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(54) **Title:** DRIVER CIRCUITS FOR ELECTRO-OPTIC DISPLAYS

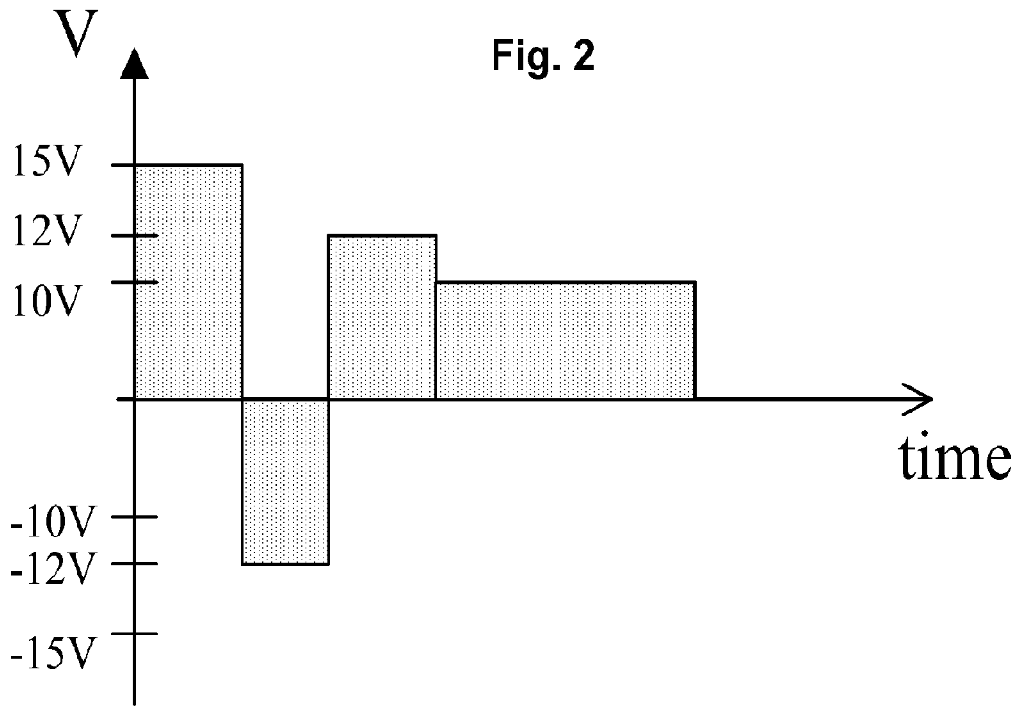

Fig. 2

(57) **Abstract:** An electro-optic display is driven using an intermediate image of reduced bit depth. In a second driving method, an electro-optic display is driven using a limited number of differing drive voltages, with higher voltage pulses being used before lower voltage pulses.

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DRIVER CIRCUITS FOR ELECTRO-OPTIC DISPLAYS

[Para 1] This application is related to:

(a) U.S. Patent No. 7,202,847;

(b) International Application No. WO 2004/090857; and

(c) International Application No. WO 03/044765.

[Para 2] The present invention relates to driver circuits for electro-optic displays. These driver circuits are especially, though not exclusively, intended for use in driving bistable electrophoretic displays.

[Para 3] The term "electro-optic" as applied to a material or a display, is used herein in its conventional meaning in the imaging art to refer to a material having first and second display states differing in at least one optical property, the material being changed from its first to its second display state by application of an electric field to the material.

[Para 4] The term "gray state" is used herein in its conventional meaning in the imaging art to refer to a state intermediate two extreme optical states of a pixel, and does not necessarily imply a black-white transition between these two extreme states.

[Para 5] The terms "bistable" and "bistability" are used herein in their conventional meaning in the imaging art to refer to displays comprising display elements having first and second display states differing in at least one optical property, and such that after any given element has been driven, by means of an addressing pulse of finite duration, to assume either its first or second display state, after the addressing pulse has terminated, that state will persist for at least several times, for example at least four times, the minimum duration of the addressing pulse required to change the state of the display element.

[Para 6] The term "impulse" is used herein in its conventional meaning in the imaging art of the integral of voltage with respect to time. However, some bistable electro-optic media act as charge transducers, and with such media an alternative definition of impulse, namely the integral of current over time (which is equal to the total charge applied) may be used. The appropriate definition of impulse should be used, depending on whether the medium acts as a voltage-time impulse transducer or a charge impulse transducer.

[Para 7] Several types of electro-optic displays are known, for example:

(a) rotating bichromal member displays (see, for example, U.S. Patents Nos. 5,808,783; 5,777,782; 5,760,761; 6,054,071 6,055,091; 6,097,531; 6,128,124; 6,137,467; and 6,147,791);

(b) electrochromic displays (see, for example, O'Regan, B., et al., Nature 1991, *353*, 737; Wood, D., Information Display, *18(3)*, 24 (March 2002); Bach, U., et al., Adv. Mater., 2002, *14(11)*, 845; and U.S. Patents Nos. 6,301,038; 6,870.657; and 6,950,220);

(c) electro-wetting displays (see Hayes, R.A., et al., "Video-Speed Electronic Paper Based on Electrowetting", Nature, *425*, 383-385 (25 September 2003) and U.S. Patent Publication No. 2005/0151709);

(d) particle-based electrophoretic displays, in which a plurality of charged particles move through a fluid under the influence of an electric field (see U.S. Patents Nos. 5,930,026; 5,961,804; 6,017,584; 6,067,185; 6,118,426; 6,120,588; 6,120,839; 6,124,851; 6,130,773; and 6,130,774; U.S. Patent Applications Publication Nos. 2002/0060321; 2002/0090980; 2003/0011560; 2003/0102858; 2003/0151702; 2003/0222315; 2004/0014265; 2004/0075634; 2004/0094422; 2004/0105036; 2005/0062714; and 2005/0270261; and International Applications Publication Nos. WO 00/38000; WO 00/36560; WO 00/67110; and WO 01/07961; and European Patents Nos. 1,099,207 B1; and 1,145,072 B1; and the other MIT and E Ink patents and applications discussed in the aforementioned WO 03/044765).

