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(54) **APPARATUS AND METHOD FOR SELF-REFRESH IN A DISPLAY DEVICE**

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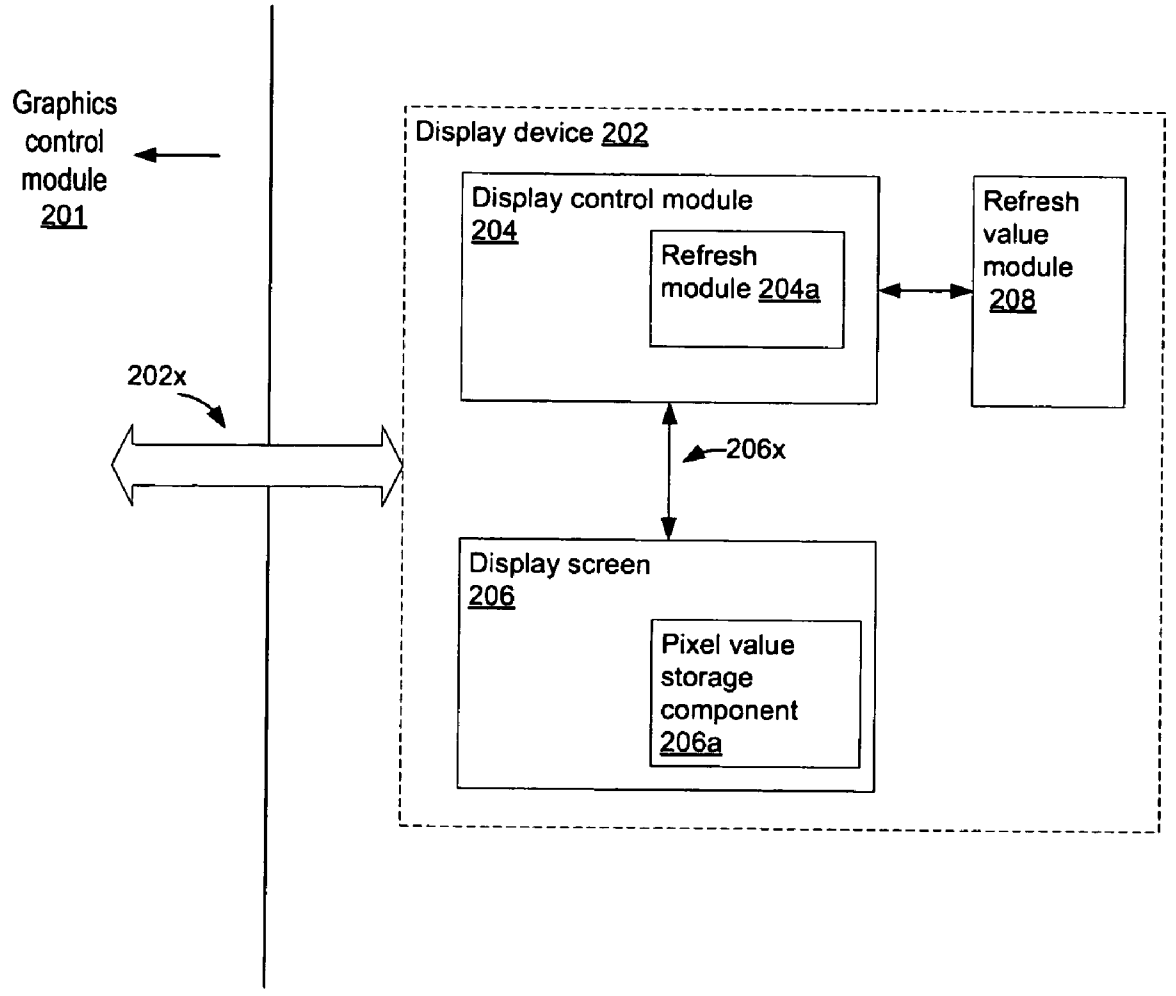
(57) **ABSTRACT**

A method and apparatus for self-refresh in a display device is described. In an embodiment, a system display has a display screen that includes a pixel value storage component. The system display is coupled with a graphics control module via a display bus and enables a self-refresh mode based on a first indication from the graphics control module. The self-refresh mode includes refreshing pixel values stored within the pixel value storage component. The self-refresh rate is not greater than, a refresh rate provided by the graphics control module.



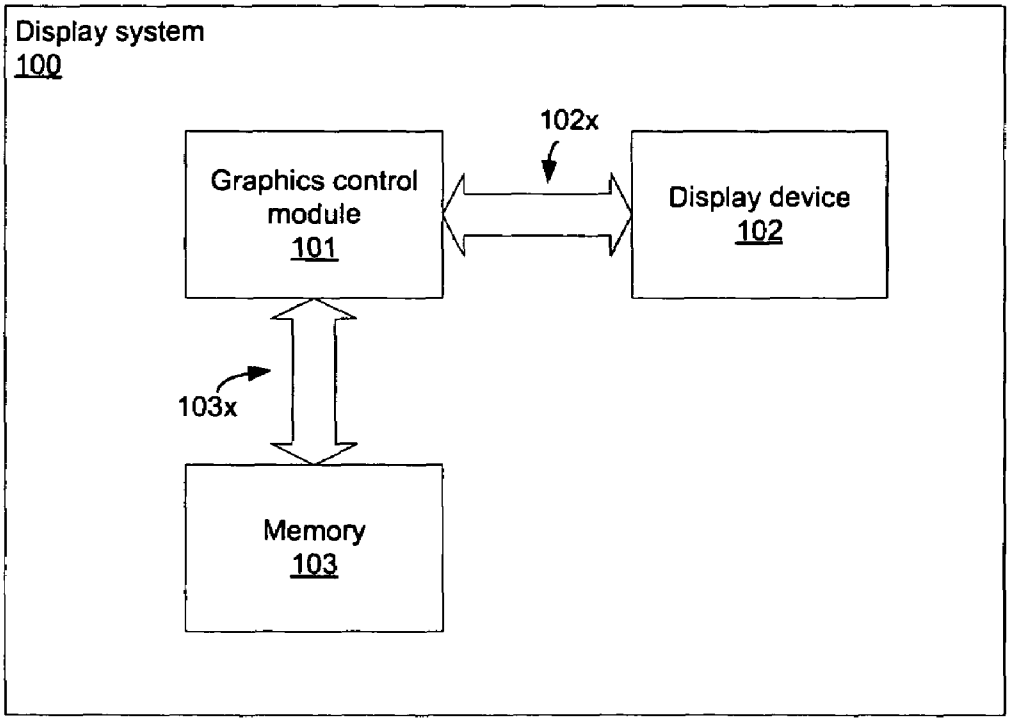

Display system
100
102x
Graphics control module
101
Display device
102
103x
Memory
103

Figure 1

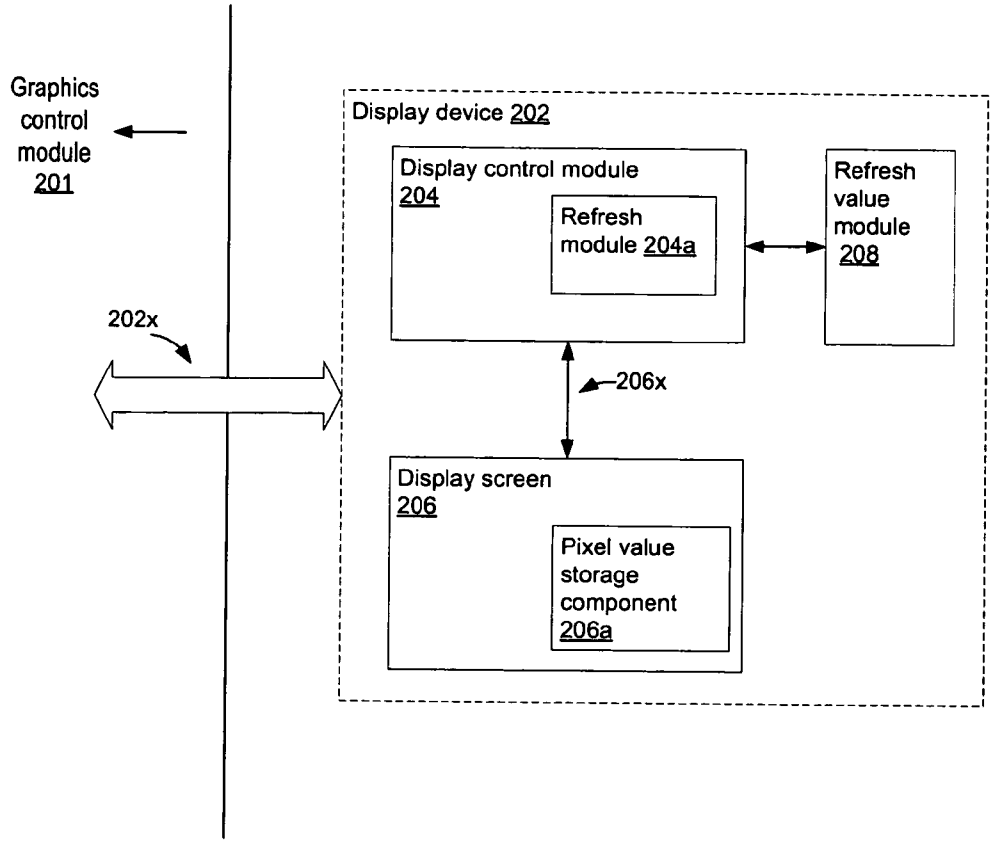

Graphics control module 201
202x
Display device 202
Display control module 204
Refresh module 204a
Refresh value module 208
206x
Display screen 206
Pixel value storage component 206a

