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(54) **CONTENT-AWARE DYNAMIC POWER CONVERTER SWITCHING FOR POWER OPTIMIZATION**

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G09G 3/20 (2006.01)

(52) **U.S. Cl.**
CPC ***G09G 3/20*** (2013.01); *G09G 2320/103* (2013.01); *G09G 2330/021* (2013.01); *G09G 2360/16* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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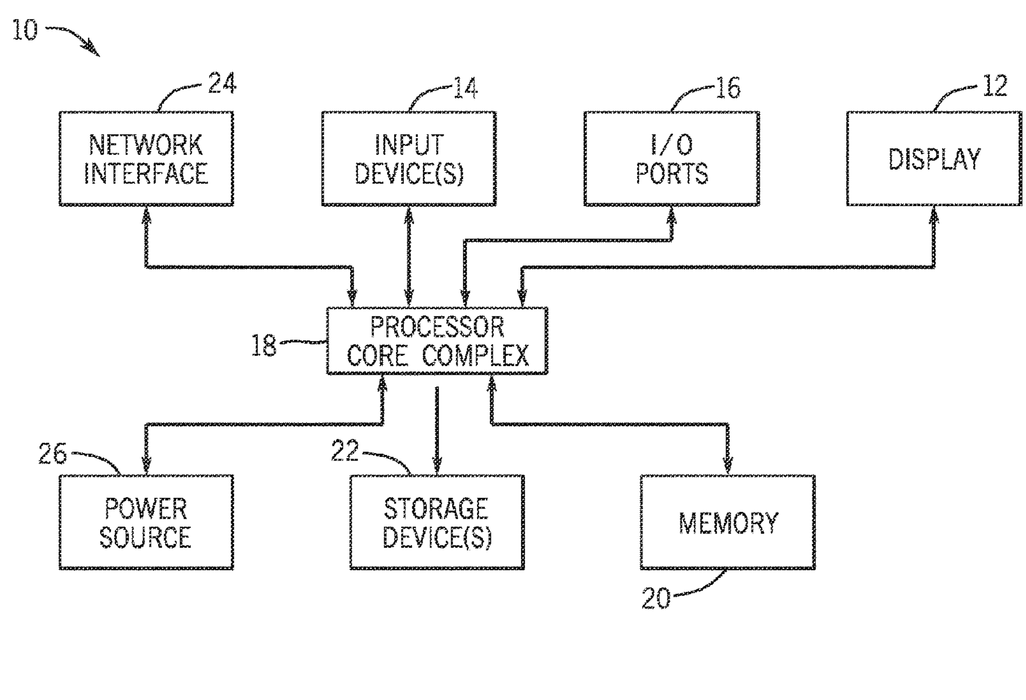
(57) **ABSTRACT**

To reduce overall power consumption for an electronic display power management integrated circuit (PMIC), one of multiple electric power converters and/or electric power regulators may be selected based on an electrical load (e.g., due to the total brightness of the content displayed) on the electronic display at a given moment. In some embodiments, the PMIC may include a less efficient heavy load converter designed with high-current handling capability and a more efficient light load (e.g., low current) converter with lower current handling capability. A controller may dynamically select between the converters depending on a present load or an expected load on the electronic display.

20 Claims, 8 Drawing Sheets



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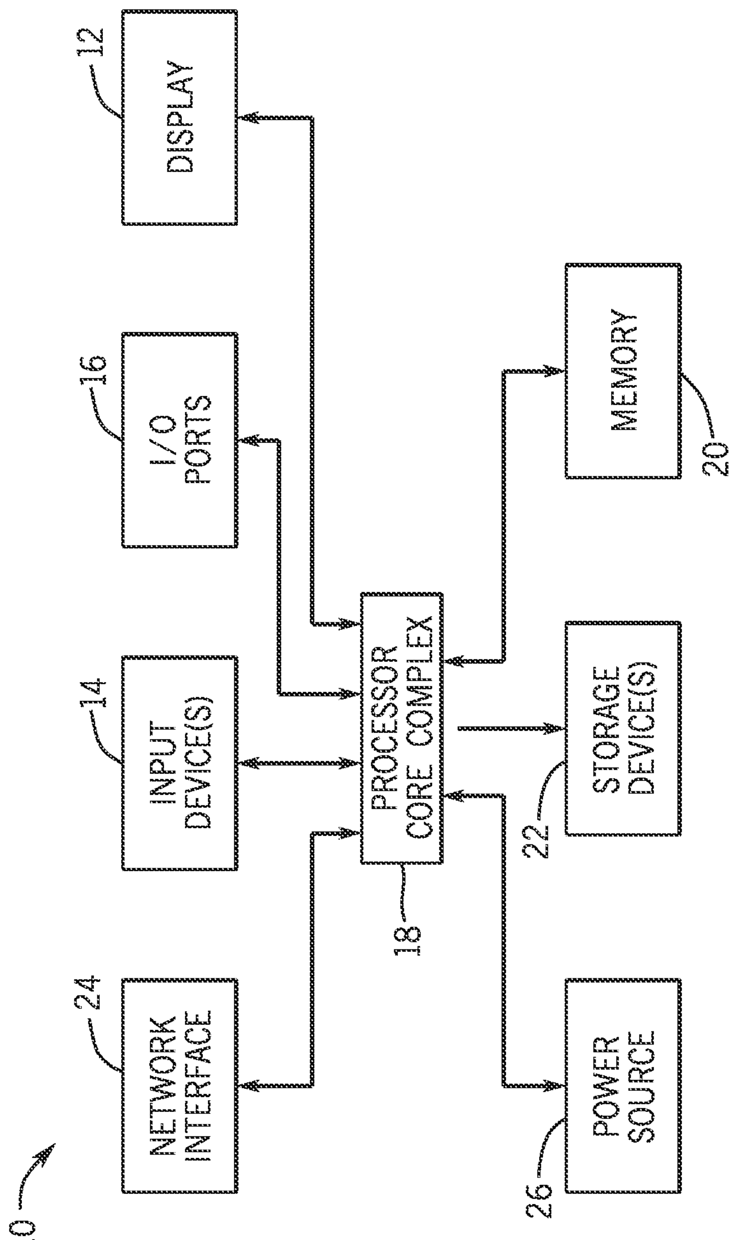
10
NETWORK INTERFACE
24
INPUT DEVICE(S)
14
I/O PORTS
16
DISPLAY
12
PROCESSOR CORE COMPLEX
18
MEMORY
20
STORAGE DEVICE(S)
22
POWER SOURCE
26

