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Brightness Adjustment for Foldable Displays

Abstract:

When placed in a folded configuration, foldable computing-device displays include several different portions such as a front, back, exterior, or interior portion. In practical operation, various portions of the foldable display will be in an active or illuminated condition for different lengths of time, which can result in one or more of the portions of the display appearing to be brighter than adjacent portions because of variations in display decay. A boundary or stark dividing line between two adjacent portions of differing brightness can be distracting to a user when the foldable computing-device display is used in a fully-extended configuration. To reduce the appearance of brightness variation, the brightness of a brighter of two adjacent portions can be reduced or the brightness of a dimmer portion of the two adjacent can be increased in a gradient pattern in a transition region between the two adjacent portions of the foldable display.

Keywords:

Display panel, active-matrix organic light-emitting diode, AMOLED, OLED, LED, foldable display, flexible display, fold, unfold, gradient effect, fade effect, black and white effect, grain effect, transition, smooth change over, brightness decay, brightness compensator, luminance match, brightness match, frequently used display, active display, recently used display, long time used display.

Background:

From cathode tubes to plasma and liquid-crystal displays to solid state devices, such as light-emitting diodes and organic light-emitting diodes, computing-device displays come in many

different varieties. Each of these display types offers functionality to a user. Some of these display types, such as an active-matrix organic light-emitting diode, are flexible enough to be incorporated into foldable computing devices and still retain their functionality. For example, the display of a foldable computing device may include an exterior portion and an interior portion or a front portion and a back portion when placed in a folded configuration. The exterior or front portions of a foldable display may be used more often than the interior or back portions. Over time, the interior or back portions of the foldable display may appear to be brighter than the more used exterior or front portions because they have been used less frequently. To maintain a consistent overall look when in a completely-extended configuration, foldable computing devices necessitate customized display operations because different portions of the display may have been used for differing lengths of time.

Description:

When placed in a folded configuration, foldable computing-device displays include several different portions such as a front, back, exterior, or interior portion. In practical operation, various portions of the foldable display will be in an active or illuminated condition for different lengths of time, which can result in one or more of the portions of the display appearing to be brighter than adjacent portions because of variations in display decay. A boundary or stark dividing line between two adjacent portions of differing brightness can be distracting to a user when the foldable computing-device display is used in a fully-extended configuration. To reduce the appearance of brightness variation, the brightness of a brighter of two adjacent portions can be reduced or the brightness of a dimmer portion of the two adjacent can be increased in a gradient pattern in a transition region between the two adjacent portions of the foldable display.

Consider the idyllic countryside and farm presented on the foldable display of a computing device, as shown Figure 1. Two locations of the foldable display (shown as indentations in the perimeter on the top and the bottom edges of the computing device) indicated positions at which the foldable display can be bent roughly in half to reduce its overall size, convert the foldable display and computing device into a multi-display device, or allow the computing device to stand on an edge like an easel. Any of these, or many other, configurations can add to the user experience and engagement with the computing device.

Side A **Side B**

Figure 1

When placed in a folded configuration, the foldable display of the computing device may be divided into several different portions. Figure 2A shows a rear portion of the foldable display with the computing device in an easel-like configuration, which corresponds to Side A of Figure 1. Here, the presented image has been zoomed in to a central region of the countryside shown in Figure 1. Figure 2B shows a front portion of the foldable display, which corresponding to Side B of Figure 1, where the presented image has been zoomed out to show the entire countryside of Figure 1 but on a smaller scale. As can be surmised, any number of different views of the

countryside of Figure 1 or an entirely different scene altogether could be shown on either the front or rear portion of the foldable display.

Figure 2A

Figure 2B

Figures 2A and 2B also include a series of dashed lines near the top of the display screen areas of the front and rear portions of the foldable display: one with smaller and one with larger dashes. The smaller-dashed line represents the dividing line between the front and rear portions where the presentation changes from either the front or rear portion respectively when the foldable display is placed into a folded configuration from the completely-extended configuration. The larger-dashed line represents a transition region near the dividing line between the front and rear portions of the foldable display. When returned to a completely-extended configuration, as shown in Figure 3, the smaller-dashed dividing line between the rear portion (Side A) and the front portion (Side B) and the larger-dashed lines marking the transition region between the two sides roughly corresponds to the indentations on the perimeter of the computing device marking the locations at which the foldable display can be bent into its configurations.