Figure 2

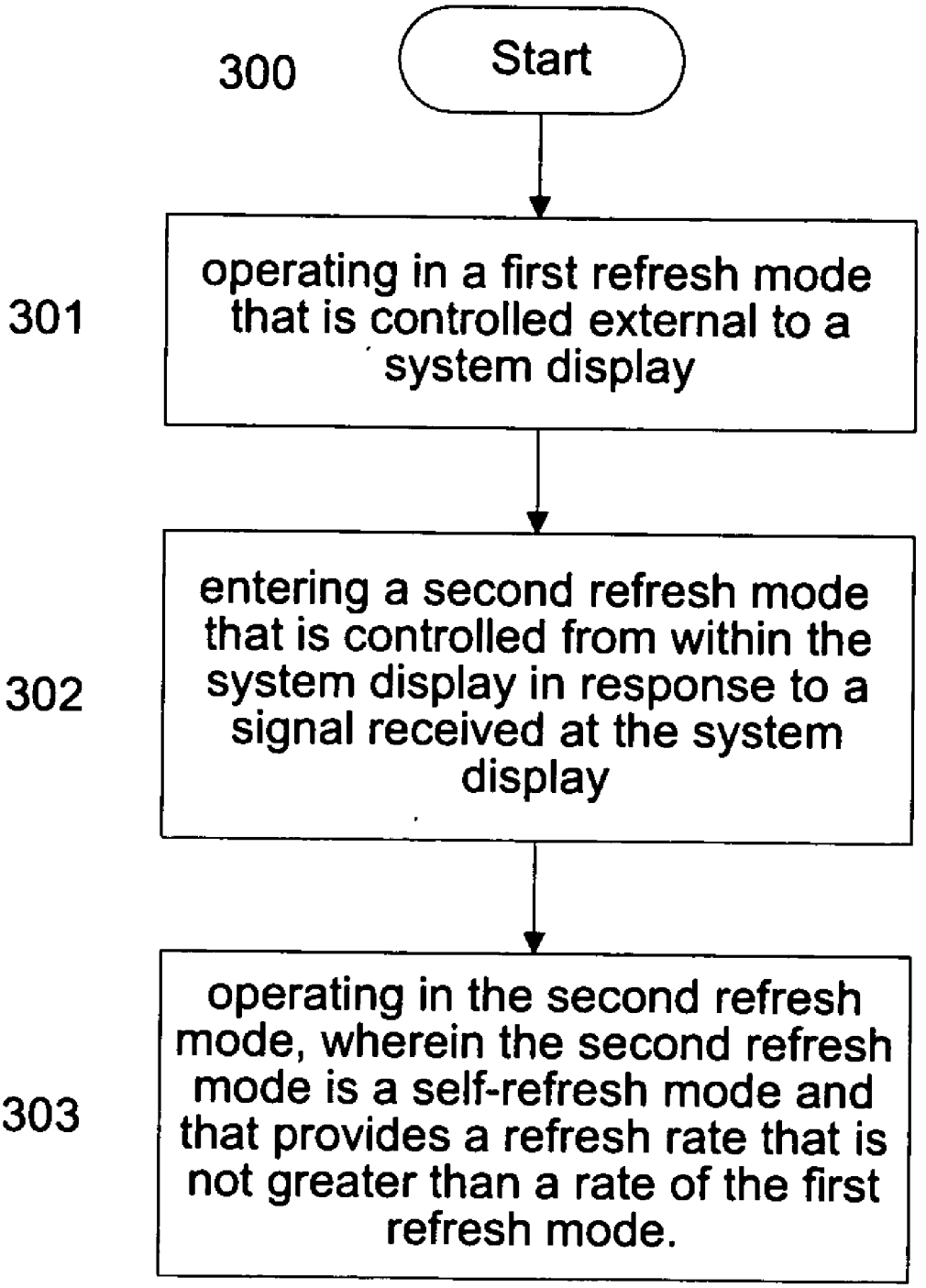

300
Start
301
operating in a first refresh mode that is controlled external to a system display
302
entering a second refresh mode that is controlled from within the system display in response to a signal received at the system display
303
operating in the second refresh mode, wherein the second refresh mode is a self-refresh mode and that provides a refresh rate that is not greater than a rate of the first refresh mode.

Figure 3

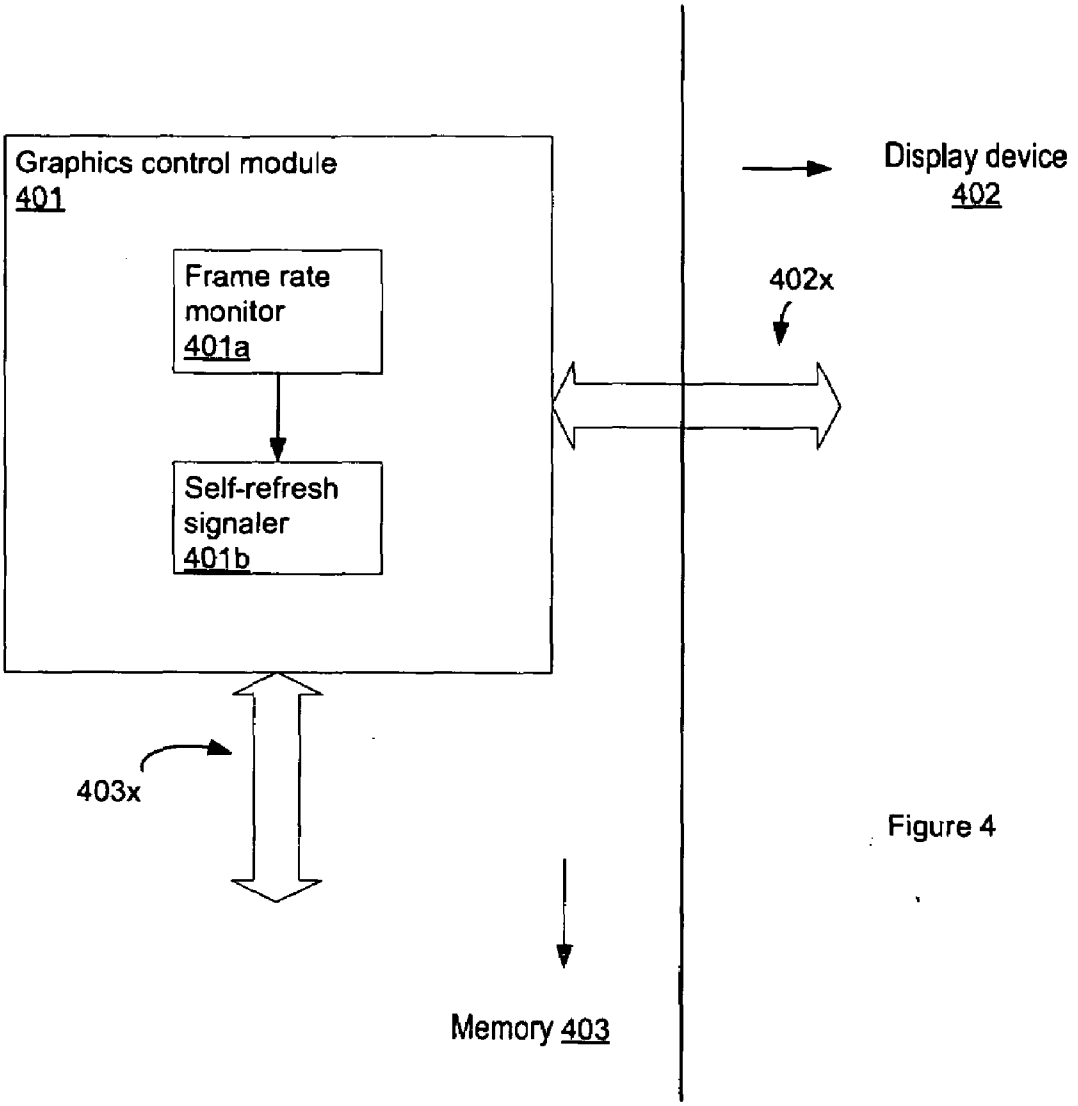

Graphics control module
401
Frame rate monitor
401a
Self-refresh signaler
401b
Display device
402
402x
403x
Memory 403