FIG. 1

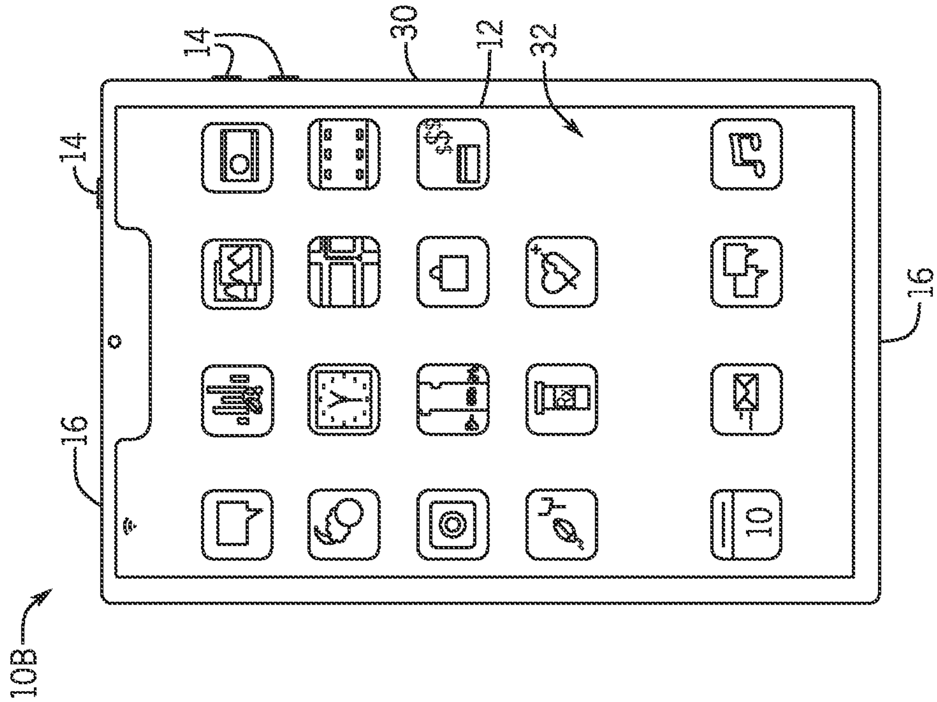

FIG. 3

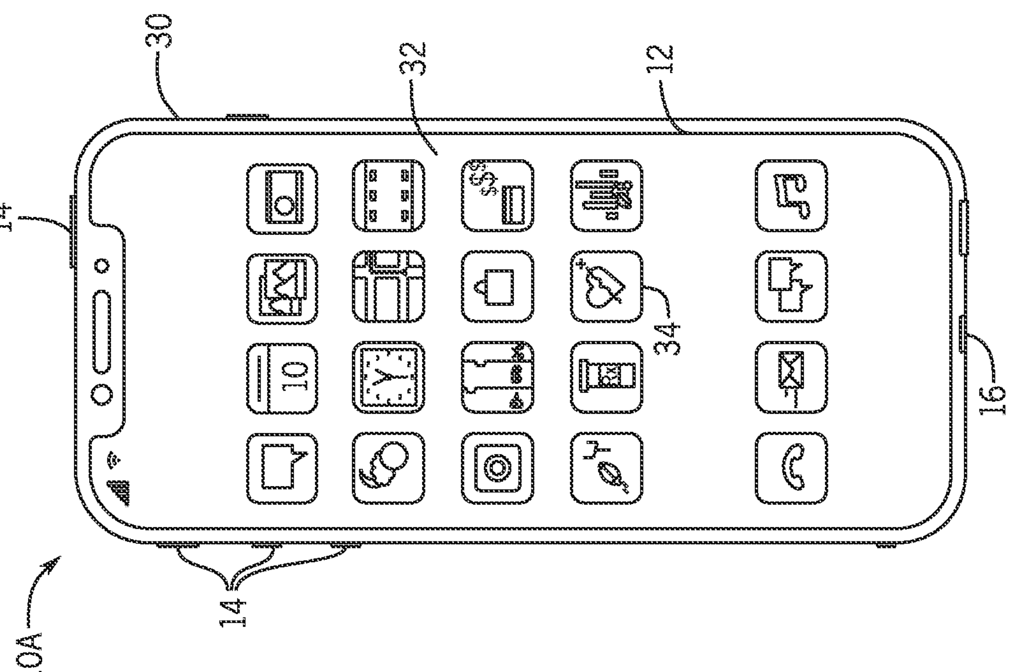

FIG. 2

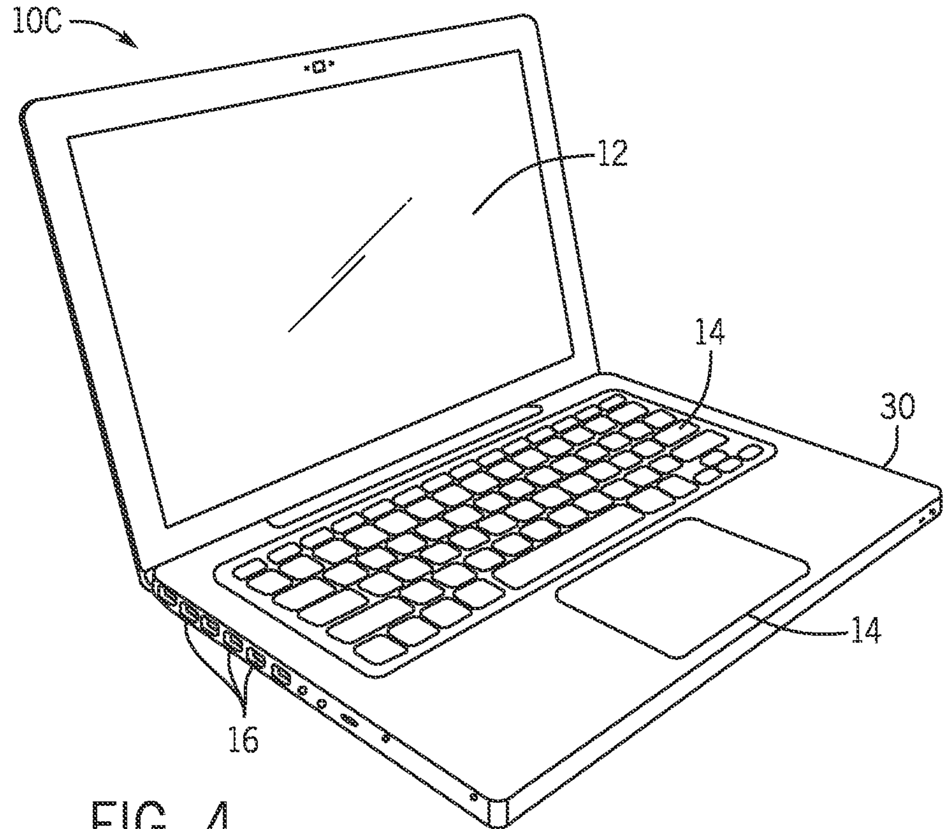

FIG. 4

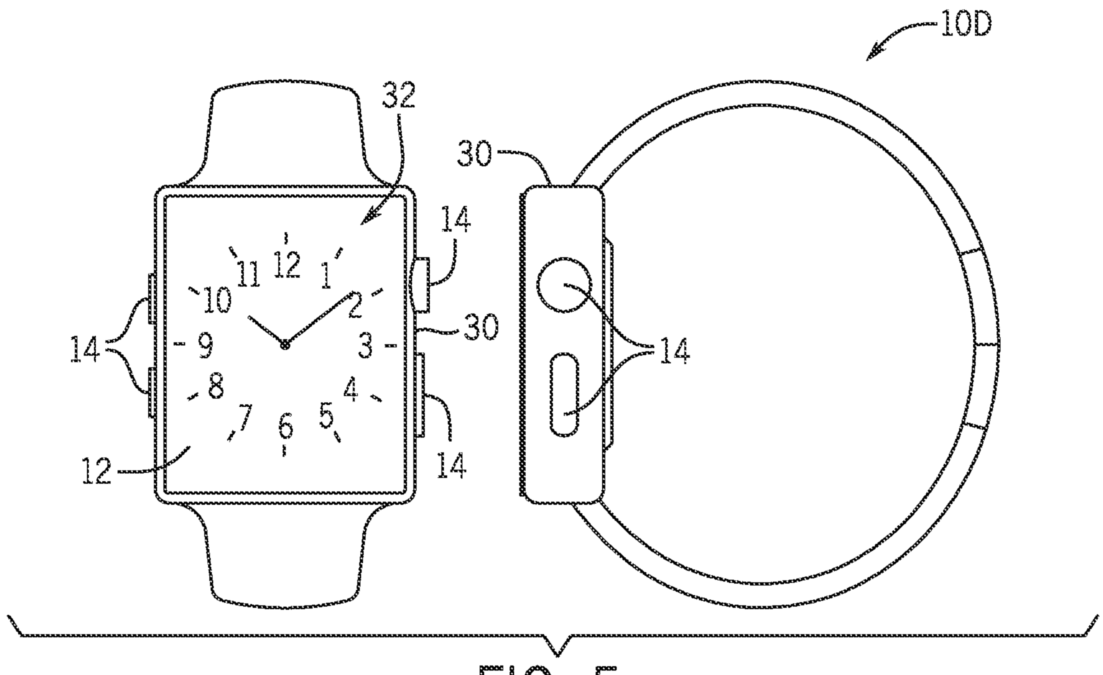

FIG. 5

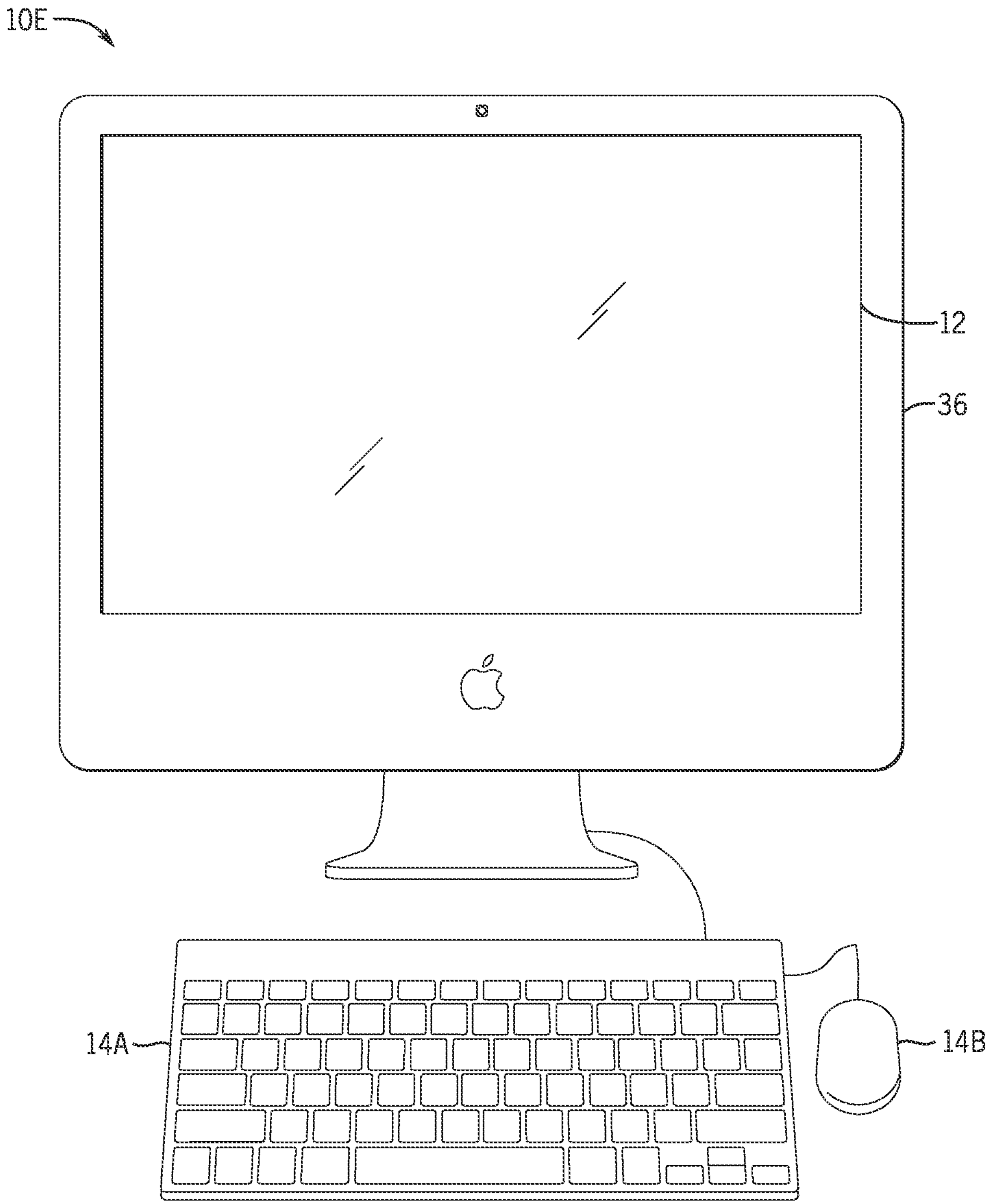

FIG. 6

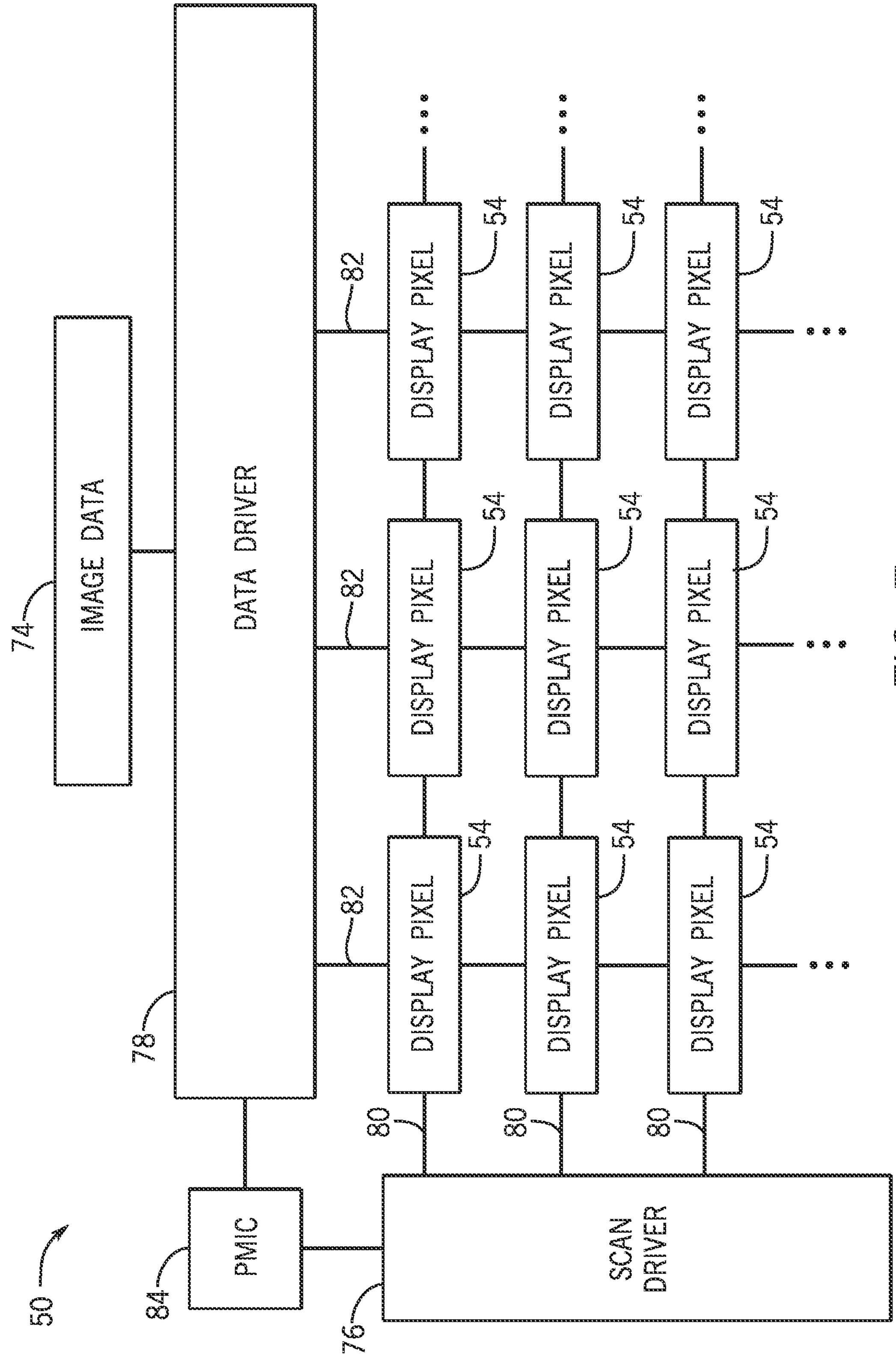
