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(54) Title: INFRARED DETECTOR ARRAY WITH SELECTABLE PIXEL BINNING SYSTEMS AND METHODS

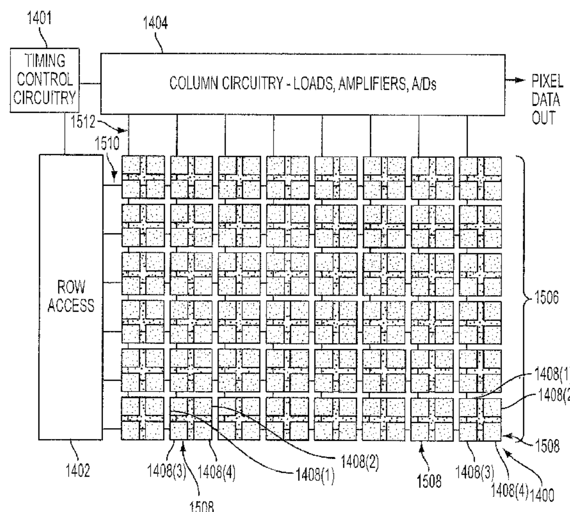

FIG. 15

(57) Abstract: Various techniques are provided for binning (e.g., clustering or grouping) two or more infrared sensors of a focal plane array (FPA) to permit configuration of the FPA to various dimensions and/or pixel sizes. For example, according to one or more embodiments, switchable interconnects may be implemented within the FPA, wherein the switchable interconnects comprise a plurality of switches adapted to selectively connect or disconnect infrared sensors of the FPA to/from column lines, row lines, and between each other. The switchable interconnects may also comprise another set of switches adapted to selectively connect adjacent column lines together. By selectively opening and closing appropriate switches of the switchable interconnects, two or more neighboring infrared sensors may be binned together to form a binned detector. Advantageously, the binned detector, along with the array and associated circuitry, may provide increased sensitivity, reduced power consumption, and/or increased frame rate.

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Infrared Detector Array With Selectable Pixel Binning Systems and Methods

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No.
10 61/748,012 filed December 31, 2012 and entitled "INFRARED DETECTOR ARRAY WITH SELECTABLE PIXEL BINNING SYSTEMS AND METHODS" which is hereby incorporated by reference in its entirety.

This application is a continuation-in-part of U.S. Patent Application No. 14/101,245 filed December 9, 2013 and entitled "LOW POWER AND SMALL FORM FACTOR
15 INFRARED IMAGING" which is hereby incorporated by reference in its entirety.

This application is a continuation-in-part of U.S. Patent Application No. 14/099,818 filed December 6, 2013 and entitled "NON-UNIFORMITY CORRECTION TECHNIQUES FOR INFRARED IMAGING DEVICES" which is hereby incorporated by reference in its entirety.

20 This application is a continuation-in-part of U.S. Patent Application No. 14/101,258 filed December 9, 2013 and entitled "INFRARED CAMERA SYSTEM ARCHITECTURES" which is hereby incorporated by reference in its entirety.

This application is a continuation-in-part of U.S. Patent Application No. 14/138,058 filed December 21, 2013 and entitled "COMPACT MULTI-SPECTRUM IMAGING WITH
25 FUSION" which is hereby incorporated by reference in its entirety.

U.S. Patent Application No. 14/138,058 claims the benefit of U.S. Provisional Patent Application No. 61/748,018 filed December 31, 2012 and entitled "COMPACT MULTI-SPECTRUM IMAGING WITH FUSION" which is hereby incorporated by reference in its entirety.

This application is a continuation-in-part of U.S. Patent Application No. 14/138,040 filed December 21, 2013 and entitled "TIME SPACED INFRARED IMAGE ENHANCEMENT" which is hereby incorporated by reference in its entirety.

U.S. Patent Application No. 14/138,040 claims the benefit of U.S. Provisional Patent Application No. 61/792,582 filed March 15, 2013 and entitled "TIME SPACED INFRARED IMAGE ENHANCEMENT" which is hereby incorporated by reference in its entirety.

U.S. Patent Application No. 14/138,040 also claims the benefit of U.S. Provisional Patent Application No. 61/746,069 filed December 26, 2012 and entitled "TIME SPACED INFRARED IMAGE ENHANCEMENT" which is hereby incorporated by reference in its entirety.

This application is a continuation-in-part of U.S. Patent Application No. 14/138,052 filed December 21, 2013 and entitled "INFRARED IMAGING ENHANCEMENT WITH FUSION" which is hereby incorporated by reference in its entirety.

U.S. Patent Application No. 14/138,052 claims the benefit of U.S. Provisional Patent Application No. 61/793,952 filed March 15, 2013 and entitled "INFRARED IMAGING ENHANCEMENT WITH FUSION" which is hereby incorporated by reference in its entirety.

U.S. Patent Application No. 14/138,052 also claims the benefit of U.S. Provisional Patent Application No. 61/746,074 filed December 26, 2012 and entitled "INFRARED IMAGING ENHANCEMENT WITH FUSION" which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

One or more embodiments of the invention relate generally to thermal imaging devices and more particularly, for example, to infrared detector arrays with selectable pixel binning configurations.

BACKGROUND

Microbolometer structures are generally fabricated on monolithic silicon substrates to form an array of microbolometers, with each microbolometer functioning as a pixel to produce a two-dimensional image. The change in resistance of each microbolometer is translated into a time-multiplexed electrical signal by circuitry known as the read out integrated circuit (ROIC). The combination of the ROIC and the microbolometer array are commonly known as a microbolometer focal plane array (FPA).

A microbolometer array typically provides a static array of a predetermined size, such as for example an array having 320 rows and 256 columns which would represent a 320 by 256 microbolometer array (i.e., 81,920 pixels). Thus, a potential drawback of this conventional type of microbolometer array is that the pixel size and array size is fixed along with the associated infrared camera performance parameters. As a results, there is a need for improved techniques for implementing microbolometer focal plane arrays.

SUMMARY

Various techniques are provided for binning (e.g., clustering or grouping) two or more infrared sensors of a focal plane array (FPA) to permit configuration of the FPA to various dimensions and/or pixel sizes. For example, according to one or more embodiments, switchable interconnects may be implemented within the FPA, wherein the switchable interconnects comprise a plurality of switches adapted to selectively connect or disconnect infrared sensors of the FPA to/from column lines, row lines, and between each other. The switchable interconnects may also comprise another set of switches adapted to selectively connect adjacent column lines together. By selectively opening and closing appropriate switches of the switchable interconnects, two or more neighboring infrared sensors may be binned together to form a binned detector. Advantageously, the binned detector, along with the array and associated circuitry, may provide increased sensitivity, reduced power consumption, and/or increased frame rate.

In one embodiment, a device includes a focal plane array (FPA) adapted to capture image frames of a scene, the FPA comprising: a plurality of bolometers arranged in an array, a plurality of column lines adapted to supply a bias voltage to the bolometers, a plurality of row lines adapted to provide a reference voltage to the bolometers, a first plurality of switches adapted to selectively connect two or more adjacent column lines, a second plurality

of switches adapted to selectively connect some of the bolometers to row lines, a third plurality of switches adapted to selectively connect some of the bolometers to column lines, a fourth plurality of switches adapted to selectively connect some of the bolometers in a series; and wherein the first, second, third, and fourth switches are adapted to be opened or closed to 5 bin every two or more of the neighboring bolometers together to form binned detectors.

In another embodiment, a method of binning bolometers of a FPA adapted to capture imaging frames of a scene includes selectively connecting adjacent column lines of the FPA using a first plurality of switches, wherein the column lines are adapted to supply a bias voltage to the bolometers; selectively connecting some of the bolometers to row lines of the 10 FPA using a second plurality of switches, wherein the row lines are adapted to provide a reference voltage to the bolometers; selectively connecting some of the bolometers to the column lines using a third plurality of switches; and selectively connecting some of the bolometers in series using a fourth plurality of switches, wherein the selectively connecting using the first, second, third, and fourth switches bin every two or more of the neighboring 15 bolometers together to form binned detectors.

The scope of the invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description of one or more embodiments. 20 Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates an infrared imaging module configured to be implemented in a host device in accordance with an embodiment of the disclosure.

Fig. 2 illustrates an assembled infrared imaging module in accordance with an 25 embodiment of the disclosure.

Fig. 3 illustrates an exploded view of an infrared imaging module juxtaposed over a socket in accordance with an embodiment of the disclosure.

Fig. 4 illustrates a block diagram of an infrared sensor assembly including an array of infrared sensors in accordance with an embodiment of the disclosure.

Fig. 5 illustrates a flow diagram of various operations to determine non-uniformity correction (NUC) terms in accordance with an embodiment of the disclosure.

5 Fig. 6 illustrates differences between neighboring pixels in accordance with an embodiment of the disclosure.

Fig. 7 illustrates a flat field correction technique in accordance with an embodiment of the disclosure.

Fig. 8 illustrates various image processing techniques of Fig. 5 and other operations
10 applied in an image processing pipeline in accordance with an embodiment of the disclosure.

Fig. 9 illustrates a temporal noise reduction process in accordance with an embodiment of the disclosure.

Fig. 10 illustrates particular implementation details of several processes of the image processing pipeline of Fig. 8 in accordance with an embodiment of the disclosure.

15 Fig. 11 illustrates spatially correlated fixed pattern noise (FPN) in a neighborhood of pixels in accordance with an embodiment of the disclosure.

Fig. 12 illustrates a block diagram of another implementation of an infrared sensor assembly including an array of infrared sensors and a low-dropout regulator in accordance with an embodiment of the disclosure.

20 Fig. 13 illustrates a circuit diagram of a portion of the infrared sensor assembly of Fig. 12 in accordance with an embodiment of the disclosure.

Fig. 14 illustrates a block diagram of another implementation of an infrared sensor assembly including an array of infrared sensors in accordance with an embodiment of the disclosure.

25 Fig. 15 illustrates the infrared sensor assembly of Fig. 14 configured using a binning technique in accordance with an embodiment of the disclosure.

Fig. 16 illustrates a circuit diagram for a portion of the infrared sensor assembly of Fig. 14 in accordance with an embodiment of the disclosure.

Figs. 17-19 illustrate the circuit diagram of Fig. 16 configured in a first mode of operation in accordance with an embodiment of the disclosure.

5 Fig. 20 illustrates the circuit diagram of Fig. 16 configured in a second mode of operation in accordance with an embodiment of the disclosure.

Fig. 21 illustrates a timing diagram for the first and second modes of operation, in reference to Figs. 17-20, in accordance with an embodiment of the disclosure.

Embodiments of the invention and their advantages are best understood by referring 10 to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

Fig. 1 illustrates an infrared imaging module 100 (e.g., an infrared camera or an infrared imaging device) configured to be implemented in a host device 102 in accordance 15 with an embodiment of the disclosure. Infrared imaging module 100 may be implemented, for one or more embodiments, with a small form factor and in accordance with wafer level packaging techniques or other packaging techniques.

In one embodiment, infrared imaging module 100 may be configured to be implemented in a small portable host device 102, such as a mobile telephone, a tablet 20 computing device, a laptop computing device, a personal digital assistant, a visible light camera, a music player, or any other appropriate mobile device. In this regard, infrared imaging module 100 may be used to provide infrared imaging features to host device 102. For example, infrared imaging module 100 may be configured to capture, process, and/or otherwise manage infrared images and provide such infrared images to host device 102 for 25 use in any desired fashion (e.g., for further processing, to store in memory, to display, to use by various applications running on host device 102, to export to other devices, or other uses).

In various embodiments, infrared imaging module 100 may be configured to operate at low voltage levels and over a wide temperature range. For example, in one embodiment,

infrared imaging module 100 may operate using a power supply of approximately 2.4 volts, 2.5 volts, 2.8 volts, or lower voltages, and operate over a temperature range of approximately -20 degrees C to approximately +60 degrees C (e.g., providing a suitable dynamic range and performance over an environmental temperature range of approximately 80 degrees C). In one embodiment, by operating infrared imaging module 100 at low voltage levels, infrared imaging module 100 may experience reduced amounts of self heating in comparison with other types of infrared imaging devices. As a result, infrared imaging module 100 may be operated with reduced measures to compensate for such self heating.

As shown in Fig. 1, host device 102 may include a socket 104, a shutter 105, motion sensors 194, a processor 195, a memory 196, a display 197, and/or other components 198. Socket 104 may be configured to receive infrared imaging module 100 as identified by arrow 101. In this regard, Fig. 2 illustrates infrared imaging module 100 assembled in socket 104 in accordance with an embodiment of the disclosure.

Motion sensors 194 may be implemented by one or more accelerometers, gyroscopes, or other appropriate devices that may be used to detect movement of host device 102. Motion sensors 194 may be monitored by and provide information to processing module 160 or processor 195 to detect motion. In various embodiments, motion sensors 194 may be implemented as part of host device 102 (as shown in Fig. 1), infrared imaging module 100, or other devices attached to or otherwise interfaced with host device 102.

Processor 195 may be implemented as any appropriate processing device (e.g., logic device, microcontroller, processor, application specific integrated circuit (ASIC), or other device) that may be used by host device 102 to execute appropriate instructions, such as software instructions provided in memory 196. Display 197 may be used to display captured and/or processed infrared images and/or other images, data, and information. Other components 198 may be used to implement any features of host device 102 as may be desired for various applications (e.g., clocks, temperature sensors, a visible light camera, or other components). In addition, a machine readable medium 193 may be provided for storing non-transitory instructions for loading into memory 196 and execution by processor 195.

In various embodiments, infrared imaging module 100 and socket 104 may be implemented for mass production to facilitate high volume applications, such as for implementation in mobile telephones or other devices (e.g., requiring small form factors). In

one embodiment, the combination of infrared imaging module 100 and socket 104 may exhibit overall dimensions of approximately 8.5 mm by 8.5 mm by 5.9 mm while infrared imaging module 100 is installed in socket 104.

Fig. 3 illustrates an exploded view of infrared imaging module 100 juxtaposed over socket 104 in accordance with an embodiment of the disclosure. Infrared imaging module 100 may include a lens barrel 110, a housing 120, an infrared sensor assembly 128, a circuit board 170, a base 150, and a processing module 160.

Lens barrel 110 may at least partially enclose an optical element 180 (e.g., a lens) which is partially visible in Fig. 3 through an aperture 112 in lens barrel 110. Lens barrel 110 may include a substantially cylindrical extension 114 which may be used to interface lens barrel 110 with an aperture 122 in housing 120.

Infrared sensor assembly 128 may be implemented, for example, with a cap 130 (e.g., a lid) mounted on a substrate 140. Infrared sensor assembly 128 may include a plurality of infrared sensors 132 (e.g., infrared detectors) implemented in an array or other fashion on substrate 140 and covered by cap 130. For example, in one embodiment, infrared sensor assembly 128 may be implemented as a focal plane array (FPA). Such a focal plane array may be implemented, for example, as a vacuum package assembly (e.g., sealed by cap 130 and substrate 140). In one embodiment, infrared sensor assembly 128 may be implemented as a wafer level package (e.g., infrared sensor assembly 128 may be singulated from a set of vacuum package assemblies provided on a wafer). In one embodiment, infrared sensor assembly 128 may be implemented to operate using a power supply of approximately 2.4 volts, 2.5 volts, 2.8 volts, or similar voltages.

Infrared sensors 132 may be configured to detect infrared radiation (e.g., infrared energy) from a target scene including, for example, mid wave infrared wave bands (MWIR), long wave infrared wave bands (LWIR), and/or other thermal imaging bands as may be desired in particular implementations. In one embodiment, infrared sensor assembly 128 may be provided in accordance with wafer level packaging techniques.

Infrared sensors 132 may be implemented, for example, as microbolometers or other types of thermal imaging infrared sensors arranged in any desired array pattern to provide a plurality of pixels. In one embodiment, infrared sensors 132 may be implemented as

vanadium oxide (VOx) detectors with a 17 μm pixel pitch. In various embodiments, arrays of approximately 32 by 32 infrared sensors 132, approximately 64 by 64 infrared sensors 132, approximately 80 by 64 infrared sensors 132, or other array sizes may be used.

Substrate 140 may include various circuitry including, for example, a read out integrated circuit (ROIC) with dimensions less than approximately 5.5 mm by 5.5 mm in one embodiment. Substrate 140 may also include bond pads 142 that may be used to contact complementary connections positioned on inside surfaces of housing 120 when infrared imaging module 100 is assembled as shown in Fig. 3. In one embodiment, the ROIC may be implemented with low-dropout regulators (LDO) to perform voltage regulation to reduce power supply noise introduced to infrared sensor assembly 128 and thus provide an improved power supply rejection ratio (PSRR). Moreover, by implementing the LDO with the ROIC (e.g., within a wafer level package), less die area may be consumed and fewer discrete die (or chips) are needed.

Fig. 4 illustrates a block diagram of infrared sensor assembly 128 including an array of infrared sensors 132 in accordance with an embodiment of the disclosure. In the illustrated embodiment, infrared sensors 132 are provided as part of a unit cell array of a ROIC 402. ROIC 402 includes bias generation and timing control circuitry 404, column amplifiers 405, a column multiplexer 406, a row multiplexer 408, and an output amplifier 410. Image frames (e.g., thermal images) captured by infrared sensors 132 may be provided by output amplifier 410 to processing module 160, processor 195, and/or any other appropriate components to perform various processing techniques described herein. Although an 8 by 8 array is shown in Fig. 4, any desired array configuration may be used in other embodiments. Further descriptions of ROICs and infrared sensors (e.g., microbolometer circuits) may be found in U.S. Patent No. 6,028,309 issued February 22, 2000, which is incorporated herein by reference in its entirety.