Figure 4

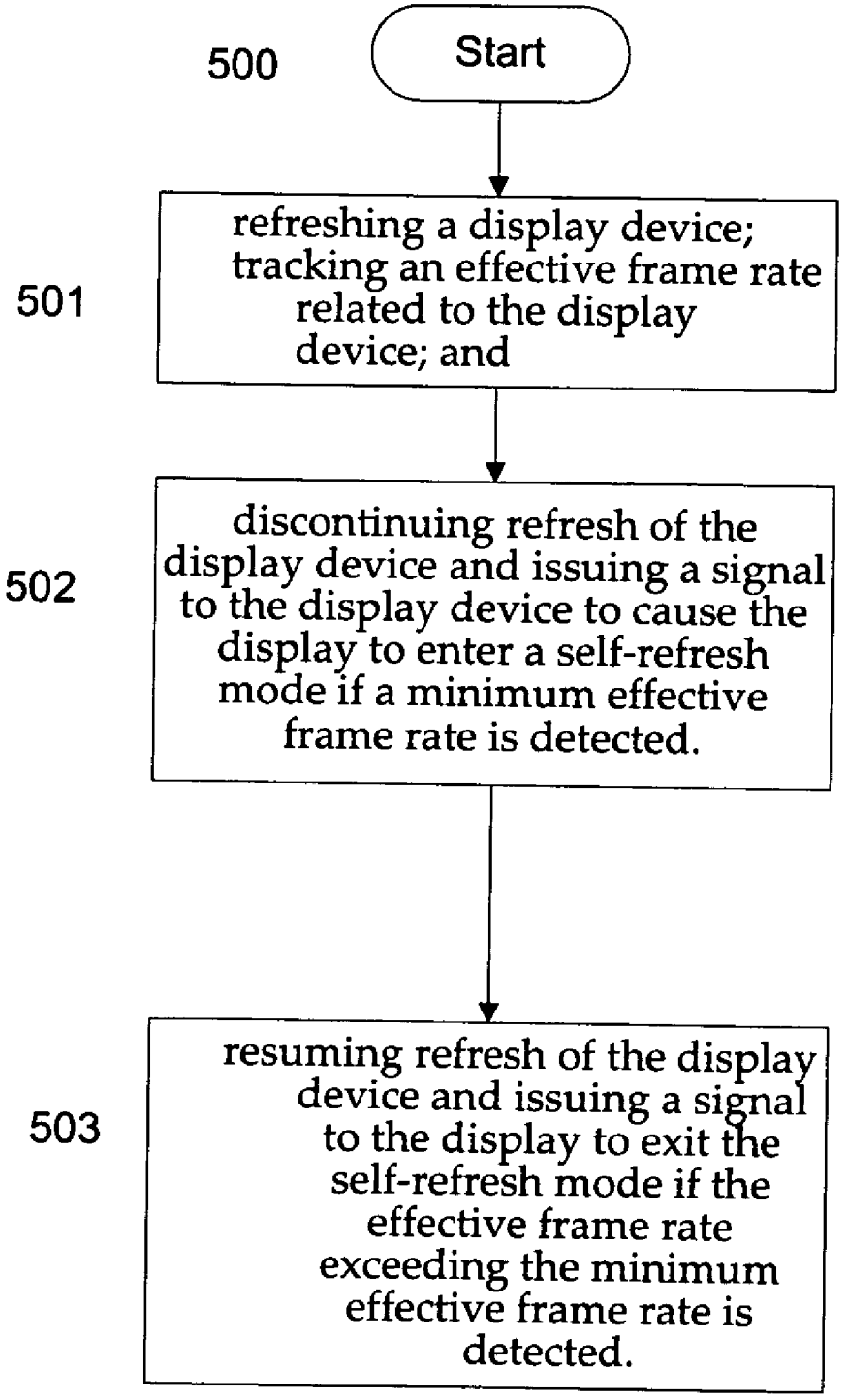

500
Start
refreshing a display device; tracking an effective frame rate related to the display device; and
501
discontinuing refresh of the display device and issuing a signal to the display device to cause the display to enter a self-refresh mode if a minimum effective frame rate is detected.
502
resuming refresh of the display device and issuing a signal to the display to exit the self-refresh mode if the effective frame rate exceeding the minimum effective frame rate is detected.
503

Figure 5

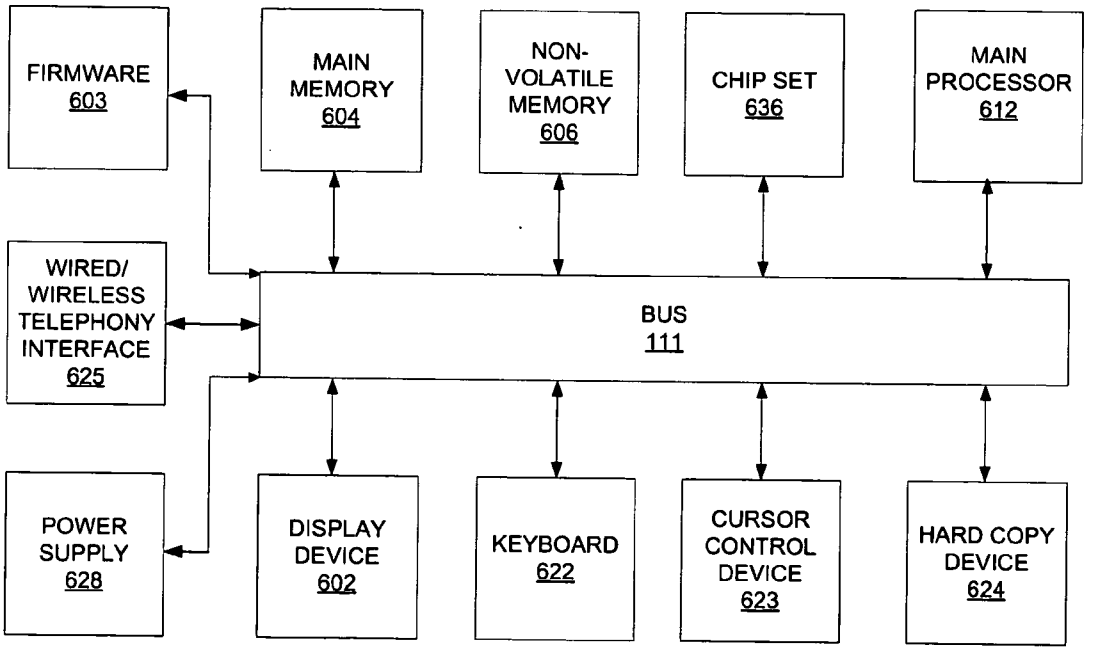

FIRMWARE
603
MAIN
MEMORY
604
NON-
VOLATILE
MEMORY
606
CHIP SET
636
MAIN
PROCESSOR
612
WIRED/
WIRELESS
TELEPHONY
INTERFACE
625
BUS
111
POWER
SUPPLY
628
DISPLAY
DEVICE
602
KEYBOARD
622
CURSOR
CONTROL
DEVICE
623
HARD COPY
DEVICE
624

