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Dynamically Altering Clock Signal Frequencies in LTPO AMOLED Displays

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Abstract:

This publication describes systems and techniques for dynamically altering clock signal frequencies in low-temperature polysilicon metal oxide (LTPO) active-matrix organic light-emitting diode (AMOLED) displays. In an aspect, a display manager may identify a refresh rate implemented by an operating system of an electronic device, as well as a use case enacted by a user. As a result of the identification, the display manager can implement a suitable clock signal frequency for self-refresh operations. By dynamically altering clock signal frequencies, the display manager can reduce the number of transactions (e.g., passing high signals, passing low signals) in display panel circuitry associated with self-refresh operations. In so doing, the display manager can dynamically alter clock signal frequencies in LTPO AMOLED displays to reduce power consumption without degrading user experience.

Keywords:

Display panel, active-matrix organic light-emitting diode (AMOLED), active-matrix organic diode, organic light-emitting diode (OLED), low-temperature polysilicon metal oxide (LTPO), display driver integrated circuit, frame rate, refresh rate, pixel, pixel array, variable frequency, dynamic frequency, dynamic refresh, self-refresh frequency, power consumption, clock frequency

Background:

Many electronic devices (e.g., smartphones, tablets, laptops, handheld video game consoles, smartwatches, televisions) include displays having tens of thousands of pixels. Display panel drivers (e.g., scan drivers, gate drivers) in these displays control the brightness, color, and other features of the individual pixels to generate an image. Such displays may use low-temperature polysilicon metal oxide (LTPO) active-matrix organic light-emitting diode (AMOLED) technology to provide variable refresh rates, reduced display response times, and lower power consumption in comparison to other display technologies. Further, LTPO AMOLED displays may include metal oxide thin-film transistors (TFTs) in LTPO pixel circuits, enabling a constant pixel luminance. These advantages make LTPO AMOLED displays well-suited for electronic devices and highly valued by users.

One of the leading factors of power consumption in LTPO AMOLED displays results from power dissipation during self-refresh operations in display panel circuitry, including display panel drivers and pixel circuits. For example, during execution of a self-refresh operation in display panel circuitry of an LTPO AMOLED display, metal driver lines may charge and discharge, producing parasitic capacitance in the driver lines leading to power loss. These self-refresh operations may execute at a frequency defined by a clock generator (“clock signal frequency”). In many cases, a clock signal frequency driving a self-refresh operation may be excessively high, increasing the power consumption due to power dissipation in the driver lines. Unfortunately, altering the clock signal frequency to minimize the power consumption resulting from excessive self-refresh operations may temporarily introduce noticeable optical artifacts on LTPO AMOLED displays, including display flickering, and as a result, degrade user experience.

Description:

This publication describes systems and techniques for dynamically altering clock signal frequencies in low-temperature polysilicon metal oxide (LTPO) active-matrix organic light-emitting diode (AMOLED) displays. In an aspect, a display manager may identify a refresh rate of an electronic device, as well as a use case. As a result of the identification, the display manager may implement a suitable clock signal frequency for self-refresh operations. In so doing, the display manager can dynamically alter self-refresh frequencies in LTPO AMOLED displays to reduce power consumption without degrading user experience.

Figure 1 illustrates an example electronic device in which systems and techniques for dynamically altering self-refresh frequencies in LTPO AMOLED displays can be implemented.