Infrared sensor assembly 128 may capture images (e.g., image frames) and provide such images from its ROIC at various rates. Processing module 160 may be used to perform appropriate processing of captured infrared images and may be implemented in accordance with any appropriate architecture. In one embodiment, processing module 160 may be implemented as an ASIC. In this regard, such an ASIC may be configured to perform image processing with high performance and/or high efficiency. In another embodiment, processing

module 160 may be implemented with a general purpose central processing unit (CPU) which may be configured to execute appropriate software instructions to perform image processing, coordinate and perform image processing with various image processing blocks, coordinate interfacing between processing module 160 and host device 102, and/or other operations. In yet another embodiment, processing module 160 may be implemented with a field programmable gate array (FPGA). Processing module 160 may be implemented with other types of processing and/or logic circuits in other embodiments as would be understood by one skilled in the art.

In these and other embodiments, processing module 160 may also be implemented with other components where appropriate, such as, volatile memory, non-volatile memory, and/or one or more interfaces (e.g., infrared detector interfaces, inter-integrated circuit (I2C) interfaces, mobile industry processor interfaces (MIPI), joint test action group (JTAG) interfaces (e.g., IEEE 1149.1 standard test access port and boundary-scan architecture), and/or other interfaces).

In some embodiments, infrared imaging module 100 may further include one or more actuators 199 which may be used to adjust the focus of infrared image frames captured by infrared sensor assembly 128. For example, actuators 199 may be used to move optical element 180, infrared sensors 132, and/or other components relative to each other to selectively focus and defocus infrared image frames in accordance with techniques described herein. Actuators 199 may be implemented in accordance with any type of motion-inducing apparatus or mechanism, and may positioned at any location within or external to infrared imaging module 100 as appropriate for different applications.

When infrared imaging module 100 is assembled, housing 120 may substantially enclose infrared sensor assembly 128, base 150, and processing module 160. Housing 120 may facilitate connection of various components of infrared imaging module 100. For example, in one embodiment, housing 120 may provide electrical connections 126 to connect various components as further described.

Electrical connections 126 (e.g., conductive electrical paths, traces, or other types of connections) may be electrically connected with bond pads 142 when infrared imaging module 100 is assembled. In various embodiments, electrical connections 126 may be embedded in housing 120, provided on inside surfaces of housing 120, and/or otherwise

provided by housing 120. Electrical connections 126 may terminate in connections 124 protruding from the bottom surface of housing 120 as shown in Fig. 3. Connections 124 may connect with circuit board 170 when infrared imaging module 100 is assembled (e.g., housing 120 may rest atop circuit board 170 in various embodiments). Processing module 160 may be electrically connected with circuit board 170 through appropriate electrical connections. As a result, infrared sensor assembly 128 may be electrically connected with processing module 160 through, for example, conductive electrical paths provided by: bond pads 142, complementary connections on inside surfaces of housing 120, electrical connections 126 of housing 120, connections 124, and circuit board 170. Advantageously, such an arrangement may be implemented without requiring wire bonds to be provided between infrared sensor assembly 128 and processing module 160.

In various embodiments, electrical connections 126 in housing 120 may be made from any desired material (e.g., copper or any other appropriate conductive material). In one embodiment, electrical connections 126 may aid in dissipating heat from infrared imaging module 100.

Other connections may be used in other embodiments. For example, in one embodiment, sensor assembly 128 may be attached to processing module 160 through a ceramic board that connects to sensor assembly 128 by wire bonds and to processing module 160 by a ball grid array (BGA). In another embodiment, sensor assembly 128 may be mounted directly on a rigid flexible board and electrically connected with wire bonds, and processing module 160 may be mounted and connected to the rigid flexible board with wire bonds or a BGA.

The various implementations of infrared imaging module 100 and host device 102 set forth herein are provided for purposes of example, rather than limitation. In this regard, any of the various techniques described herein may be applied to any infrared camera system, infrared imager, or other device for performing infrared/thermal imaging.

Substrate 140 of infrared sensor assembly 128 may be mounted on base 150. In various embodiments, base 150 (e.g., a pedestal) may be made, for example, of copper formed by metal injection molding (MIM) and provided with a black oxide or nickel-coated finish. In various embodiments, base 150 may be made of any desired material, such as for example zinc, aluminum, or magnesium, as desired for a given application and may be

formed by any desired applicable process, such as for example aluminum casting, MIM, or zinc rapid casting, as may be desired for particular applications. In various embodiments, base 150 may be implemented to provide structural support, various circuit paths, thermal heat sink properties, and other features where appropriate. In one embodiment, base 150 may be a multi-layer structure implemented at least in part using ceramic material.

In various embodiments, circuit board 170 may receive housing 120 and thus may physically support the various components of infrared imaging module 100. In various embodiments, circuit board 170 may be implemented as a printed circuit board (e.g., an FR4 circuit board or other types of circuit boards), a rigid or flexible interconnect (e.g., tape or other type of interconnects), a flexible circuit substrate, a flexible plastic substrate, or other appropriate structures. In various embodiments, base 150 may be implemented with the various features and attributes described for circuit board 170, and vice versa.

Socket 104 may include a cavity 106 configured to receive infrared imaging module 100 (e.g., as shown in the assembled view of Fig. 2). Infrared imaging module 100 and/or socket 104 may include appropriate tabs, arms, pins, fasteners, or any other appropriate engagement members which may be used to secure infrared imaging module 100 to or within socket 104 using friction, tension, adhesion, and/or any other appropriate manner. Socket 104 may include engagement members 107 that may engage surfaces 109 of housing 120 when infrared imaging module 100 is inserted into a cavity 106 of socket 104. Other types of engagement members may be used in other embodiments.

Infrared imaging module 100 may be electrically connected with socket 104 through appropriate electrical connections (e.g., contacts, pins, wires, or any other appropriate connections). For example, socket 104 may include electrical connections 108 which may contact corresponding electrical connections of infrared imaging module 100 (e.g., interconnect pads, contacts, or other electrical connections on side or bottom surfaces of circuit board 170, bond pads 142 or other electrical connections on base 150, or other connections). Electrical connections 108 may be made from any desired material (e.g., copper or any other appropriate conductive material). In one embodiment, electrical connections 108 may be mechanically biased to press against electrical connections of infrared imaging module 100 when infrared imaging module 100 is inserted into cavity 106 of socket 104. In one embodiment, electrical connections 108 may at least partially secure

infrared imaging module 100 in socket 104. Other types of electrical connections may be used in other embodiments.

Socket 104 may be electrically connected with host device 102 through similar types of electrical connections. For example, in one embodiment, host device 102 may include electrical connections (e.g., soldered connections, snap-in connections, or other connections) that connect with electrical connections 108 passing through apertures 190. In various embodiments, such electrical connections may be made to the sides and/or bottom of socket 104.

Various components of infrared imaging module 100 may be implemented with flip chip technology which may be used to mount components directly to circuit boards without the additional clearances typically needed for wire bond connections. Flip chip connections may be used, as an example, to reduce the overall size of infrared imaging module 100 for use in compact small form factor applications. For example, in one embodiment, processing module 160 may be mounted to circuit board 170 using flip chip connections. For example, infrared imaging module 100 may be implemented with such flip chip configurations.

In various embodiments, infrared imaging module 100 and/or associated components may be implemented in accordance with various techniques (e.g., wafer level packaging techniques) as set forth in U.S. Patent Application No. 12/844,124 filed July 27, 2010, and U.S. Provisional Patent Application No. 61/469,651 filed March 30, 2011, which are incorporated herein by reference in their entirety. Furthermore, in accordance with one or more embodiments, infrared imaging module 100 and/or associated components may be implemented, calibrated, tested, and/or used in accordance with various techniques, such as for example as set forth in U.S. Patent No. 7,470,902 issued December 30, 2008, U.S. Patent No. 6,028,309 issued February 22, 2000, U.S. Patent No. 6,812,465 issued November 2, 2004, U.S. Patent No. 7,034,301 issued April 25, 2006, U.S. Patent No. 7,679,048 issued March 16, 2010, U.S. Patent No. 7,470,904 issued December 30, 2008, U.S. Patent Application No. 12/202,880 filed September 2, 2008, and U.S. Patent Application No. 12/202,896 filed September 2, 2008, which are incorporated herein by reference in their entirety.

In some embodiments, host device 102 may include other components 198 such as a non-thermal camera (e.g., a visible light camera or other type of non-thermal imager). The

non-thermal camera may be a small form factor imaging module or imaging device, and may, in some embodiments, be implemented in a manner similar to the various embodiments of infrared imaging module 100 disclosed herein, with one or more sensors and/or sensor arrays responsive to radiation in non-thermal spectrums (e.g., radiation in visible light wavelengths, ultraviolet wavelengths, and/or other non-thermal wavelengths). For example, in some embodiments, the non-thermal camera may be implemented with a charge-coupled device (CCD) sensor, an electron multiplying CCD (EMCCD) sensor, a complementary metal-oxide-semiconductor (CMOS) sensor, a scientific CMOS (sCMOS) sensor, or other filters and/or sensors.

In some embodiments, the non-thermal camera may be co-located with infrared imaging module 100 and oriented such that a field-of-view (FOV) of the non-thermal camera at least partially overlaps a FOV of infrared imaging module 100. In one example, infrared imaging module 100 and a non-thermal camera may be implemented as a dual sensor module sharing a common substrate according to various techniques described in U.S. Provisional Patent Application No. 61/748,018 filed December 31, 2012, which is incorporated herein by reference.

For embodiments having such a non-thermal light camera, various components (e.g., processor 195, processing module 160, and/or other processing component) may be configured to superimpose, fuse, blend, or otherwise combine infrared images (e.g., including thermal images) captured by infrared imaging module 100 and non-thermal images (e.g., including visible light images) captured by a non-thermal camera, whether captured at substantially the same time or different times (e.g., time-spaced over hours, days, daytime versus nighttime, and/or otherwise).

In some embodiments, thermal and non-thermal images may be processed to generate combined images (e.g., one or more processes performed on such images in some embodiments). For example, scene-based NUC processing may be performed (as further described herein), true color processing may be performed, and/or high contrast processing may be performed.

Regarding true color processing, thermal images may be blended with non-thermal images by, for example, blending a radiometric component of a thermal image with a corresponding component of a non-thermal image according to a blending parameter, which

may be adjustable by a user and/or machine in some embodiments. For example, luminance or chrominance components of the thermal and non-thermal images may be combined according to the blending parameter. In one embodiment, such blending techniques may be referred to as true color infrared imagery. For example, in daytime imaging, a blended image may comprise a non-thermal color image, which includes a luminance component and a chrominance component, with its luminance value replaced and/or blended with the luminance value from a thermal image. The use of the luminance data from the thermal image causes the intensity of the true non-thermal color image to brighten or dim based on the temperature of the object. As such, these blending techniques provide thermal imaging for daytime or visible light images.

Regarding high contrast processing, high spatial frequency content may be obtained from one or more of the thermal and non-thermal images (e.g., by performing high pass filtering, difference imaging, and/or other techniques). A combined image may include a radiometric component of a thermal image and a blended component including infrared (e.g., thermal) characteristics of a scene blended with the high spatial frequency content, according to a blending parameter, which may be adjustable by a user and/or machine in some embodiments. In some embodiments, high spatial frequency content from non-thermal images may be blended with thermal images by superimposing the high spatial frequency content onto the thermal images, where the high spatial frequency content replaces or overwrites those portions of the thermal images corresponding to where the high spatial frequency content exists. For example, the high spatial frequency content may include edges of objects depicted in images of a scene, but may not exist within the interior of such objects. In such embodiments, blended image data may simply include the high spatial frequency content, which may subsequently be encoded into one or more components of combined images.

For example, a radiometric component of thermal image may be a chrominance component of the thermal image, and the high spatial frequency content may be derived from the luminance and/or chrominance components of a non-thermal image. In this embodiment, a combined image may include the radiometric component (e.g., the chrominance component of the thermal image) encoded into a chrominance component of the combined image and the high spatial frequency content directly encoded (e.g., as blended image data but with no thermal image contribution) into a luminance component of the combined image. By doing

so, a radiometric calibration of the radiometric component of the thermal image may be retained. In similar embodiments, blended image data may include the high spatial frequency content added to a luminance component of the thermal images, and the resulting blended data encoded into a luminance component of resulting combined images.

5 For example, any of the techniques disclosed in the following applications may be used in various embodiments: U.S. Patent Application No. 12/477,828 filed June 3, 2009; U.S. Patent Application No. 12/766,739 filed April 23, 2010; U.S. Patent Application No. 13/105,765 filed May 11, 2011; U.S. Patent Application No. 13/437,645 filed April 2, 2012; U.S. Provisional Patent Application No. 61/473,207 filed April 8, 2011; U.S. Provisional 10 Patent Application No. 61/746,069 filed December 26, 2012; U.S. Provisional Patent Application No. 61/746,074 filed December 26, 2012; U.S. Provisional Patent Application No. 61/748,018 filed December 31, 2012; U.S. Provisional Patent Application No. 61/792,582 filed March 15, 2013; U.S. Provisional Patent Application No. 61/793,952 filed March 15, 2013; and International Patent Application No. PCT/EP2011/056432 filed April 15 21, 2011, all of such applications are incorporated herein by reference in their entirety. Any of the techniques described herein, or described in other applications or patents referenced herein, may be applied to any of the various thermal devices, non-thermal devices, and uses described herein.

Referring again to Fig. 1, in various embodiments, host device 102 may include 20 shutter 105. In this regard, shutter 105 may be selectively positioned over socket 104 (e.g., as identified by arrows 103) while infrared imaging module 100 is installed therein. In this regard, shutter 105 may be used, for example, to protect infrared imaging module 100 when not in use. Shutter 105 may also be used as a temperature reference as part of a calibration process (e.g., a NUC process or other calibration processes) for infrared imaging module 100 25 as would be understood by one skilled in the art.

In various embodiments, shutter 105 may be made from various materials such as, for example, polymers, glass, aluminum (e.g., painted or anodized) or other materials. In various embodiments, shutter 105 may include one or more coatings to selectively filter electromagnetic radiation and/or adjust various optical properties of shutter 105 (e.g., a 30 uniform blackbody coating or a reflective gold coating).

In another embodiment, shutter 105 may be fixed in place to protect infrared imaging module 100 at all times. In this case, shutter 105 or a portion of shutter 105 may be made from appropriate materials (e.g., polymers or infrared transmitting materials such as silicon, germanium, zinc selenide, or chalcogenide glasses) that do not substantially filter desired
5 infrared wavelengths. In another embodiment, a shutter may be implemented as part of infrared imaging module 100 (e.g., within or as part of a lens barrel or other components of infrared imaging module 100), as would be understood by one skilled in the art.

Alternatively, in another embodiment, a shutter (e.g., shutter 105 or other type of external or internal shutter) need not be provided, but rather a NUC process or other type of
10 calibration may be performed using shutterless techniques. In another embodiment, a NUC process or other type of calibration using shutterless techniques may be performed in combination with shutter-based techniques.

Infrared imaging module 100 and host device 102 may be implemented in accordance with any of the various techniques set forth in U.S. Provisional Patent Application No.
15 61/495,873 filed June 10, 2011, U.S. Provisional Patent Application No. 61/495,879 filed June 10, 2011, and U.S. Provisional Patent Application No. 61/495,888 filed June 10, 2011, which are incorporated herein by reference in their entirety.

In various embodiments, the components of host device 102 and/or infrared imaging module 100 may be implemented as a local or distributed system with components in
20 communication with each other over wired and/or wireless networks. Accordingly, the various operations identified in this disclosure may be performed by local and/or remote components as may be desired in particular implementations.

Fig. 5 illustrates a flow diagram of various operations to determine NUC terms in accordance with an embodiment of the disclosure. In some embodiments, the operations of
25 Fig. 5 may be performed by processing module 160 or processor 195 (both also generally referred to as a processor) operating on image frames captured by infrared sensors 132.

In block 505, infrared sensors 132 begin capturing image frames of a scene. Typically, the scene will be the real world environment in which host device 102 is currently located. In this regard, shutter 105 (if optionally provided) may be opened to permit infrared
30 imaging module to receive infrared radiation from the scene. Infrared sensors 132 may

continue capturing image frames during all operations shown in Fig. 5. In this regard, the continuously captured image frames may be used for various operations as further discussed. In one embodiment, the captured image frames may be temporally filtered (e.g., in accordance with the process of block 826 further described herein with regard to Fig. 8) and be processed by other terms (e.g., factory gain terms 812, factory offset terms 816, previously determined NUC terms 817, column FPN terms 820, and row FPN terms 824 as further described herein with regard to Fig. 8) before they are used in the operations shown in Fig. 5.

In block 510, a NUC process initiating event is detected. In one embodiment, the NUC process may be initiated in response to physical movement of host device 102. Such movement may be detected, for example, by motion sensors 194 which may be polled by a processor. In one example, a user may move host device 102 in a particular manner, such as by intentionally waving host device 102 back and forth in an "erase" or "swipe" movement. In this regard, the user may move host device 102 in accordance with a predetermined speed and direction (velocity), such as in an up and down, side to side, or other pattern to initiate the NUC process. In this example, the use of such movements may permit the user to intuitively operate host device 102 to simulate the "erasing" of noise in captured image frames.