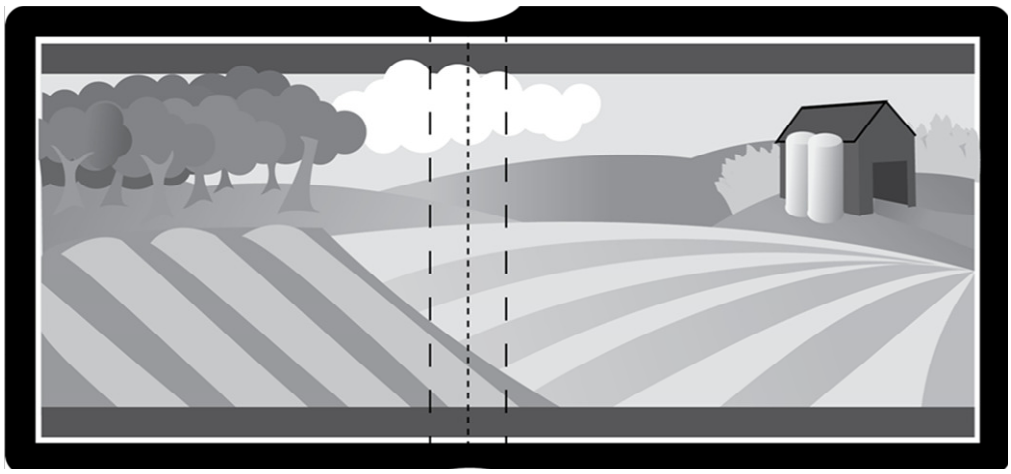


Figure 3

Foldable displays may include any number of locations at which they may be folded into a variety of configurations. Figure 4 illustrates another computing device that includes two locations at which the foldable display may be folded and divided into three sections.

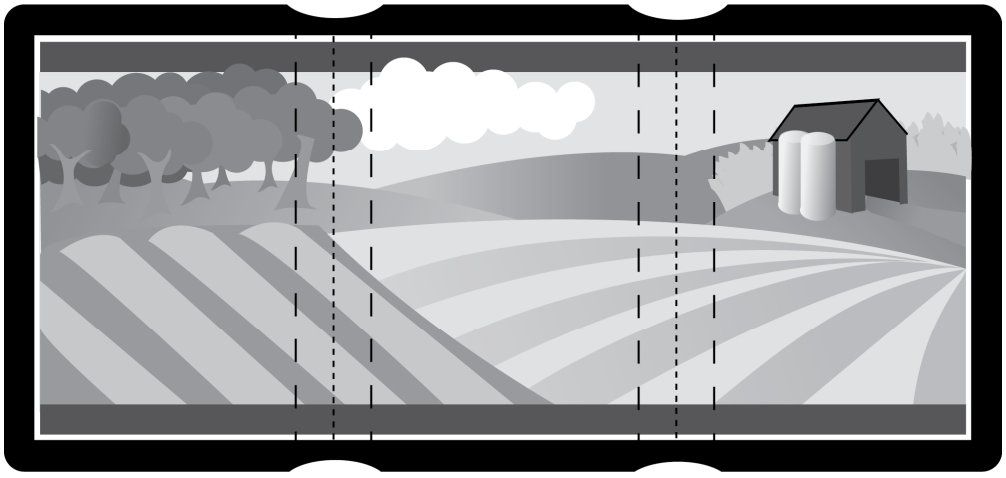
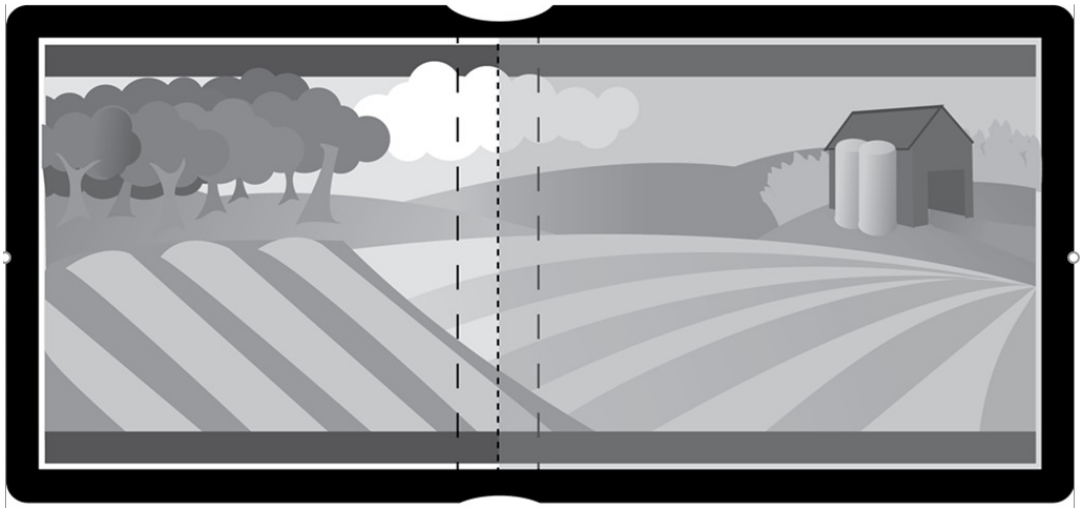


Figure 4

Over time, use of the computing device with a foldable display in any of its non-fully-extended configurations will result in different portions of the foldable display being used or illuminated for different lengths of time. The foldable display includes individual light-emitting

pixels or diodes. When these individual pixels or diodes emit light, they begin to decay or break down as part of their natural operation. As they break down, the pixels or diodes lose their color accuracy. Additionally, the performance of the foldable display as a whole suffers because the individual pixels or diodes do not decay or break down at the exact same rate. In a foldable display, certain whole portions of the display are used for different lengths of time. But, within those portions, some pixels that are used more frequently than others (e.g., the pixels of elements of a lock screen that are used often) may breakdown at an increased rate, which may result in variations at local locations within an entire portion of the foldable display.