[Para 8] There are several different variants of electrophoretic media. Electrophoretic media can use liquid or gaseous fluids; for gaseous fluids see, for example, Kitamura, T., et al., "Electrical toner movement for electronic paper-like display", IDW Japan, 2001, Paper HCS1-1, and Yamaguchi, Y., et al., "Toner display using insulative particles charged triboelectrically", IDW Japan, 2001, Paper AMD4-4); U.S. Patent Publication No. 2005/0001810; European Patent Applications 1,462,847; 1,482,354; 1,484,635; 1,500,971; 1,501,194; 1,536,271; 1,542,067; 1,577,702; 1,577,703; and 1,598,694; and International Applications WO 2004/090626; WO 2004/079442; and WO 2004/001498. The media may be encapsulated, comprising numerous small capsules, each of which itself comprises an internal phase containing electrophoretically-mobile particles suspended in a liquid suspending medium, and a capsule wall surrounding the internal phase. Typically, the capsules are themselves held within a polymeric binder to form a coherent layer positioned between two electrodes; see the aforementioned MIT and E Ink patents and applications. Alternatively, the walls surrounding the discrete microcapsules in an encapsulated electrophoretic medium may be replaced by a continuous phase, thus producing a so-called polymer-dispersed electrophoretic display, in which the electrophoretic medium comprises a plurality of discrete droplets of an electrophoretic fluid and a continuous phase of a polymeric material; see for example, U.S. Patent No. 6,866,760. For purposes of the present application, such polymer-dispersed electrophoretic media are regarded as sub-species of encapsulated electrophoretic media. Another variant is a so-called "microcell electrophoretic display" in which the charged particles and the fluid are retained within a plurality of cavities formed within a carrier medium, typically a polymeric film; see, for example, U.S. Patents Nos. 6,672,921 and 6,788,449.

[Para 9] Electrophoretic media can operate in a "shutter mode" in which one display state is substantially opaque and one is light-transmissive. See, for example, U.S. Patents Nos. 6,130,774 and 6,172,798, and U.S. Patents Nos. 5,872,552; 6,144,361; 6,271,823; 6,225,971; and 6,184,856. Dielectrophoretic displays can operate in a similar mode; see U.S. Patent No. 4,418,346. Other types of electro-optic displays may also be capable of operating in shutter mode.

[Para 10] One aspect of the present invention relates to a method for addressing a bistable electro-optic medium which improves the appearance of the display as the display is being updated. Electro-optic displays are driven from an initial state to a final state by means of a waveform comprising a series of voltage pulses, which may include pulses of zero voltage. Each voltage pulse induces part of a transition from an initial gray level to a final gray level. The optical nature of the transition from one image to another is an important attribute of the display performance. Also, the time of a transition (here, referred to as the update time) is a second important attribute of the display performance. The update time of many electro-optic displays is sufficiently long (typically of the order of several hundred milliseconds) that a user can observe intermediate states of the display between the initial and final states. For example, the aforementioned WO 03/044765 describes so-called "slide show" waveforms in which each pixel is driven from its initial gray level to one extreme optical state (for example, white), then to the opposite extreme optical state (for example, black) and finally to the desired final gray level; the "excursions" to the two extreme optical states may be repeated.

Although such slide show waveforms can produce accurate gray levels in the final image, they have the disadvantage that if all the pixels of the display are driven simultaneously to white and then to black, the user sees at least one "flash" between the initial and final images on the display. Most users find such flashes distracting and annoying.

[Para 11] Another problem in updating bistable displays is that, in practice, because it normally necessary to use drivers with only a limited number of voltage levels, the greater the number of gray levels which have to be written, the greater the update time. For this reason, it has been suggested that when rapid updating of a display is desirable, for example when a user is entering text in a dialogue box, the display should make use of two discrete drive schemes (the term "drive scheme" being used herein to denote a collection of waveforms sufficient to effect all possible transitions between the desired gray levels), one drive scheme typically being a monochrome drive scheme with a short update time and the other a non-monochrome gray level drive scheme; see for example, the aforementioned WO 2004/090857. However, such a "double drive scheme" approach can give rise to additional problems. The gray levels of the monochrome drive scheme may not correspond exactly to gray levels of the non-monochrome gray level drive scheme and, in view of the need to consider such factors as DC balance (again, see the aforementioned WO 2004/090857), special arrangements may be needed when a given pixel of the display switches between the two drive schemes.

[Para 12] One aspect of the present invention relates to a method of driving a bistable display which reduces or eliminates flashing and produces a more pleasing transition for a user. The method also eliminates the problems associated with switching between different drive schemes.

[Para 13] A second aspect of the present invention relates to optimizing gray levels using drivers having only a limited number of voltage levels. As already indicated, it is normally necessary to drive bistable electro-optic displays using drivers capable of providing only a limited number of voltage levels, because drivers capable of applying large numbers of voltage levels are considerably more expensive. Such drivers are normally arranged to operate with a series of timing or clock pulses with the driver applying the same voltage to a pixel during the interval between successive clock pulses, i.e., a graph of applied voltage against time essentially consists of a series of rectangles with the time dimension of each rectangle being an integral multiple of a predetermined clock period. Since only a limited number of driving voltages are available, the impulses which can be applied to the pixel (these impulses being proportional to the areas of the aforementioned rectangles) are quantized, and it may be difficult to combine such quantized impulses to reproduce accurately the impulse needed for a particular gray level transition, and there may be some inaccuracy in the final gray level resulting from the transition.

