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Image Data Compensation to Prevent Display Artifacts on an OLED Display

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Abstract:

This publication describes techniques for image data compensation that prevent display artifacts on an organic light-emitting diode (OLED) display when the refresh rate and the clock speed of the display are changed. The OLED display may be implemented in a mobile device that supports multiple refresh rates. To conserve power, the mobile device may alter the refresh rate and clock speed of the OLED display from a first refresh rate and clock speed to a second refresh rate and clock speed. Image data intended to be displayed on a particular pixel row of the OLED display may be compensated based on the first refresh rate, the second refresh rate, and the location of the particular pixel row within the OLED display to generate compensated image data. Using the techniques described herein, the compensated image data may be output for use in preventing display artifacts while the image data is displayed in a first frame after the refresh rate and clock speed are changed.

Keywords:

Dynamic refresh rate, refresh rate (RR) change, organic light-emitting diode (OLED) display, image compensation, line-by-line image compensation, pulse width modulation (PWM) duty ratio distortion compensation, frame compensation, clock frequency, distortion, flickering, brightness distortion

Background:

The increase in capability of mobile devices continue to require increased power draw from the device power supply, which effectively lowers the battery life of the mobile device. Consequently, mobile devices need to incorporate power saving techniques to lower the power draw of the mobile device in appropriate circumstances, such as lowering the clock speed in instances where a higher refresh rate provides little noticeable difference to the user. However, changes in clock speed and display refresh rate can cause display artifacts, such as duty ratio distortion and flicker. As a result of such display artifacts, a user may have a less desirable user experience. Consequently, mobile devices may be forced to choose between providing optimal user satisfaction or extended battery life.

Description:

This publication describes techniques for image data compensation that prevent display artifacts on an organic light-emitting diode (OLED) display when the refresh rate and the clock speed of the display are changed. In an effort to save power, a mobile device (e.g., a smartphone) may alter clock speed when the refresh rate of the display is changed from a first refresh rate to a second refresh rate. The mobile device may compensate for image data intended to be displayed on a particular pixel row in a first frame after the refresh rate is changed from the first refresh rate to the second refresh rate. For example, the mobile device may compensate for image data based on the first refresh rate, the second refresh rate, and a location of the particular pixel row within the OLED display. Additionally, the compensated image data may be output to a controller for use in displaying the compensated image data on the particular pixel row in a first frame after the refresh rate has been changed to the second refresh rate. For example, image data compensation could be performed at a hardware level at which a system-on-chip (SoC) is configured to alter the image data or at a software level at which the image data is altered on rendering. In doing so, the techniques described in this publication may prevent display artifacts on an OLED display when refresh rate and clock speed are changed.

Often, mobile devices perform pulse width modulation (PWM) at a clock frequency to control the brightness of an image on the display. In general, the clock frequency linearly increases/decreases according to the refresh rate on the display. When the refresh rate of the display is lowered from the highest frame rate of the display, power may be wasted when the previous clock frequency is maintained. To save power, the clock frequency may be set to a new clock frequency (e.g. 94 kHz for 1440x3120 resolution 60 Hz refresh rate) lower than the previous clock frequency (e.g. 188 kHz for 1440x3120 resolution 120 Hz refresh rate). For example, the clock frequency may be set to the same frequency as the corresponding one, 94 kHz, for the lowered refresh rate, 60 Hz. As a result, duty ratio distortion, flickering, or other display artifacts may appear in the first frame after the refresh rate and clock frequency are changed to the second refresh rate and second clock frequency.

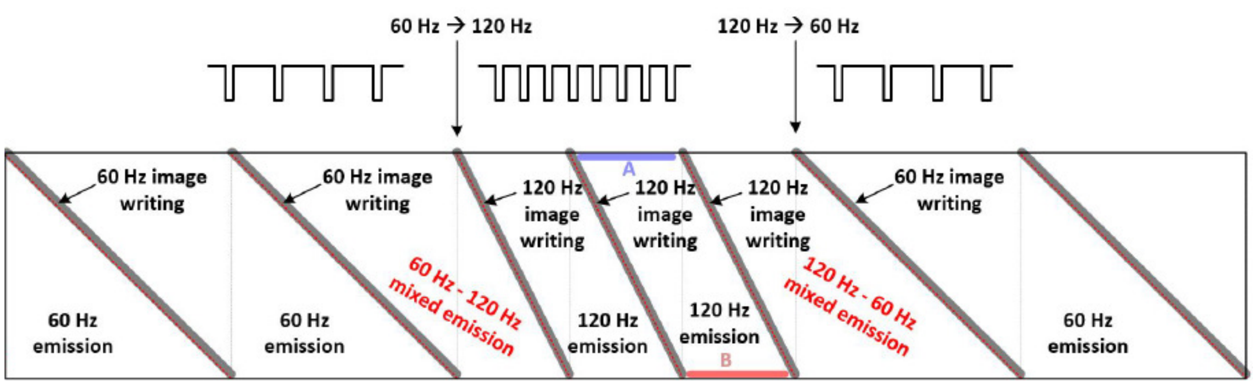

Figure 1

Figure 1 illustrates an example of image distortion when image date is not compensated for clock speed and refresh rate changes in an OLED display. Specifically, the refresh rate of the