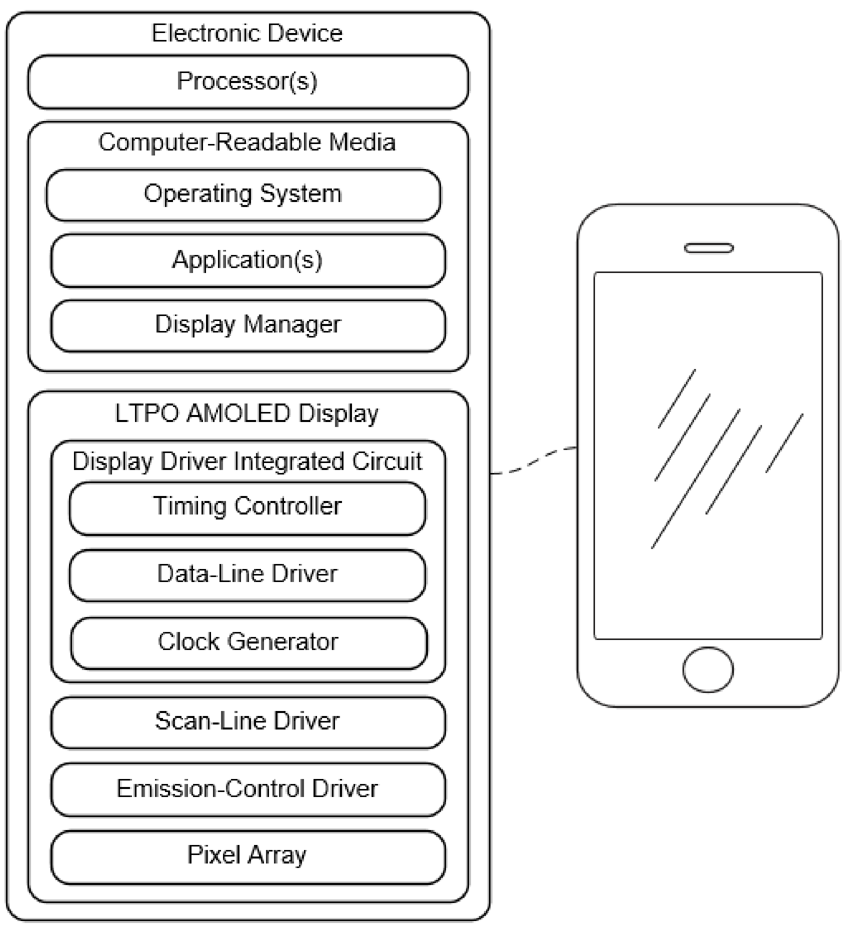

Figure 1

As illustrated in Figure 1, the electronic device is a smartphone. In some implementations, the electronic device can be a variety of other consumer electronic devices. The electronic device may include one or more processors. The processor(s) may be configured to execute instructions or commands stored within the computer-readable media to implement an operating system, application(s), and a display manager. For example, the processor(s) may execute instructions of the operating system to implement a display refresh rate of 120 Hz. The computer-readable storage media may include one or more non-transitory storage devices suitable for storing electronic instructions, each coupled with a computer system bus.

The electronic device may further include an LTPO AMOLED display. The LTPO AMOLED display may include display panel circuitry having a display driver integrated circuit (DDIC), drivers, and a pixel array of LTPO pixel circuits. The DDIC may include a timing controller and a data-line driver. The timing controller may provide interfacing functionality between the processor(s) and the drivers (e.g., data-line driver, scan-line driver, emission-control driver). For example, the timing controller can accept commands and data from the processor(s) and generate signals with appropriate voltage, current, timing, and demultiplexing. The timing controller can then pass the signals to the drivers. The drivers may be operably coupled to LTPO pixel circuits via driver lines.

As an example, the timing controller may receive display data from a processor (e.g., graphics processing unit) and separate the display data into input signals (e.g., image data, control signals). The timing controller may then pass the input signals to a data-line driver, a scan-line driver, and an emission-control driver. In response, the drivers may pass time-variant and amplitude-variant signals (e.g., voltage signals, current signals) to control the pixel array. The data-line driver may pass data-line signals containing voltage data to the pixel array to control the luminance of an organic light-emitting diode. The scan-line driver may pass a scan-line signal to enable or disable an organic light-emitting diode to receive the data voltage from the data-line driver. The emission-control driver may supply an emission-control signal to the pixel array. Together, the drivers can control the pixel array to generate light to create an image on the LTPO AMOLED display.

In a configuration, the electronic device may include a DDIC separate from the LTPO AMOLED display. In still other configurations, the electronic device may include a timing controller separate from the DDIC and the LTPO AMOLED display. Additional implementations and components may be configured to control the pixel array and still implement the techniques described herein.