[Para 14] Such inaccuracy in final gray level can give rise to a "areal ghosting" problem. "Areal ghosting" refers to a phenomenon whereby, when a display bearing a first image is rewritten to display a second image, a vague "ghost" of the first image can be seen in the second image. One cause of such ghost images is inaccuracy in gray levels during the rewriting of the display. For example, consider a situation where a first image comprises a white shape on a black background, whereas the second image comprises a uniform field at an intermediate gray level. If, because of the limitations of the drivers and waveforms employed, the actual gray level resulting from the rewriting of the originally white pixels to the intermediate gray level differs visibly from the actual gray level resulting from the rewriting of the originally black pixels to the intermediate gray level, a "ghost" of the originally white shape will be visible in the second image. (Note that it does not matter whether it is the originally white pixels or the originally black pixels which are darker in the second image, a ghost image will still be visible; the ghost image may be similar to or an inverse of the first image.) Such ghost images are frequently objectionable to users of electro-optic displays, and the second aspect of the present invention seeks to reduce or eliminate such ghost effects.

[Para 15] In a first aspect, the present invention provides a method for writing a final gray scale image on a bistable electro-optic display having a plurality of pixels each of which is capable of displaying at least four gray levels (including the two extreme optical states of each pixel), the method comprising applying a first set of waveforms to the display, thereby producing an intermediate image, and thereafter applying a second set of waveforms to the display, thereby producing the final image, wherein the first set of waveforms are chosen such that the intermediate image is a projection of the final image on to a subset of the gray levels of the display. In a preferred form of this method, each of the pixels of the display is capable of displaying 2^n gray levels (where n is an integer greater than 1) and the intermediate image is a projection of the final image on to a subset of 2^m gray levels (where m is an integer less than n). Accordingly, this first aspect of the present invention may hereinafter for convenience be called the "lower bit depth intermediate image" or "LBDII" method of the invention, although as noted above in the most general form of this method it is not essential that the ratio between the number of gray levels in the final image and the number of gray levels in the subset be an integral power of 2. For example, if the final image is a 16 gray level (4 bit, i.e., n = 4) image, the intermediate image could be a 4 gray level (2 bit, i.e., m = 2) image. However, more generally for the same 16 gray level final image, the intermediate image could make use of (say) 3 or 6 gray levels, even though 16/3 and 16/6 are not integral powers of 2.

[Para 16] The term "projection" is used herein in accordance with its conventional meaning in the imaging art to refer to a rendering of a gray scale image into a similar image using a smaller number of gray levels, such that the relationships between the gray levels of the various pixels are substantially preserved. More formally, such a projection requires that:

(a) all pixels in the final image which are at the same gray level have the same gray level in the projection;

(b) for at least one gray level in the projection, all pixels in the final image which are at one of a group of contiguous gray levels are mapped to the same gray levels in the projection; and

(c) there are no inversions of relative gray levels in the projection (i.e., if in the final image pixel A is darker than pixel B, in the projection either pixels A and B have the same gray level - if the relevant gray levels are two of a contiguous group of gray levels in the final image which are mapped to the same gray level in the intermediate image - or pixel A is darker than pixel B in the intermediate image).

For example, if the final image has 16 gray levels denoted 0 (black) to 15 (white), the intermediate image could be a 4 gray level projection of the final image using only gray levels 2, 6, 10 and 14, with the mapping of the final image gray levels (shown within []) to the intermediate gray levels (shown within {}) being as follows:

[0, 1, 2, 3] → {2}

[4, 5, 6, 7] → {6}

[8, 9, 10, 11] → {10}

[12, 13, 14, 15]→ {14}.

[Para 17] In a second aspect, the present invention provides a method of driving a bistable electro-optic display having a plurality of pixels each of which is capable of displaying at least two different optical states, which method comprises applying to at least one pixel of the display a waveform comprising a first drive pulse followed by a second drive pulse, wherein the absolute value of the voltage of the second drive pulse is less than the absolute value of the voltage of the first drive pulse. This method may for convenience be called the "Reducing voltage drive method" or RVD method.

[Para 18] The term "absolute value" is used herein in its normal algebraic sense to denote the magnitude of a number without regard to the sign thereof. In other words, in the method of the second aspect of the present invention, the voltage of the second drive pulse is less than the voltage of the first drive pulse, but the two voltages may be of opposite sign.

[Para 19] In one preferred form of the second aspect of the present invention, there is applied to at least one pixel of the display a first drive pulse of one polarity followed by a second drive pulse of the same polarity but lower voltage. The method may further comprise applying a third drive pulse of the same polarity as the first or second drive pulse but of lower voltage than the second drive pulse.

[Para 20] In another preferred form of the second aspect of the present invention, there is applied to at least one pixel of the display a first drive pulse of one polarity followed by a second drive pulse of the opposite polarity but lower voltage, followed in turn by a third drive pulse of the same polarity as the first drive pulse but of lower voltage than the second drive pulse.

[Para 21] Any of the methods of the present invention can be used to drive any of the types of electro-optic medium previously described. Thus, for example, the display used in the present processes may comprise a rotating bichromal member or electrochromic material. Alternatively, the display may comprise an electrophoretic material comprising a plurality of electrically charged particles disposed in a fluid and capable of moving through the fluid under the influence of an electric field. The electrically charged particles and the fluid may be confined within a plurality of capsules or microcells. Alternatively, the electrically charged particles and the fluid may be present as a plurality of discrete droplets surrounded by a continuous phase comprising a polymeric material. The fluid may be liquid or gaseous.