OLED display is changed from 60 Hz to 120 Hz as the clock frequency is simultaneously changed from 60 Hz to 120 Hz. Each segment of Figure 1 represents a single frame of the OLED display where the pixel rows are scanned from top to bottom and updated accordingly. Additionally, the display undergoes PWM based on the clock frequency at each frame. In the example above, the refresh rate and clock speed are changed at the beginning of each frame, which maintains the number of pulses for each frame, but causes duty ratio distortion depending on the location of the pixel row within the display.

In Figure 1, the first row of pixels will not undergo duty ratio distortion as the refresh rate and PWM are altered at a same instant the top pixel row is updated. However, in the first frame, after the refresh rate and clock frequency are changed, all lines below the first line will experience duty ratio distortion. In the illustrative example of Figure 1, each frame will include one pulse per frame (e.g., each frame experiences a binary value of zero during the first half of the frame and a binary value of one during the second half of the frame). In this example, the refresh rate of the OLED display and clock frequency are changed from 120 Hz to 60 Hz in the sixth frame. As a result, image data displayed on a row of pixels in the middle of the OLED display will be displayed for one and a half times the duration of image data displayed on the first row of pixels. Due to the change in clock frequency, the image data displayed on the first row of pixels will be modulated with a one binary value for half of the time the image data is displayed while image data displayed on the middle row of pixels will be modulated with a one binary value for one third of the time the image data is displayed. As a result, the display artifacts, such as perceived brightness differences in a portion or portions of the screen, may occur. It should be noted that the clock frequency and refresh rate provided in this example are for example only and duty ratio distortion may occur when the clock frequency is altered to a multitude of values based on the ratio of the previous refresh rate with respect to the changed refresh rate.

The techniques for image data compensation described herein may prevent the occurrence of display artifacts when the clock frequency and refresh rate of an OLED display are changed. In an aspect, duty ratio distortion is modeled for a particular row of pixels of the OLED display. For example, duty ratio distortion (DR_D) for each row of pixels may be determined based on the total number of pulses (N), the pulses per single frame (m), the previous refresh rate (f1), the changed refresh rate (f2), and the duty ratio of the first row of pixels (DR). More specifically, the duty ratio distortion may be modeled using Equation 1.

If $\mathrm{mod}\left(N - i + 1, \frac{N}{m}\right) = r \geq \frac{DR*N}{m} = k$:

$$DR_D = \frac{1}{m}\left(DR(m-1) + \frac{k}{\left(r + \frac{f1}{f2}\left(\frac{N}{m} - r\right)\right)}\right)$$

Else:

$$DR_D = \frac{1}{m}\left(DR(m-1) + \left(r + \frac{f1}{f2}\left(\frac{k-r}{r + \frac{f1}{f2}\left(\frac{N}{m} - r\right)}\right)\right)\right)$$

Equation 1

It should be noted that when m = 1, many operations may evaluate to zero and simplify Equation 1. As such, a single pulse per frame may allow duty ratio distortion to be determined through less expensive computation.

Once the duty ratio distortion has been determined for a particular row of pixels, compensation image data (I_C) intended for display on the particular row of pixels can be determined based on the ratio of DR to DR_D. Specifically, compensated image data (I_C) may be determined for image data (I) intended for display on a pixel having a row (i) and column (j) within the display based on Equation 2:

$$I_C(i,j) = I(i,j) * \sqrt[2.2]{\frac{DR}{DR_D(i)}}$$

Equation 2

It should be noted that image data compensation may be performed at the software level, the hardware level, or both. For example, the compensated image data may be determined at a software level of the analytic modification of the image data when rendered. Alternatively, or in addition, the compensated image data may be determined at a hardware level through an image compensation block performed in a display driver integrated circuit (DDIC) or a system-on-chip (SoC).

The techniques for image data compensation that prevent display artifacts on an OLED display when the refresh rate and the clock speed of the display are changed may include a method comprising: determining, at a first time, a first refresh rate of a display containing one or more rows of pixels based on a first clock frequency; determining, at a subsequent time, a second refresh rate of the display based on a second clock frequency; determining, for image data intended for display on a particular row of pixels of the one or more rows of pixels, an image data compensation based on the first clock frequency, the second clock frequency, and a location of the particular row of pixels within the display; and outputting the image data compensation for the image data intended for display on the particular row of pixels to a controller for use in adjusting the image data intended for display on the particular row of pixels in a subsequent frame when the display is configured from the first refresh rate to the second refresh rate.

References:

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