Figure 6

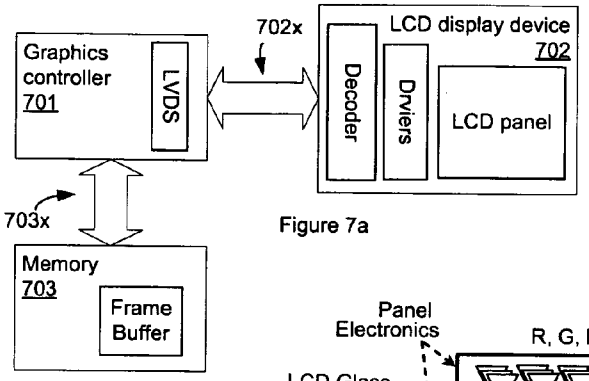


Figure 7a

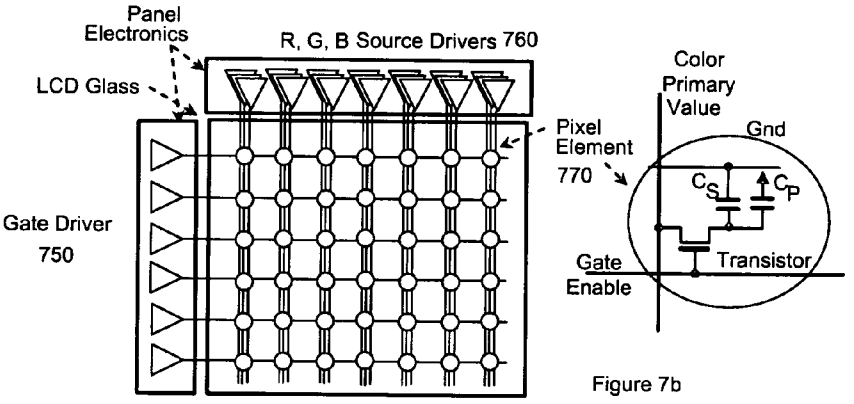


Figure 7b

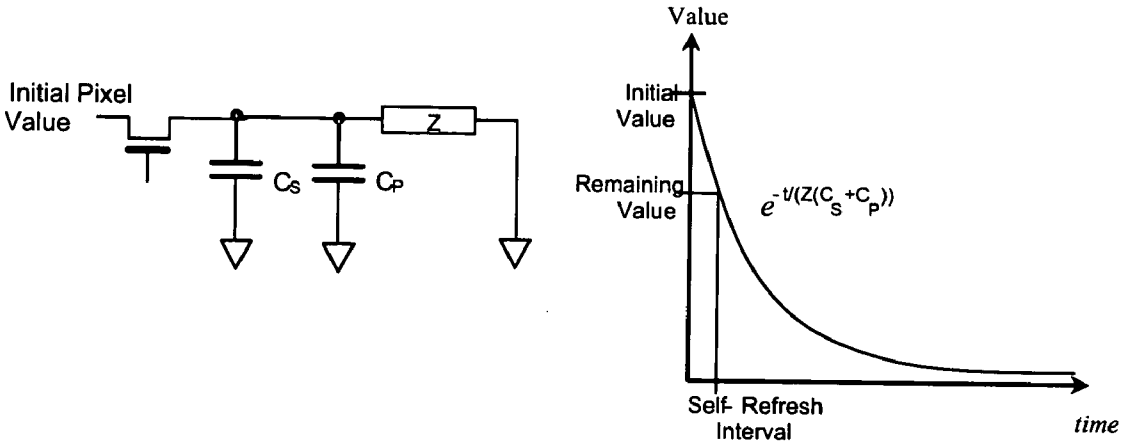


Figure 8. TFT Pixel RC Decay

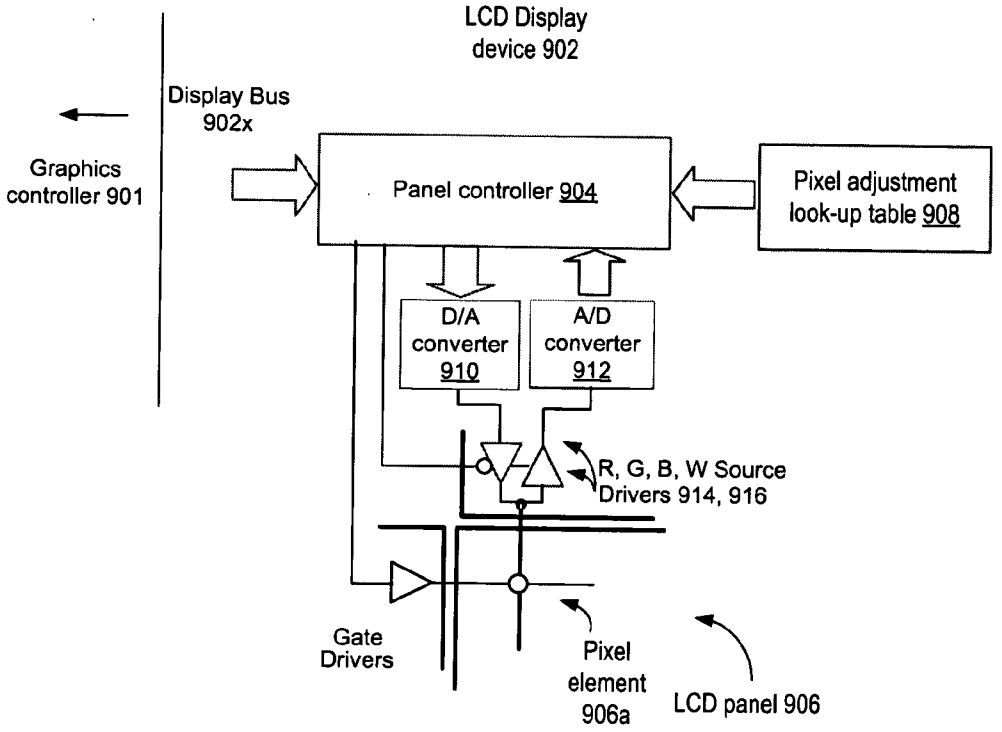

LCD Display device 902
Display Bus 902x
Graphics controller 901
Panel controller 904
Pixel adjustment look-up table 908
D/A converter 910
A/D converter 912
R, G, B, W Source Drivers 914, 916
Gate Drivers
Pixel element 906a
LCD panel 906

Figure 9

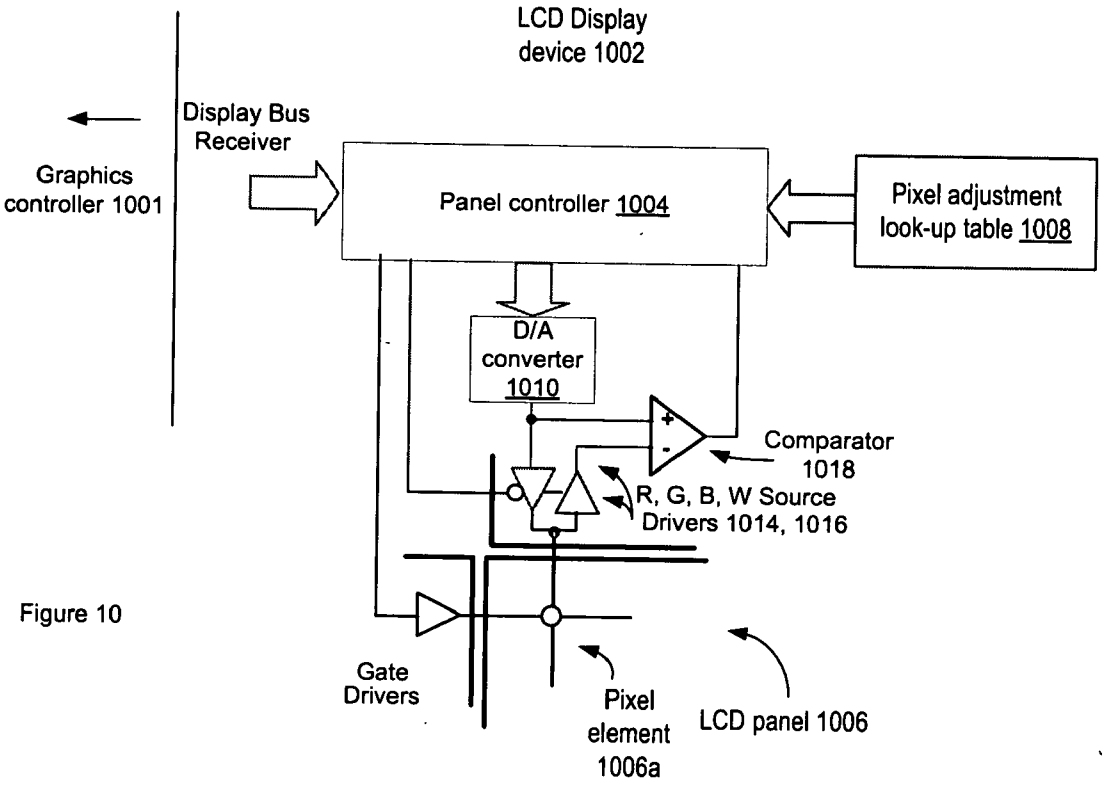

LCD Display device 1002
Display Bus Receiver
Graphics controller 1001
Panel controller 1004
Pixel adjustment look-up table 1008
D/A converter 1010
Comparator 1018
R, G, B, W Source Drivers 1014, 1016
Gate Drivers
Pixel element 1006a
LCD panel 1006