[Para 22] This invention extends to a display controller arranged to carry out any of the methods of the present invention.

[Para 23] The displays of the present invention may be used in any application in which prior art electro-optic displays have been used. Thus, for example, the present displays may be used in electronic book readers, portable computers, tablet computers, cellular telephones, smart cards, signs, watches, shelf labels and flash drives.

[Para 24] Preferred forms of the invention will now be described with reference to the accompanying drawings, which are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention, and in which:

[Para 25] Figures 1A and 1B show respectively a prior art waveform for driving a bistable display and a modified waveform in accordance with the second aspect of the present invention.

[Para 26] Figure 2 shows a second waveform in accordance with the second aspect of the present invention.

[Para 27] Figure 3 is a graph showing reflectance of an electrophoretic medium as a function of time for various applied drive voltages.

[Para 28] As discussed above, this invention has two principal aspects, and these two principal aspects will primarily be described separately below. However, it should be understood that a single physical display may make use of both aspects of the present invention.

[Para 29] **Part A : Lower Bit Depth Intermediate Image Method**

[Para 30] As already mentioned, the first aspect of the present invention relates to a method for writing a final gray scale image on a bistable electro-optic display having a plurality of pixels each of which is capable of displaying at least four gray levels, the method comprising applying a first set of waveforms to the display, thereby producing an intermediate image, and thereafter applying a second set of waveforms to the display, thereby producing the final image, wherein the first set of waveforms are chosen such that the intermediate image is a projection of the final image on to a subset of the gray levels of the display. In a preferred form of this method, each of the pixels of the display is capable of displaying 2^n gray levels (where n is an integer greater than 1) and the intermediate image is a projection of the final image on to a subset of 2^m gray levels (where m is an integer less than n). In other words, this aspect of the invention relates to rendering images in a "higher bit depth" through an intermediate image rendering at a "lower bit depth", with the understanding that higher and lower bit depth do not necessarily refer to an image having exactly 2^x gray levels, where x is a positive integer. Such an LBDII method can be advantageous in two ways:

(a) It may be more pleasing to the viewer for an image to be quickly rendered in a lower bit depth and then refined to a higher bit depth. This could be seen as more pleasing than a transition to a new image that does not first render the image in a lower bit depth; and

(b) With proper controller functionality, a drive scheme (a term which is used herein to refer to a set of waveforms capable of effecting all possible transitions between gray levels of a display) of this sort could be used to support updates to a variety of bit depths in a manner that affords the greatest uniformity in update appearance.

[Para 31] A standard transition from one image to another on a display can be represented schematically as:

{initial image; n-bit} → {final image; n-bit}

[Para 32] Here, within each bracket the text after the semicolon indicates the bit depth of the image. The aforementioned E Ink and MIT patents and applications describe numerous drive schemes for achieving transitions between images of various bit depth, including 1-bit, 2-bit, and 4-bit. A 1-bit drive scheme makes transitions between images where the images are all rendered using a 1-bit grayscale, that is monochrome images:

{initial image; 1-bit} → {final image; 1-bit}

A 4-bit gray level drive scheme makes transitions between gray levels of a 4-bit gray scale, allowing rendering images using a 4-bit gray scale:

{initial image; 4-bit} → {final image; 4-bit}

[Para 33] The LBDII drive method may be represented schematically as:

{initial image; n-bit} → {intermediate image; m-bit} → {final image; n-bit} (A)

and

{initial image; m-bit} → {intermediate image; m-bit} → {final image; n-bit} (B)

where m is less than n, and both m and n are greater than unity.

[Para 34] The LBDII drive method has the inherent property that any transition of Type (A) can be halted at an intermediate point to achieve a transition:

{initial image; n-bit} → {"final" image; m-bit} (C)

so that what was originally the intermediate m-bit image becomes the "final" image of the truncated transition. A single transition of Type (C) may be followed by one or more transitions of the type:

{initial image; m-bit} → {final image; m-bit} (D)

before a final transition of Type (B) restores the display to "normal" n-bit operation allowing later transitions to be of Type (A). Note that while transitions of Type (D) are occurring, the display is in effect using a lower bit depth, and typically more rapid drive scheme, without the need to use a completely separate drive scheme, as in the prior art.

[Para 35] The LBDII drive method has the advantages that:

(a) rendering the image in a lower bit depth on the way to a higher bit depth rendering will typically be more pleasing to a viewer than the use of a drive scheme where there is no clear low-bit-depth rendering on the way to a final bit depth rendering; and

(b) the drive scheme allow the display to make faster transitions to a lower bit depth image rendering and slower transition to a higher bit depth rendering. This flexibility allows one to select one of these options for one application and another for another application. For example, when a fast update is important, the rendering at a lower bit depth can be used, and when a higher bit depth rendering is more important, the full update can be used. Having one drive scheme be able to achieve two bit depths adds coherence to all the transitions. Such coherence would not be as great when two separate drive schemes are used to render images to two distinct bit depths. Furthermore, such issues as DC balance are more easily handled within a single transition than in two separate drive schemes.

[Para 36] **Part B : Reducing voltage drive method**

[Para 37] As already mentioned, the second aspect of the present invention is a method of driving a bistable electro-optic display by applying to at least one pixel thereof a waveform comprising a first drive pulse followed by a second drive pulse, wherein the absolute value of the voltage of the second drive pulse is less than the absolute value of the voltage of the first drive pulse.