50
74
IMAGE DATA
78
DATA DRIVER
82
82
82
DISPLAY PIXEL
54
80
80
80
84
PMIC
76
SCAN DRIVER

FIG. 7

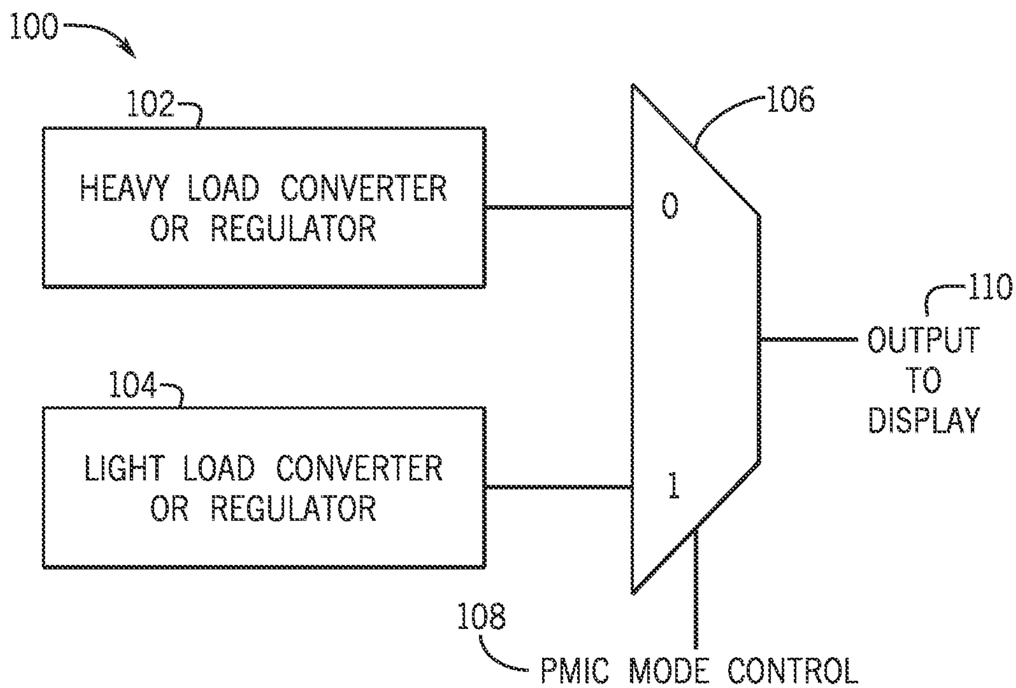
100
102
HEAVY LOAD CONVERTER OR REGULATOR
104
LIGHT LOAD CONVERTER OR REGULATOR
106
0
1
110
OUTPUT TO DISPLAY
108
PMIC MODE CONTROL