Consider the active-matrix organic light-emitting diode (AMOLED) display of the computing device shown in Figure 5 (for clarity, the computing device is shown in a fully-extended configuration in the remaining figures). As shown by the reduced brightness, Side B (the front portion of the display) has been used more often than Side A (the rear portion of the display). The smaller-dashed line illustrates the division between Side A and Side B and the variation in brightness between each side respectively.



Side A **Side B**

Figure 5

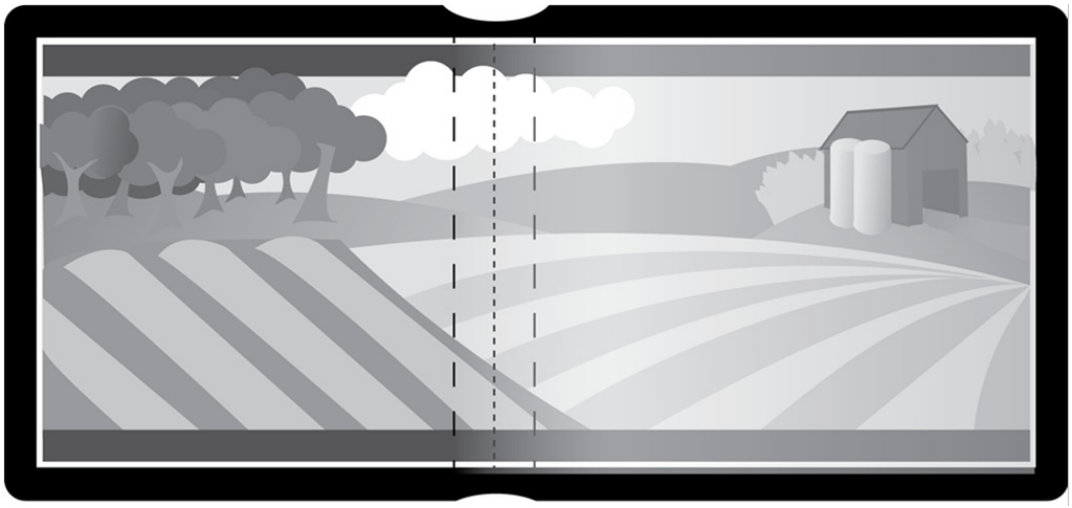
Without the smaller-dashed and larger-dashed lines, Figure 6 illustrates the difference in brightness and the stark contrast between the two sides at the transition. This change in contrast can be disruptive for the user of the computing device when using the device in the completely-extended configuration.

Side A **Side B**

Figure 6

To reduce the overall visual impact of the variation among the various portions of the foldable display, the computing device may include a brightness-adjustment module to blend the differing sides or portions of the foldable display. In the transition region (bounded by the two larger-dashed lines), the brightness-adjustment module, which may be a component of an operating system, instructions in firmware or hardware, a standalone application, or implemented in other manners, can blend the brightness between Side A and Side B. The brightness-adjustment module may increase or decrease the brightness of either Side A or Side B individually or collectively to reduce the appearance of a change in brightness at the transition. Figure 7 illustrates the countryside scene of Figure 1 with the brightness-adjustment module engaged in mediating the

brightness differences of Side A and Side B in the transition region between the larger-dashed lines.



Side A **Side B**

Figure 7

Figure 8 illustrates the same scene as Figure 7 but without the dashed reference guidelines.

Side A **Side B**

Figure 8

Figure 9 illustrates the appreciable visual difference between a foldable display without a brightness-adjustment module (similar to Figure 6) and a foldable display with a brightness-adjustment module actively mediating the transition between portions of the foldable display (similar to Figure 8).

Figure 9A) Display without a brightness-adjustment module

Figure 9B) Display with a brightness-adjustment module

Figure 9

Additionally, the brightness-adjustment module can proactively mediate locations of transition between portions of the foldable display, which may prevent or reduce the visibility of the stark transition line between portions of the foldable display illustrated above in Figures 5, 6, and 9. Consider again the foldable display in a folded configuration, as shown in Figures 2A and 2B. When placed into a folded configuration, the brightness-adjustment module can apply the same gradient-style reduction in brightness in the region between the larger-dashed and smaller-dashed lines. In this manner, pixels in the transition region between the dashed lines are used less or are used at a lower brightness and may not decay as quickly as those pixels used at a higher brightness level further from the transition region. Over time, the pixels in the transition region may more naturally blend with their adjacent counterparts.

Foldable computing-device displays include several different portions that will be in an active or illuminated condition for different lengths of time, which can result in one or more of the portions of the display appearing to be brighter or dimmer than an adjacent portion because of variations in display decay. A variation in brightness between two adjacent portions of differing brightness can be distracting to a user when the foldable computing-device display is used in a fully-extended configuration. To reduce the appearance of brightness variation, the brightness of a brighter adjacent portion can be reduced, or the brightness of a dimmer adjacent portion can be increased, in a gradient-style transition region between the portions of the foldable display.