[Para 38] As discussed in the introductory part of this application, bistable electro-optic imaging media undergo changes in optical state when an impulse is applied, and an image can be retained for a substantial period without application of voltage. Because of this characteristic, the methods used to apply voltage impulses to such displays need to be well designed. For example, one prior art drive scheme for a monochrome (black and white) display comprises the following four waveforms:

[Para 39] **Table 1**

transition	**waveform**
black to black	0 V for 420 ms
black to white	-15 V for 400 ms, then 0 V for 20 ms
white to black	+15 V for 400 ms, then 0 V for 20 ms
white to white	0 V for 420 ms

[Para 40] For a black-to-white transition, the voltage impulse is:

-15V * 400 milliseconds = -6 Volt seconds

Numerous different waveforms can be used to provide this impulse to a pixel of the display; to a first approximation, the impulse for this particular transition should be maintained constant to ensure that the final white state of the transition is also maintained constant. (As discussed in some of the E Ink and MIT patents and applications discussed above, the "white state" of a pixel may vary slightly depending upon the impulse and waveform applied during a transition.) Table 2 below list three possible waveforms which could be used for the same black-to-white transition:

[Para 41] **Table 2**

transition	**waveform**
black to white	-15 V for 400 ms, then 0 V for 20 ms
	-12 V for 500 ms, then 0 V for 20 ms
	-10 V for 600 ms, then 0 V for 20 ms

[Para 42] From Table 2, it will be seen that one advantage of using varying drive voltages is control of update time. A low driving voltage can be used for a long update time or a high driving voltage for a fast update. Another advantage of variable driving voltages is fine tuning of optical states. Consider a driver that provides a 50 Hz maximum refresh rate, which is a 20 ms minimum update time. A single driving voltage, -15V, for example, limits the minimum voltage impulse of –15 V*20 ms = -0.3 V-s; this also defines the minimum change of optical state. Because of this minimum impulse, the ability to achieve higher bit-depth in gray levels is limited. However, variable drive voltages allow fine tuning of gray levels when the minimum update time is limited by the driver, and thus help to achieve higher bit-depth in gray levels. The following Table 3 lists minimum voltage impulses for several different drive voltages, assuming a 20 ms minimum update time.

[Para 43] **Table 3**

driving voltage, V	update time, ms	voltage impulse, V-s
-15	20	-0.3
-12	20	-0.24
-10	20	-0.2

[Para 44] The reducing voltage method of the present invention makes use of a first relatively high drive voltage to provide a fast change in optical state, followed by a second lower drive voltages for fine-tuning of the final optical state. In contrast to prior art driving methods, in which often only a single drive voltage is employed, the RVD method of the present invention uses multiple drive voltages for each transition.

[Para 45] For example, Figure 1A is a prior art waveform using only a single drive voltage. In this waveform, a drive voltage of 12 V is applied for 600 milliseconds to apply an impulse of 12V*600ms = 7.2 V-s. In accordance with the RVD method of the present invention, the waveform shown in Figure 1A can be replaced by that shown in Figure 1B, in which a first drive voltage of 15 V is applied for 300 milliseconds, a second drive voltage of 12 V is applied for 100 milliseconds and a third drive voltage of 10 V is applied for 200 milliseconds, to deliver the same 7.2 V-s impulse as the waveform shown in Figure 1A.

[Para 46] The RVD method of the present invention may also be employed in so-called "slide show" waveforms as described in the aforementioned WO 03/044765. As mentioned above, in such slide show waveforms, each pixel is driven from its initial gray level to one extreme optical state (for example, white), then to the opposite extreme optical state (for example, black) and finally to the desired final gray level; the "excursions" to the two extreme optical states may be repeated. Such waveforms are effective in securing accurate gray levels but distracting to the user because of the black and white flashes which they produce during image transitions.

[Para 47] Figure 2 illustrates a slide show RVD waveform of the present invention. This waveform comprises a first drive pulse of +15 V, a second drive pulse of -12 V, and a third drive pulse of +12 V. All of these drive pulses are used to effect the slide show transitions to the extreme optical states, although it will be appreciated that the second and third drive pulses may not drive the display completely to an extreme optical state. The slide show RVD waveform shown in Figure 2 further comprises a fourth drive pulse of +10 V which drives the pixel to the desired gray level.

[Para 48] Figure 3 illustrates the effect of applying, to a typical electrophoretic medium of the type described in U.S. Patent No. 7,002,728, 5, 10 and 15 V pulses for various numbers of 20 millisecond frames; the pulses are applied starting from the extreme white optical state of the medium and drive the medium towards its black optical state. It will be seen that, during the first few five to ten frames, the rate of change of the reflectance is very high at both 10 and 15 V; in several cases, a single frame produces a change in reflectance of about 6 L* units or more. Since a typical display controller only allows one to apply drive pulses comprising an integral number of frames, a change in reflectance of 6 L* units per frame means that the gray level produced by the controller may be in error by about ± 3 L* units. This is unacceptable, since in many images even casual observers can detect errors of 2 L* units. However, such errors can be greatly reduced using the RVD method of the present invention.

[Para 49] To take one extreme example, Figure 3 shows that a 2-frame 15 V drive pulse produces a reflectance of about 57 L*, whereas a 3-frame 15 V drive pulse produces a reflectance of about 49 L*. Hence, if one desired a gray level of 53 L*, use of 15 V drive pulses only would result in an unacceptable error of 4 L* units in this gray level. However, Figure 3 also shows that it take 13 frames of 5 V drive voltage to change reflectance from 57 L* to 49 L*, the former being reached after 8 frames and the latter only after 21 frames. Accordingly, any desired gray level within the range of 57 L* to 49 L* can be achieved with high precision by first applying 15 V for two frames, and then 5 V for from 1 to 12 additional frames. More specifically, if one desires to achieve the aforementioned gray level of 53 L*, this may be done by first applying 15 V for two frames, and then 5 V for 5 or 6 additional frames, with the final error in gray level being less than 0.5 L*, an error which is acceptable for most uses of electro-optic displays.