The DDIC may further include a clock generator (e.g., internal oscillator, crystal oscillator), that may produce a constant clock signal oscillating between a high and a low state. The clock signal may be in a form of a square wave with a 50% duty cycle. Further, the clock signal may synchronize different parts of the display panel circuitry, including the LTPO pixel circuits. Operably coupled to the clock generator, a latch (not illustrated) may receive a clock signal. The latch may be, for example, a D-type Flip-Flop, configured to function as a binary divider for frequency division. A D-type Flip-Flop may receive a first clock signal and output a second clock signal at half the frequency of the first clock signal.

In aspects, the display panel circuitry of the LTPO AMOLED display may be configured to implement self-refresh operations in order to minimize optical artifacts associated with metal oxide thin-film transistors (TFTs) in LTPO pixel circuits. Self-refresh operations may include initializing LTPO pixel circuit TFTs and resetting an anode electrode voltage of an organic light-emitting diode. The frequency at which these self-refresh operations execute may be determined by the frequency of the clock signals generated and passed by the clock generator into display panel circuitry.

In addition, the operating system of the electronic device may support multiple refresh rates. Refresh-rate frequencies may include, for example, 10 Hz, 30 Hz, 60 Hz, 90 Hz, and 120 Hz. In an aspect, a display manager can identify a refresh rate implemented by an operating system of an electronic device. For example, the display manager may identify that the operating system implemented a refresh rate for the LTPO AMOLED display at 120 Hz. The display manager may further identify a use case. Use cases may include, for example, a user interacting with an application, a user idling on a home screen, a user watching an on-screen video, or a user performing other similar actions on the electronic device. Various use cases enacted by a user may cause the operating system to implement a certain refresh rate. As an example, if a user is scrolling through a page presented by a web browser application, the operating system may implement a refresh rate of 120 Hz to support a responsive user interface. In another example, if a user is watching a video on a movie application, the operating system may implement a refresh rate of 60 Hz. The operating system implementing various refresh rates enables the electronic device to provide fluid graphics, a responsive user interface, and power-saving techniques.

Figure 2 illustrates a timing diagram of an operating system implementing a refresh rate, as well as a clock generator passing a clock signal.

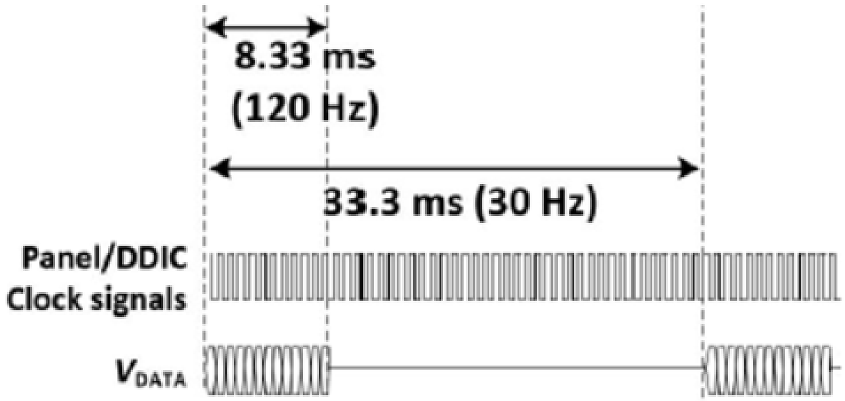

Figure 2

As illustrated in Figure 2, the operating system may implement a refresh rate of 30 Hz. Further, the operating system may implement a refresh rate of 30 Hz because an application in a particular use case, enacted by a user, may specify an appropriate refresh rate frequency. For instance, a user may be watching a full-screen video in a camera application. Upon a user starting a video, the camera application may direct the operating system to implement a refresh rate frequency of 30 Hz during video playback.