FIG. 8

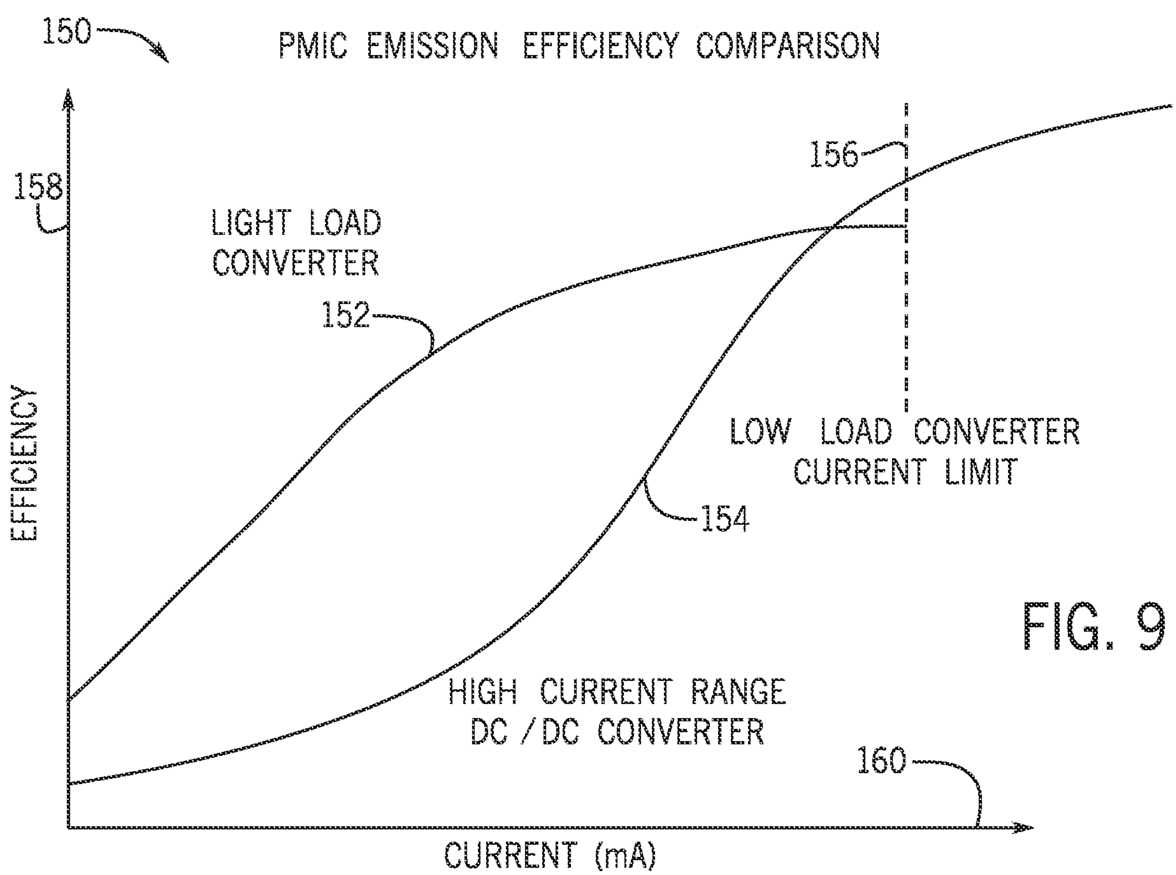
150
PMIC EMISSION EFFICIENCY COMPARISON
158
EFFICIENCY
LIGHT LOAD CONVERTER
152
156
LOW LOAD CONVERTER CURRENT LIMIT
154
HIGH CURRENT RANGE DC / DC CONVERTER
160
CURRENT (mA)

FIG. 9

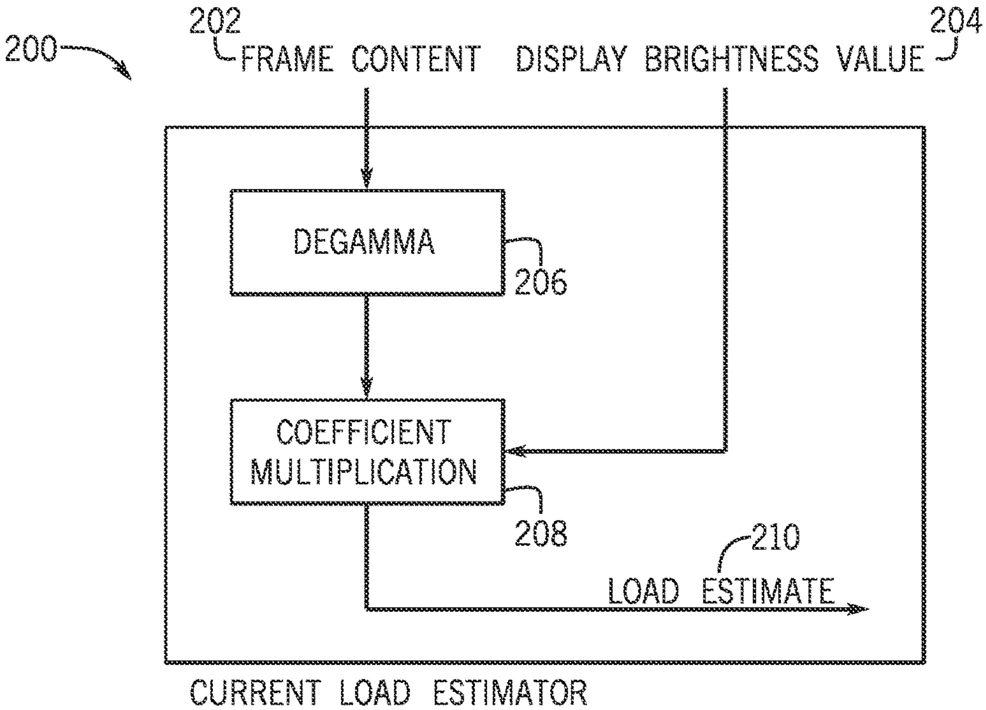
200
202
FRAME CONTENT
DISPLAY BRIGHTNESS VALUE
204
DEGAMMA
206
COEFFICIENT MULTIPLICATION
208
210
LOAD ESTIMATE
CURRENT LOAD ESTIMATOR

FIG. 10

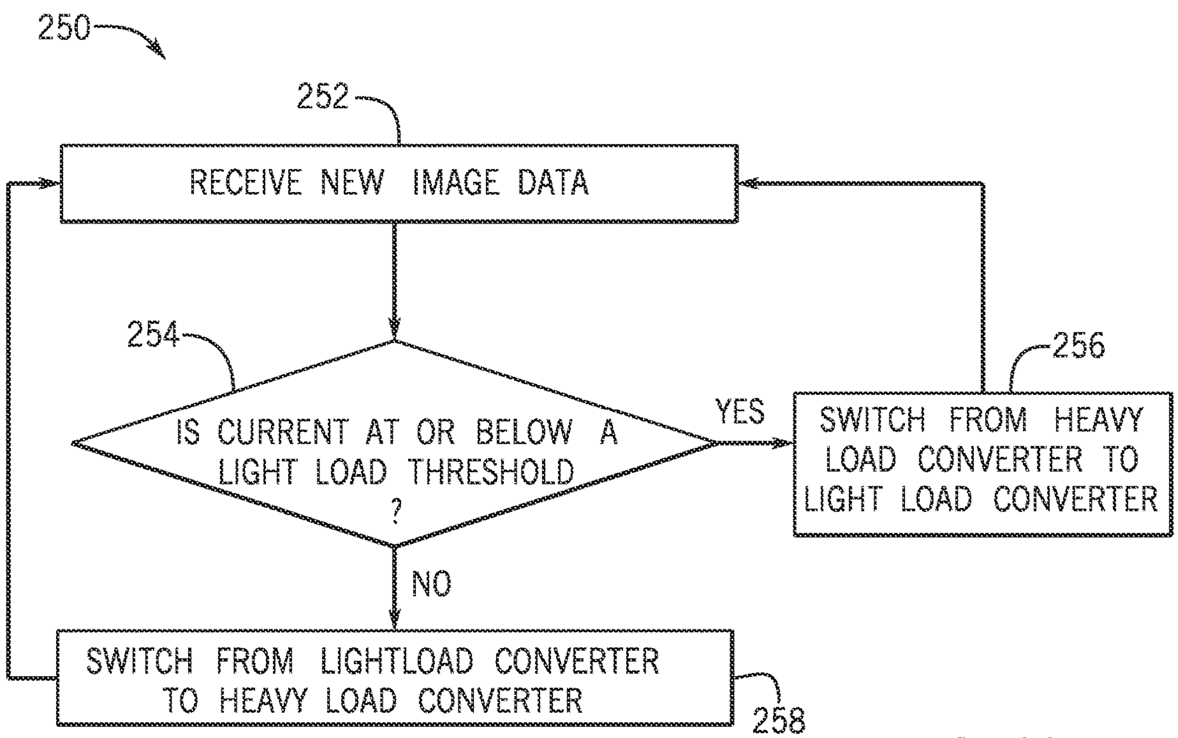
250
252
RECEIVE NEW IMAGE DATA
254
IS CURRENT AT OR BELOW A LIGHT LOAD THRESHOLD ?
YES
256
SWITCH FROM HEAVY LOAD CONVERTER TO LIGHT LOAD CONVERTER
NO
SWITCH FROM LIGHTLOAD CONVERTER TO HEAVY LOAD CONVERTER
258