In another example, a NUC process may be initiated by host device 102 if motion exceeding a threshold value is detected (e.g., motion greater than expected for ordinary use). It is contemplated that any desired type of spatial translation of host device 102 may be used to initiate the NUC process.

In yet another example, a NUC process may be initiated by host device 102 if a minimum time has elapsed since a previously performed NUC process. In a further example, a NUC process may be initiated by host device 102 if infrared imaging module 100 has experienced a minimum temperature change since a previously performed NUC process. In a still further example, a NUC process may be continuously initiated and repeated.

In block 515, after a NUC process initiating event is detected, it is determined whether the NUC process should actually be performed. In this regard, the NUC process may be selectively initiated based on whether one or more additional conditions are met. For example, in one embodiment, the NUC process may not be performed unless a minimum time has elapsed since a previously performed NUC process. In another embodiment, the

NUC process may not be performed unless infrared imaging module 100 has experienced a minimum temperature change since a previously performed NUC process. Other criteria or conditions may be used in other embodiments. If appropriate criteria or conditions have been met, then the flow diagram continues to block 520. Otherwise, the flow diagram returns to
5 block 505.

In the NUC process, blurred image frames may be used to determine NUC terms which may be applied to captured image frames to correct for FPN. As discussed, in one embodiment, the blurred image frames may be obtained by accumulating multiple image frames of a moving scene (e.g., captured while the scene and/or the thermal imager is in
10 motion). In another embodiment, the blurred image frames may be obtained by defocusing an optical element or other component of the thermal imager.

Accordingly, in block 520 a choice of either approach is provided. If the motion-based approach is used, then the flow diagram continues to block 525. If the defocus-based approach is used, then the flow diagram continues to block 530.

15 Referring now to the motion-based approach, in block 525 motion is detected. For example, in one embodiment, motion may be detected based on the image frames captured by infrared sensors 132. In this regard, an appropriate motion detection process (e.g., an image registration process, a frame-to-frame difference calculation, or other appropriate process) may be applied to captured image frames to determine whether motion is present (e.g.,
20 whether static or moving image frames have been captured). For example, in one embodiment, it can be determined whether pixels or regions around the pixels of consecutive image frames have changed more than a user defined amount (e.g., a percentage and/or threshold value). If at least a given percentage of pixels have changed by at least the user defined amount, then motion will be detected with sufficient certainty to proceed to block
25 535.

In another embodiment, motion may be determined on a per pixel basis, wherein only pixels that exhibit significant changes are accumulated to provide the blurred image frame. For example, counters may be provided for each pixel and used to ensure that the same number of pixel values are accumulated for each pixel, or used to average the pixel values
30 based on the number of pixel values actually accumulated for each pixel. Other types of image-based motion detection may be performed such as performing a Radon transform.

In another embodiment, motion may be detected based on data provided by motion sensors 194. In one embodiment, such motion detection may include detecting whether host device 102 is moving along a relatively straight trajectory through space. For example, if host device 102 is moving along a relatively straight trajectory, then it is possible that certain objects appearing in the imaged scene may not be sufficiently blurred (e.g., objects in the scene that may be aligned with or moving substantially parallel to the straight trajectory). Thus, in such an embodiment, the motion detected by motion sensors 194 may be conditioned on host device 102 exhibiting, or not exhibiting, particular trajectories.

In yet another embodiment, both a motion detection process and motion sensors 194 may be used. Thus, using any of these various embodiments, a determination can be made as to whether or not each image frame was captured while at least a portion of the scene and host device 102 were in motion relative to each other (e.g., which may be caused by host device 102 moving relative to the scene, at least a portion of the scene moving relative to host device 102, or both).

It is expected that the image frames for which motion was detected may exhibit some secondary blurring of the captured scene (e.g., blurred thermal image data associated with the scene) due to the thermal time constants of infrared sensors 132 (e.g., microbolometer thermal time constants) interacting with the scene movement.

In block 535, image frames for which motion was detected are accumulated. For example, if motion is detected for a continuous series of image frames, then the image frames of the series may be accumulated. As another example, if motion is detected for only some image frames, then the non-moving image frames may be skipped and not included in the accumulation. Thus, a continuous or discontinuous set of image frames may be selected to be accumulated based on the detected motion.

In block 540, the accumulated image frames are averaged to provide a blurred image frame. Because the accumulated image frames were captured during motion, it is expected that actual scene information will vary between the image frames and thus cause the scene information to be further blurred in the resulting blurred image frame (block 545).

In contrast, FPN (e.g., caused by one or more components of infrared imaging module 100) will remain fixed over at least short periods of time and over at least limited changes in

scene irradiance during motion. As a result, image frames captured in close proximity in time and space during motion will suffer from identical or at least very similar FPN. Thus, although scene information may change in consecutive image frames, the FPN will stay essentially constant. By averaging, multiple image frames captured during motion will blur
5 the scene information, but will not blur the FPN. As a result, FPN will remain more clearly defined in the blurred image frame provided in block 545 than the scene information.

In one embodiment, 32 or more image frames are accumulated and averaged in blocks 535 and 540. However, any desired number of image frames may be used in other embodiments, but with generally decreasing correction accuracy as frame count is decreased.

10 Referring now to the defocus-based approach, in block 530, a defocus operation may be performed to intentionally defocus the image frames captured by infrared sensors 132. For example, in one embodiment, one or more actuators 199 may be used to adjust, move, or otherwise translate optical element 180, infrared sensor assembly 128, and/or other components of infrared imaging module 100 to cause infrared sensors 132 to capture a
15 blurred (e.g., unfocused) image frame of the scene. Other non-actuator based techniques are also contemplated for intentionally defocusing infrared image frames such as, for example, manual (e.g., user-initiated) defocusing.

Although the scene may appear blurred in the image frame, FPN (e.g., caused by one or more components of infrared imaging module 100) will remain unaffected by the
20 defocusing operation. As a result, a blurred image frame of the scene will be provided (block 545) with FPN remaining more clearly defined in the blurred image than the scene information.

In the above discussion, the defocus-based approach has been described with regard to a single captured image frame. In another embodiment, the defocus-based approach may
25 include accumulating multiple image frames while the infrared imaging module 100 has been defocused and averaging the defocused image frames to remove the effects of temporal noise and provide a blurred image frame in block 545.

Thus, it will be appreciated that a blurred image frame may be provided in block 545 by either the motion-based approach or the defocus-based approach. Because much of the
30 scene information will be blurred by either motion, defocusing, or both, the blurred image

frame may be effectively considered a low pass filtered version of the original captured image frames with respect to scene information.

In block 550, the blurred image frame is processed to determine updated row and column FPN terms (e.g., if row and column FPN terms have not been previously determined then the updated row and column FPN terms may be new row and column FPN terms in the first iteration of block 550). As used in this disclosure, the terms row and column may be used interchangeably depending on the orientation of infrared sensors 132 and/or other components of infrared imaging module 100.

In one embodiment, block 550 includes determining a spatial FPN correction term for each row of the blurred image frame (e.g., each row may have its own spatial FPN correction term), and also determining a spatial FPN correction term for each column of the blurred image frame (e.g., each column may have its own spatial FPN correction term). Such processing may be used to reduce the spatial and slowly varying (1/f) row and column FPN inherent in thermal imagers caused by, for example, 1/f noise characteristics of amplifiers in ROIC 402 which may manifest as vertical and horizontal stripes in image frames.

Advantageously, by determining spatial row and column FPN terms using the blurred image frame, there will be a reduced risk of vertical and horizontal objects in the actual imaged scene from being mistaken for row and column noise (e.g., real scene content will be blurred while FPN remains unblurred).

In one embodiment, row and column FPN terms may be determined by considering differences between neighboring pixels of the blurred image frame. For example, Fig. 6 illustrates differences between neighboring pixels in accordance with an embodiment of the disclosure. Specifically, in Fig. 6 a pixel 610 is compared to its 8 nearest horizontal neighbors: d0-d3 on one side and d4-d7 on the other side. Differences between the neighbor pixels can be averaged to obtain an estimate of the offset error of the illustrated group of pixels. An offset error may be calculated for each pixel in a row or column and the average result may be used to correct the entire row or column.

To prevent real scene data from being interpreted as noise, upper and lower threshold values may be used (thPix and –thPix). Pixel values falling outside these threshold values (pixels d1 and d4 in this example) are not used to obtain the offset error. In addition, the

maximum amount of row and column FPN correction may be limited by these threshold values.

Further techniques for performing spatial row and column FPN correction processing are set forth in U.S. Patent Application No. 12/396,340 filed March 2, 2009 which is
5 incorporated herein by reference in its entirety.

Referring again to Fig. 5, the updated row and column FPN terms determined in block 550 are stored (block 552) and applied (block 555) to the blurred image frame provided in block 545. After these terms are applied, some of the spatial row and column FPN in the blurred image frame may be reduced. However, because such terms are applied generally to
10 rows and columns, additional FPN may remain such as spatially uncorrelated FPN associated with pixel to pixel drift or other causes. Neighborhoods of spatially correlated FPN may also remain which may not be directly associated with individual rows and columns. Accordingly, further processing may be performed as discussed below to determine NUC terms.

15 In block 560, local contrast values (e.g., edges or absolute values of gradients between adjacent or small groups of pixels) in the blurred image frame are determined. If scene information in the blurred image frame includes contrasting areas that have not been significantly blurred (e.g., high contrast edges in the original scene data), then such features may be identified by a contrast determination process in block 560.

20 For example, local contrast values in the blurred image frame may be calculated, or any other desired type of edge detection process may be applied to identify certain pixels in the blurred image as being part of an area of local contrast. Pixels that are marked in this manner may be considered as containing excessive high spatial frequency scene information that would be interpreted as FPN (e.g., such regions may correspond to portions of the scene
25 that have not been sufficiently blurred). As such, these pixels may be excluded from being used in the further determination of NUC terms. In one embodiment, such contrast detection processing may rely on a threshold that is higher than the expected contrast value associated with FPN (e.g., pixels exhibiting a contrast value higher than the threshold may be considered to be scene information, and those lower than the threshold may be considered to be
30 exhibiting FPN).

In one embodiment, the contrast determination of block 560 may be performed on the blurred image frame after row and column FPN terms have been applied to the blurred image frame (e.g., as shown in Fig. 5). In another embodiment, block 560 may be performed prior to block 550 to determine contrast before row and column FPN terms are determined (e.g., to prevent scene based contrast from contributing to the determination of such terms).

Following block 560, it is expected that any high spatial frequency content remaining in the blurred image frame may be generally attributed to spatially uncorrelated FPN. In this regard, following block 560, much of the other noise or actual desired scene based information has been removed or excluded from the blurred image frame due to: intentional blurring of the image frame (e.g., by motion or defocusing in blocks 520 through 545), application of row and column FPN terms (block 555), and contrast determination (block 560).

Thus, it can be expected that following block 560, any remaining high spatial frequency content (e.g., exhibited as areas of contrast or differences in the blurred image frame) may be attributed to spatially uncorrelated FPN. Accordingly, in block 565, the blurred image frame is high pass filtered. In one embodiment, this may include applying a high pass filter to extract the high spatial frequency content from the blurred image frame. In another embodiment, this may include applying a low pass filter to the blurred image frame and taking a difference between the low pass filtered image frame and the unfiltered blurred image frame to obtain the high spatial frequency content. In accordance with various embodiments of the present disclosure, a high pass filter may be implemented by calculating a mean difference between a sensor signal (e.g., a pixel value) and its neighbors.

In block 570, a flat field correction process is performed on the high pass filtered blurred image frame to determine updated NUC terms (e.g., if a NUC process has not previously been performed then the updated NUC terms may be new NUC terms in the first iteration of block 570).

For example, Fig. 7 illustrates a flat field correction technique 700 in accordance with an embodiment of the disclosure. In Fig. 7, a NUC term may be determined for each pixel 710 of the blurred image frame using the values of its neighboring pixels 712 to 726. For each pixel 710, several gradients may be determined based on the absolute difference between the values of various adjacent pixels. For example, absolute value differences may

be determined between: pixels 712 and 714 (a left to right diagonal gradient), pixels 716 and 718 (a top to bottom vertical gradient), pixels 720 and 722 (a right to left diagonal gradient), and pixels 724 and 726 (a left to right horizontal gradient).

These absolute differences may be summed to provide a summed gradient for pixel 710. A weight value may be determined for pixel 710 that is inversely proportional to the summed gradient. This process may be performed for all pixels 710 of the blurred image frame until a weight value is provided for each pixel 710. For areas with low gradients (e.g., areas that are blurry or have low contrast), the weight value will be close to one. Conversely, for areas with high gradients, the weight value will be zero or close to zero. The update to the NUC term as estimated by the high pass filter is multiplied with the weight value.

In one embodiment, the risk of introducing scene information into the NUC terms can be further reduced by applying some amount of temporal damping to the NUC term determination process. For example, a temporal damping factor λ between 0 and 1 may be chosen such that the new NUC term (NUC_{NEW}) stored is a weighted average of the old NUC term (NUC_{OLD}) and the estimated updated NUC term (NUC_{UPDATE}). In one embodiment, this can be expressed as $NUC_{NEW} = \lambda \cdot NUC_{OLD} + (1-\lambda) \cdot (NUC_{OLD} + NUC_{UPDATE})$.

Although the determination of NUC terms has been described with regard to gradients, local contrast values may be used instead where appropriate. Other techniques may also be used such as, for example, standard deviation calculations. Other types flat field correction processes may be performed to determine NUC terms including, for example, various processes identified in U.S. Patent No. 6,028,309 issued February 22, 2000, U.S. Patent No. 6,812,465 issued November 2, 2004, and U.S. Patent Application No. 12/114,865 filed May 5, 2008, which are incorporated herein by reference in their entirety.

Referring again to Fig. 5, block 570 may include additional processing of the NUC terms. For example, in one embodiment, to preserve the scene signal mean, the sum of all NUC terms may be normalized to zero by subtracting the NUC term mean from each NUC term. Also in block 570, to avoid row and column noise from affecting the NUC terms, the mean value of each row and column may be subtracted from the NUC terms for each row and column. As a result, row and column FPN filters using the row and column FPN terms determined in block 550 may be better able to filter out row and column noise in further iterations (e.g., as further shown in Fig. 8) after the NUC terms are applied to captured

images (e.g., in block 580 further discussed herein). In this regard, the row and column FPN filters may in general use more data to calculate the per row and per column offset coefficients (e.g., row and column FPN terms) and may thus provide a more robust alternative for reducing spatially correlated FPN than the NUC terms which are based on high pass filtering to capture spatially uncorrelated noise.

In blocks 571-573, additional high pass filtering and further determinations of updated NUC terms may be optionally performed to remove spatially correlated FPN with lower spatial frequency than previously removed by row and column FPN terms. In this regard, some variability in infrared sensors 132 or other components of infrared imaging module 100 may result in spatially correlated FPN noise that cannot be easily modeled as row or column noise. Such spatially correlated FPN may include, for example, window defects on a sensor package or a cluster of infrared sensors 132 that respond differently to irradiance than neighboring infrared sensors 132. In one embodiment, such spatially correlated FPN may be mitigated with an offset correction. If the amount of such spatially correlated FPN is significant, then the noise may also be detectable in the blurred image frame. Since this type of noise may affect a neighborhood of pixels, a high pass filter with a small kernel may not detect the FPN in the neighborhood (e.g., all values used in high pass filter may be taken from the neighborhood of affected pixels and thus may be affected by the same offset error). For example, if the high pass filtering of block 565 is performed with a small kernel (e.g., considering only immediately adjacent pixels that fall within a neighborhood of pixels affected by spatially correlated FPN), then broadly distributed spatially correlated FPN may not be detected.

For example, Fig. 11 illustrates spatially correlated FPN in a neighborhood of pixels in accordance with an embodiment of the disclosure. As shown in a sample image frame 1100, a neighborhood of pixels 1110 may exhibit spatially correlated FPN that is not precisely correlated to individual rows and columns and is distributed over a neighborhood of several pixels (e.g., a neighborhood of approximately 4 by 4 pixels in this example). Sample image frame 1100 also includes a set of pixels 1120 exhibiting substantially uniform response that are not used in filtering calculations, and a set of pixels 1130 that are used to estimate a low pass value for the neighborhood of pixels 1110. In one embodiment, pixels 1130 may be a number of pixels divisible by two in order to facilitate efficient hardware or software calculations.

Referring again to Fig. 5, in blocks 571-573, additional high pass filtering and further determinations of updated NUC terms may be optionally performed to remove spatially correlated FPN such as exhibited by pixels 1110. In block 571, the updated NUC terms determined in block 570 are applied to the blurred image frame. Thus, at this time, the blurred image frame will have been initially corrected for spatially correlated FPN (e.g., by application of the updated row and column FPN terms in block 555), and also initially corrected for spatially uncorrelated FPN (e.g., by application of the updated NUC terms applied in block 571).

In block 572, a further high pass filter is applied with a larger kernel than was used in block 565, and further updated NUC terms may be determined in block 573. For example, to detect the spatially correlated FPN present in pixels 1110, the high pass filter applied in block 572 may include data from a sufficiently large enough neighborhood of pixels such that differences can be determined between unaffected pixels (e.g., pixels 1120) and affected pixels (e.g., pixels 1110). For example, a low pass filter with a large kernel can be used (e.g., an N by N kernel that is much greater than 3 by 3 pixels) and the results may be subtracted to perform appropriate high pass filtering.