As illustrated, the V_{DATA} signal may be a data-line signal, passed by the data-line driver to the pixel array, containing voltage data to control the luminance of organic light-emitting diodes. Further illustrated, a clock generator of the DDIC may generate and pass clock signals optimized for 120-Hz refresh rates. In so doing, self-refresh operations may execute, for example, three times in 33.3 milliseconds (ms). Each self-refresh operation may involve the DDIC passing input signals to drivers and the drivers passing data-line signals, scan-line signals, and emission-control signals to the LTPO pixel circuits. Executing self-refresh operations so many times in a single frame time may increase the power consumption of the electronic device due to power dissipation in the driver lines, and yet may provide little-to-no additional benefit in minimizing optical artifacts associated with LTPO pixel circuits.

To address these excessive self-refresh operations, an electronic device may implement a display manager to identify a refresh rate implemented by the operating system, as well as a use case, and then implement a suitable clock signal frequency to reduce the number of self-refresh operations. Figure 3 illustrates a timing diagram of an operating system implementing a refresh rate, as well as a clock generator passing a clock signal.

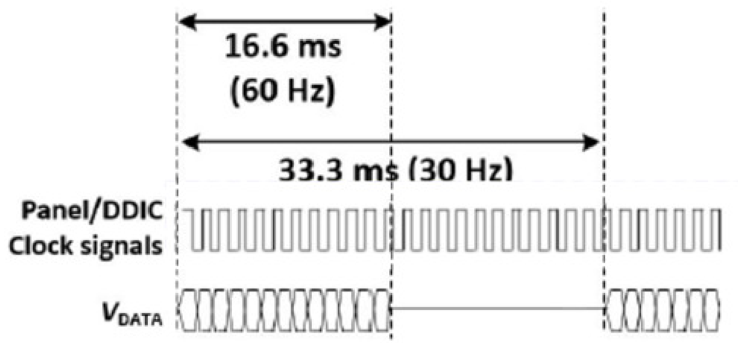

Figure 3

As illustrated in Figure 3, the operating system may implement a refresh rate of 30 Hz. The use case may involve a user watching a full-screen video in a camera application. To watch the full-screen video, the user may rotate the electronic device such that the user can watch the video on the LTPO AMOLED display in a landscape mode screen layout.

The display manager may identify the refresh rate implemented by the operating system, as well as the use case. As a result of the identification, the display manager may implement a clock signal frequency optimized for 60-Hz refresh rates. The display manager may achieve this, for example, by passing the clock signal through a latch. As a result, a clock signal optimized for 60 Hz refresh rates may be passed through display panel circuitry. In so doing, self-refresh operations may be reduced down to one, minimizing the number of transactions in display panel circuitry. Minimizing the number of transactions in display panel circuitry can decrease the power consumption of the electronic device. Further to the above descriptions, reducing the number of self-refresh operations may avoid the introduction of any noticeable optical artifacts.

In some cases, the display manager altering the clock signal frequency from a first frequency (e.g., optimized for 120-Hz refresh rates) to a second frequency (e.g., optimized for 60 Hz refresh rates) may temporarily introduce noticeable optical artifacts, such as display flickering. However, the display manager may be configured to identify use cases in which, for example, entire screen content may be changing, such as when the operating system changes a screen layout from portrait mode to landscape mode. As a result of the use case identification, the display manager may implement a clock signal frequency alteration only when such optical artifacts may be imperceptible to users. In so doing, the techniques of the display manager can afford a satisfying user experience and still minimize power consumption.

In addition to the above descriptions, the display manager may implement various clock signal frequencies to reduce the number of self-refresh operations. Further, the display manager may implement a clock signal frequency for various self-refresh rates. For example, in one implementation, the highest-range and lowest-range refresh rates may execute with a clock signal frequency optimized for 120 Hz, while the mid-range refresh rates may execute with a clock signal frequency optimized for 60 Hz.

The systems and techniques described herein enable dynamic alteration of clock signal frequencies in LTPO AMOLED displays. In an aspect, a display manager may identify a refresh rate implemented by an operating system of an electronic device, as well as a use case. As a result of the identification, the display manager can implement a suitable clock signal frequency for self-refresh operations. By dynamically altering clock signal frequencies, the display manager can reduce the number of transactions in display panel circuitry associated with self-refresh operations. In so doing, the display manager can dynamically alter clock signal frequencies in LTPO AMOLED displays to reduce power consumption without degrading user experience.

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