a respective TFT for  $SW_1$  and  $SW_2$  brings the total per pixel to nine.

[0036] A description will now be given of various aspects of implementing a display panel incorporating the above described embodiment of pixel level circuitry.

[0037] **FIG. 4** illustrates waveforms which can be used with the circuit of **FIG. 2**. **FIG. 4** comprise two diagrams, (a) and (b), in which the waveforms  $V_{scan}$ ,  $V_{saw}$  and  $V_{out}$  are shown.  $V_{out}$  is the driving pulse applied to the OELD. **FIGS. 4(a)** and **(b)** differ in the shape of the waveform used for  $V_{saw}$ . In **FIG. 4(a)** the waveform of  $V_{saw}$  is a sawtooth whereas in **FIG. 4(b)** the waveform of  $V_{saw}$  is triangular. Using the sawtooth waveform of **FIG. 4(a)** the output pulse always starts at the beginning of each frame. Thus the sawtooth waveform of **FIG. 4(a)** provides a linear gray scale, as it provides a reference time point for the eye to start integrating for each frame. For the triangular waveform of **FIG. 4(b)** the centre of the output pulse always occurs at mid-cycle.

[0038] Basically all pixels in the same row of the matrix share the same driving waveform, denoted by  $V_{saw/m}$  where m indicates that it is the  $m^{th}$ -row of the matrix which is being considered. When rows are addressed sequentially, the driving waveforms for the next row, denoted by  $V_{saw/m+1}$ , should incorporate a delay or phase shift of  $T_{frame}/M$ , where  $T_{frame}$  is the frame period and M is the total number of rows in the matrix. Thus if the display is driven externally a total of M interconnections are required. This can be a problem for high resolution displays. Thus, according to one embodiment of the present invention there is provided an integrated waveform generator, by which the number of interconnections required can be reduced.

[0039] **FIG. 5** is a circuit diagram illustrating the use of an integrated waveform generator. The waveform generator **30** receives separate master and reference voltage inputs,  $V_{master}$  and  $V_{ref}$ . The waveform generator **30** also receives an input from  $V_{scan/m}$ . The generator output  $V_{saw/m}$  is applied to all of the pixels **10** in a particular row of the matrix.

[0040] Ideally, however, the function of the generators is to provide the same waveform with a unique phase shift for each row of pixel elements. The precise timing and data voltage relationship becomes a major challenge when the spatial variation of TFT characteristics over a display panel is taken into account. However, this problem can be solved by providing the master clock  $V_{master}$  and the reference voltage source  $V_{ref}$  to ensure that outputs from all waveform generators are the same but different in phase shift.

[0041] The waveform generator should be synchronised to  $V_{scan/m}$ , and thus the signal  $V_{scan/m}$  can be used as a trigger.

[0042] From the foregoing description, a generalised synchronous driving scheme is illustrated in FIG. 6. Two rows and six columns of pixels are illustrated. As denoted by R, G, B indicating red, green and blue; the light emitting element in each pixel may be designed to emit light of different colours thus implementing a full colour display. The pixels are driven by a data driver 32 and a row driver 34. A separate waveform generator, WG, is provided for each row and the signals applied are indicated in FIG. 6. Each waveform generator is synchronised to the scan line signal and the minimum operating frequency is equal to the frame rate.

[0043] The display can also be driven asynchronously. An asynchronous driving scheme is shown in FIG. 7. The difference between this arrangement and that illustrated in FIG. 6 is that a single waveform generator is used for the whole display rather than using one per row. With this arrangement the waveform generator can be integrated on the display panel or can easily be provided externally of the panel. The waveform is independent of the scan line signal and higher operating frequencies can thus be used, thereby obtaining better image quality. The significance of using higher frequencies can be appreciated from FIGS. 8A and 8B, that is the improved gray scale accuracy of FIG. 8B (high frequency  $V_{DRV}$ ) compared with FIG. 8A (low frequency  $V_{DRV}$ ) is readily apparent. This phenomenon is important for moving images but can effectively be ignored for still images.

[0044] It is also possible to incorporate gamma compensation into the driving waveform. This is illustrated in FIGS. 9A and 9B, which show gamma correction incorporated into the driving voltage  $V_{DRV}$ .

[0045] FIG. 10 is a detailed circuit diagram of a sawtooth waveform generator such as may be employed in the above described embodiments of the present invention. The circuit receives an input signal  $V_{gray}$  which is applied to one terminal of a capacitor  $C_{20}$ . The other terminal of capacitor  $C_{20}$  is connected to one side of each of switches  $SW_{10}$  and  $SW_{20}$ . These switches  $SW_{10}$  and  $SW_{20}$  are controlled by signals  $\phi_1$  and  $\phi_2$ , respectively. The other side of switch  $SW_{20}$  is connected to ground via a capacitor  $C_{10}$  and also via a switch  $SW_{30}$  which is controlled by signal  $V_{scan}$ . Switches  $SW_{20}$ ,  $SW_{30}$  and capacitor  $C_{10}$  are connected to the input of a unity gain buffer 36. Switch  $SW_{10}$  controls a feedback loop from the output of the buffer 36. The output of the buffer 36 is applied to a low-pass filter L.P. consisting of a resistor and a capacitor. The output of the filter L.P. provides the generator output  $V_{saw}$ .