FIG. 11

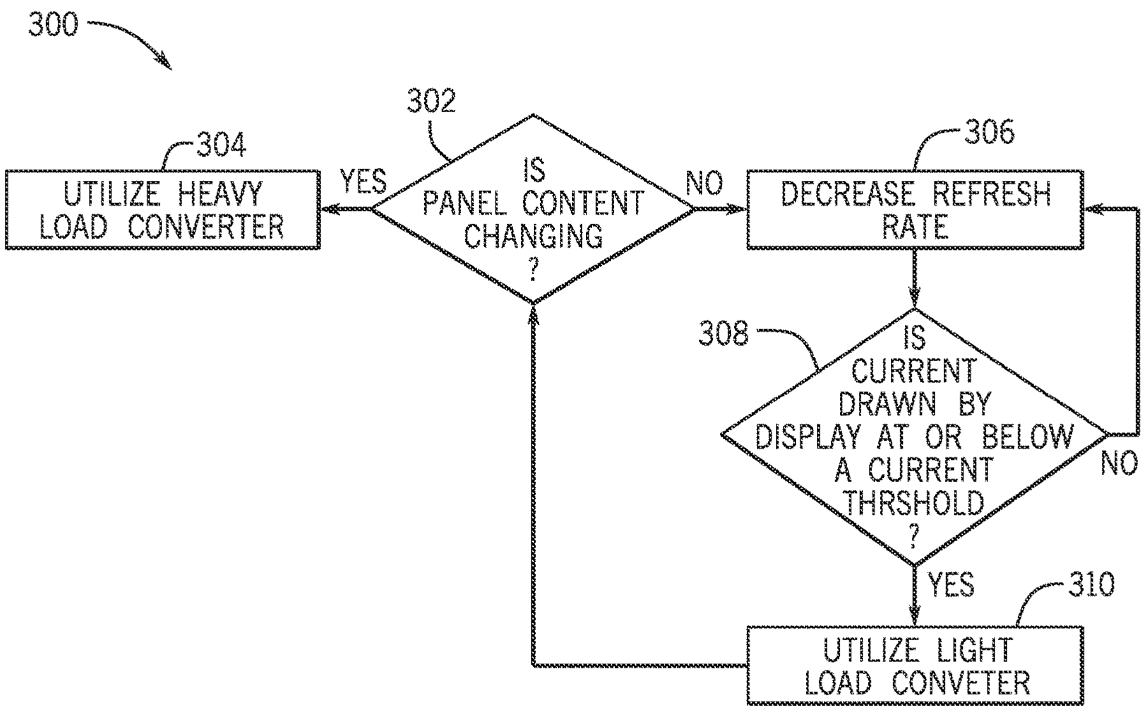
300
302
IS PANEL CONTENT CHANGING ?
YES
NO
304
UTILIZE HEAVY LOAD CONVERTER
306
DECREASE REFRESH RATE
308
IS CURRENT DRAWN BY DISPLAY AT OR BELOW A CURRENT THRSHOLD ?
NO
YES
310
UTILIZE LIGHT LOAD CONVETER

FIG. 12

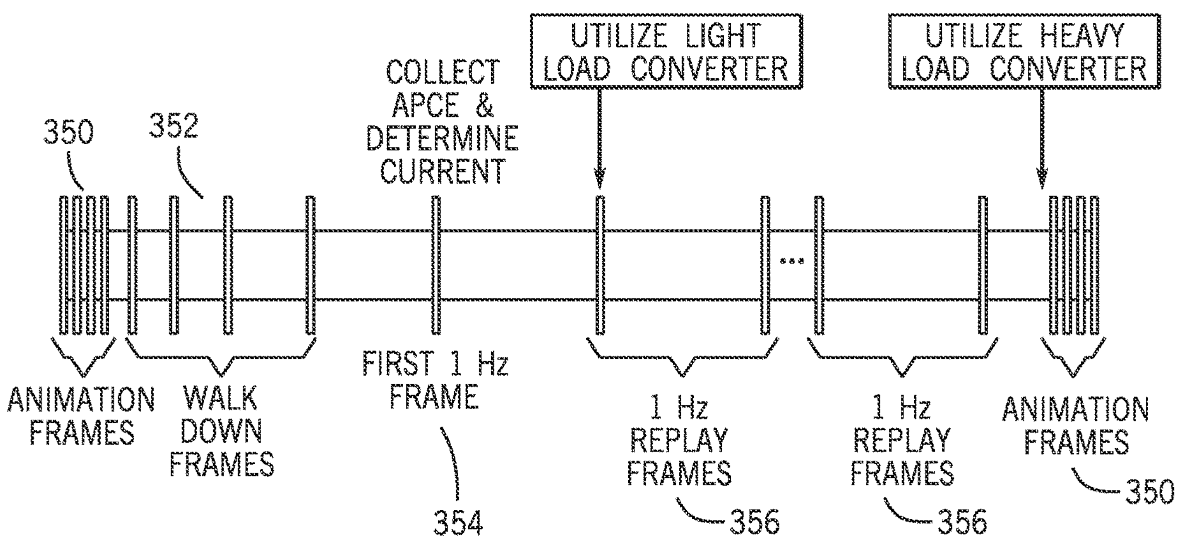
UTILIZE LIGHT LOAD CONVERTER
UTILIZE HEAVY LOAD CONVERTER
COLLECT APCE & DETERMINE CURRENT
350
352
...
ANIMATION FRAMES
WALK DOWN FRAMES
FIRST 1 Hz FRAME
354
1 Hz REPLAY FRAMES
356
1 Hz REPLAY FRAMES
356
ANIMATION FRAMES
350

FIG. 13

CONTENT-AWARE DYNAMIC POWER CONVERTER SWITCHING FOR POWER OPTIMIZATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application No. 63/359,563, filed Jul. 8, 2022, entitled "CONTENT-AWARE DYNAMIC POWER CONVERTER SWITCHING FOR POWER OPTIMIZATION," the disclosure of which is incorporated by reference in its entirety for all purposes.

SUMMARY

This disclosure relates to switching between electric power converters for an electronic display based on content that is to be displayed on the electronic display to reduce power consumption.

Numerous electronic devices—including televisions, portable phones, computers, wearable devices, vehicle dashboards, virtual-reality glasses, and more—display images on an electronic display. Certain electronic displays may have pixels that emit light in pulses. The total amount of light emitted in the pulses may be integrated by the human eye over time to produce the perception of a seamless image on the electronic display. An electronic device that houses such an electronic display may power the electronic display with a power source (e.g., a power source controlled by a power management integrated circuit (PMIC)). The power source may provide the electrical power that is used to produce the pulses of light emitted via the pixels.

Electronic displays may display a wide variety of content at a wide range of brightness values. For example, under bright ambient conditions, a global brightness value may be set very high and the electronic display may display content at a very high brightness level so the content can be seen. Under dark ambient conditions, the global brightness value may be set much lower and the electronic display may display content at a much lower brightness level. Displaying brighter content consumes more power than displaying darker content. To ensure that the electronic display has enough power to operate at both high and low brightness levels, a power management integrated circuit (PMIC) may use an electric power converter that provides a sufficiently high current regardless of the brightness of the content being displayed on the electronic display.

To reduce power consumption while displaying content at lower brightness levels, the PMIC may have multiple different electric power converters and/or electric power regulators sized to provide different levels of current corresponding to the total brightness of the content to be displayed on the electronic display. For example, to display brighter content, the PMIC may use a lower-efficiency, higher-power converter (e.g., a buck-boost converter) to ensure that enough current is provided for light emission. To display darker content where a higher current would be excessive, the PMIC may use a higher-efficiency, lower-power converter (e.g., a low dropout (LDO) converter). In the case where darker content is being displayed, the lower-power converter may provide sufficient current but may consume much less power. The PMIC may switch between the two converters based on a variety of factors, such as a current mode of the electronic device in which the electronic display is housed, a current application program running on the electronic device, and the total brightness of the content.

Various refinements of the features noted above may exist in relation to various aspects of the present disclosure. Further features may also be incorporated in these various aspects as well. These refinements and additional features may exist individually or in any combination. For instance, various features discussed below in relation to one or more of the illustrated embodiments may be incorporated into any of the above-described aspects of the present disclosure alone or in any combination. The brief summary presented above is intended only to familiarize the reader with certain aspects and contexts of embodiments of the present disclosure without limitation to the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings in which:

FIG. **1** is a block diagram of an electronic device including an electronic display, in accordance with an embodiment;

FIG. **2** is an example of the electronic device of FIG. **1** in the form of a handheld device, in accordance with an embodiment;

FIG. **3** is another example of the electronic device of FIG. **1** in the form of a tablet device, in accordance with an embodiment;

FIG. **4** is another example of the electronic device of FIG. **1** in the form of a notebook computer, in accordance with an embodiment;

FIG. **5** is another example of the electronic device of FIG. **1** in the form of a wearable device, in accordance with an embodiment;

FIG. **6** is another example of the electronic device of FIG. **1** in the form of a front view of a desktop computer, in accordance with an embodiment;

FIG. **7** is a block diagram of a display pixel array of the electronic display, in accordance with an embodiment;

FIG. **8** is a schematic diagram of a switching circuit for toggling between a high current DC/DC converter (e.g., a heavy load converter) and a light load high efficiency electric power converter (e.g., a light load converter), in accordance with an embodiment;

FIG. **9** is a diagram illustrating the operating behavior of the light load converter and the heavy load converter, in accordance with an embodiment;

FIG. **10** is a flow diagram illustrating how a controller determines a present load on the electronic display, in accordance with an embodiment;

FIG. **11** is a flowchart of a method for determining the present load on the electronic display and determining whether to activate the low load converter or the high load converter, in accordance with an embodiment;

FIG. **12** is a flowchart of a method for determining the present load on the electronic display and determining whether to activate the light load converter or the heavy load converter based on whether the content displayed on the electronic display is changing or static, according to embodiments of the present disclosure; and

FIG. **13** is an illustration of when the controller may switch from the light load converter to the heavy load converter based on the content displayed on the electronic display, according to embodiments of the present disclosure.