Figure 10

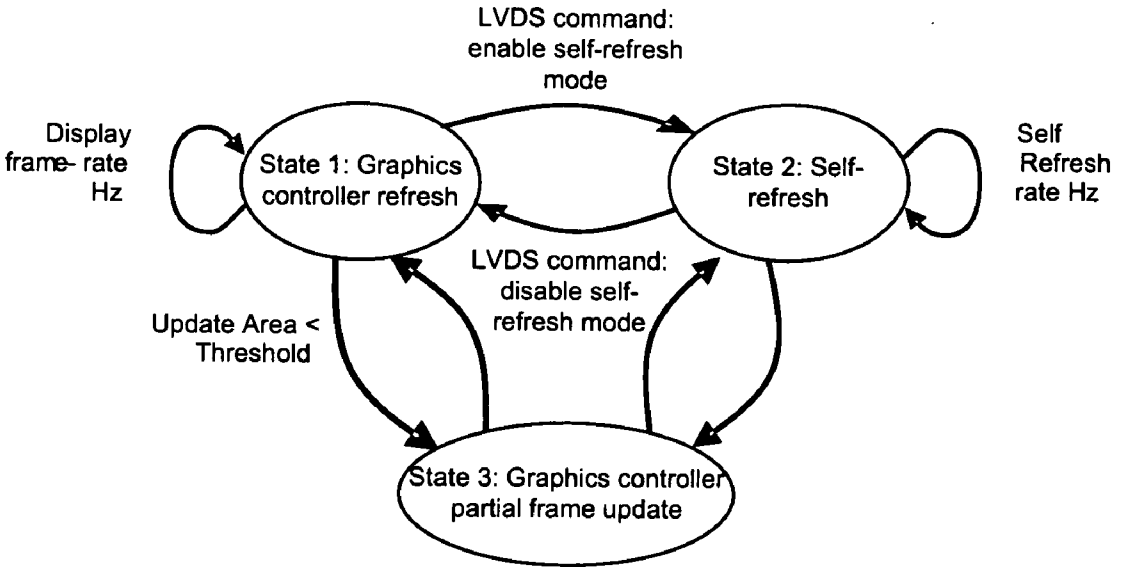


Figure 11. Self -Refresh Display State Machine

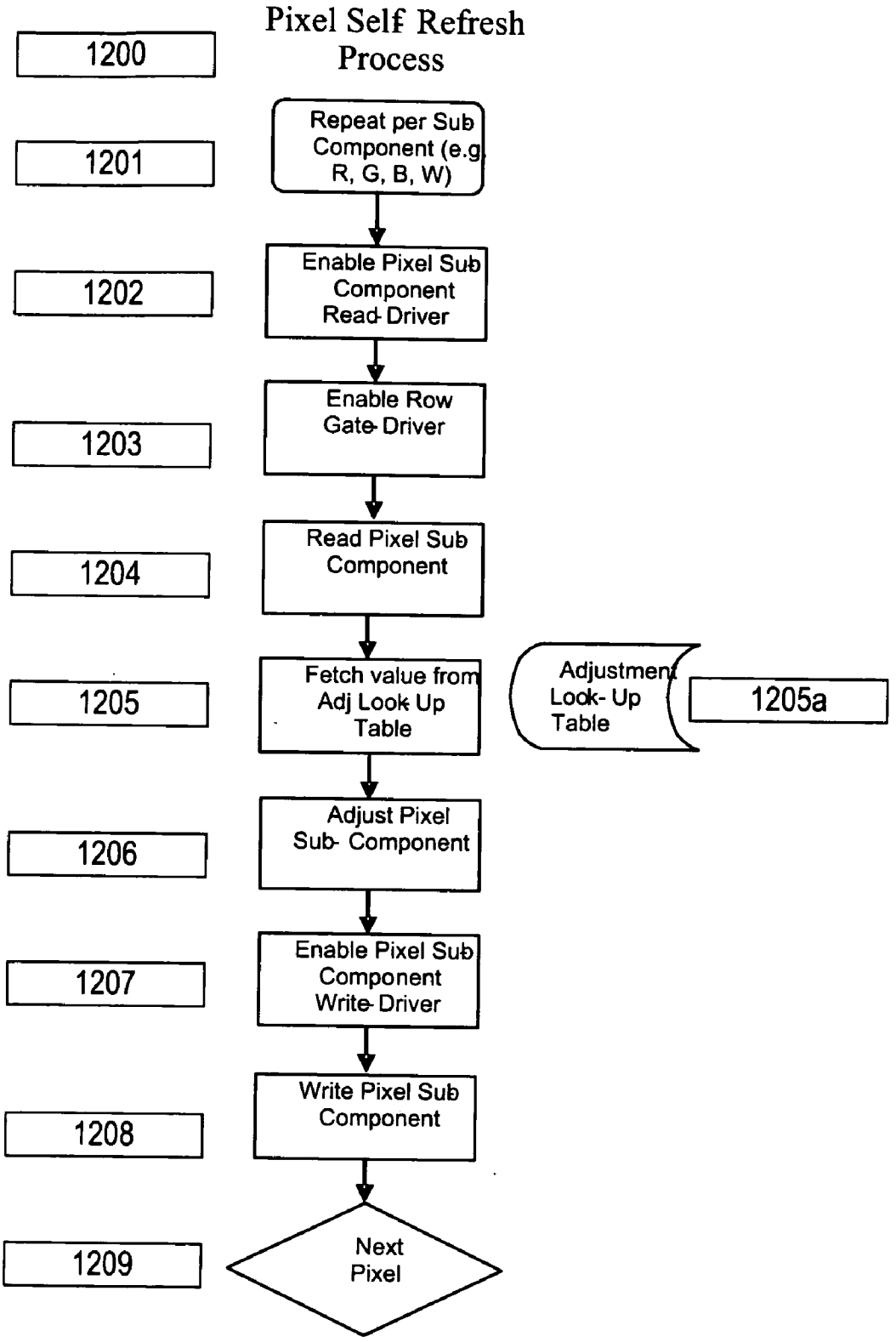

Pixel Self Refresh Process
1200
1201
Repeat per Sub Component (e.g. R, G, B, W)
1202
Enable Pixel Sub Component Read Driver
1203
Enable Row Gate Driver
1204
Read Pixel Sub Component
1205
Fetch value from Adj Look Up Table
Adjustment Look-Up Table
1205a
1206
Adjust Pixel Sub-Component
1207
Enable Pixel Sub Component Write Driver
1208
Write Pixel Sub Component
1209
Next Pixel

Figure 12

APPARATUS AND METHOD FOR SELF-REFRESH IN A DISPLAY DEVICE

FIELD

[0001] Embodiments of the invention relate generally to display technology. More specifically, the invention involves reducing power consumed in mobile computer systems by minimizing power associated with refreshing the display.

BACKGROUND

[0002] Various display technologies exist that create an appearance that images on a screen are in motion. The basic technique involves displaying a succession of frames, each frame including a slightly different image. For static images, a frame of the same image is displayed over and over again.

[0003] In modern image display technology (e.g. cathode ray tube (CRT) television, plasma, liquid crystal diode (LCD)), each frame is made up of a collection of picture elements called pixels. Mobile computer system displays typically have panels with pixel resolutions in the range of 800×600 to 1900×1200 pixels per horizontal and vertical line. The intensity and color of each pixel can be adjusted so that together, the pixels compose a recognizable image. In typical mobile computer color displays, the color that each pixel describes may be composed of red (R), green (G), and blue (B), and possibly also including white (W).

[0004] Drawing a frame involves producing the proper light and color intensities at each pixel position. In most display technologies, as soon as a frame is drawn to a screen, the levels of intensity at each pixel begin to decay, which degrades the image. The rate at which a frame must be re-drawn to maintain the desired appearance of an image is called the refresh rate. Between frames that contain different images, there are typically multiple refreshes of each image. Thus, the refresh rate must typically be greater than the frame rate.

[0005] Mobile devices that use display technology rely on battery power to power their displays. Each time a display is refreshed, power is consumed across many components of the system and a mobile device's limited reserve of battery life is reduced. Mobile devices using modern display technology are commonly designed with a refresh rate that attempts to balance image quality with reduced power consumption. Unfortunately, refresh rates often are higher than necessary to achieve desired image quality.

[0006] Since minimizing power consumption is a key design goal for mobile devices, there is need to reduce refresh rates in mobile device displays while still providing the display images of a desired quality.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Embodiments of the invention are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

[0008] FIG. **1** illustrates a block diagram of an embodiment of a display system;

[0009] FIG. **2** illustrates a block diagram of an embodiment of a display device;

[0010] FIG. **3** is a flow diagram of an embodiment of a process of operating a display device in different refresh modes;

[0011] FIG. **4** illustrates a block diagram of an embodiment of a graphics control module;

[0012] FIG. **5** s a flow diagram of an embodiment of a process for causing a display device to enter a self-refresh mode;

[0013] FIG. **6** illustrates a block diagram of an embodiment of a mobile device;

[0014] FIG. **7***a* is a block diagram illustrating an embodiment of an LCD display device configured to be refreshed by a graphics controller;

[0015] FIG. **7***b* is a block diagram illustrating an embodiment of LCD display panel electronics;

[0016] FIG. **8** is a circuit diagram illustrating an embodiment of thin film transistor electronics that hold a charge and a graph illustrating an example discharge rate;

[0017] FIG. **9** is a block diagram illustrating an embodiment of a self-refreshing LCD display device;

[0018] FIG. **10** is a block diagram illustrating an embodiment of a self-refreshing LCD display device;

[0019] FIG. **11** is a state diagram illustrating an embodiment of a self-refresh display state machine

[0020] FIG. **12** is a algorithm of an embodiment of a process for self-refresh.

DETAILED DESCRIPTION

[0021] In the following detailed description of the embodiments, reference is made to the accompanying drawings that show, by way of illustration, specific embodiments in which the invention may be practiced. In the drawings, like numerals describe substantially similar components throughout the several views. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention. Other embodiments may be utilized and structural, logical, and electrical changes may be made without departing from the scope of the present invention. Moreover, it is to be understood that the various embodiments of the invention, although different, are not necessarily mutually exclusive. For example, a particular feature, structure, or characteristic described in an embodiment may be included within other embodiments. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

[0022] In general, a method and apparatus for self-refreshing in a display device are disclosed. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that the present invention can be practiced without these specific details.

[0023] Described herein are embodiments of a system display with a display screen that includes a pixel value storage component. The system display can be coupled with a graphics control module over a display bus. The system display enables a self-refresh mode based on a first indication from the graphics control module. Self-refresh mode includes refreshing pixel values stored within the pixel value storage component. The self-refresh rate is not greater than a first refresh rate provided by the graphics control module.

[0024] Also described herein are embodiments of a graphics control module that has a first output terminal to couple with a memory over a memory bus and a second output terminal to couple with a system display over a display bus.