In one embodiment, for computational efficiency, a sparse kernel may be used such that only a small number of neighboring pixels inside an N by N neighborhood are used. For any given high pass filter operation using distant neighbors (e.g., a large kernel), there is a risk of modeling actual (potentially blurred) scene information as spatially correlated FPN. Accordingly, in one embodiment, the temporal damping factor λ may be set close to 1 for updated NUC terms determined in block 573.

In various embodiments, blocks 571-573 may be repeated (e.g., cascaded) to iteratively perform high pass filtering with increasing kernel sizes to provide further updated NUC terms further correct for spatially correlated FPN of desired neighborhood sizes. In one embodiment, the decision to perform such iterations may be determined by whether spatially correlated FPN has actually been removed by the updated NUC terms of the previous performance of blocks 571-573.

After blocks 571-573 are finished, a decision is made regarding whether to apply the updated NUC terms to captured image frames (block 574). For example, if an average of the absolute value of the NUC terms for the entire image frame is less than a minimum threshold

value, or greater than a maximum threshold value, the NUC terms may be deemed spurious or unlikely to provide meaningful correction. Alternatively, thresholding criteria may be applied to individual pixels to determine which pixels receive updated NUC terms. In one embodiment, the threshold values may correspond to differences between the newly
5 calculated NUC terms and previously calculated NUC terms. In another embodiment, the threshold values may be independent of previously calculated NUC terms. Other tests may be applied (e.g., spatial correlation tests) to determine whether the NUC terms should be applied.

If the NUC terms are deemed spurious or unlikely to provide meaningful correction,
10 then the flow diagram returns to block 505. Otherwise, the newly determined NUC terms are stored (block 575) to replace previous NUC terms (e.g., determined by a previously performed iteration of Fig. 5) and applied (block 580) to captured image frames.

Fig. 8 illustrates various image processing techniques of Fig. 5 and other operations applied in an image processing pipeline 800 in accordance with an embodiment of the
15 disclosure. In this regard, pipeline 800 identifies various operations of Fig. 5 in the context of an overall iterative image processing scheme for correcting image frames provided by infrared imaging module 100. In some embodiments, pipeline 800 may be provided by processing module 160 or processor 195 (both also generally referred to as a processor) operating on image frames captured by infrared sensors 132.

20 Image frames captured by infrared sensors 132 may be provided to a frame averager 804 that integrates multiple image frames to provide image frames 802 with an improved signal to noise ratio. Frame averager 804 may be effectively provided by infrared sensors 132, ROIC 402, and other components of infrared sensor assembly 128 that are implemented to support high image capture rates. For example, in one embodiment, infrared sensor
25 assembly 128 may capture infrared image frames at a frame rate of 240 Hz (e.g., 240 images per second). In this embodiment, such a high frame rate may be implemented, for example, by operating infrared sensor assembly 128 at relatively low voltages (e.g., compatible with mobile telephone voltages) and by using a relatively small array of infrared sensors 132 (e.g., an array of 64 by 64 infrared sensors in one embodiment).

30 In one embodiment, such infrared image frames may be provided from infrared sensor assembly 128 to processing module 160 at a high frame rate (e.g., 240 Hz or other frame

rates). In another embodiment, infrared sensor assembly 128 may integrate over longer time periods, or multiple time periods, to provide integrated (e.g., averaged) infrared image frames to processing module 160 at a lower frame rate (e.g., 30 Hz, 9 Hz, or other frame rates). Further information regarding implementations that may be used to provide high image 5 capture rates may be found in U.S. Provisional Patent Application No. 61/495,879 filed June 10, 2011 which is incorporated herein by reference in its entirety.

Image frames 802 proceed through pipeline 800 where they are adjusted by various terms, temporally filtered, used to determine the various adjustment terms, and gain compensated.

10 In blocks 810 and 814, factory gain terms 812 and factory offset terms 816 are applied to image frames 802 to compensate for gain and offset differences, respectively, between the various infrared sensors 132 and/or other components of infrared imaging module 100 determined during manufacturing and testing.

In block 580, NUC terms 817 are applied to image frames 802 to correct for FPN as 15 discussed. In one embodiment, if NUC terms 817 have not yet been determined (e.g., before a NUC process has been initiated), then block 580 may not be performed or initialization values may be used for NUC terms 817 that result in no alteration to the image data (e.g., offsets for every pixel would be equal to zero).

In blocks 818 and 822, column FPN terms 820 and row FPN terms 824, respectively, 20 are applied to image frames 802. Column FPN terms 820 and row FPN terms 824 may be determined in accordance with block 550 as discussed. In one embodiment, if the column FPN terms 820 and row FPN terms 824 have not yet been determined (e.g., before a NUC process has been initiated), then blocks 818 and 822 may not be performed or initialization values may be used for the column FPN terms 820 and row FPN terms 824 that result in no 25 alteration to the image data (e.g., offsets for every pixel would be equal to zero).

In block 826, temporal filtering is performed on image frames 802 in accordance with a temporal noise reduction (TNR) process. Fig. 9 illustrates a TNR process in accordance with an embodiment of the disclosure. In Fig. 9, a presently received image frame 802a and a previously temporally filtered image frame 802b are processed to determine a new temporally 30 filtered image frame 802e. Image frames 802a and 802b include local neighborhoods of

pixels 803a and 803b centered around pixels 805a and 805b, respectively. Neighborhoods 803a and 803b correspond to the same locations within image frames 802a and 802b and are subsets of the total pixels in image frames 802a and 802b. In the illustrated embodiment, neighborhoods 803a and 803b include areas of 5 by 5 pixels. Other neighborhood sizes may be used in other embodiments.

Differences between corresponding pixels of neighborhoods 803a and 803b are determined and averaged to provide an averaged delta value 805c for the location corresponding to pixels 805a and 805b. Averaged delta value 805c may be used to determine weight values in block 807 to be applied to pixels 805a and 805b of image frames 802a and 802b.

In one embodiment, as shown in graph 809, the weight values determined in block 807 may be inversely proportional to averaged delta value 805c such that weight values drop rapidly towards zero when there are large differences between neighborhoods 803a and 803b. In this regard, large differences between neighborhoods 803a and 803b may indicate that changes have occurred within the scene (e.g., due to motion) and pixels 802a and 802b may be appropriately weighted, in one embodiment, to avoid introducing blur across frame-to-frame scene changes. Other associations between weight values and averaged delta value 805c may be used in various embodiments.

The weight values determined in block 807 may be applied to pixels 805a and 805b to determine a value for corresponding pixel 805e of image frame 802e (block 811). In this regard, pixel 805e may have a value that is a weighted average (or other combination) of pixels 805a and 805b, depending on averaged delta value 805c and the weight values determined in block 807.

For example, pixel 805e of temporally filtered image frame 802e may be a weighted sum of pixels 805a and 805b of image frames 802a and 802b. If the average difference between pixels 805a and 805b is due to noise, then it may be expected that the average change between neighborhoods 805a and 805b will be close to zero (e.g., corresponding to the average of uncorrelated changes). Under such circumstances, it may be expected that the sum of the differences between neighborhoods 805a and 805b will be close to zero. In this case, pixel 805a of image frame 802a may both be appropriately weighted so as to contribute to the value of pixel 805e.

However, if the sum of such differences is not zero (e.g., even differing from zero by a small amount in one embodiment), then the changes may be interpreted as being attributed to motion instead of noise. Thus, motion may be detected based on the average change exhibited by neighborhoods 805a and 805b. Under these circumstances, pixel 805a of image frame 802a may be weighted heavily, while pixel 805b of image frame 802b may be weighted lightly.

Other embodiments are also contemplated. For example, although averaged delta value 805c has been described as being determined based on neighborhoods 805a and 805b, in other embodiments averaged delta value 805c may be determined based on any desired criteria (e.g., based on individual pixels or other types of groups of sets of pixels).

In the above embodiments, image frame 802a has been described as a presently received image frame and image frame 802b has been described as a previously temporally filtered image frame. In another embodiment, image frames 802a and 802b may be first and second image frames captured by infrared imaging module 100 that have not been temporally filtered.

Fig. 10 illustrates further implementation details in relation to the TNR process of block 826. As shown in Fig. 10, image frames 802a and 802b may be read into line buffers 1010a and 1010b, respectively, and image frame 802b (e.g., the previous image frame) may be stored in a frame buffer 1020 before being read into line buffer 1010b. In one embodiment, line buffers 1010a-b and frame buffer 1020 may be implemented by a block of random access memory (RAM) provided by any appropriate component of infrared imaging module 100 and/or host device 102.

Referring again to Fig. 8, image frame 802e may be passed to an automatic gain compensation block 828 for further processing to provide a result image frame 830 that may be used by host device 102 as desired.

Fig. 8 further illustrates various operations that may be performed to determine row and column FPN terms and NUC terms as discussed. In one embodiment, these operations may use image frames 802e as shown in Fig. 8. Because image frames 802e have already been temporally filtered, at least some temporal noise may be removed and thus will not

inadvertently affect the determination of row and column FPN terms 824 and 820 and NUC terms 817. In another embodiment, non-temporally filtered image frames 802 may be used.

In Fig. 8, blocks 510, 515, and 520 of Fig. 5 are collectively represented together. As discussed, a NUC process may be selectively initiated and performed in response to various NUC process initiating events and based on various criteria or conditions. As also discussed, the NUC process may be performed in accordance with a motion-based approach (blocks 525, 535, and 540) or a defocus-based approach (block 530) to provide a blurred image frame (block 545). Fig. 8 further illustrates various additional blocks 550, 552, 555, 560, 565, 570, 571, 572, 573, and 575 previously discussed with regard to Fig. 5.

As shown in Fig. 8, row and column FPN terms 824 and 820 and NUC terms 817 may be determined and applied in an iterative fashion such that updated terms are determined using image frames 802 to which previous terms have already been applied. As a result, the overall process of Fig. 8 may repeatedly update and apply such terms to continuously reduce the noise in image frames 830 to be used by host device 102.

Referring again to Fig. 10, further implementation details are illustrated for various blocks of Figs. 5 and 8 in relation to pipeline 800. For example, blocks 525, 535, and 540 are shown as operating at the normal frame rate of image frames 802 received by pipeline 800. In the embodiment shown in Fig. 10, the determination made in block 525 is represented as a decision diamond used to determine whether a given image frame 802 has sufficiently changed such that it may be considered an image frame that will enhance the blur if added to other image frames and is therefore accumulated (block 535 is represented by an arrow in this embodiment) and averaged (block 540).

Also in Fig. 10, the determination of column FPN terms 820 (block 550) is shown as operating at an update rate that in this example is 1/32 of the sensor frame rate (e.g., normal frame rate) due to the averaging performed in block 540. Other update rates may be used in other embodiments. Although only column FPN terms 820 are identified in Fig. 10, row FPN terms 824 may be implemented in a similar fashion at the reduced frame rate.

Fig. 10 also illustrates further implementation details in relation to the NUC determination process of block 570. In this regard, the blurred image frame may be read to a line buffer 1030 (e.g., implemented by a block of RAM provided by any appropriate

component of infrared imaging module 100 and/or host device 102). The flat field correction technique 700 of Fig. 7 may be performed on the blurred image frame.

In view of the present disclosure, it will be appreciated that techniques described herein may be used to remove various types of FPN (e.g., including very high amplitude
5 FPN) such as spatially correlated row and column FPN and spatially uncorrelated FPN.

Other embodiments are also contemplated. For example, in one embodiment, the rate at which row and column FPN terms and/or NUC terms are updated can be inversely proportional to the estimated amount of blur in the blurred image frame and/or inversely proportional to the magnitude of local contrast values (e.g., determined in block 560).

10 In various embodiments, the described techniques may provide advantages over conventional shutter-based noise correction techniques. For example, by using a shutterless process, a shutter (e.g., such as shutter 105) need not be provided, thus permitting reductions in size, weight, cost, and mechanical complexity. Power and maximum voltage supplied to, or generated by, infrared imaging module 100 may also be reduced if a shutter does not need
15 to be mechanically operated. Reliability will be improved by removing the shutter as a potential point of failure. A shutterless process also eliminates potential image interruption caused by the temporary blockage of the imaged scene by a shutter.

Also, by correcting for noise using intentionally blurred image frames captured from a real world scene (not a uniform scene provided by a shutter), noise correction may be
20 performed on image frames that have irradiance levels similar to those of the actual scene desired to be imaged. This can improve the accuracy and effectiveness of noise correction terms determined in accordance with the various described techniques.

As discussed, in various embodiments, infrared imaging module 100 may be configured to operate at low voltage levels. In particular, infrared imaging module 100 may
25 be implemented with circuitry configured to operate at low power and/or in accordance with other parameters that permit infrared imaging module 100 to be conveniently and effectively implemented in various types of host devices 102, such as mobile devices and other devices.

For example, Fig. 12 illustrates a block diagram of another implementation of infrared sensor assembly 128 including infrared sensors 132 and an LDO 1220 in accordance with an
30 embodiment of the disclosure. As shown, Fig. 12 also illustrates various components 1202,

1204, 1205, 1206, 1208, and 1210 which may implemented in the same or similar manner as corresponding components previously described with regard to Fig. 4. Fig. 12 also illustrates bias correction circuitry 1212 which may be used to adjust one or more bias voltages provided to infrared sensors 132 (e.g., to compensate for temperature changes, self-heating,
5 and/or other factors).

In some embodiments, LDO 1220 may be provided as part of infrared sensor assembly 128 (e.g., on the same chip and/or wafer level package as the ROIC). For example, LDO 1220 may be provided as part of an FPA with infrared sensor assembly 128. As discussed, such implementations may reduce power supply noise introduced to infrared
10 sensor assembly 128 and thus provide an improved PSRR. In addition, by implementing the LDO with the ROIC, less die area may be consumed and fewer discrete die (or chips) are needed.

LDO 1220 receives an input voltage provided by a power source 1230 over a supply line 1232. LDO 1220 provides an output voltage to various components of infrared sensor
15 assembly 128 over supply lines 1222. In this regard, LDO 1220 may provide substantially identical regulated output voltages to various components of infrared sensor assembly 128 in response to a single input voltage received from power source 1230, in accordance with various techniques described in, for example, U.S. Patent Application No. 14/101,245 filed December 9, 2013 incorporated herein by reference in its entirety.

20 For example, in some embodiments, power source 1230 may provide an input voltage in a range of approximately 2.8 volts to approximately 11 volts (e.g., approximately 2.8 volts in one embodiment), and LDO 1220 may provide an output voltage in a range of approximately 1.5 volts to approximately 2.8 volts (e.g., approximately 2.8, 2.5, 2.4, and/or lower voltages in various embodiments). In this regard, LDO 1220 may be used to provide a
25 consistent regulated output voltage, regardless of whether power source 1230 is implemented with a conventional voltage range of approximately 9 volts to approximately 11 volts, or a low voltage such as approximately 2.8 volts. As such, although various voltage ranges are provided for the input and output voltages, it is contemplated that the output voltage of LDO 1220 will remain fixed despite changes in the input voltage.

30 The implementation of LDO 1220 as part of infrared sensor assembly 128 provides various advantages over conventional power implementations for FPAs. For example,

conventional FPAs typically rely on multiple power sources, each of which may be provided separately to the FPA, and separately distributed to the various components of the FPA. By regulating a single power source 1230 by LDO 1220, appropriate voltages may be separately provided (e.g., to reduce possible noise) to all components of infrared sensor assembly 128 with reduced complexity. The use of LDO 1220 also allows infrared sensor assembly 128 to operate in a consistent manner, even if the input voltage from power source 1230 changes (e.g., if the input voltage increases or decreases as a result of charging or discharging a battery or other type of device used for power source 1230).

The various components of infrared sensor assembly 128 shown in Fig. 12 may also be implemented to operate at lower voltages than conventional devices. For example, as discussed, LDO 1220 may be implemented to provide a low voltage (e.g., approximately 2.5 volts). This contrasts with the multiple higher voltages typically used to power conventional FPAs, such as: approximately 3.3 volts to approximately 5 volts used to power digital circuitry; approximately 3.3 volts used to power analog circuitry; and approximately 9 volts to approximately 11 volts used to power loads. Also, in some embodiments, the use of LDO 1220 may reduce or eliminate the need for a separate negative reference voltage to be provided to infrared sensor assembly 128.

Additional aspects of the low voltage operation of infrared sensor assembly 128 may be further understood with reference to Fig. 13. Fig. 13 illustrates a circuit diagram of a portion of infrared sensor assembly 128 of Fig. 12 in accordance with an embodiment of the disclosure. In particular, Fig. 13 illustrates additional components of bias correction circuitry 1212 (e.g., components 1326, 1330, 1332, 1334, 1336, 1338, and 1341) connected to LDO 1220 and infrared sensors 132. For example, bias correction circuitry 1212 may be used to compensate for temperature-dependent changes in bias voltages in accordance with an embodiment of the present disclosure. The operation of such additional components may be further understood with reference to similar components identified in U.S. Patent No. 7,679,048 issued March 16, 2010 which is hereby incorporated by reference in its entirety. Infrared sensor assembly 128 may also be implemented in accordance with the various components identified in U.S. Patent No. 6,812,465 issued November 2, 2004 which is hereby incorporated by reference in its entirety.

In various embodiments, some or all of the bias correction circuitry 1212 may be implemented on a global array basis as shown in Fig. 13 (e.g., used for all infrared sensors 132 collectively in an array). In other embodiments, some or all of the bias correction circuitry 1212 may be implemented an individual sensor basis (e.g., entirely or partially duplicated for each infrared sensor 132). In some embodiments, bias correction circuitry 1212 and other components of Fig. 13 may be implemented as part of ROIC 1202.