DETAILED DESCRIPTION

One or more specific embodiments of the present disclosure will be described below. These described embodiments are only examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but may nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Furthermore, the phrase A "based on" B is intended to mean that A is at least partially based on B. Moreover, the term "or" is intended to be inclusive (e.g., logical OR) and not exclusive (e.g., logical XOR). In other words, the phrase A "or" B is intended to mean A, B, or both A and B.

To reduce overall power consumption for an electronic display PMIC, one of multiple electric power converters (e.g., a direct current-to-direct current (DC/DC) converter) and/or electric power regulators may be selected based on an electrical load (e.g., due to the total brightness of the content displayed) on the electronic display at a given moment. In some embodiments, the PMIC may include a heavy load (e.g., high current) converter designed with high-current handling capability that may be relatively inefficient and a light load (e.g., low current) converter designed to be more efficient but with lower current handling capability.

The electronic device may dynamically select between the converters (e.g., via the PMIC, via a processor) depending on a present load or on an expected load on the electronic display. For example, if bright content is displayed or is anticipated to be displayed on the electronic display, the PMIC may select the heavy load converter (e.g., a buck-boost converter). However, if dim content is displayed or is anticipated to be displayed on the electronic display, the PMIC may select the light load converter (e.g., a low-dropout (LDO) converter). In this way, the PMIC and multiple converters may enable seamless switching between the heavy load operation and the light load operation without restricting user activity with regard to content or brightness.

To help illustrate, one embodiment of an electronic device **10** that utilizes an electronic display **12** is shown in FIG. **1**. As will be described in more detail below, the electronic device **10** may be any suitable electronic device, such as a handheld electronic device, a tablet electronic device, a notebook computer, or the like. Thus, it should be noted that FIG. **1** is merely one example of a particular implementation and is intended to illustrate the types of components that may be present in the electronic device **10**.

The electronic device **10** may include one or more electronic displays **12**, input devices **14**, input/output (I/O) ports **16**, a processor core complex **18** having one or more processors or processor cores, local memory **20**, a main memory storage device **22**, a network interface **24**, a power source **26**. The various components described in FIG. **1** may include hardware elements (e.g., circuitry), software elements (e.g., a tangible, non-transitory computer-readable medium storing instructions), or a combination of both hardware and software elements. As should be appreciated, the various components may be combined into fewer components or separated into additional components. For example, the local memory **20** and the main memory storage device **22** may be included in a single component.

The processor core complex **18** may be operably coupled with local memory **20** and the main memory storage device **22**. The local memory **20** and/or the main memory storage device **22** may include tangible, non-transitory, computer-readable media that store instructions executable by the processor core complex **18** and/or data to be processed by the processor core complex **18**. For example, the local memory **20** may include random access memory (RAM) and the main memory storage device **22** may include read only memory (ROM), rewritable non-volatile memory such as flash memory, hard drives, optical discs, and/or the like.

The processor core complex **18** may execute instructions stored in local memory **20** and/or the main memory storage device **22** to perform operations, such as generating source image data. As such, the processor core complex **18** may include one or more general purpose microprocessors, one or more application specific processors (ASICs), one or more field programmable gate arrays (FPGAs), or any combination thereof.

The network interface **24** may connect the electronic device **10** to a personal area network (PAN), such as a Bluetooth network, a local area network (LAN), such as an 802.11x Wi-Fi network, and/or a wide area network (WAN), such as a 4G or LTE cellular network. In this manner, the network interface **24** may enable the electronic device **10** to transmit image data to a network and/or receive image data from the network.

The power source **26** may provide electrical power to operate the processor core complex **18** and/or other components in the electronic device **10**. Thus, the power source **26** may include any suitable source of energy, such as a rechargeable lithium polymer (Li-poly) battery and/or an alternating current (AC) power converter.

The I/O ports **16** may enable the electronic device **10** to interface with various other electronic devices. The input devices **14** may enable a user to interact with the electronic device **10**. For example, the input devices **14** may include buttons, keyboards, mice, trackpads, and the like. Additionally or alternatively, the electronic display **12** may include touch sensing components that enable user inputs to the electronic device **10** by detecting occurrence and/or position of an object touching its screen (e.g., surface of the electronic display **12**).

The electronic display **12** may display a graphical user interface (GUI) of an operating system, an application interface, text, a still image, or video content. To facilitate displaying images, the electronic display **12** may include a display panel with an array of display pixels. Each display pixel may represent a sub-pixel that controls the luminance of a color component (e.g., red, green, or blue).

As described above, the electronic display **12** may display an image by controlling the luminance of the sub-pixels based at least in part on corresponding image data. In some embodiments, the image data may be received from another electronic device, for example, via the network interface **24** and/or the I/O ports **16**. Additionally or alternatively, the image data may be generated by the processor core complex

18. Moreover, in some embodiments, the electronic device **10** may include multiple electronic displays **12**.

The electronic device **10** may be any suitable electronic device. One example of a suitable electronic device **10**, specifically a handheld device **10**A, is shown in FIG. **2**. In some embodiments, the handheld device **10**A may be a portable phone, a media player, a personal data organizer, a handheld game platform, and/or the like. For example, the handheld device **10**A may be a smart phone, such as any iPhone® model available from Apple Inc.

The handheld device **10**A may include an enclosure **30** (e.g., housing) to, for example, protect interior components from physical damage and/or shield them from electromagnetic interference. Additionally, the enclosure **30** may surround, at least partially, the electronic display **12**. In the depicted embodiment, the electronic display **12** is displaying a graphical user interface (GUI) **32** having an array of icons **34**. By way of example, when an icon **34** is selected either by an input device **14** or a touch-sensing component of the electronic display **12**, an application program may launch.

Furthermore, input devices **14** may be provided through openings in the enclosure **30**. As described above, the input devices **14** may enable a user to interact with the handheld device **10**A. For example, the input devices **14** may enable the user to activate or deactivate the handheld device **10**A, navigate a user interface to a home screen, navigate a user interface to a user-configurable application screen, activate a voice-recognition feature, provide volume control, and/or toggle between vibrate and ring modes. Moreover, the I/O ports **16** may also open through the enclosure **30**.

Another example of a suitable electronic device **10**, specifically a tablet device **10**B, is shown in FIG. **3**. For illustrative purposes, the tablet device **10**B may be any iPad® model available from Apple Inc. A further example of a suitable electronic device **10**, specifically a computer **10**C, is shown in FIG. **4**. For illustrative purposes, the computer **10**C may be any MacBook® or iMac® model available from Apple Inc. Another example of a suitable electronic device **10**, specifically a watch **10**D, is shown in FIG. **5**. For illustrative purposes, the watch **10**D may be any Apple Watch® model available from Apple Inc. As depicted, the tablet device **10**B, the computer **10**C, and the watch **10**D each also includes an electronic display **12**, input devices **14**, I/O ports **16**, and an enclosure **30**.

Turning to FIG. **6**, a computer **10**E may represent another embodiment of the electronic device **10** of FIG. **1**. The computer **10**E may be any computer, such as a desktop computer, a server, or a notebook computer, but may also be a standalone media player or video gaming machine. By way of example, the computer **10**E may be an iMac®, a MacBook®, or other similar device by Apple Inc. of Cupertino, California. It should be noted that the computer **10**E may also represent a personal computer (PC) by another manufacturer. A similar enclosure **36** may be provided to protect and enclose internal components of the computer **10**E, such as the electronic display **12**. In certain embodiments, a user of the computer **10**E may interact with the computer **10**E using various peripheral input devices **14**, such as the keyboard **14**A or mouse **14**B (e.g., the input structures **14**), which may connect to the computer **10**E.

FIG. **7** is a block diagram of a display pixel array **50** of the electronic display **12**. It should be understood that, in an actual implementation, additional or fewer components may be included in the display pixel array **50**. The electronic display **12** may receive any suitable image data for presentation on the electronic display **12**. The electronic display **12** includes display driver circuitry that includes scan driver circuitry **76** and data driver circuitry **78**. The display driver circuitry controls programing the image data **74** into the display pixels **54** for presentation of an image frame via light emitted according to each respective bit of image data **74** programmed into one or more of the display pixels **54**.

The display pixels **54** may each include one or more self-emissive elements, such as a light-emitting diodes (LEDs) (e.g., organic light emitting diodes (OLEDs) or micro-LEDs (μLEDs)); however, other pixels may be used with the systems and methods described herein including but not limited to liquid-crystal devices (LCDs), digital mirror devices (DMD), or the like, and include use of displays that use different driving methods than those described herein, including partial image frame presentation modes, variable refresh rate modes, or the like.