[0046] As noted above, the circuit has four inputs ( $V_{gray}$ ,  $\phi_1$ ,  $\phi_2$  and  $V_{scan}$ ) and one output ( $V_{saw}$ ). The input waveforms are shown in FIG. 11.

[0047] Waveform  $V_{gray}$  operates between 0V and a maximum level, say h. Waveforms  $\phi_1$  and  $\phi_2$  are non-overlapping clock pulses and  $V_{scan}$  is the same signal as in the scan line. When  $V_{scan}$  goes HI, data is transferred to the pixel storage capacitor as described above. At the same time,  $V_{scan}$  signals  $SW_{30}$  to close so that the input of the unity gain buffer is at 0V and  $C_{10}$  is discharged. Effectively, this acts as a reset and zeros the output. When  $V_{scan}$  goes LO,  $SW_{30}$  is opened. Waveform  $V_{gray}=0V$  when  $SW_{20}$  is closed and  $SW_{10}$  is opened. The transition of  $V_{gray}$  from 0V to h raises the input voltage at the unity gain buffer. If  $C_{10}=C_{20}$ , this increment

equals h/2. When  $V_{gray}=h$ ,  $SW_{20}$  is opened and  $SW_{10}$  is closed. The unity gain buffer 32 input voltage is stored by  $C_{10}$ . This voltage is reflected by the output of the unity gain buffer and is connected to  $C_{20}$  while  $V_{gray}$  returns to 0V. Next  $SW_{10}$  is opened and then  $SW_{20}$  is closed, and then  $V_{gray}$  will transit from 0V to h. This will increase further the voltage at the input of the unity gain buffer 32. If  $C_{10}=C_{20}$ , this increment equals h/2 and the resulting voltage becomes h. This continues and the output of the unity gain buffer 36 takes on a step shape. If the output is passed through the low pass filter L.P. the output signal becomes a smooth ramp.

[0048] It may be appreciated that the described arrangements according to the present invention can utilise existing analog video signals as input signals.

#### EXAMPLE

[0049] An example was implemented using the circuits described above, with polysilicon TFTs. Using a data voltage range of 0V to 5V, 256 gray scales were implemented.

[0050] After the data transfer, which typically occurs in the first 20  $\mu s$ , the frame period was divided into 256 sections. For a frame rate of 50 cycles/s, the time difference for each additional gray scale is given by  $\Delta t=1/50+256=78.125 \mu s$ , and the corresponding data voltage difference is given by  $\Delta V=5+256=19.53 mV$ . It is noted that for gray scale=0 the OLED must not be turned on at all.

[0051] FIGS. 12A and 12B show the first five (GS=1 to 5) and last five (GS=252 to 256) gray scales, respectively. The area under the pulses are calculated and plotted against the gray scale. As shown in FIGS. 12A and 12B, there is good linearity of pixel brightness within the gray scaling. However, a difference in slope is noted. This is believed to be due to the round corner in the pulse trailing edges, caused by the circuit's stray capacitance. This results in a smaller change in brightness for the lower gray scale values. This is not a serious problem and can be corrected by adjusting the input signal.

[0052] The current required by the driver is small compared to the current flowing in to the electroluminescent element.

[0053] Generally, the image quality which can be achieved with the present invention has been found to be superior to conventional Liquid Crystal Displays and at least equal to that of conventional CRT displays. In addition, the low power consumption required by the display device of the present invention makes it ideal for mobile and portable apparatus.

[0054] Modifications

[0055] As will already be appreciated, although much of the detail given above in relation to specific embodiments has been in terms of organic electroluminescent display devices; the present invention is also applicable to other types of display devices. Further, although the above described embodiments have mentioned specific implementation using TFT technology, usually in polysilicon; the present invention is not limited to the use of TFT technology. The invention is applicable not only to thin film transistor technology but also to silicon based transistors. Silicon based transistors can be arranged on a display substrate



using several different methods. For example, silicon based transistors can be arranged in a liquid.

[0056] The present invention is advantageous for use in small, mobile electronic products such as mobile phones, computers, CD players, DVD players and the like—although it is not limited thereto.

[0057] Several electronic apparatuses using a display device according to the present invention will now be described.

[0058] <1: Mobile Computer>

[0059] An example in which the display device according to one of the above embodiments is applied to a mobile personal computer will now be described.

[0060] FIG. 13 is an isometric view illustrating the configuration of this personal computer. In the drawing, the personal computer 1100 is provided with a body 1104 including a keyboard 1102 and a display unit 1106. The display unit 1106 is implemented using a display panel fabricated according to the present invention, as described above.