As shown in Fig. 13, LDO 1220 provides a load voltage Vload to bias correction circuitry 1212 along one of supply lines 1222. As discussed, in some embodiments, Vload may be approximately 2.5 volts which contrasts with larger voltages of approximately 9 volts to approximately 11 volts that may be used as load voltages in conventional infrared imaging devices.

Based on Vload, bias correction circuitry 1212 provides a sensor bias voltage Vbolo at a node 1360. Vbolo may be distributed to one or more infrared sensors 132 through appropriate switching circuitry 1370 (e.g., represented by broken lines in Fig. 13). In some examples, switching circuitry 1370 may be implemented in accordance with appropriate components identified in U.S. Patent Nos. 6,812,465 and 7,679,048 previously referenced herein.

Each infrared sensor 132 includes a node 1350 which receives Vbolo through switching circuitry 1370, and another node 1352 which may be connected to ground, a substrate, and/or a negative reference voltage. In some embodiments, the voltage at node 1360 may be substantially the same as Vbolo provided at nodes 1350. In other embodiments, the voltage at node 1360 may be adjusted to compensate for possible voltage drops associated with switching circuitry 1370 and/or other factors.

Vbolo may be implemented with lower voltages than are typically used for conventional infrared sensor biasing. In one embodiment, Vbolo may be in a range of approximately 0.2 volts to approximately 0.7 volts. In another embodiment, Vbolo may be in a range of approximately 0.4 volts to approximately 0.6 volts. In another embodiment, Vbolo may be approximately 0.5 volts. In contrast, conventional infrared sensors typically use bias voltages of approximately 1 volt.

The use of a lower bias voltage for infrared sensors 132 in accordance with the present disclosure permits infrared sensor assembly 128 to exhibit significantly reduced power consumption in comparison with conventional infrared imaging devices. In particular, the power consumption of each infrared sensor 132 is reduced by the square of the bias voltage. As a result, a reduction from, for example, 1.0 volt to 0.5 volts provides a significant reduction in power, especially when applied to many infrared sensors 132 in an infrared sensor array. This reduction in power may also result in reduced self-heating of infrared sensor assembly 128.

In accordance with additional embodiments of the present disclosure, various techniques are provided for reducing the effects of noise in image frames provided by infrared imaging devices operating at low voltages. In this regard, when infrared sensor assembly 128 is operated with low voltages as described, noise, self-heating, and/or other phenomena may, if uncorrected, become more pronounced in image frames provided by infrared sensor assembly 128.

For example, referring to Fig. 13, when LDO 1220 maintains Vload at a low voltage in the manner described herein, Vbolo will also be maintained at its corresponding low voltage and the relative size of its output signals may be reduced. As a result, noise, self-heating, and/or other phenomena may have a greater effect on the smaller output signals read out from infrared sensors 132, resulting in variations (e.g., errors) in the output signals. If uncorrected, these variations may be exhibited as noise in the image frames. Moreover, although low voltage operation may reduce the overall amount of certain phenomena (e.g., self-heating), the smaller output signals may permit the remaining error sources (e.g., residual self-heating) to have a disproportionate effect on the output signals during low voltage operation.

To compensate for such phenomena, infrared sensor assembly 128, infrared imaging module 100, and/or host device 102 may be implemented with various array sizes, frame rates, and/or frame averaging techniques. For example, as discussed, a variety of different array sizes are contemplated for infrared sensors 132. In some embodiments, infrared sensors 132 may be implemented with array sizes ranging from 32 by 32 to 160 by 120 infrared sensors 132. Other example array sizes include 80 by 64, 80 by 60, 64 by 64, and 64 by 32. Any desired array size may be used.

Advantageously, when implemented with such relatively small array sizes, infrared sensor assembly 128 may provide image frames at relatively high frame rates without requiring significant changes to ROIC and related circuitry. For example, in some embodiments, frame rates may range from approximately 120 Hz to approximately 480 Hz.

5 In some embodiments, the array size and the frame rate may be scaled relative to each other (e.g., in an inversely proportional manner or otherwise) such that larger arrays are implemented with lower frame rates, and smaller arrays are implemented with higher frame rates. For example, in one embodiment, an array of 160 by 120 may provide a frame rate of approximately 120 Hz. In another embodiment, an array of 80 by 60 may provide a
10 correspondingly higher frame rate of approximately 240 Hz. Other frame rates are also contemplated.

By scaling the array size and the frame rate relative to each other, the particular readout timing of rows and/or columns of the FPA may remain consistent, regardless of the actual FPA size or frame rate. In one embodiment, the readout timing may be approximately
15 63 microseconds per row or column.

As previously discussed with regard to Fig. 8, the image frames captured by infrared sensors 132 may be provided to a frame averager 804 that integrates multiple image frames to provide image frames 802 (e.g., processed image frames) with a lower frame rate (e.g., approximately 30 Hz, approximately 60 Hz, or other frame rates) and with an improved
20 signal to noise ratio. In particular, by averaging the high frame rate image frames provided by a relatively small FPA, image noise attributable to low voltage operation may be effectively averaged out and/or substantially reduced in image frames 802. Accordingly, infrared sensor assembly 128 may be operated at relatively low voltages provided by LDO 1220 as discussed without experiencing additional noise and related side effects in the
25 resulting image frames 802 after processing by frame averager 804.

Other embodiments are also contemplated. For example, although a single array of infrared sensors 132 is illustrated, it is contemplated that multiple such arrays may be used together to provide higher resolution image frames (e.g., a scene may be imaged across multiple such arrays). Such arrays may be provided in multiple infrared sensor assemblies
30 128 and/or provided in the same infrared sensor assembly 128. Each such array may be operated at low voltages as described, and also may be provided with associated ROIC

circuitry such that each array may still be operated at a relatively high frame rate. The high frame rate image frames provided by such arrays may be averaged by shared or dedicated frame averagers 804 to reduce and/or eliminate noise associated with low voltage operation. As a result, high resolution infrared images may be obtained while still operating at low voltages.

In various embodiments, infrared sensor assembly 128 may be implemented with appropriate dimensions to permit infrared imaging module 100 to be used with a small form factor socket 104, such as a socket used for mobile devices. For example, in some embodiments, infrared sensor assembly 128 may be implemented with a chip size in a range of approximately 4.0 mm by approximately 4.0 mm to approximately 5.5 mm by approximately 5.5 mm (e.g., approximately 4.0 mm by approximately 5.5 mm in one example). Infrared sensor assembly 128 may be implemented with such sizes or other appropriate sizes to permit use with socket 104 implemented with various sizes such as: 8.5 mm by 8.5 mm, 8.5 mm by 5.9 mm, 6.0 mm by 6.0 mm, 5.5 mm by 5.5 mm, 4.5 mm by 4.5 mm, and/or other socket sizes such as, for example, those identified in Table 1 of U.S. Provisional Patent Application No. 61/495,873 filed June 10, 2011 incorporated herein by reference in its entirety.

As discussed, in various embodiments, infrared imaging module 100 may be configured to operate at low voltage levels and/or in various types of configurations (e.g., hardware and/or software configurations). As discussed further herein in accordance with one or more embodiments, novel switching techniques may be implemented within the array of infrared sensors (e.g., in reference to Figs. 4 and/or 12) such that the array may be configured to various dimensions and/or pixel sizes as desired for a given application.

For example, Fig. 14 illustrates a block diagram of another implementation of an infrared sensor assembly 1400 including an array of infrared sensors 1406 in accordance with an embodiment of the disclosure. As shown, infrared sensor assembly 1400 may be implemented in a similar fashion as described in reference to infrared sensor assembly 128 of Figs. 4 and 12, but further include novel switching techniques as described further herein.

Infrared sensor assembly 1400 may include row access circuitry 1402 adapted to enable an appropriate one of row lines 1410 to read outputs associated with infrared sensors 1408 connected to the enabled line. In various embodiments, row access circuitry 1402 may

be adapted to selectively enable one of row lines 1410 in response to signals from timing control circuitry 1401, as would be understood by one skilled in the art. In one or more embodiments, row access circuitry 1402 may be implemented in a similar manner as row multiplexer 408/1208 of Figs. 4 and 12, but may be further adapted to selectively enable row
5 lines 1410 according to detector-binning techniques further described herein. Similarly, in one or more embodiments, timing control circuitry 1401 may be implemented in a similar manner as the timing control portion of bias generation and timing control circuitry 404/1204 to control timing of row access circuitry 1402 and column circuitry 1404, but may be further adapted to alter such timing to provide detector-binning as further described herein.

10 Infrared sensor assembly 1400 may also include column circuitry 1404, which may represent column amplifiers 405/1205, bias correction circuitry 412/1212, offset correction circuitry, and/or column analog-to-digital (A/D) converters. Thus, for example, column circuitry 1404 may be adapted to provide bias voltage (e.g., Vbolo described above with respect to Fig. 13), correct biasing, correct offsets, amplify outputs, convert outputs to digital
15 signals, and/or perform other operations for each infrared sensor 1408 of column lines 1410 for a selected row line 1410. That is, during a read cycle of one image frame in general (e.g., with infrared sensor assembly 1400 in an unbinned mode further described herein), successive row lines 1410 are enabled one at a time by row access circuitry 1402 according to timing signals, whereas column circuitry 1410 performs operations for all infrared sensors
20 1408 in the enabled row line 1410 in parallel during the time the row line 1410 is enabled (e.g., also referred to herein as "row access time").

Infrared sensors 1408 may be implemented in a similar manner as infrared sensors 132 of Figs. 3 and 4. Thus, for example, infrared sensors 1408 may be implemented using microbolometers each adapted to be connected to one column line 1412 and one row line
25 1412 when its output is being detected. However, as further described herein, array 1406 of such infrared sensors 1408 may include novel switching circuitry that may be adapted to selectively connect or disconnect infrared sensors 1408 to/from column lines 1412 and/or row lines 1410 to allow detector-binning.

Fig. 15 illustrates a block diagram of infrared sensor assembly 1400 configured using
30 a detector-binning technique in accordance with an embodiment of the disclosure. As briefly mentioned, infrared sensors 1408 in array 1406 may be selectively connected or disconnected

to/from column lines 1412 and row lines 1410 according to one or more embodiments disclosed herein. Further, two or more infrared sensors 1408 in array 1406 may be selectively connected to each other according to one or more embodiments disclosed herein. As such, in one or more embodiments, a cluster of neighboring infrared sensors 1408 in array 1406 may be grouped (or "binned") together to form a binned detector 1508. In the illustrated embodiment and others, a cluster of four neighboring infrared sensor 1408(1), 1408(2), 1408(3), and 1408(4) in a two-by-two arrangement may be grouped together to form binned detector 1508. Thus, according to such embodiments, the resulting binning mode array 1506 of binned detectors 1508 may utilize half the number of row lines 1510 and half the number of column lines 1512 as the physical array 1406. As may be appreciated, row lines 1510 and column lines 1512 are shown in half the number as row lines 1410 and column lines 1412 in order to represent that some row lines 1410 and column lines 1412 may be unutilized, disabled, or combined for binning mode array 1506 as further described herein.

The resulting binning mode array 1506 may provide a higher frame rate, increased detector sensitivity, and/or reduced power consumption, according to various embodiments. In the example above, because the number of row lines 1510 utilized is halved (e.g., relative to the number of row lines 1410) in binning mode array 1506, the row access time may be doubled. As described above, the row access time may be the duration of time each available row line 1510 is enabled for parallel operations of column circuitry 1404. By way of a specific example, a frame rate of 60 Hz for an unbinned, normal array 1406 may result in a row access time of 65 microseconds, whereas for binning mode array 1506 the row access time may be 130 microseconds. Since binned detector 1508 for every column line 1512 in a selected row line 1510 may be biased, offset corrected, sampled, amplified, A/D converted, or otherwise have their outputs detected during the row access time, the doubling of the row access time permits doubling of an integration time for sampling outputs of binned detector 1508. The doubling of the integration time in turn may permit an increase in detector sensitivity. In a particular implementation of ROIC, for example, the doubling of the integration time may result in a 40% increase in sensitivity.

At the same time, the doubling of the row access time may reduce power consumption, according to various embodiments. For example, since the A/D converters and/or other readout circuits may be run at half speed and still complete their intended operations within the row access time owing to the doubling of the row access time, the clock

rate for the ROIC may be reduced by up to 50% to save power. Further power consumption is also possible according to various embodiments. For example, as discussed above, the number of column lines 1512 being utilized may also be halved (e.g., relative to the number of column lines 1412), which may allow every other column circuit in column circuitry 1404 to be shut down or otherwise put in a low power mode to reduce power, according to various embodiments.

Further, four neighboring infrared sensors 1408(1), 1408(2), 1408(3), and 1408(4) in the example above may be connected in a serial-parallel fashion (e.g., a parallel connection of two sets of series connections or a series connection of two sets of parallel connections) to form binned detector 1508, according to various embodiments. Thus, binned detector 1508 as a group may present to the ROIC the same combined resistance as one individual unbinned infrared sensor 1408, resulting in the same noise level as one individual unbinned infrared sensor 1408. Also, each of the four infrared sensors in binned detector 1508 may receive 1/4 of the bias that it received when unbinned, resulting in 1/4 of the responsivity it exhibited when unbinned. However, since binned detector 1508 has four times the detector area, the combined responsivity of binned detector 1508 (e.g., four times the responsivity of individual infrared sensors) will be the same. Thus, by increasing the bias up to four times to bias the four infrared sensors up to a level they received individually when unbinned, responsivity may be increased up to four times.

Therefore, various combinations of tradeoffs between power consumption, sensitivity, and frame rates may be possible to utilize binning mode array 1506 as desired for particular applications. In one example configuration, the frame rate at which image frames are provided from binning mode array 1506 may be maintained at the same rate as unbinned mode array 1406, and thus may achieve a reduction in power consumption due to the doubling of the row access time as discussed above. Also, at the same frame rate, the sensitivity of binned detector 1508 may be 140% of unbinned individual infrared sensors 1408, and may be increased up to four times to 560% by increasing the bias as discussed above.

In another example configuration, the frame rate may be doubled (e.g., by keeping the row access time for binning mode array 1508 the same as the row access time for un-binned mode array 1408), but without reduction in power consumption or increase in sensitivity

attributable to doubling of the row access time. The sensitivity can still be increased, however, to up to 400% by increasing the bias as discussed above.

As may be appreciated, other configurations having different tradeoffs among power consumption, sensitivity, and frame rates may be possible. Also, different levels of power saving, sensitivity increase, and/or frame rate increase may be achievable if the number of infrared sensors 1408 forming binned detector 1508 is varied (e.g., numbers other than four given for the example above) for other embodiments. Various different configurations may be selected or otherwise defined by a user, automatically and/or dynamically depending on operating conditions (e.g., based on power consumption), or otherwise selected as desired for particular applications of infrared sensor assembly 128, infrared imaging module 100, and/or host device 102, according to various embodiments.

As discussed, switching circuitry provided in array 1406/1506 may be adapted to selectively connect or disconnect infrared sensors 1408 to/from row lines 1410, column lines 1412, and/or between each other to permit detector-binning according to various embodiments. Such switching circuitry according to one or more embodiments may be better understood with reference to Figs. 16–20. Fig. 16 illustrates a circuit diagram 1600 for a portion of the infrared sensor assembly of Fig. 14 in accordance with an embodiment of the disclosure. In the illustrated embodiment, a cluster of infrared sensors 1408(1), 1408(2), 1408(3), and 1408(4), each of which may be implemented with a respective one of bolometers R1 through R4, may be selectively connected to row lines 1410, column lines 1412, and/or with each other through switches S1 through S6 as shown. Also, adjacent column lines 1412 may be selectively connected via column switches 1602.

Switches S1–S6 and column switches 1602 may define a switchable interconnect for the cluster of infrared sensors 1408(1), 1408(2), 1408(3), and 1408(4). As shown, bolometer R1 (infrared sensor 1408(1)) may be connected to its adjacent column line 1412 (e.g., labeled "Col 1") and may also be selectively connected to its adjacent row line 1410 (e.g., labeled "Row 1") via switch S1, according to one or more embodiments. Similarly, bolometer R2 (infrared sensor 1408(2)) may be connected to its adjacent column line 1512 (e.g., labeled "Col 2") and may also be selectively connected to its adjacent row line 1410 (e.g., labeled "Row 1") via switch S4. Switches S1 and S4 may be adapted to selectively connect bolometers R1 and R2, respectively, to their adjacent row line 1410 (e.g., labeled "Row 1"),

according to one or more embodiments. In one or more embodiments, bolometers R3 and R4 may be connected in a complimentary fashion. That is, they may be connected to their adjacent row line 1410 (e.g., labeled "Row 2"), and each of them may be selectively connected to its adjacent column lines 1412 (e.g., labeled "Col 1" and "Col 2," respectively) via switches S3 and S6 respectively. Switch S2 may be adapted to selectively connect bolometers R1 and R3 in serial, and similarly switch S5 may be adapted to selectively connect bolometers R2 and R4 in serial, according to one or more embodiments. The switchable interconnect in the illustrated embodiment may be repeated for every cluster of four infrared sensors 1408 in array 1406/1506. Circuit 1600 in Fig. 16 is shown with all switches S1–S6 and 1602 in the switchable interconnect shown in an open (e.g., non-actuated) position for purposes of illustrating the switchable interconnect.