Different display pixels **54** may emit different colors. For example, some of the display pixels **54** may emit red light, some may emit green light, and some may emit blue light. Thus, the display pixels **54** may be driven to emit light at different brightness levels to cause a user viewing the electronic display **12** to perceive an image formed from different colors of light. The display pixels **54** may also correspond to hue and/or luminance levels of a color to be emitted and/or to alternative color combinations, such as combinations that use red (R), green (G), blue (B), or others.

The scan driver circuitry **76** may provide scan signals (e.g., pixel reset, data enable, on-bias stress, emission (EM)) on scan lines **80** to control the display pixels **54** by row. For example, the scan driver circuitry **76** may cause a row of the display pixels **54** to become enabled to receive a portion of the image data **74** from data lines **82** from the data driver circuitry **78**. In this way, an image frame of the compensated image data **74** may be programmed onto the display pixels **54** row by row. Other examples of the electronic display **12** may program the display pixels **54** in groups other than by row. When the scan driver circuitry **76** provides an emission signal to certain display pixels **54**, those display pixels **54** may emit light according to the image data **74** with which those display pixels **54** were programmed.

The display pixel array **50** includes a power management integrated circuit (PMIC) **84**. The PMIC **84** may provide power to the display pixel array **50** (e.g., to the data driver circuitry **78** and the scan driver circuitry **76**). As will be discussed in greater detail below, the PMIC **84** may receive the image data **74** and adjust (e.g., via a controller of the PMIC **84**) the power delivered to the display pixel array **50** based on the image data **74**.

FIG. **8** is a schematic diagram of a switching circuit **100** for toggling between a lower-efficiency high current DC/DC converter (heavy load converter) **102** and a light load high efficiency converter (light load converter) **104** or regulator, according to embodiments of the present disclosure. The switching circuit **100** may include selection circuitry such as a multiplexer **106**. The multiplexer **106** may receive a PMIC mode control signal **108** from a controller (e.g., from the PMIC **84**, from the processor core complex **18**, and so on). Based on the PMIC mode control signal **108**, the multiplexer **106** may either activate the heavy load converter **102** or the light load converter **104**. The heavy load converter **102** may include a converter with high current handling capabilities but low operating efficiency (e.g., a buck-boost converter), while the light load converter **104** may include a converter with lower current handling capability but high operating efficiency (e.g., a low-dropout (LDO) converter). Upon selection, the switching circuit **100** may output an output power signal **110** supplied by the heavy load converter **102** or the light load converter **104**.

FIG. **9** is a diagram **150** illustrating the operating behavior of the light load converter **104** and the heavy load converter **102**, according to embodiments of the present disclosure. The diagram includes curve **152** representing the efficiency of the light load converter **104** (represented by the y-axis **158**) as a function of the present load (represented by the x-axis **160**) of the electronic display **12**. The diagram includes curve **154** representing the efficiency of the heavy load converter **102** as a function of the present load of the electronic display **12**. As may be observed from the diagram, the light load converter **104** operates at a higher efficiency than the heavy load converter at lower present loads. Accordingly, during lower present load applications (e.g., low-power mode, such as an always-on display mode), the controller may activate the light load converter **104** to reduce overall display power consumption.

As the present load on the electronic display **12** increases toward a light load converter current limit **156**, however, the controller may deactivate the light load converter **104** (if activated) and activate the heavy load converter **102** to meet the power demands of the electronic display **12** during high current operation (e.g., video streaming) and prevent the light load converter **104** from exceeding its power limit and potentially collapsing the power supply, causing display panel shutoff or front-of-screen issues that may negatively impact user experience. Indeed, the controller may deactivate the light load converter **104** (if activated) and activate the heavy load converter **102** at a lower current to ensure that sufficient power may be provided when a higher current is to be provided. For example, the controller may deactivate the light load converter **104** (if activated) and activate the heavy load converter **102** if the current that is to be drawn reaches or is approaching a crossover point between the curves **152** and **154**.

The controller may determine the extent of the load on the electronic display **12** based on content that is currently or is anticipated to be displayed on the electronic display **12** and/or based on the display brightness value (DBV) of the electronic device **10**. FIG. **10** is a flow diagram **200** illustrating how the controller determines the present load on the electronic display **12**, according to embodiments of the present disclosure. The controller may receive frame content **202** (e.g., the image data for a given frame) and the display brightness value (DBV) **204** for the electronic display **12**. The controller may use the frame content **202** to determine the present load as the present load on a display PMIC (e.g., **84**) may be based on content being displayed on the electronic display **12** at a given moment. Thus, the controller may use the frame content **202** to determine the brightness at which the display pixels **54** may emit light to display the frame content **202**, which will determine the load on the PMIC **84**. The controller may transmit the frame content **202** to a degamma block **206** (e.g., gamma decoding circuitry or a gamma decoding operation) to convert the frame content **202** from the gamma domain (e.g., from a gray value of 0 to 255) to a domain that accurately represents the power (e.g., current) that may be supplied to the display pixels **54** to display the frame content **202** as intended.

To accurately determine the present load, the controller may take into account the individual brightness values of the pixel emissions on the electronic display **12** (e.g., ascertained from the frame content **202**) scaled to the global brightness value of the electronic display **12** itself (e.g., the DBV **204**). The controller may multiply the gamma decoded signal by a coefficient corresponding to the DBV **204** in multiplication circuitry **208** to obtain a load estimate **210** for the electronic display **12**.

FIG. **11** is a flowchart of a method **250** for determining the present load on the electronic display **12** and determining whether to activate the light load converter **104** or the heavy load converter **102**, according to embodiments of the present disclosure. Any suitable device (e.g., a controller) that may control components of the electronic device **10**, such as the processor core complex **18** or the PMIC **84**, may perform the method **250**. In some embodiments, the method **250** may be implemented by executing instructions stored in a tangible, non-transitory, computer-readable medium, such as the memory **20** or storage **22**, using the processor core complex **18**. For example, the method **250** may be performed at least in part by one or more software components, such as an operating system of the electronic device **10**, one or more software applications of the electronic device **10**, and the like. While the method **250** is described using steps in a specific sequence, it should be understood that the present disclosure contemplates that the described steps may be performed in different sequences than the sequence illustrated, and certain described steps may be skipped or not performed altogether.

In process block **252**, the controller may receive new image data **74** (e.g., the frame content **202**). In query block **254**, the controller may determine the present load on the electronic display **12** based at least in part on the image data **74** and the DBV **204** of the electronic display **12** and determine whether the present load is at or below a light load threshold (e.g., the light load converter current limit **156**, an efficiency crossover point, a lower value of current selected to provide margin to avoid possibly drawing excessive current from the light load converter **104**). The threshold may be set based on brightness of the frame content **202** being displayed on the electronic display **12** (e.g., as both a function of the frame content **202** itself and the DBV **204** of the electronic display **12**).

If the controller determines that the present load is at or below a light load threshold, in process block **256** the controller switches from operating the heavy load converter **102** and activates the light load converter **104** (e.g., by sending the PMIC mode control signal **108** indicating a command to select the light load converter **104**). However, if the controller determines that the present load exceeds the light load threshold, in process block **258** the controller switches from the light load converter **104** and activates the heavy load converter **102** (e.g., by sending the PMIC mode control signal **108** indicating a command to select the heavy load converter **102**). In this manner, the controller may determine the present load currently experienced on the electronic display **12** or anticipated to be experienced on the electronic display **12** and select the appropriate converter or regulator accordingly.

In some embodiments, method **250** may be performed at each new frame. However, if the new image data **74** is the same as the previous image data **74** (e.g., there is no change to the frame content **202**) the controller may forego performing the method **250** until new image data **74** associated with different frame content **202** is received to further conserve power. In some embodiments, the controller may have a default preference for the heavy load converter **102** (e.g., to ensure that the light load converter **104** is not overloaded). For example, if new frame content **202** is being received (e.g., frame content **202** is changing with each new frame), the controller may activate the heavy load converter **102** until new frame content **202** received is the same as the previous frame content, at which time the controller will perform the method **250**. By doing so, the controller may prevent overloading the light load converter **104** in the event that new incoming frame content **202** draws more power than the light load converter **104** may supply. It should be noted that, while only two converters are discussed, there may be any appropriate number of converters that may be implemented on the PMIC **84** (e.g., three converters or more, four converters or more, five converters or more).

As previously mentioned, using the light load converter **104** when current drawn by the electronic display **12** exceeds the power limit of the light load converter **104** may result in collapse of the power supply. To prevent power supply collapse, the display panel may be prevented from drawing current above the light load threshold (e.g., current threshold, average pixel current equivalent threshold, and so on). Current control systems (e.g., a real-time peak luminance control (RTPLC) system) may determine current or APCE at each frame displayed on the electronic display **12**. However, determining current or APCE for each frame may in some cases be insufficient for preventing the light load converter **104** from exceeding its limit, as peak current draw may occur while a new frame is being programmed onto the display panel. However, as will be discussed in greater detail below, exceeding the limit of the light load converter **104** may be prevented by only using the light load converter **104** when the content displayed on the electronic display **12** is static.