The graphics control module is configured to control refresh of the system display and has a frame rate monitor to track an effective frame rate value of the system display. When the threshold effective frame rate value has been detected, the graphics control module stops controlling the refresh and transmits one or more signals to the system display with a self-refresh signaler to trigger the system display to enter a self-refresh mode.

[0025] FIG. **1** is a block diagram of an embodiment of a display system **100**. Display system **100** includes graphics control module **101** communicatively coupled with display device **102** via a display bus **102***x* and communicatively coupled with memory **103** via a memory bus **103***x*. Graphics control module **101** controls the transfer of content to display device **102**. Display device **102** displays content transferred from memory **103**.

[0026] Graphics control module **101** may process logic to operate a state machine (e.g. with an integrated circuit) to control various operations related to display device **102** (e.g. applying a refresh rate) and/or access memory **103**. Graphic control module **101** may also process logic that generates signals (e.g. commands) and transmits signals over display bus **102***x* and memory **103***x* bus.

[0027] Memory **103** is any storage medium known by one having ordinary skill in the art with the ability to store digital information that can be accessed by graphic control module **101** during performance of the functions of the graphic control module **101** described herein. Memory may be for example random access memory (RAM).

[0028] Display device **102** may is a screen that illustrates images to be viewed by users of display system **100** (e.g. a computer system monitor). Display device **102** may utilize various hardware and software known in the art to display static and dynamic images. As such, display device may need to be refreshed periodically in order to provide the desired display output.

[0029] Thus, graphics control module **101** retrieves information located within memory **103** over memory bus **103***x* and sends the information to display device **102** over display bus **102***x*. The information may be related to a frame containing an image. Display device **102** may then use the information to display the frame containing the image.

[0030] FIG. **2** is a block diagram illustrating an embodiment of a display device **202**. Display device **202** includes display control module **204** coupled to display screen **206**. Display control module implements logic (e.g. with circuitry or software) designed to control the operation of display screen **206** (e.g. a timing controller (TCON)). Display control module **204** may be in communication with graphics control module **201** via display bus **202***x* to receive image information and control signals (e.g. commands) related to control of display screen **206**.

[0031] Display screen **206** may be the actual housing and surface of the screen as well as the material displaying individual pixels (e.g. housing, glass screen and phosphor coat, etc. on CRT display or the LCD's housing, polarized planes, liquid crystals, glass, electrode planes, color filters, etc). Display screen **206** includes pixel value storage component **206***a*. Pixel value storage component **206***a* may be a memory or memories that store(s) digital values (e.g. pixel values) that correspond to light and color intensities to be projected at each pixel. Pixel value storage component **206***a* stores pixel values representing what is currently being displayed on display screen **206**. Pixel value storage component **206***a* may also store past or future pixel values.

[0032] Thus, an embodiment of an apparatus is disclosed that includes a display device **202** having a display screen **206** that includes a pixel value storage component **206***a*. The display device **202** is coupled with a graphics control module **201** via a display bus **202***x* and is configured to enable a self-refresh mode based on a first indication from the graphics control module **202**. Self-refresh mode includes refreshing pixel values stored within the pixel value storage component **206***a*, and where the self-refresh rate is not greater than a first refresh rate provided by the graphics control module **201**.

[0033] In an embodiment, display device **202** includes a display control module **204** that reads pixel values from the pixel value storage component **206***a* and refreshes them before writing the refreshed pixel values back into the pixel value storage component **206***a*.

[0034] Display device **202** includes refresh module **204***a* that is configured to encode and/or decode messages (e.g. low voltage differential signaling (LVDS)) sent between graphics control module **201** and display control module **202** via display bus **202***a*. One example of refresh module **204***a* is a hardwired circuit implementation of an encoder/decoder state machine.

[0035] Thus, in an embodiment, refresh module **204***a* receives a first indication from graphics control module **201** and triggers the display device **202** to enter self-refresh mode based on the first indication. Conversely, refresh module **204***a* triggers the self-refresh mode to be disabled based on the receipt of a second indication from the graphic control module **201**.

[0036] Display device **202** may also include a refresh value module **208** coupled with display controller **204**. The refresh value module **208** contains pixel values that are to replace the pixel values that are being refreshed. In other words, each pixel value stored in refresh value module **208** corresponds to one of the pixels from pixel value storage component **206***a* being refreshed. In an embodiment, pixel value storage component **206***a* is a read only memory (ROM) to store the pixel values.

[0037] Thus, in an embodiment, the refresh value module **208** stores new pixel values that correspond to old pixel values read from within the pixel value storage component **206***a*. In this embodiment, display control module **204** refreshes the old pixel values by exchanging the old pixel values with corresponding new pixel values that it retrieves from the refresh value module **208**.

[0038] FIG. **3** is a flow diagram of an embodiment of a process **300** for entering a system into to a self-refresh mode. In FIG. **3**, process **300** starts with processing logic operating in a first refresh mode that is controlled external to a system display (processing block **301**)

[0039] The sequence continues when processing logic causes the system to enter a second refresh mode that is controlled from within the system display in response to a signal received at the system display (processing block **302**).

[0040] Process **300** concludes when processing logic causes operation in the second refresh mode, wherein the second refresh mode is a self-refresh mode and that provides refresh rates that are not greater than a rate of the first refresh mode.

[0041] Through the practice of embodiments described herein, reduced power consumption by a computer system

including display device may be realized by using a self-refresh rate that temporarily removes power consumption involved with refresh operations performed by a graphics control module or dependant memory sub-systems.

[0042] FIG. **4** is a block diagram of an embodiment of a graphics control module **401** coupled between a memory **403** and a display device **402**. Graphic control module **401** includes frame rate monitor **401***a* and self-refresh signaler **401***b*.

[0043] Frame rate monitor **401***a* is logic to detect the effective frame rate per second (EFPS) being delivered to display device **402**. Frame rate monitor **401***a* may use information indicating rendering or updating activity in memory **403** to arrive at current EFPS. Alternatively, if graphics control module **401** was for example to send ten different frames to display device **402** to be displayed one after another over one second, then frame rate monitor may detect a frame rate of 10 frames per second (FPS). Frame rate monitor **401***a* may compare the frame rate it detects with a frame rate threshold to determine whether conditions warrant display device **402** self-refresh.

[0044] Self-refresh signaler **401***b* is configured to receive signals from frame rate monitor **401***a*. Self-refresh signaler **401***b* is configured to encode and/or decode messages (e.g. LVDS) sent between graphics control module **401** and display control module **402** via display bus **402***x*. One example of self-refresh signaler **404***b* is a hardwired circuit implementation of an encoder/decoder state machine.

[0045] Thus, in an embodiment, a graphics control module **401** has a first output terminal to couple with memory **403** via memory bus **403***x* and a second output terminal to couple to display device **402** via display bus **402***x*. During some operations, graphics control module **401** controls refresh of the display device **402**. Graphics control module **401** also includes a frame rate monitor **401***a* to track an effective frame rate of the display device **402** and to cause the graphics control module **401** to stop controlling the refresh when a threshold frame rate value has been detected. The self-refresh signaler **401***b* transmits a signal to the display device **402** upon detection of the threshold effective frame rate value to trigger the display device **402** to enter a self-refresh mode.

[0046] FIG. **5** is a flow diagram of an embodiment of a process **500** for bringing a display device in and out of a self-refresh mode.

[0047] Process **500** begins with processing logic refreshing a display device (processing block **501**). The process continues with processing logic tracking an effective frame rate related to the display device (processing block **502**). The process concludes with processing logic discontinuing refresh of the display device and issuing a signal to the display device to cause the display to enter a self-refresh mode if a minimum effective frame rate is detected (processing block **503**).

[0048] In an embodiment process **500** may continue with processing logic resuming refresh of the display device and issuing a signal to the display to exit the self-refresh mode if the effective frame rate exceeding the minimum effective frame rate is detected (processing block **504**).

[0049] Through the practice of embodiments described herein, reduced power consumption by a computer system including display device may be realized by using a self-refresh rate that temporarily removes power consumption involved with refresh operations performed by a graphics control module or dependent memory subsystems.

[0050] Other embodiments of the present invention can be accomplished by way of software. For example, in some embodiments, the present invention may be provided as a computer program product or software which may include a machine or computer-readable medium having stored thereon instructions which may be used to program a computer (or other electronic devices) to perform a process according to the present invention. In other embodiments, processes of the present invention might be performed by specific hardware components that contain hardwired logic for performing the processes, or by any combination of programmed computer components and custom hardware components.

[0051] In an embodiment, the software used to facilitate the routine can be embedded onto a machine-readable medium. A machine-readable medium includes any mechanism that provides (i.e., stores and/or transmits) information in a form accessible by a machine (e.g., a computer, network device, personal digital assistant, manufacturing tool, any device with a set of one or more processors, etc.). For example, a machine-readable medium includes recordable/non-recordable media (e.g., read only memory (ROM) including firmware; random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; etc.), as well as electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.); etc.