Figs. 17 illustrates circuit diagram 1600 of Fig. 16 configured in a first mode (e.g., a normal or unbinned mode) of operation in accordance with an embodiment of the disclosure. As shown, in a normal/un-binned mode, switches S1 and S4 may be closed to connect respective bolometers R1 and R2 to their adjacent row line 1410 (Row 1), and switches S3 and S6 may be closed to connect respective bolometers R3 and R4 to their adjacent row line 1410 (Row 2), according to one or more embodiments. Switches S2, S5, and column switch 1602 may remain open, according to one or more embodiments. As a result, bolometer R1 through R4 may each be connected both to its corresponding row line 1410 and column line 1412, but not connected to each other in serial or in parallel (e.g., by column switch 1602), thereby permitting a corresponding column circuit (e.g., including a biasing, offset correction, sampling, amplifier, and/or A/D converter circuit) in column circuitry 1402 to read its output when its adjacent row line 1410 is enabled.

Such readout operations in a normal mode may be better understood with references to Figs. 18 and 19. Figs. 18 and 19 illustrate circuit diagram 1600 of Fig. 16 configured in a first mode (e.g., a normal or unbinned mode) of operation, showing how current flows through bolometers when a row line is enabled, in accordance with an embodiment of the disclosure. As shown in Fig. 18, when row line 1410 (Row 1) is enabled (e.g., connected to a reference voltage line), a bias current flows from each column circuit (e.g., in response to a bias voltage provided by each column circuit) to a corresponding bolometer and out to row line 1410 (Row 1) connected to the corresponding bolometer via a corresponding closed switch S1 or S4, according to one or more embodiments. Each column circuit in column

circuitry 1404 may then detect a voltage created by the current flow, and perform other appropriate operations as described above (e.g., sampling, amplification, A/D conversion, and other appropriate operations) to read out an output associated with each bolometer adjacent to the enabled row line 1410 (Row 1) as would be understood by one skilled in the art.
5 Similarly, as shown in Fig. 19, closed switches S3 and S6 may allow bolometers R3 and R4 to be connected to corresponding adjacent column lines 1412 (Col 1 and Col 2) respectively, thereby allowing bias current from column circuitry 1404 to flow through corresponding bolometers R3 and R4 and out to the enabled row line 1410 (Row 2), according to one or more embodiments. This process may be repeated for every row of the array.

10 Fig. 20 illustrates circuit diagram 1600 of Fig. 16 configured in a second mode (e.g., a binning mode) of operation in accordance with an embodiment of the disclosure. As shown, switches S1 and S3 may now be open while switch S2 may be closed, according to one or more embodiments. As a result, bolometers R1 and R3 may form a series connection, with row line 1510 (Row 1', relabeled from Row 2 for row lines 1410) serving as an adjacent row
15 line for the series of bolometers R1 and R3. Similarly, switches S4 and S6 may be open while switch S5 may be closed to form a series connection of bolometers R2 and R4, with the series connected to Row 1'. In addition, column switch 1602 may be closed to combine two adjacent column lines 1412 (previously labeled Col 1 and Col 2) to form column line 1512 (labeled Col 1'), according to one or more embodiments. This has an effect of connecting
20 the two series connections (e.g., bolometers R1+R3 in one series and bolometers R2+R4 in another series) in parallel, resulting in a serial-parallel connection of the four bolometers R1–R4 as discussed above with respect to Fig. 15. As discussed above for Fig. 15, four bolometers R1–R4 may thus form binned detector 1508 having the same resistance as a single bolometer R1, R2, R3, or R4, and permitting an increase in sensitivity, reduction in
25 power consumption, and/or increase in frame rate compared with a single bolometer R1, R2, R3, or R4.

As also shown in Fig. 20, only half of the column circuits may need to be enabled to provide a bias voltage and perform other readout operations for binned detector (e.g., Col 1' performing readout operations for both Col 1 and Col 2 of Figs. 16–19). For example, as
30 shown, a bias current from Col 1' or Col 2' flow through all four bolometers R1–R4 and out to a corresponding row line 1510 (Row 1') for binned detector 1508.

In various embodiments, appropriate control circuitry may be provided as part of infrared sensor assembly 128, and may be adapted to selectively open or close switches S1–S6 and column switch 1602 in the switchable interconnects to appropriately configure the array of infrared sensors 1408 for an unbinned mode or binning mode of operation. For example, the control circuitry for the switchable interconnects may be implemented as part of timing control circuitry 1401, processing module 160, and/or other control circuitry of infrared sensor assembly 128. In another example, the control circuitry for the switchable interconnects may be implemented separately from other components, and adapted to appropriately configure the switches of the switchable interconnects for different modes in response to control bits loaded or otherwise transmitted to the control circuitry.

Fig. 21 illustrates a timing diagram for the first (e.g., normal) and second (e.g., binning) modes of operation, in reference to Figs. 17-20, in accordance with an embodiment of the disclosure. For example, timing diagrams 2100 and 2102 may represent control signals asserted (e.g., to enable) and deasserted by timing control circuitry 1401 and received by row access circuitry 1402 to sequentially enable row lines during readout operations, as discussed above with respect to Fig. 14. As shown in timing diagram 2100, in a normal mode every row line may be successively enabled for the duration of a row access time 2104, according to one or more embodiments. In comparison, in a binning mode (e.g., according to timing diagram 2102), only every other row line may be successively enabled, since bolometers in two rows are connected in series as discussed above. Also, as discussed above with respect to Fig. 15, a row access time 2106 for each enabled row line may be twice as long as row access time 2104, which may permit a longer integration for increased sensitivity of binned detector 1508. Row access time 2106 may be decreased to a similar duration as row access time 2104 to correspondingly increase frame rates while trading off power consumption and sensitivity, as also discussed above.

Therefore, in one or more embodiments, detector-binning techniques using switchable interconnects implemented within the array of infrared sensors 1408 may beneficially permit configuration of the array to various dimensions and/or pixel sizes as desired for particular applications. For example, the array configured for a binning mode having binned detectors 1508 according to one or more embodiments may provide increased sensitivity, reduced power consumption, and/or an increased frame rate, at the expense of pixel resolution. While various detector-binning techniques have been described above using a two-by-two binning

as specific examples, the techniques may be modified to provide other binning granularities (e.g., three-by-three, or other square binned detectors, or non-square binned detectors) based on and within the scope and spirit of the disclosure. Furthermore, it should be understood that the techniques disclosed herein may be applied to various types of microbolometer arrays
5 and are not limited to the specific microbolometer array implementations disclosed herein. As used in this disclosure, the terms row and column may be used interchangeably depending on the orientation of array 1406/1506 and/or other components of infrared sensor assembly 128 and therefore the term row and the term column are not limiting.

Where applicable, various embodiments provided by the present disclosure can be
10 implemented using hardware, software, or combinations of hardware and software. Also where applicable, the various hardware components and/or software components set forth herein can be combined into composite components comprising software, hardware, and/or both without departing from the spirit of the present disclosure. Where applicable, the various hardware components and/or software components set forth herein can be separated
15 into sub-components comprising software, hardware, or both without departing from the spirit of the present disclosure. In addition, where applicable, it is contemplated that software components can be implemented as hardware components, and vice-versa.

Software in accordance with the present disclosure, such as non-transitory instructions, program code, and/or data, can be stored on one or more non-transitory machine
20 readable mediums. It is also contemplated that software identified herein can be implemented using one or more general purpose or specific purpose computers and/or computer systems, networked and/or otherwise. Where applicable, the ordering of various steps described herein can be changed, combined into composite steps, and/or separated into sub-steps to provide features described herein.

25 Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the invention. Accordingly, the scope of the invention is defined only by the following claims.

CLAIMS

What is claimed is:

1. A device comprising:

5 a focal plane array (FPA) adapted to capture image frames of a scene, the FPA comprising:

a plurality of bolometers arranged in an array to provide a corresponding plurality of pixels;

a plurality of column lines adapted to supply a bias voltage to the bolometers;

10 a plurality of row lines adapted to provide a reference voltage to the bolometers; and

a first plurality of switches adapted to selectively connect two or more adjacent column lines to group two or more of the bolometers to form binned bolometers in the array.

15

2. The device of claim 1, wherein the FPA further comprises:

a second plurality of switches adapted to selectively connect some of the bolometers to row lines;

a third plurality of switches adapted to selectively connect some of the bolometers to 20 column lines;

a fourth plurality of switches adapted to selectively connect some of the bolometers in a series; and

wherein the first, second, third, and fourth plurality of switches are adapted to be selectively opened or closed to bin every two or more of the neighboring bolometers together 25 to form the binned bolometers.

3. The device of claim 2, wherein the binned bolometers are formed when the first and fourth switches are closed and the second and third switches are open.

4. The device of claim 1, wherein the binned bolometers have a resistance
5 substantially equal to a resistance of the bolometers.

5. The device of claim 1, wherein each binned bolometer comprises four of the bolometers in a two-by-two configuration.

10 6. The device of claim 1, wherein:

the FPA further comprises a read out integrated circuitry (ROIC) electrically connected to the column lines and adapted to provide the image frames; and

the ROIC is further adapted to increase a rate at which the image frames are provided when the binned bolometers are formed in the array.

15

7. The device of claim 1, wherein:

the FPA further comprises a read out integrated circuitry (ROIC) electrically connected to the column lines and adapted to provide the bias voltage to the bolometers; and

the ROIC is further adapted to increase the bias voltage when the binned bolometers
20 are formed so as to increase sensitivity of the binned bolometers.

8. The device of claim 1, wherein the bolometers are adapted to receive the bias voltage from a range of approximately 0.2 volts to approximately 0.7 volts.

9. The device of claim 1, wherein:

the FPA is adapted to capture an intentionally blurred image frame of the scene; and

the device further comprises a processor adapted to:

communicate with the FPA,

5 determine a plurality of non-uniform correction (NUC) terms based on the intentionally blurred image frame, and

apply the NUC terms to the image frames to remove noise from the image frames.

10 10. A method of binning bolometers of a focal plane array (FPA) adapted to capture imaging frames of a scene, the method comprising:

selectively connecting adjacent column lines of the FPA using a first plurality of switches, wherein the column lines are adapted to supply a bias voltage to the bolometers;

selectively connecting some of the bolometers to row lines of the FPA using a second 15 plurality of switches, wherein the row lines are adapted to provide a reference voltage to the bolometers;

selectively connecting some of the bolometers to the column lines using a third plurality of switches; and

selectively connecting some of the bolometers in series using a fourth plurality of 20 switches, wherein the selectively connecting using the first, second, third, and fourth plurality of switches group every two or more of the neighboring bolometers together to form binned bolometers within the array.

11. The method of claim 10, wherein the binned bolometers are formed when the 25 first and fourth switches are closed and the second and third switches are open.

12. The method of claim 10, wherein the selectively connecting using the first, second, third, and fourth plurality of switches forms the binned bolometers having a resistance substantially equal to a resistance of the bolometers.

5 13. The method of claim 10, wherein the selectively connecting using the first, second, third, and fourth plurality of switches group four of the bolometers in a two-by-two configuration to form each binned bolometer.

14. The method of claim 10, further comprising increasing a rate at which the
10 image frames are provided from the FPA when the binned bolometers are formed in the array.

15. The method of claim 10, further comprising increasing the bias voltage supplied by the column lines when the binned bolometers are formed so as to increase
15 sensitivity of the binned bolometers.

16. The method of claim 10, further comprising providing, to the bolometers, the bias voltage selected from a range of approximately 0.2 volts to approximately 0.7 volts.

20 17. The method of claim 10, wherein:

capturing, using the FPA, an intentionally blurred image frame of the scene;

determining a plurality of non-uniform correction (NUC) terms based on the intentionally blurred image frame; and

applying the NUC terms to the image frames to remove noise from the image frames.