FIG. **12** is a flowchart of a method **300** for determining the present load on the electronic display **12** and determining whether to activate the light load converter **104** or the heavy load converter **102** based on whether the content displayed on the electronic display **12** is changing or static, according to embodiments of the present disclosure. Any suitable device (e.g., a controller) that may control components of the electronic device **10**, such as the processor core complex **18** or the PMIC **84**, may perform the method **300**. In some embodiments, the method **300** may be implemented by executing instructions stored in a tangible, non-transitory, computer-readable medium, such as the memory **20** or storage **22**, using the processor core complex **18**. For example, the method **300** may be performed at least in part by one or more software components, such as an operating system of the electronic device **10**, one or more software applications of the electronic device **10**, and the like. While the method **300** is described using steps in a specific sequence, it should be understood that the present disclosure contemplates that the described steps may be performed in different sequences than the sequence illustrated, and certain described steps may be skipped or not performed altogether.

In query block **302**, the controller may determine whether content displayed on the electronic display **12** is presently dynamically changing (e.g., an animated frame) based on presently displayed frames or if an upcoming frame will be dynamically changing based on anticipated upcoming frames. If the controller determines that the content is presently dynamically changing or will by dynamically changing in upcoming frames, in process block **304**, the controller may cause the electronic display to utilize the heavy load converter **102**. If the controller determines that the content is not changing (e.g., the frames are repeating frames such that the content displayed is a static image), the controller may, in process block **306**, gradually decrease (e.g., walk down) refresh rate of the electronic display **12** until a minimum refresh rate is reached. Once a first frame having the minimum refresh rate is reached, the controller may use a current control system (e.g., RTPLC system) to determine an APCE of the first minimum refresh rate frame to determine if the brightness of the display panel is at or a below a brightness threshold. In some embodiments, the first refresh rate frame may be written back to memory within a system-on-a-chip (SOC) so that replay can be utilized. If there is sufficient confidence that lookup tables (LUTs) below a certain refresh rate will not cause an increase in APCE, changing from the heavy load converter **102** to the light load converter **104** may occur once a temporal pixel modification block has acquiesced.

Current draw of the electronic display **12** may be determined based on the APCE for the first minimum refresh rate frame and a panel brightness value to determine if the current drawn is at or below a threshold value. In query block **308**, the controller may determine if the current drawn by the electronic display **12** is at or below a current threshold. If the controller determines that the current drawn by the electronic display **12** is not at or below the current threshold, the controller may cause the electronic display **12** to continue to decrease luminance in the process block **306**. If the controller determines that the current drawn by the electronic display **12** is at or below the current threshold, in process block **310**, the controller may cause the electronic display to utilize the light load converter **104**, which may cause the electronic display **12** to operate in a low-luminance mode and may reduce the power consumed by the electronic display **12**. The controller may iteratively perform the method **300** at every frame to determine if the electronic display **12** is displaying dynamic content or static content, and may continue using the light load converter **104** until immediately prior to the next dynamic frame (e.g., non-replay frame), at which time the controller may cause the electronic display **12** to utilize the heavy load converter **102**. In this manner, the method **300** may enable determining the present load on the electronic display **12** and determining whether to activate the light load converter **104** or the heavy load converter **102** based on whether the content displayed on the electronic display **12** is changing or static.

FIG. **13** is an illustration of when the controller may switch from the light load converter to the heavy load converter based on the content displayed on the electronic display, according to embodiments of the present disclosure. During animation frames **350** (e.g., dynamic frames) the controller may select (e.g., via the PMIC mode control signal **108**) the heavy load converter **102** to ensure that the PMIC **84** can safely provide the amount of current needed for displaying the animation frames **350**. During walk down frames **352**, the content displayed may remain static (e.g., the content displayed may be a still image), and the controller may cause the refresh rate of the electronic display **12** to be gradually reduced or walked down to a minimum refresh rate. The minimum refresh rate may be selected as any appropriate or desirable minimum refresh rate, such as 1 hertz (Hz) or more, 2 Hz or more, 10 Hz or more, 50 Hz or more, and so on.

Frame **354** represents the first frame where the minimum refresh rate (e.g., 1 Hz) is reached. At the frame **354**, the controller may use a current control system (e.g., an RTPLC system) to determine the APCE of the frame **354** to determine if the current drawn by the electronic display **12** during the frame **354** is at or below a given threshold current. If the controller determines that the APCE of the frame **354** is not at or below the given threshold, the controller will refrain from taking action, and the PMIC **84** will continue to use the heavy load converter **102**. However, if the controller determines that the current is at or below the given threshold, the controller may select (e.g., via the PMIC mode control signal **108**) the light load converter **104** to supply the current for the electronic display **12**, saving power during display during the minimum refresh rate frames **356** (e.g., replay frames). The electronic display **12** may continue to utilize the light load converter **104** until immediately prior to the next animation frames **350** (e.g., next non-replay frames) to ensure that the PMIC **84** can supply sufficient current for the more power hungry animation frames **350**.

The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as "means for [perform]ing [a function] . . . " or "step for [perform]ing [a function] . . . ", it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

What is claimed is:

1. A power management integrated circuit, comprising:

a first electric power converter;

a second electric power converter;

selection circuitry coupled to the first electric power converter and the second electric power converter, the selection circuitry configured to toggle between activating the first electric power converter and the second electric power converter; and

a controller configured to determine a load on the power management integrated circuit based on gamma-decoded image data and a coefficient corresponding to a display brightness value and, in response to determining the load on the power management integrated circuit, send a selection signal to the selection circuitry indicating a selection of the first electric power converter or the second electric power converter.

2. The power management integrated circuit of claim **1**, wherein the first electric power converter comprises a buck-boost electric power converter.

3. The power management integrated circuit of claim **1**, wherein the second electric power converter comprises a low-dropout electric power converter.

4. The power management integrated circuit of claim **1**, wherein the controller is configured to determine the load on the power management integrated circuit at least in part by receiving image data associated with frame content currently being displayed on an electronic display.

5. The power management integrated circuit of claim **1**, wherein the controller is configured to determine the load on the power management integrated circuit at least in part by receiving image data associated with frame content anticipated to be displayed on an electronic display.

6. A method, comprising:

receiving, at a controller of a display power management control circuitry, image data corresponding to frame content;

determining, based on the frame content, a first frame rate at a first time and a second frame rate at a second time;

activating a first electric power converter based on the first frame rate at the first time; and

activating a second electric power converter based on the second frame rate at the second time.

7. The method of claim **6**, comprising determining a present load on the display power management control circuitry by performing gamma decoding on the image data.

8. The method of claim **7**, wherein determining the present load on the display power management control circuitry comprises determining a coefficient based on a display brightness value and multiplying the coefficient by the gamma-decoded image data to obtain an estimate of the present load.

9. The method of claim **6**, wherein activating the first electric power converter comprises transmitting a mode control signal indicating that the display power management control circuitry is entering a low-power mode.

10. The method of claim **6**, wherein activating the second electric power converter comprises transmitting a mode control signal indicating that the display power management control circuitry is entering a high-power mode.

11. The method of claim **6**, comprising deactivating the second electric power converter based on determining that a present load falls beneath a threshold.

12. The method of claim **6**, comprising deactivating the first electric power converter based on determining that a present load exceeds a threshold.

13. A tangible, non-transitory, machine-readable medium, comprising machine-readable instructions that, when executed by one or more processors, cause one or more processors to:

determine an electrical load on a power management integrated circuit of an electronic display associated with new frame content and subsequent frame content to be displayed on the electronic display; and

activate a first electric power converter based on determining that the new frame content differs from the subsequent frame content.

14. The tangible, non-transitory, machine-readable medium of claim **13**, wherein determining the electrical load on the power management integrated circuit comprises, at least in part:

receiving image data associated with the frame content to be displayed on the electronic display; and

performing gamma decoding on the image data.

15. The tangible, non-transitory, machine-readable medium of claim **14**, wherein determining the electrical load on the power management integrated circuit comprises, at least in part:

receiving a display brightness value;

determining a coefficient associated with the display brightness value; and

multiplying the coefficient and the gamma decoded image data.

16. The tangible, non-transitory, machine-readable medium of claim **13**, comprising machine-readable instructions that, when executed by the one or more processors, cause the one or more processors to determine the electrical load on the power management integrated circuit at each new frame based on determining that the new frame content differs from the subsequent frame content.

17. The tangible, non-transitory, machine-readable medium of claim **13**, comprising machine-readable instructions that, when executed by the one or more processors, cause the one or more processors to determine the electrical load on the power management integrated circuit based on determining that the new frame content is the same as the subsequent frame content.

18. The method of claim **6**, wherein the first frame rate is lower than the second frame rate.

19. The tangible, non-transitory, machine-readable medium of claim **13**, wherein the machine-readable instructions that cause the one or more processors to activate a second electric power converter based on the new frame content being the same as the subsequent frame content.

20. The tangible, non-transitory, machine-readable medium of claim **13**, wherein the machine-readable instructions that cause the one or more processors to decrease a refresh rate associated with the subsequent frame content based on the new frame content being the same as the subsequent frame content.

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