[0052] FIG. **6** illustrates a block diagram of an example method and apparatus for self-refresh in a display device being used in a mobile computer system. Firmware **603** may be a combination of software and hardware, such as Electronically Programmable Read-only Memory (EPROM) that has the operations for the routine recorded on the EPROM. The firmware **603** may embed foundation code, basic input/output system code (BIOS), or other similar code. The firmware **603** may make it possible for the computer system **600** to boot itself. Computer system **600** also comprises a read-only memory (ROM) and/or other static storage device **606** coupled to bus **611** for storing static information and instructions for main processing unit **612**. The static storage device **606** may store OS level and application level software.

[0053] An alphanumeric input device (keyboard) **622**, including alphanumeric and other keys, may also be coupled to bus **611** for communicating information and command selections to main processing unit **612**. An additional user input device is cursor control device **623**, such as a mouse, trackball, trackpad, stylus, or cursor direction keys, coupled to bus **611** for communicating direction information and command selections to main processing unit **612**, and for controlling cursor movement on a display device **621**. A chipset may interface with the input output devices. Another device that may be coupled to bus **611** is a hard copy device **624**, which may be used for printing instructions, data, or other information on a medium such as paper, film, or similar types of media. Furthermore, a sound recording and playback device, such as a speaker and/or microphone (not shown) may optionally be coupled to bus **611** for audio interfacing with computer system **600**. Another device that may be coupled to bus **611** is a wireless communication module **625**. The wireless communication module **625** may employ a Wireless Application Protocol to establish a wire-

less communication channel. The wireless communication module **625** may implement a wireless networking standard such as Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard, IEEE std. 802.11-1999, published by IEEE in 1999.

[0054] Computer system **600** may further be coupled to a display device **602**, such as a cathode ray tube (CRT) or liquid crystal display (LCD), coupled to bus **611** for displaying information to a computer user. Chipset **636** may interface with the display device **621**. In an embodiment, display device **602** is an LCD and chipset **636** may include graphic controller (not shown) to control the flow of image data between non-volatile memory **606** and display device **602**. Display device **602** may also include a display controller (e.g. TCON, not shown) to control the drawing of pixels to the screen of display device **602**.

[0055] Examples of mobile computing devices may be a laptop computer, a cell phone, a personal digital assistant, or other similar device with on board processing power and wireless communications ability that is powered by a Direct Current (DC) power source that supplies DC voltage to the mobile device and that is solely within the mobile computing device and needs to be recharged on a periodic basis, such as a fuel cell or a battery.

[0056] Embodiments of the invention are described in application to thin-film transistor (TFT) LCD panels. Referring to FIG. **7***a*, graphic controller **701** draws out pixels of a source image to the LCD display device **702** in serial lines. The process involves graphics controller **701** in the computer system reading the source image pixels from a frame buffer in memory **703** and passing the pixels serially to the display panel electronics via a display bus **702***x*, such as LVDS or TMDS. Referring to the TFT LCD panel of FIG. **7***b*, the pixel sub-color is created when a transistor in a pixel element **770** (embedded in film on the glass) near the pixel asserts an electric field charge between electrodes on the glass. The field causes crystals in solution in between the glass to align creating a circular polarization filter of variable angle. Prior to entering the liquid crystal, the panel light is polarized and hence the rotation of the pixel crystals creates variable impedance to the transmission of light. In an embodiment, there are three active transistor elements per pixel; one for each primary color: red, green and blue. There could however be fewer active transistors in monochromatic displays, and four active transistors in a RGBW (W=white) display.

[0057] To select a pixel, gate driver **750** may assert a logic level on a row-line to select the appropriate pixel row. This enables the transistor in the pixel element **770**. The value of the pixel color is driven on the column-line by the source driver **760**. This proceeds from left-right, top-to-bottom, painting the pixels row-by-row until the entire screen is painted. Once the pixel value has been asserted, to allow the pixel to hold its color there is a capacitor (Cs) connected to the transistor which stores the pixel value and continues to apply the charge to the pixel sub-color RGB electrodes (Cp) after the pixel element **770** is no longer driven by gate and source drivers **750**, **760**. As the pixels are charged the image forms on the panel.

[0058] Pixels may need to change color as objects within the frame-buffer of memory **703** are changed. Additionally, the capacitor Cs does not hold the color charge at the pixel forever. Hence, the image may be "refreshed" at a regular rate. In an embodiment, a selected refresh rate is a compromise between the minimal rate necessary to keep up with the change of pixels/images in the frame-buffer (without creating tearing, juddering or other visual artifacts), and the longest the pixels can hold their charge (without dimming or creating other artifacts such as flickering). In an embodiment, refresh rate is in the 30-60 Hz range. This refresh process repeatedly paints out the entire screen image even when the pixels and source image in the frame buffer in memory **703** have not changed.

[0059] The refresh process may consume a significant amount of power since it involves repeatedly reading the source image pixels from the frame buffer in memory **703** (e.g. line buffers in memory device must drive signal levels onto the memory bus lines), driving them over the display bus **702***x* (e.g. LVDS output buffer drivers must apply the signal onto the display bus line), and then being applied by the gate driver **750**, source driver **770** and pixel sub-color transistors in pixel element **770**.

[0060] As explained above, to allow the pixel to hold its color once a pixel value has been asserted, there is a capacitor Cs connected to the transistor in pixel element **770** which stores the pixel value and continues to apply the charge to the pixel sub-color RGB electrodes Cp after the pixel element **770** is no longer driven by gate and source drivers **750**, **760**. FIG. **8** illustrates such a pixel value decaying from an initial value to a final value and shows the equation for the discharge rate of the pixel value as applied to the pixel sub-color circuit.

[0061] FIG. **9** is a block diagram illustrating embodiments of self-refresh in an LCD panel **906** controlled with panel controller **904**. When a succession of frames contain pixels of identical value at each pixel position (e.g. the frame content is not changing over time), the panel controller **904** may be used to perform a self-refresh at a rate that may be less frequent and that dissipates less energy than the refresh rate provided by graphics controller **901**. Self-refresh involves reading pixel values from the pixel element **906***a* transistor capacitor on the LCD panel **906**, adjusting the pixel value that was read for the decay due to storage capacitor discharge, and then writing the adjusted pixel value back out to the LCD panel **906**.

[0062] Graphics controller **901** may cause LCD display device **902** to enter into self-refresh mode when the detected EFPS indicates a lack of rendering or updating activity in the frame-buffer of memory. If activity (content changes) falls below a defined EFPS threshold, then self-refresh will be triggered by graphics controller **901**. The self-refresh process can be triggered by an explicit signal from graphics controller **901** (using a special sequence within the existing display bus **902***x* (e.g. LVDS), or through a separate signal) indicating the LCD panel **906** should go into self-refresh mode. Graphics controller **901** may then remove its own display mode timings and memory refresh cycles.

[0063] In another embodiment, the panel controller **904** automatically enters into self-refresh mode when it does not detect a defined threshold number of refreshes from the graphics controller **901** within a time interval.

[0064] In an embodiment, graphics controller **901** may only partially update LCD panel **906** if the EFPS and the area of a frame required to be updated are below defined threshold levels.

[0065] In an embodiment, panel controller **904** uses the pixel element transistor capacitor Cs (e.g. FIGS. **7***b*, **8***a*) as a memory storage element which holds the pixel value for

each primary color at each pixel position. After a pixel value is written to the sub-component storage of the pixel element **906***a*, the pixel value will degrade as it gradually discharges. In performing self-refresh, panel controller **904** may read the partially decayed pixel color values from each pixel element **906***a*. In an embodiment, partially decayed pixel values are read from pixel element **906***a* via A/D converter **912** and pixel source driver **916**. In an embodiment, A/D converter **912** provides twice the data resolution that that of D/A converter **910** (resolution of one pixel) so that small changes in pixel value (e.g. fractions of pixel) can be detected and to avoid quantization errors.

[0066] Referring briefly to FIG. **10**, in an alternative embodiment, successive approximation is used to read partially decayed pixel values. Here, panel controller **1004** selects a pixel value at D/A converter **1010** and uses comparator **1018** to compare the pixel value to the partially decayed value read from pixel element **1006***a* and repeats the process until the pixel values are equal (e.g. using sequential or binary-tree search methods). As described above, the read resolution may be twice that of the pixel value in order to avoid quantization error, thus the D/A converter **1010** resolution is increased in the successive approximation embodiment.

[0067] With regard to the pixel value adjustment, if the partially decayed pixel value read from the pixel element **906** is thought of as a final value, then its initial value may be found at a given time based on the known decay rate of the storage capacitor (see e.g. FIG. **8**). In an embodiment, the adjusted pixel values are stored in a pixel adjustment look-up table **908** implemented in a read only memory. Adjustment look-up table **908** contains adjusted pixel values that correspond to partially decayed pixel values when they are read from the pixel element **906***a* based on the time that has elapsed since the last refresh. In an embodiment, the table is preset with adjustment values based on one or more delay times that represent one or more intervals between self-refresh cycles. LCD display device **902** may exit self-refresh mode when graphics controller **901** resumes refreshing or as indicated by a display bus **902***x* interface signal.