1

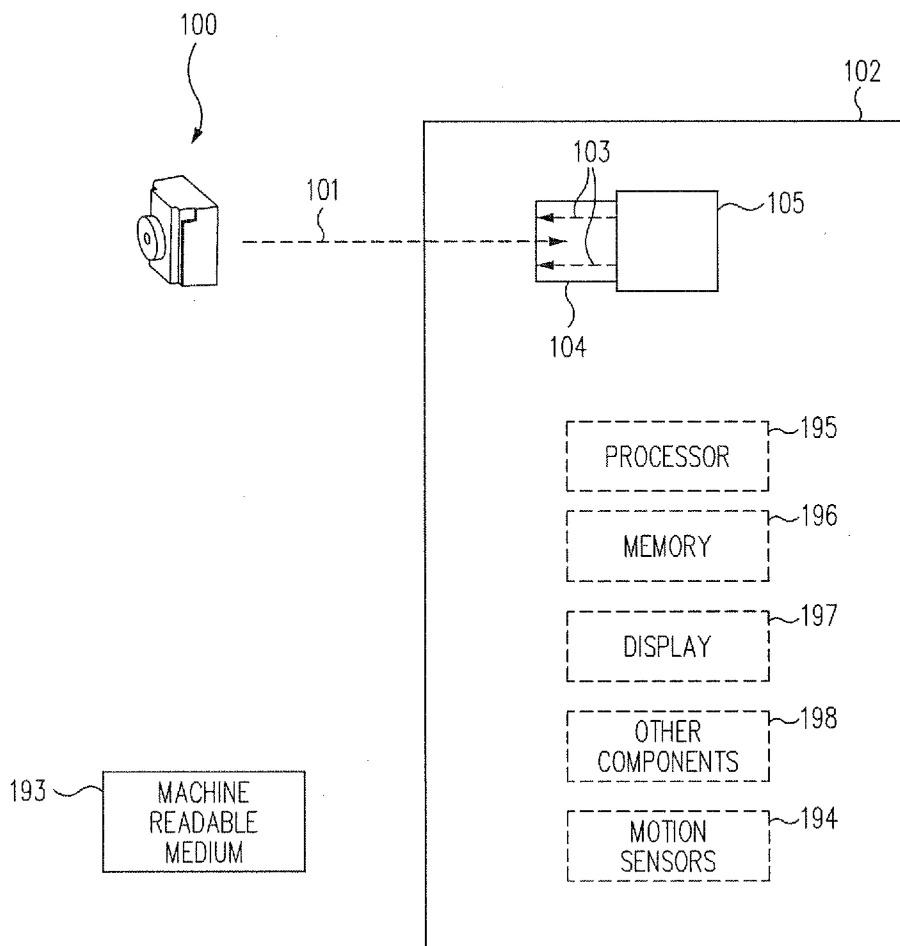

FIG. 1

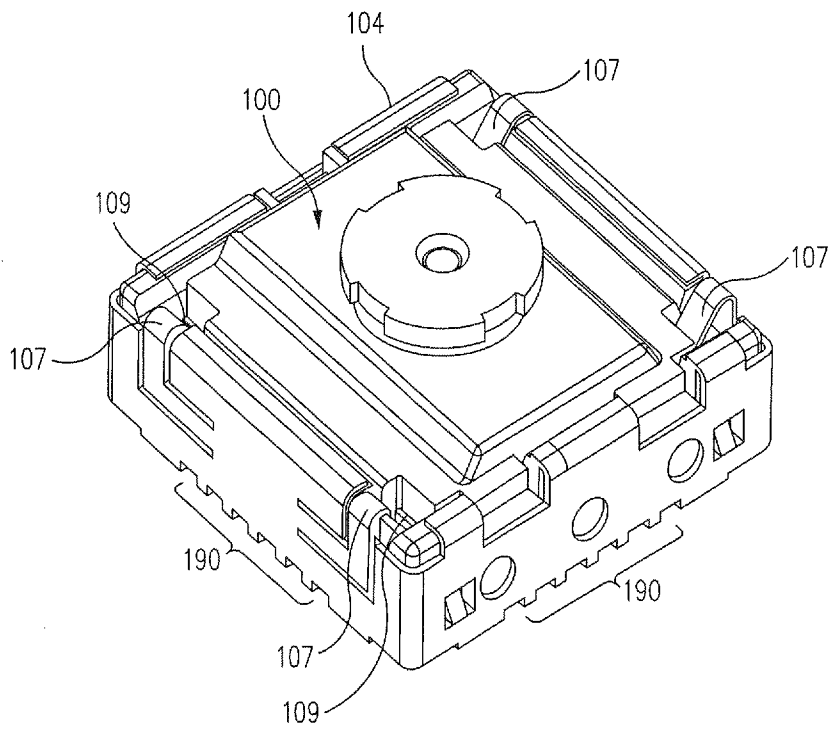

FIG. 2

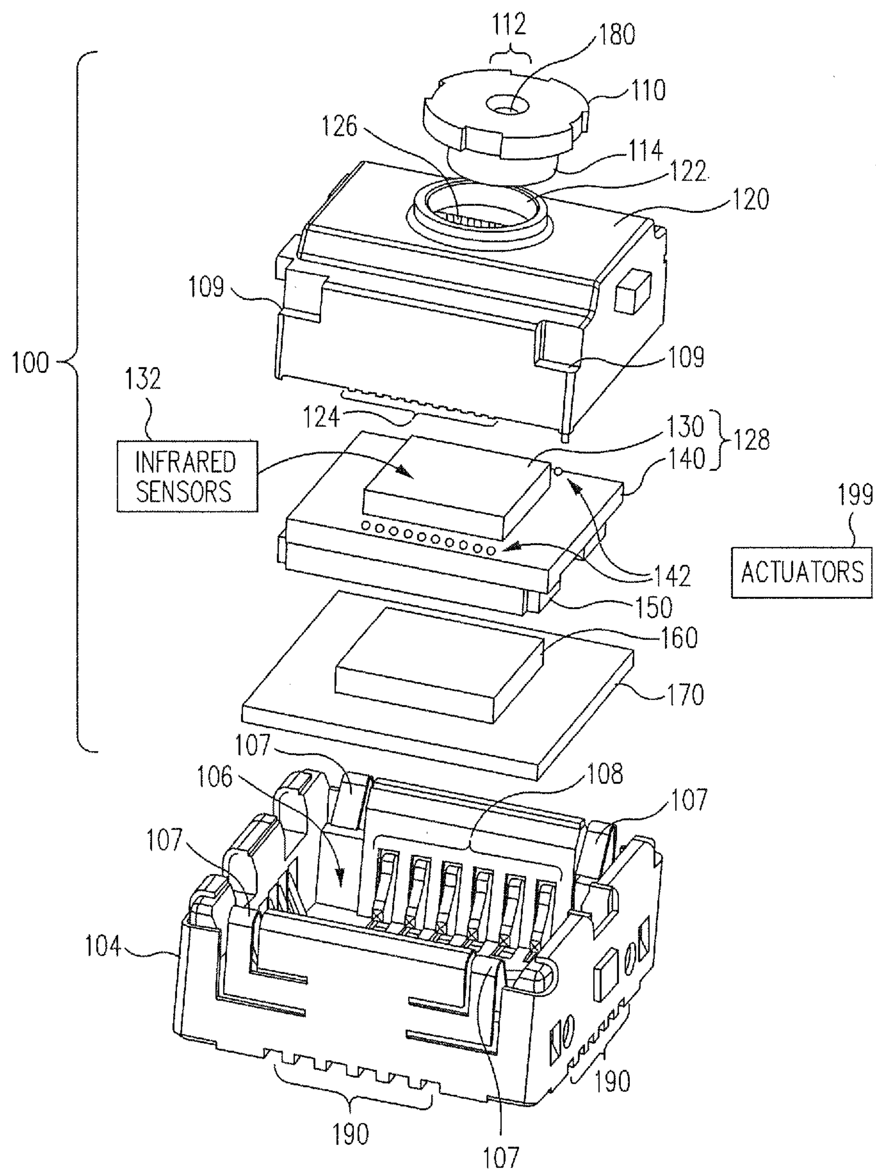

FIG. 3

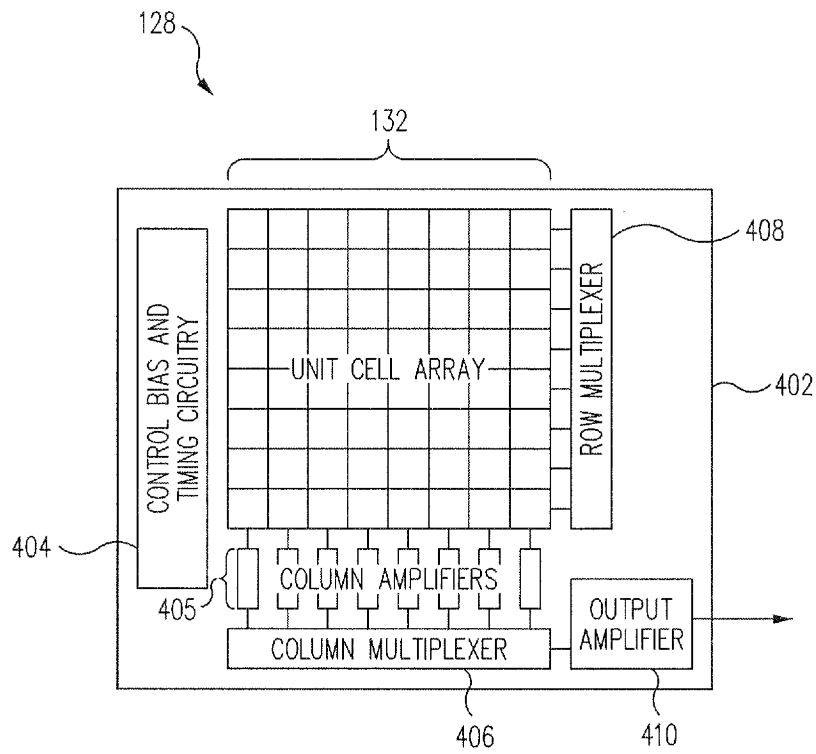

FIG. 4

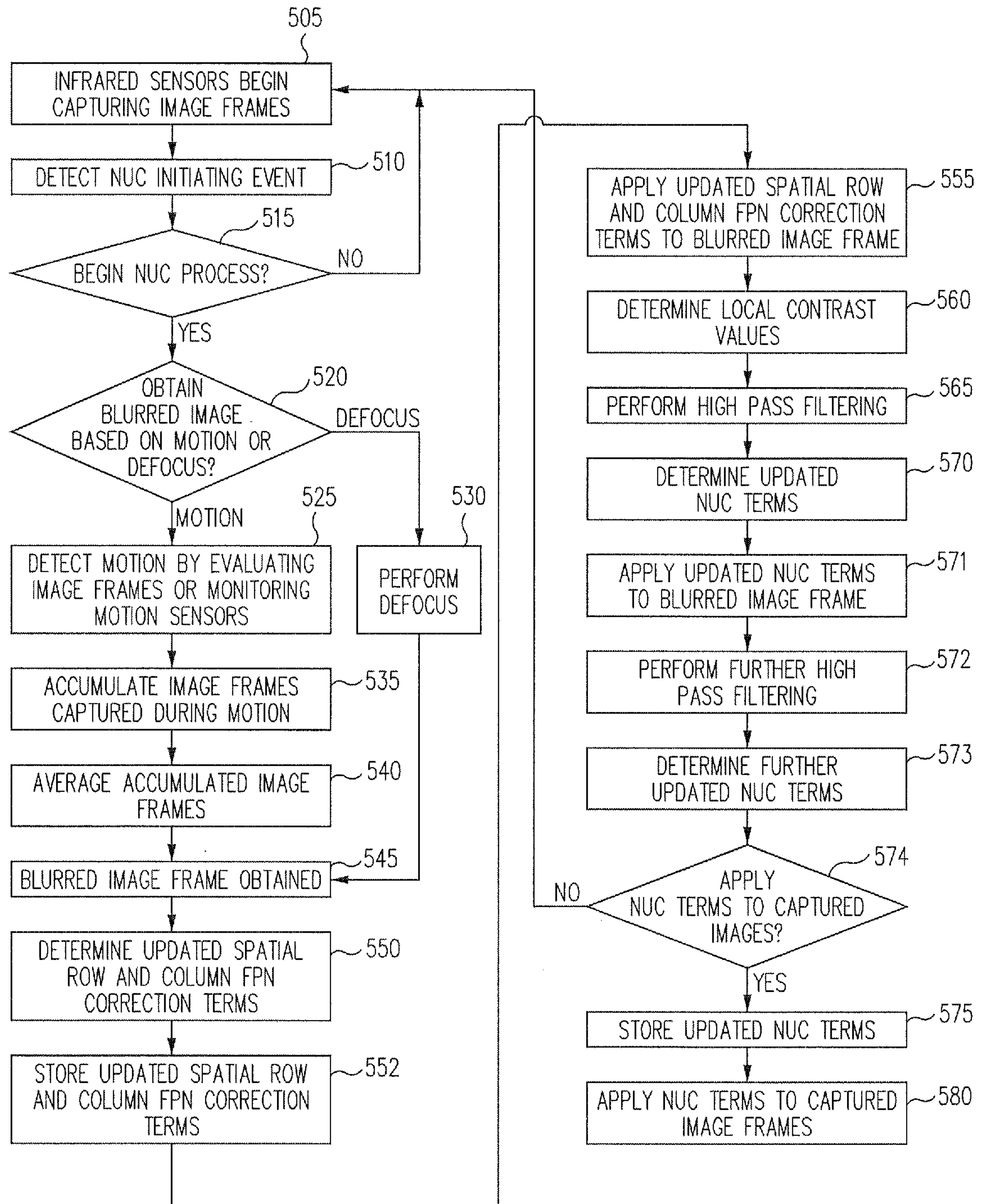

FIG. 5

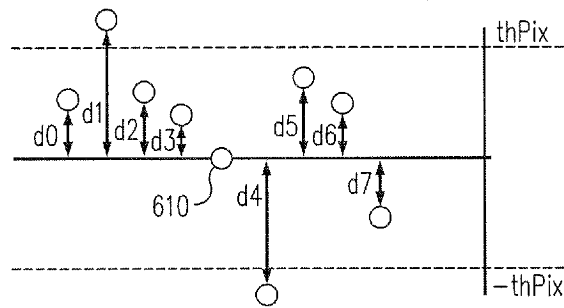

FIG. 6

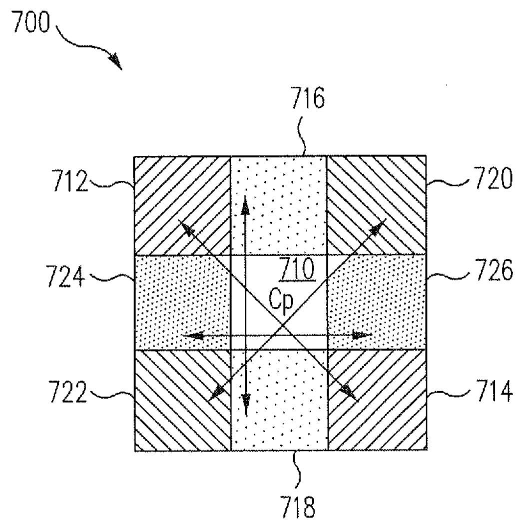

FIG. 7

800

Frame Averager 804

802

Factory Gain Terms 812

X 810

Factory Offset Terms 816

+ 814

NUC Terms 817

+ 580

Column FPN Terms 820

+ 818

Row FPN Terms 824

+ 822

Perform Temporal Filtering 826

802e

Automatic Gain Compensation 828

830

Begin NUC Process

510/515/520

Detect Motion 525

32 Frame Accum. 535

<<32 540

Perform Defocus 530

Blurred Image Obtained 545