[Para 50] It should be noted that Figure 3 also illustrates why it is important to have high drive voltages available, namely that such high drive voltages increase the dynamic range of the medium, that is to say the maximum difference between the extreme optical states. It will be seen from Figure 3 that a long drive pulse at 15 V produces a final black state having a value of about 32 L*, whereas a long drive pulse at 10 V produces a final black state having a value of about 34 L*. Similarly, as appears at the left hand side of Figure 3, driving at the extreme white optical state using a 15 V drive pulse produces a white state having a value of about 72 L*, whereas using a 10 V drive pulse produces a white state having a value of about 70 L*. Accordingly, it is desirable to have 15 V drive pulses available, since they provide a wider dynamic range, and hence a greater contrast ratio, than are available from the use of 5 and 10 V drive pulses alone.

[Para 51] The RVD method of the present invention necessarily uses at least two different (non-zero) voltages. Since electro-optic media are sensitive to the polarity of the drive voltage as well as its magnitude, the drive method must have the capability to drive the medium in both directions, and hence voltages are normally used as matched pairs of +V and -V, and the RVD method requires a minimum of five voltage levels (two negative, two positive and zero). More voltage levels can of course be used; for example, the drive method shown in Figure 1B uses three different positive voltages (10, 12 and 15 V) so that a total of seven voltage levels are required. However, since the cost and complexity of the circuitry needed to supply the various voltage levels increases with the number of voltage levels, it is desirable to limit the number of levels used. Typically, an RVD method of the present invention will use 5, 7 or 9 total voltage levels, which use 3- or 4-bit bandwidth in the driver. In summary, limited total voltage levels should be used, and the voltage levels should be chosen based on the characteristics of the electro-optic medium used.

[Para 52] The RVD method of the present invention can be used with both monochrome and gray scale displays. The method has the advantages that it can provide improved control of gray levels (i.e., the gray level achieved by a transition can very closely approach the theoretically desired level) and the display typically shows a reduced level of ghosting.

[Para 53] The preferred embodiments of the invention described above can be varied in numerous ways. For example, addressing architectures of the invention can be used in a variety of displays, for example, displays with electrophoretic or rotating ball media, and with encapsulated or unencapsulated media. The number of sub-frames of a frame may be greater or fewer than described, and the number of digits of an addressing impulse data unit may be greater or fewer than described, in the illustrative examples.

CLAIMS

1. A method for writing a final gray scale image on a bistable electro-optic display having a plurality of pixels each of which is capable of displaying at least four gray levels, the method comprising applying a first set of waveforms to the display, thereby producing an intermediate image, and thereafter applying a second set of waveforms to the display, thereby producing the final image, the method being characterized in that the first set of waveforms are chosen such that the intermediate image is a projection of the final image on to a subset of the gray levels of the display.

2. A method according to claim 1 wherein each of the pixels of the display is capable of displaying 2^n gray levels (where n is an integer greater than 1) and the intermediate image is a projection of the final image on to a subset of 2^m gray levels (where m is an integer less than n).

3. A method according to claim 1 wherein each of the pixels of the display is capable of displaying at least 16 gray levels.

4. A method according to claim 1 wherein the intermediate image is a 2 or 4 gray level image.

5. A method according to claim 1 wherein the first set of waveforms are applied to the display to produce the intermediate image using the subset of gray levels, thereafter at least some of the pixels of the display are subjected to at least one transition to produce a second image using the subset of gray levels, and finally the display is subjected to a final transition to produce a final image using the full set of gray levels.

6. A method according to claim 1 wherein the display comprises a rotating bichromal member or electrochromic material.

7. A method according to claim 1 wherein the display comprises an electrophoretic material comprising a plurality of electrically charged particles disposed in a fluid and capable of moving through the fluid under the influence of an electric field.

8. A method according to claim 7 wherein the electrically charged particles and the fluid are confined within a plurality of capsules or microcells.

9. A method according to claim 7 wherein the electrically charged particles and the fluid are present as a plurality of discrete droplets surrounded by a continuous phase comprising a polymeric material.

10. A method according to claim 7 wherein the fluid is gaseous.

11. A display controller arranged to carry out the method of claim 1.

12. A method of driving a bistable electro-optic display having a plurality of pixels each of which is capable of displaying at least two different optical states, which method comprises applying to at least one pixel of the display a waveform comprising a first drive pulse followed by a second drive pulse, the method being characterized in that the absolute value of the voltage of the second drive pulse is less than the absolute value of the voltage of the first drive pulse.

13. A method according to claim 12 wherein there is applied to at least one pixel of the display a first drive pulse of one polarity followed by a second drive pulse of the same polarity but lower voltage.

14. A method according to claim 13 further comprising applying a third drive pulse of the same polarity as the first or second drive pulse but of lower voltage than the second drive pulse.

15. A method according to claim 12 wherein there is applied to at least one pixel of the display a first drive pulse of one polarity followed by a second drive pulse of the opposite polarity but lower voltage, followed in turn by a third drive pulse of the same polarity as the first drive pulse but of lower voltage than the second drive pulse.

16. A method according to claim 12 which is effected using voltage supply circuitry capable of supplying 5, 7 or 9 voltage levels.