[0061] <2: Portable Phone>

[0062] Next, an example in which the display device is applied to a display section of a portable phone will be described. FIG. 14 is an isometric view illustrating the configuration of the portable phone. In the drawing, the portable phone 1200 is provided with a plurality of operation keys 1202, an earpiece 1204, a mouthpiece 1206, and a display panel 100. This display panel 100 is implemented using a display panel fabricated according to the present invention, as described above.

[0063] <3: Digital Still Camera>

[0064] Next, a digital still camera using an OEL display device as a finder will be described. FIG. 15 is an isometric view illustrating the configuration of the digital still camera and the connection to external devices in brief

[0065] Typical cameras sensitize films based on optical images from objects, whereas the digital still camera 1300 generates imaging signals from the optical image of an object by photoelectric conversion using, for example, a charge coupled device (CCD). The digital still camera 1300 is provided with an OEL element 100 at the back face of a case 1302 to perform display based on the imaging signals from the CCD. Thus, the display panel 100 functions as a finder for displaying the object. A photo acceptance unit 1304 including optical lenses and the CCD is provided at the front side (behind in the drawing) of the case 1302.

[0066] When a cameraman determines the object image displayed in the OEL element panel 100 and releases the shutter, the image signals from the CCD are transmitted and stored to memories in a circuit board 1308. In the digital still camera 1300, video signal output terminals 1312 and input/output terminals 1314 for data communication are provided on a side of the case 1302. As shown in the drawing, a television monitor 1430 and a personal computer 1440 are connected to the video signal terminals 1312 and the input/output terminals 1314, respectively, if necessary. The imaging signals stored in the memories of the circuit board 1308 are output to the television monitor 1430 and the personal computer 1440, by a given operation.

[0067] Examples of electronic apparatuses, other than the personal computer shown in FIG. 13, the portable phone shown in FIG. 14, and the digital still camera shown in FIG. 15, include television sets, view-finder-type and monitoring-type video tape recorders, car navigation systems, pagers, electronic notebooks, portable calculators, word processors, workstations, TV telephones, point-of-sales system (POS) terminals, and devices provided with touch panels. Of course, the above described embodiments of the present invention can be applied to the display sections of these electronic apparatuses.

1. A display device comprising a driver circuit which modulates the duty cycle of the on-state of a pixel during a frame period.

2. A display device as claimed in claim 1, wherein a respective one of the said driver circuits is provided for each pixel in the matrix.

3. A display device as claimed in claim 1 or claim 2, wherein the driver circuit comprises a comparator.

4. A display device as claimed in claim 3, wherein the comparator is formed of thin film transistors.

5. A display device as claimed in claim 4, wherein the thin film transistors are formed of polysilicon.

6. A display device as claimed in any of claims 3 to 5, wherein the said driver circuit comprises a data storage capacitor connected to one input of the comparator and a time varying signal line connected to another input of the comparator.

7. A display device as claimed in any of claims 3 to 6, wherein the comparator comprises a differential pair circuit and an inverter circuit.

8. A display device as claimed in any preceding claim, wherein the display device is an active matrix display device.

9. A display device as claimed in any preceding claim, wherein the display device is an organic electroluminescent display device.

10. A display device as claimed in claim 9, comprising a common operating voltage line for the light emitting element of each pixel and a driving circuit supply voltage line which is separate from the common operating voltage line.

11. A method of driving a display device comprising the step of modulating the duty cycle of the on-state of a pixel during a frame period.

12. A method as claimed in claim 11, wherein the step of modulating the duty cycle comprises a comparison of a data signal with a time varying signal.

13. A method as claimed in claim 12, comprising the step of providing the time varying signal in the form of a sawtooth waveform.

14. A method as claimed in claim 12, comprising the step of providing the time varying signal in the form of a triangular shaped waveform.

15. A method as claimed in any of claims 12 to 14, comprising the step of selecting the display device to be an active matrix display device.

16. A method as claimed in claim 15, comprising the step of driving the rows of the matrix using a common waveform generator which provides a row-to-row phase shift in the time varying signal applied to sequential rows.

17. An electronic apparatus including a display device as claimed in any of claims 1 to 10.

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[标]申请(专利权)人(译)	SIMON TAM 朋友RICHARD		
申请(专利权)人(译)	SIMON TAM 朋友RICHARD		
当前申请(专利权)人(译)	SIMON TAM 朋友RICHARD		
[标]发明人	TAM SIMON FRIEND RICHARD		
发明人	TAM, SIMON FRIEND, RICHARD		
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#### 摘要(译)

一种显示装置，包括驱动电路，该驱动电路在帧周期期间调制像素的导通状态的占空比。优选地，驱动器电路包括比较器，并且更优选地，比较器由构成差分对的薄膜晶体管和反相器形成。还提供了一种驱动显示装置的方法，包括在帧周期期间调制像素的导通状态的占空比的步骤。有利地，显示装置是有机电致发光有源矩阵显示装置。