[0068] FIG. **11** illustrates an embodiment of a self-refresh panel state machine. Beginning with State 1, the panel (e.g. LCD panel **906** in FIG. **9**) is refreshed by the graphics controller. While the display (e.g. LCD display device **902**) is in States 1 and 2, the graphics controller will monitor the EFPS (e.g. with frame rate monitor **401***a*, FIG. **4**) to detect the rate of content change to the panel. If the EFPS detected by the graphics controller falls below a defined threshold value, the graphics controller will transmit a signal to the display (e.g. with an LVDS semaphore) causing the display to enter State 2, the self refresh state.

[0069] When the display decodes the "enable self-refresh" signal from the graphics controller, it will enter into a mode in which the display controller (e.g. display controller **904**) refreshes the panel. In another embodiment, the display enters into State 2 automatically when the display detects a number of graphic controller refreshes that is less than a defined threshold for a defined time interval. While in State 2, the display may refresh the panel at a refresh rate that is not greater than a refresh rate offered by the graphics controller.

[0070] While in State 2, the graphics controller continues to monitor the EFPS. If the graphics controller detects that the EFPS is no longer below the defined threshold value, the graphics controller will begin refreshing the panel again. When the display decodes the "disable self-refresh" signal (e.g. an LVDS semaphore), the display will enter back into State 1.

[0071] The display may enter into State 3 from States 1 or State 2. Graphics controller may also monitor the size of the area of a frame that is to be changed when a panel is updated with a new frame. If the EFPS and the area being updated are less than a defined threshold value, the graphics controller may cause the display to enter State 3, a partial update state. In a partial update state, the graphics controller writes only frame data that has changed from the last frame. In this way, rewriting the entire frame can be avoided when a relatively small portion of the pixel values cannot be retrieved from the display itself (when going from State 2 to State 3). When the conditions for State 3 are no longer satisfied, the display will enter back into its previous state.

[0072] FIG. **12** is an algorithm of an embodiment for a pixel self-refresh process **1200**. Beginning at block **1201**, the logic of the algorithm should be followed for each of the pixel element subcomponents representing the colors red, green, blue and white. In block **1202**, the pixel sub-component read driver is enabled and in block **1203**, the row gate driver is enabled. At this point, in block **1204**, the pixel sub-component is read. Once the pixel subcomponent value is ascertained, in block **1205** the corresponding adjusted value is fetched from the look up table in block **1205***a*. With the updated value, the pixel sub-component value is adjusted in block **1206**. Finally the write component is enabled in block **1207** and the value is written in block **1208**. As described above, the process is repeated by block **1209** for each sub-component.

[0073] Through the practice of embodiments described herein, reduced power consumption by a computer system including display device may be realized by using a self-refresh rate that temporarily reduces power consumption involved with refresh operations performed by a graphics control module. Other applications may be able to leverage the ability of components of the pixel element to store pixel values coupled with the accessibility of those values to improve visual quality in a display (e.g. using the old state of a pixel and temporal compensation to account for pixel latency). Additionally, moving the refresh operation to the display device itself may free up resources previously responsible for refresh, leading to improved graphical or non-graphical performance.

[0074] Some portions of the detailed descriptions have been presented in terms of algorithms and symbolic representations of operations on data bits within a computer system's registers or memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of operations leading to a desired result. The operations are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

[0075] It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise, it is appreciated that throughout the present invention, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or the like, may refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer-system memories or registers or other such information storage, transmission or display devices.

[0076] Thus, a method and apparatus for self-refresh in a display device has been described. It is to be understood that the above description is intended to be illustrative and not restrictive. Many other embodiments will be apparent to those of skill in the art upon reading and understanding the above description. The scope of the invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

What is claimed is:

1. An apparatus, comprising:

a system display having a display screen that includes a pixel value storage component, the system display to be coupled with a graphics control module via a display bus and to enable a self-refresh mode based on a first indication from the graphics control module, the self-refresh mode to include refreshing pixel values stored within the pixel value storage component, and wherein a self-refresh rate is not greater than a first refresh rate provided by the graphics control module.

2. The apparatus of claim **1**, wherein the system display further comprises:

a display control module configured to refresh pixel values read from within the pixel value storage and to write the refreshed pixel values back into the pixel value storage.

3. The apparatus of claim **1**, wherein the system display includes a refresh module to receive the first indication from the graphics control module and to trigger the self-refresh mode based on the first indication, and to receive a second indication from the graphic control module that triggers the self-refresh mode to be disabled based on the second indication.

4. The apparatus of claim **2**, wherein the system display further comprises:

a refresh value module coupled with the display control module, the refresh value module to store new pixel values that correspond to old pixel values read from within the pixel value storage, wherein the display control module to refresh the old pixel values by exchanging them with corresponding new pixel values retrieved from the refresh value module.

5. The apparatus of claim **4**, wherein the system display is a thin film transistor liquid crystal diode (LCD) display, the display control module is a timing controller (TCON), the TCON implementing an algorithm to read a decayed sub-pixel value from each pixel element sub-pixel capacitor via an analog to digital converter, and the refresh value module is a lookup table implemented in a memory to store for each sub-pixel capacitor an initial pixel value that corresponds to the read decayed pixel value at a time that has elapsed since the sub-pixel capacitor was last refreshed.

6. A method, comprising:

operating in a first refresh mode that is controlled external to a system display;

entering a second refresh mode that is controlled from within the system display in response to a signal received at the system display;

operating in the second refresh mode, wherein the second refresh mode is a self-refresh mode and that provides a refresh rate that is not greater than a rate of the first refresh mode.

7. The method of claim **6**, wherein operating in the second refresh mode includes reading a first pixel value from a pixel value storage located on the system display, refreshing the first value, and writing the refreshed first value back to the pixel value storage.

8. The method of claim **7**, wherein refreshing the first pixel value includes retrieving a second pixel value from a refresh value module, wherein selection of the second pixel value depends on a difference between a first time the first pixel value was last refreshed and a second time it was retrieved; and refreshing the first pixel value by replacing the first pixel value with the second pixel value.

9. An apparatus, comprising:

a graphics control module having a first output terminal to couple with a memory via a memory bus and a second output terminal to couple to a display device via a display bus and configured to control refresh of the display device, and including a frame rate monitor to track an effective frame rate of the display device and to cause the graphics control module to stop controlling the refresh when a threshold effective frame rate value has been detected, and including a self-refresh signaler to transmit one or more signals to the display device upon detection of the threshold effective frame rate value to trigger the display device to enter a self-refresh mode.

10. The apparatus of claim **9**, wherein the graphics control module is a graphics controller embedded within a graphics memory controller hub (GMCH), and transmits refresh frames to the system display over the display bus using low voltage differential signaling (LVDS), and the self-refresh signaler encodes and transmits the one or more signals over the display bus using LVDS.

11. The apparatus of claim **10**, wherein the frame rate monitor tracks the frame rate by determining the effective frame rate per second from at least one of rendering activity and updating activity in a frame buffer within the memory, and the threshold frame rate is an effective frame per second threshold.

12. A method comprising:

refreshing a display device;

tracking an effective frame rate related to the display device; and

discontinuing refresh of the display device and issuing a signal to the display device to cause the display to enter a self-refresh mode if a minimum effective frame rate is detected.

13. The method of claim **12**, further comprising:

resuming refresh of the display device and issuing a signal to the display to exit the self-refresh mode if the effective frame rate exceeding the minimum effective frame rate is detected.

14. The method of claim **13**, wherein the signal to the display device is encoded into a low voltage differential signal.

15. The method of claim **13**, wherein the effective frame rate is an effective frame rate per second measured by update and rendering activity in a memory that stores frames for the display.

16. A system, comprising

a mobile computing system including a direct current power source;

a system display coupled with a graphics control module that controls a refresh rate of the system display via a display bus, the system display having a display screen that includes a pixel value storage component, the system display to enable a self-refresh mode based on a first indication from the graphics control module, the self-refresh mode to include refreshing pixel values stored within the pixel value storage component, and wherein a self-refresh rate is not greater than a first refresh rate provided by the graphics control module.

17. The system of claim **16**, wherein the system display further comprises:

a display control module configured to refresh pixel values read from within the pixel value storage and to write the refreshed pixel values back into the pixel value storage.

18. The apparatus of claim **16**, wherein the system display further comprises:

a refresh value module coupled with the display control module, the refresh value module to store new pixel values that correspond to old pixel values read from within the pixel value storage, wherein the display control module to refresh the old pixel values by exchanging them with corresponding new pixel values retrieved from the refresh value module.

19. The system of claim **16**, wherein the graphics control module further comprises:

a frame rate monitor to track an effective frame rate of the display device and to cause the graphics control module to stop controlling the refresh when a threshold effective frame rate value has been detected, and including a self-refresh signaler to transmit one or more signals to the display device upon detection of the threshold effective frame rate value to trigger the display device to enter a self-refresh mode.

20. The system of claim **19**, wherein the frame rate monitor tracks the frame rate by determining the effective frame rate per second from at least one of rendering activity and updating activity in a frame buffer within the memory, and the threshold frame rate is an effective frame per second threshold.

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