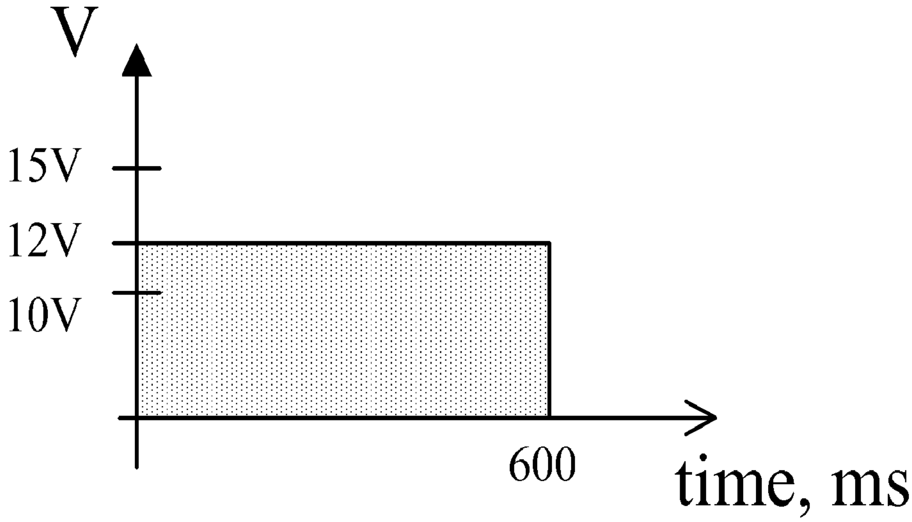

Fig. 1A (Prior Art)

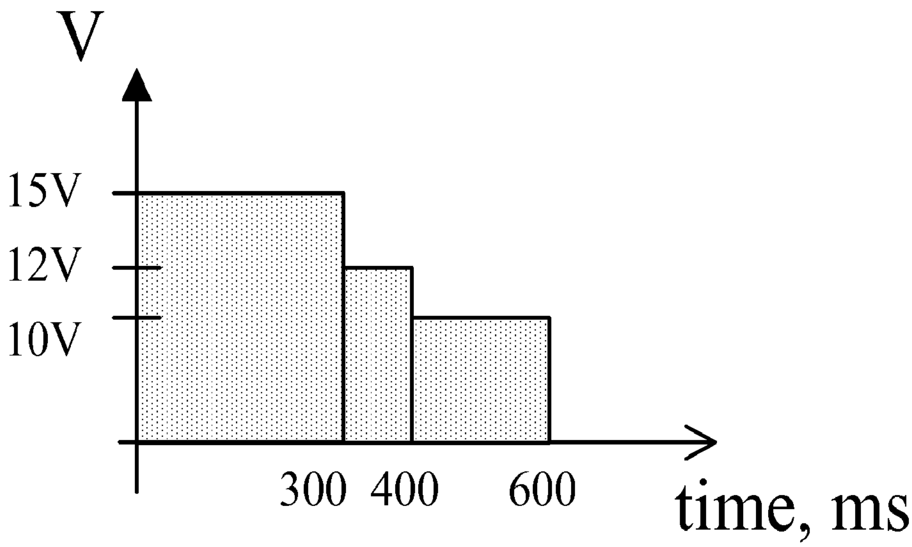

Fig. 1B

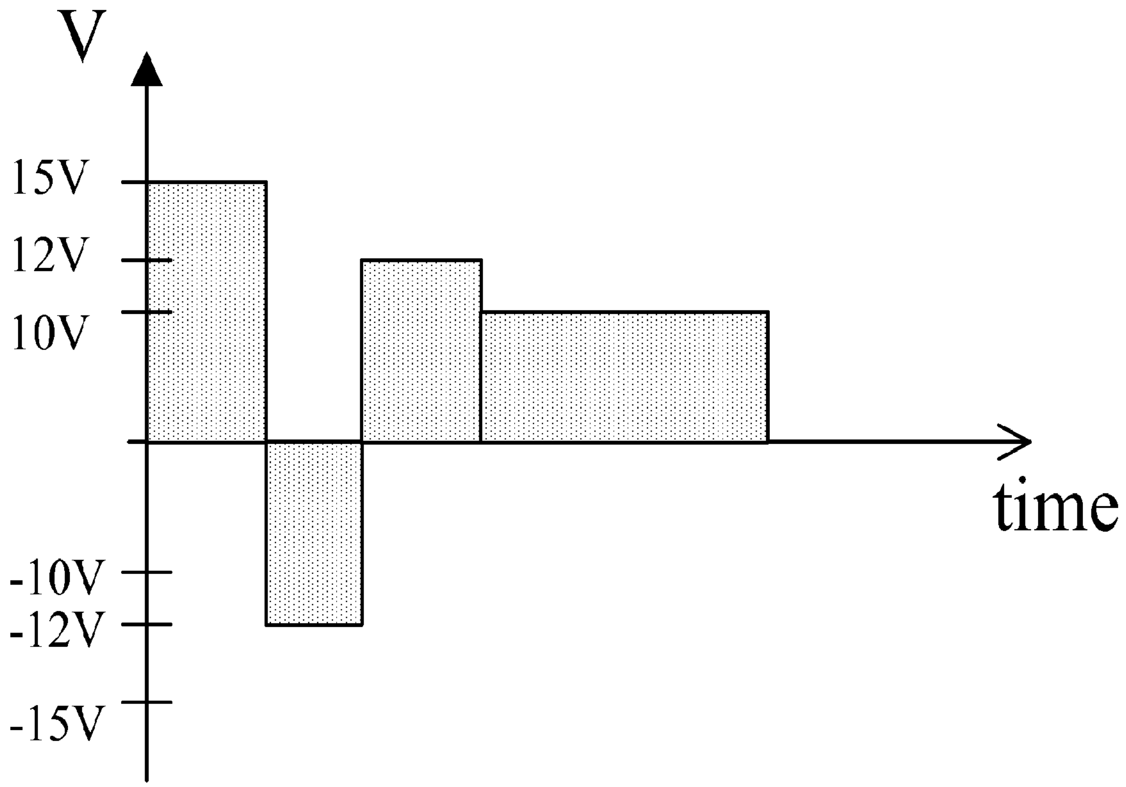

Fig. 2

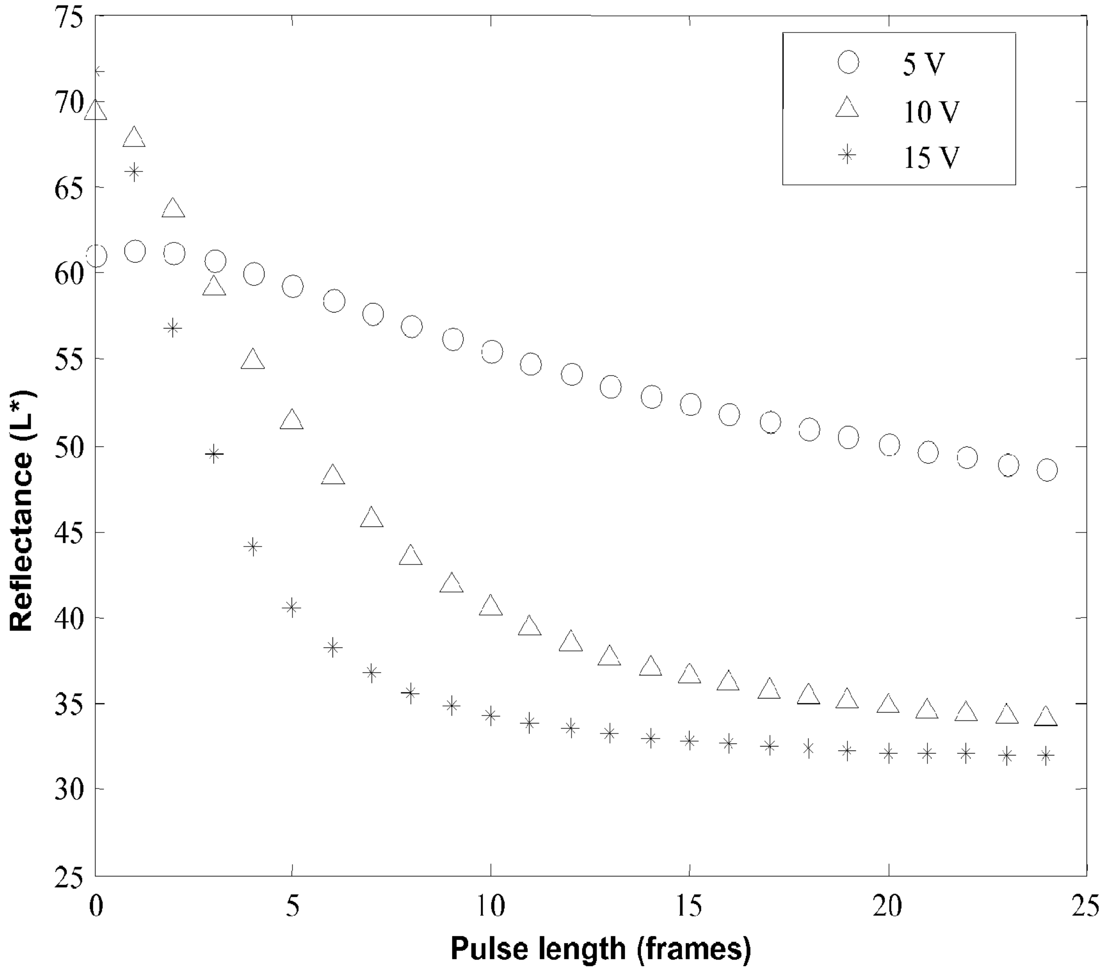
5 V
10 V
15 V
Reflectance (L*)
Pulse length (frames)
75
70
65
60
55
50
45
40
35
30
25
0
5
10
15
20
25

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 08/57777

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G09G 3/36 (2008.04)
USPC - 345/89
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC- 345/89

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC- 345/89,51,76,94,204,208

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(USPT, PGPB, EPAB, JPAB); Google Scholar
Search Terms: electro, optic, display monitor, electrophoretic, pulse, pixel, driver, circuit, gray, state, display, electrochromic, volt, waveform, wave, form, bistable, voltage, intermediate, projection

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/0280626 A1 (Amundson et al.) 22 December 2005 (22.12.2005) para [0013], para [0014], para [0016], para [0017], para [0042], para [0069], para [0071]-para [0073], para [0130]-para [0133], para [0158], para [0159], para [0165], para [0171], para [0190]-para [0193], para [0195], para [0197], para [0200], para [0206], para [0219], para [0307]-para [0309]	1-16
A	US 2003/0137521 A1 (Zehner et al.) 24 July 2003 (24.07.2003) abstract, entire document	1-16
A	US 6,219,160 B1 (Nordal et al.) 17 April 2001 (17.04.2001) entire document	1-16
A	US 6,175,355 B1 (Reddy) 16 January 2001 (16.01.2001) entire document	1-16
A	US 5,892,504 A (Knapp) 06 April 1999 (06.04.2001) abstract, entire document	1-16

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 July 2008 (30.07.2008)	06 AUG 2008

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774