Determine Update to Row Noise Terms 550

Determine Update to Column Noise Terms 550

Store Updated Row FPN Terms 552

Store Updated Column FPN Terms 552

+ 555

Determine Local Contrast Values 560

High Pass Filter 1 565

Determine Update to NUC Terms 570

Store Updated NUC Terms 575

+ 571

High Pass Filter N 572

Determine Update to NUC Terms 573

FIG. 8

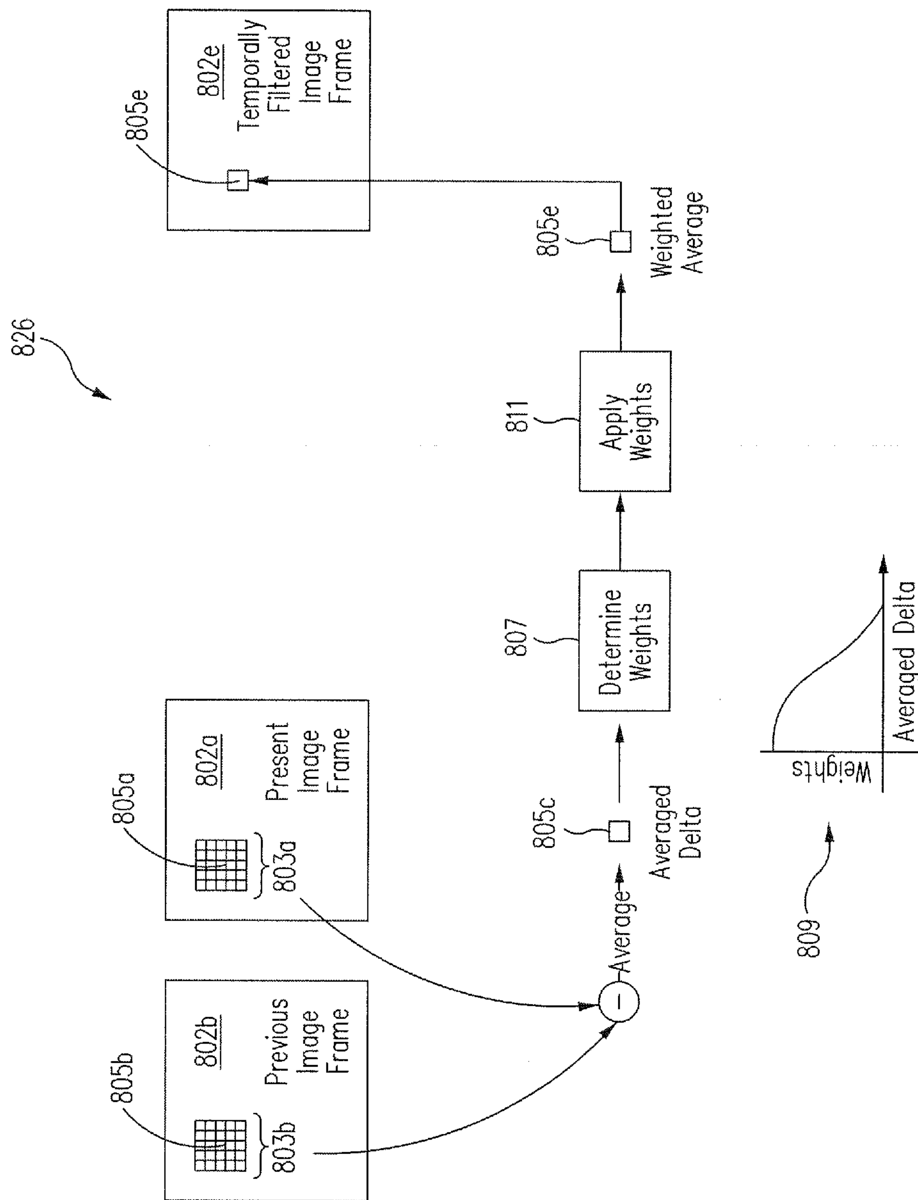

FIG. 9

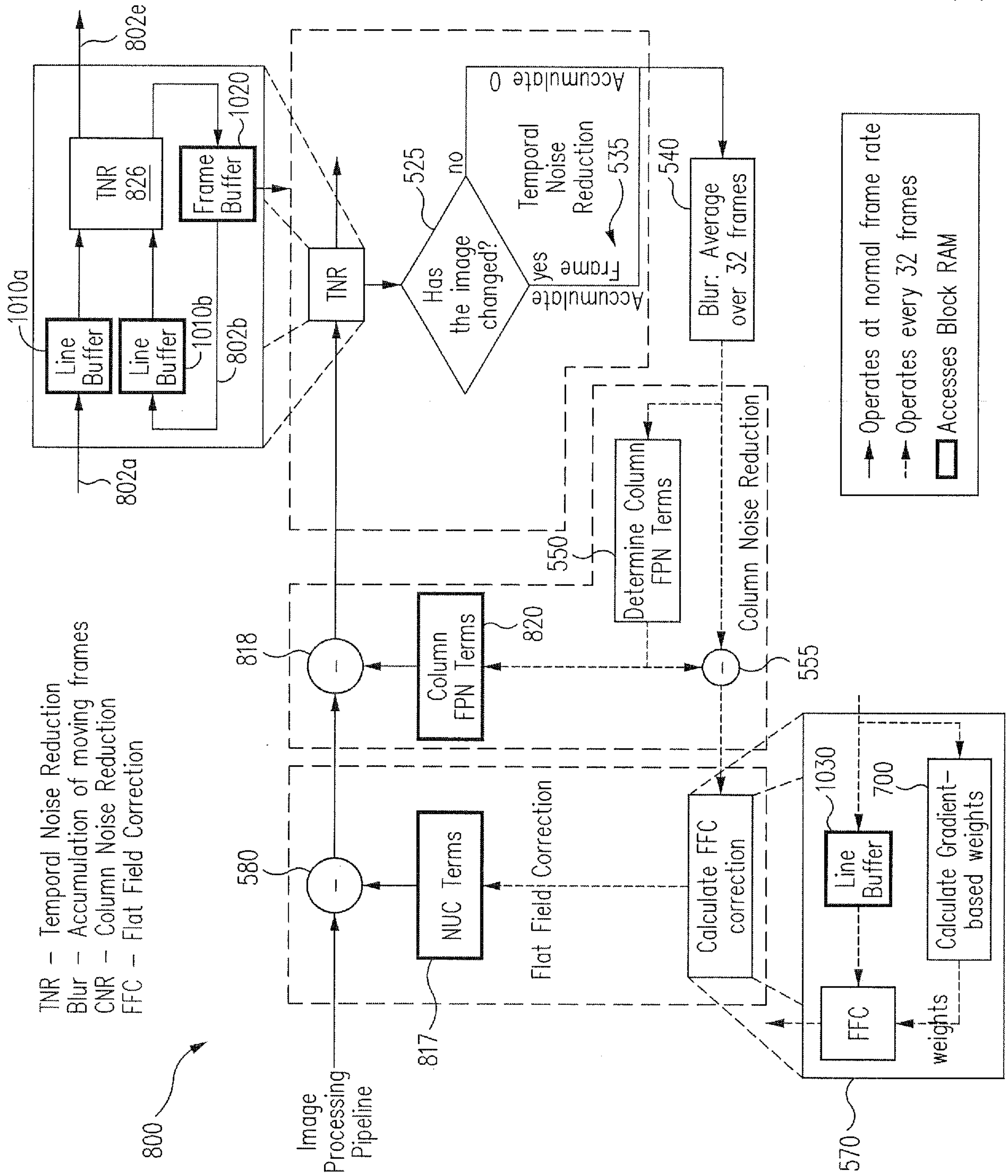

FIG. 10

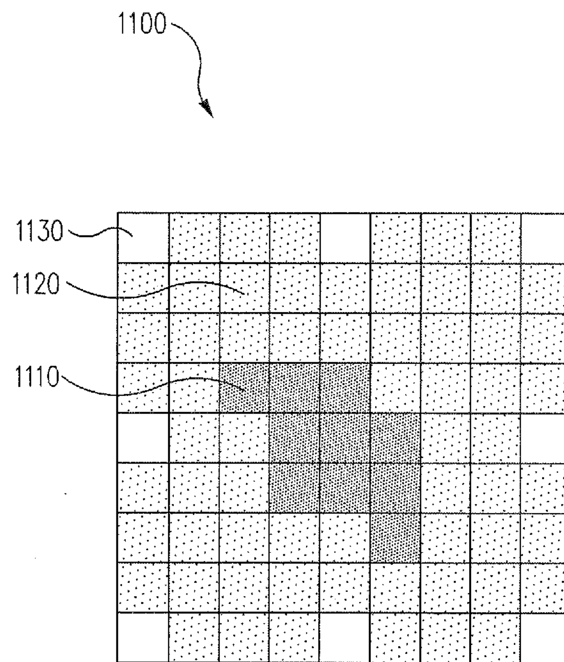

FIG. 11

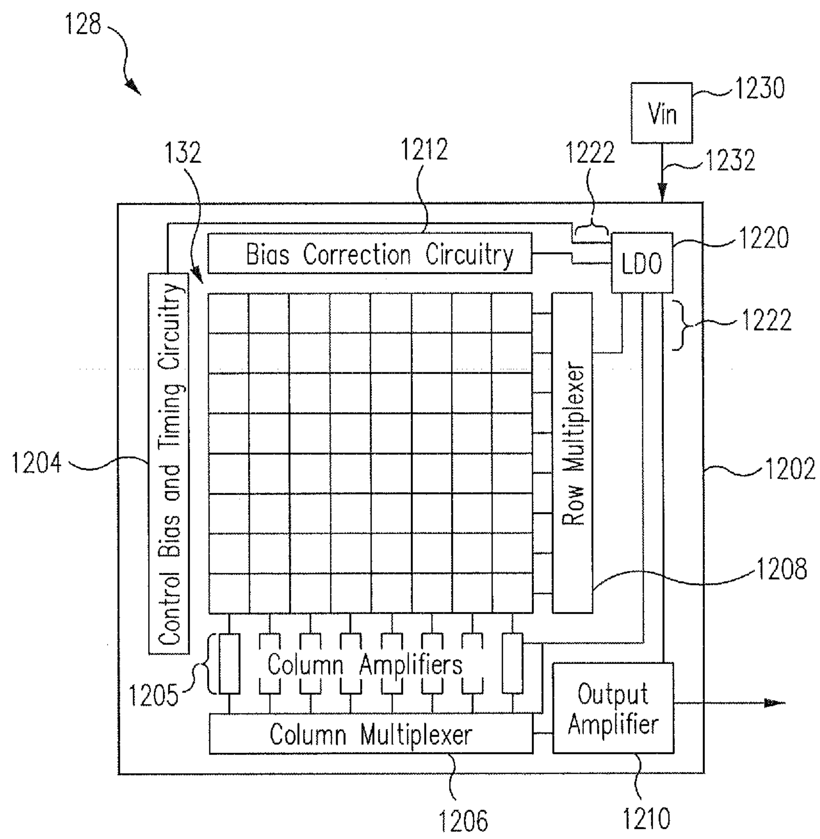

FIG. 12

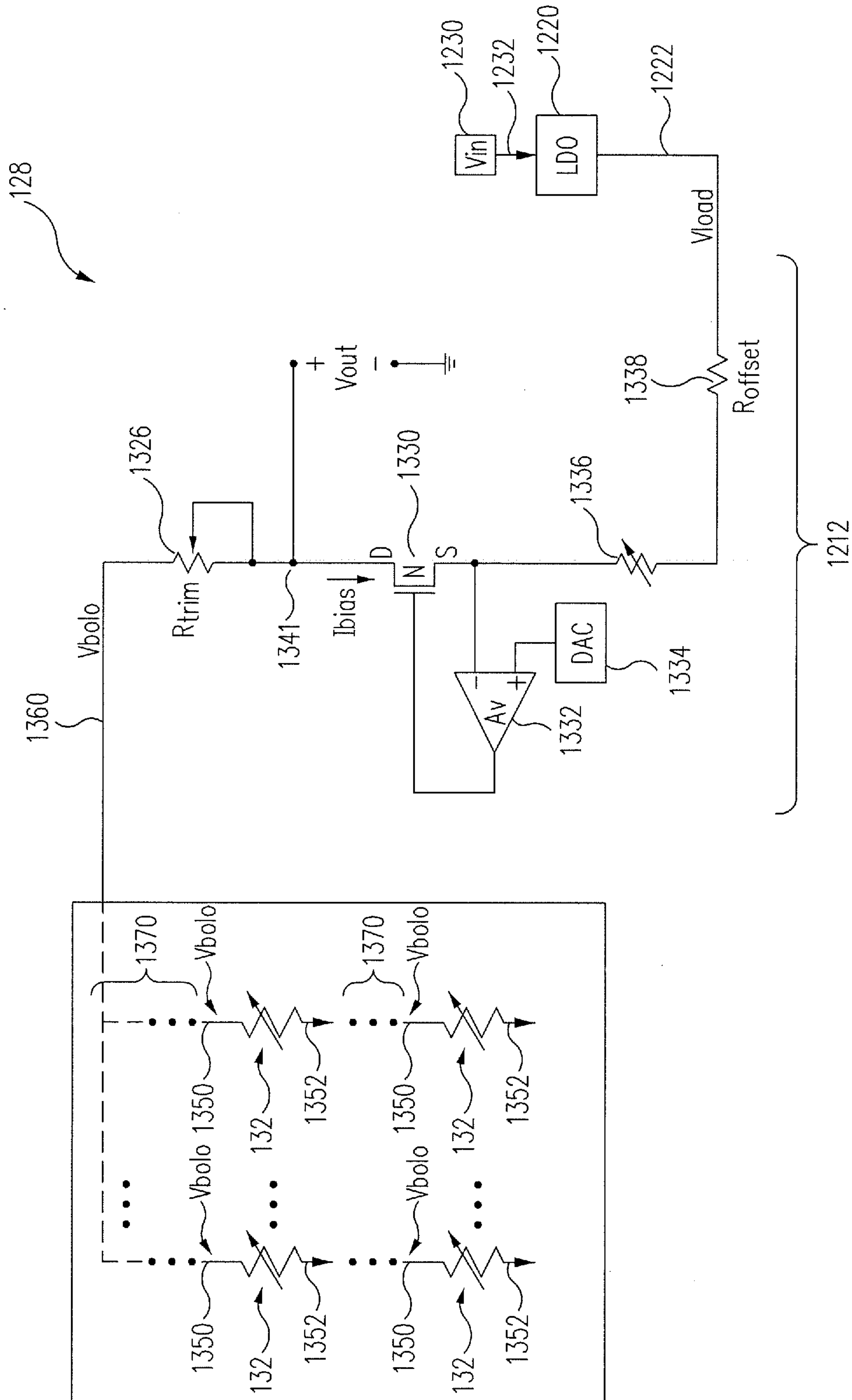

FIG. 13

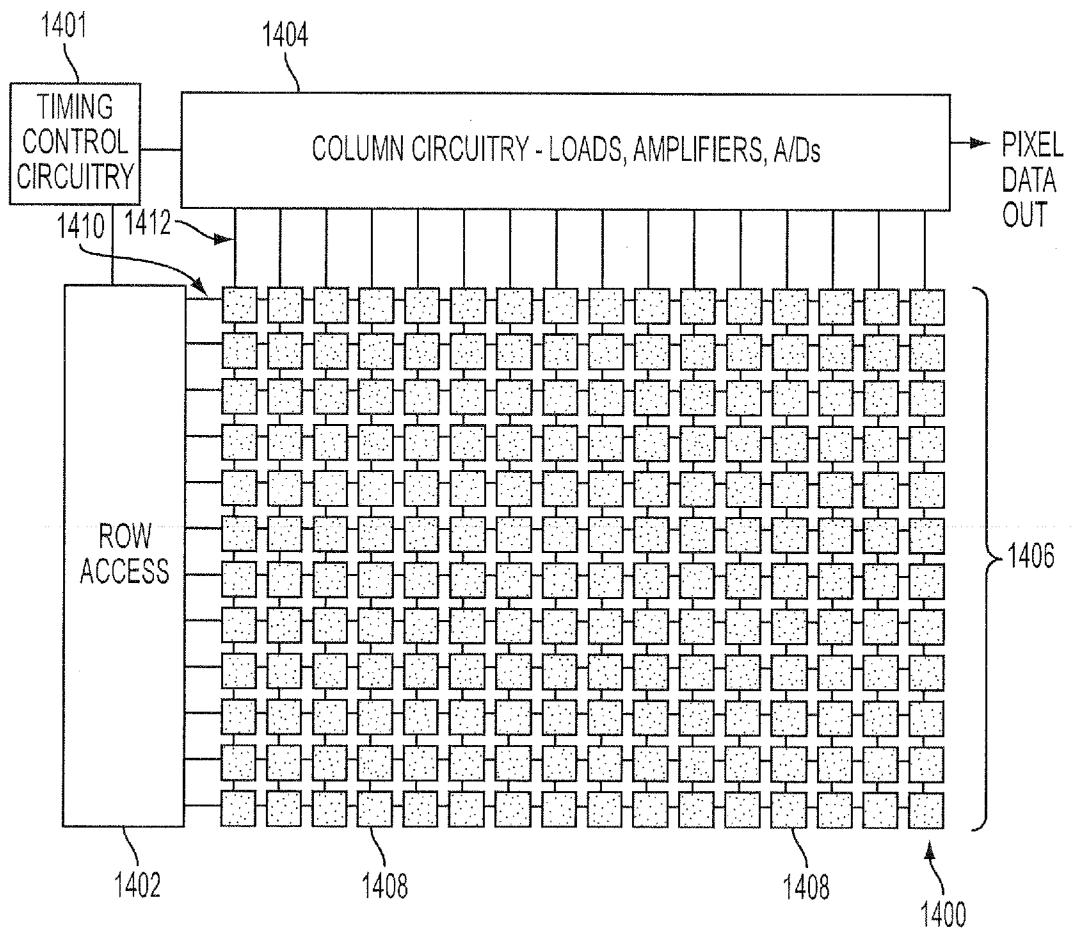

FIG. 14

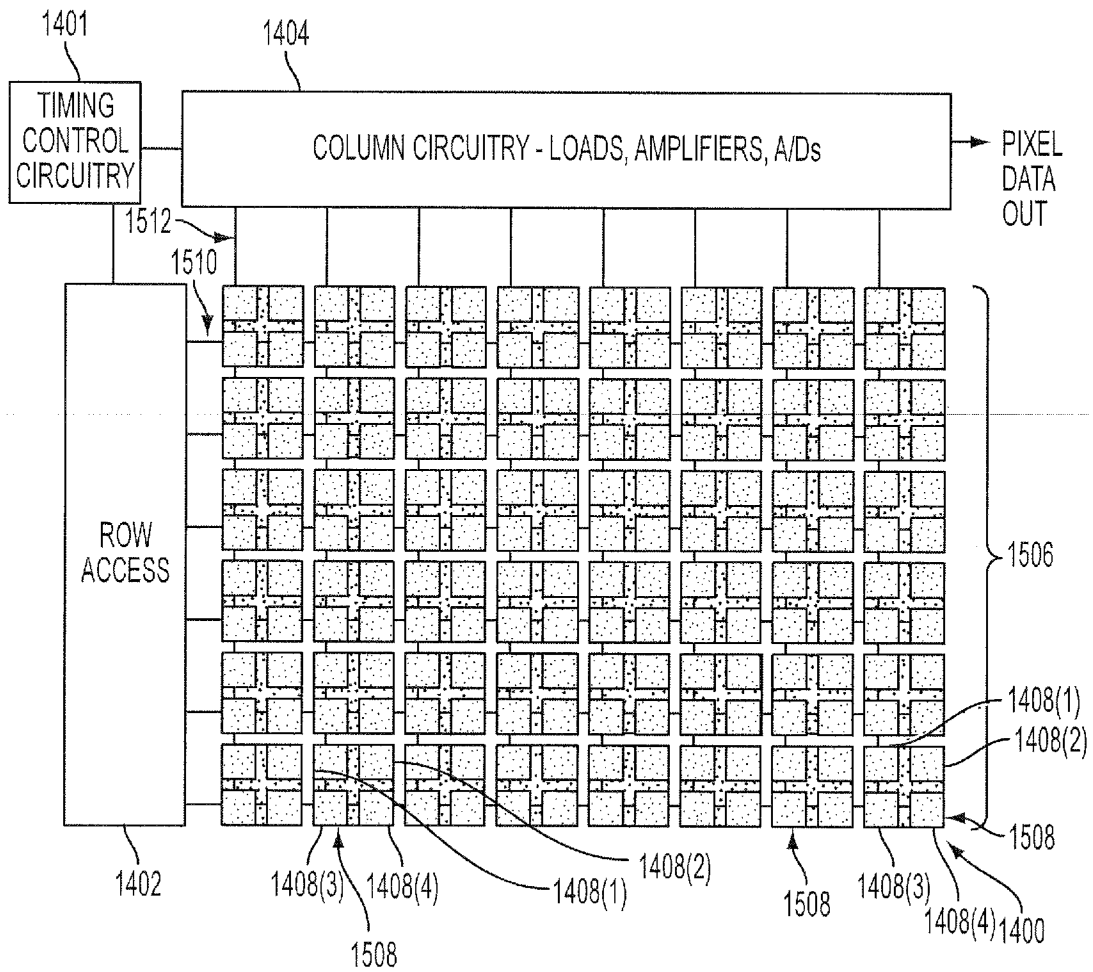

FIG. 15

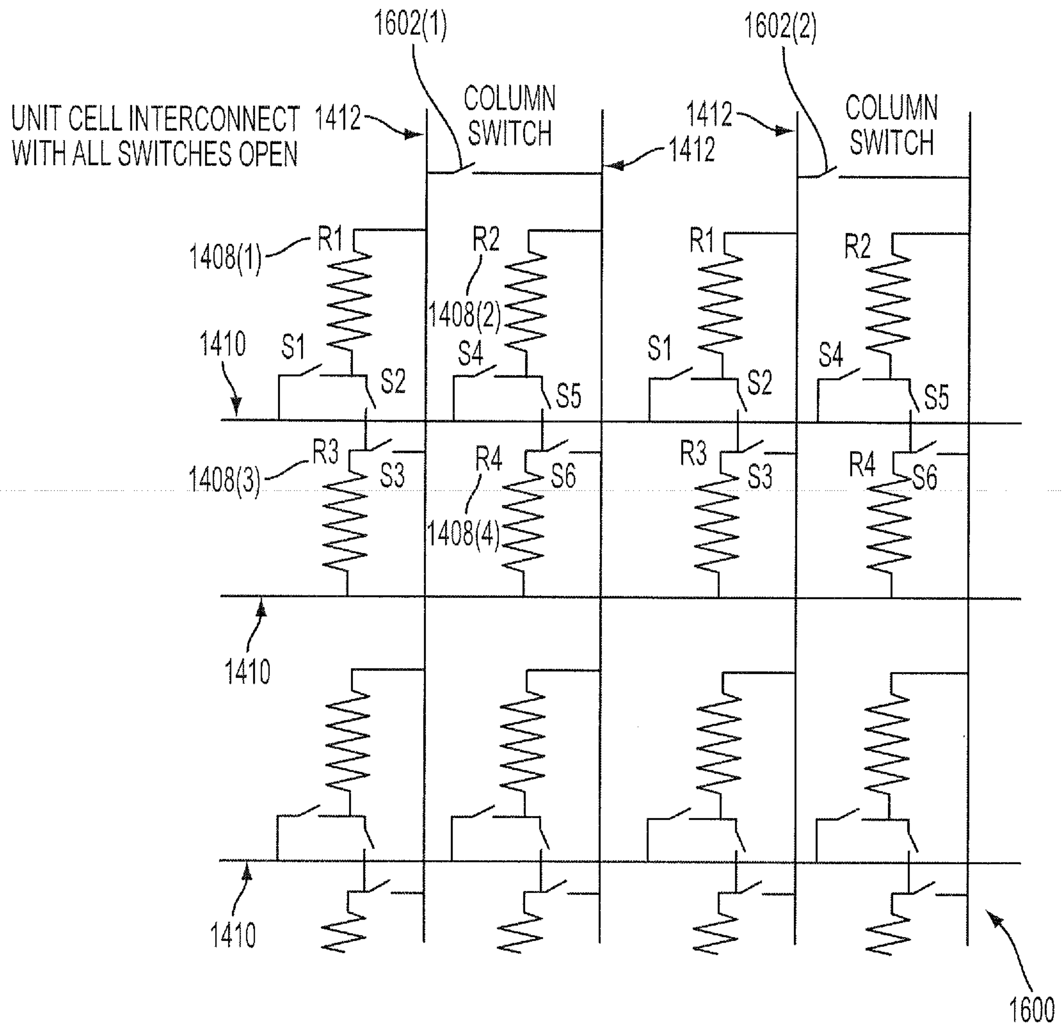

FIG. 16

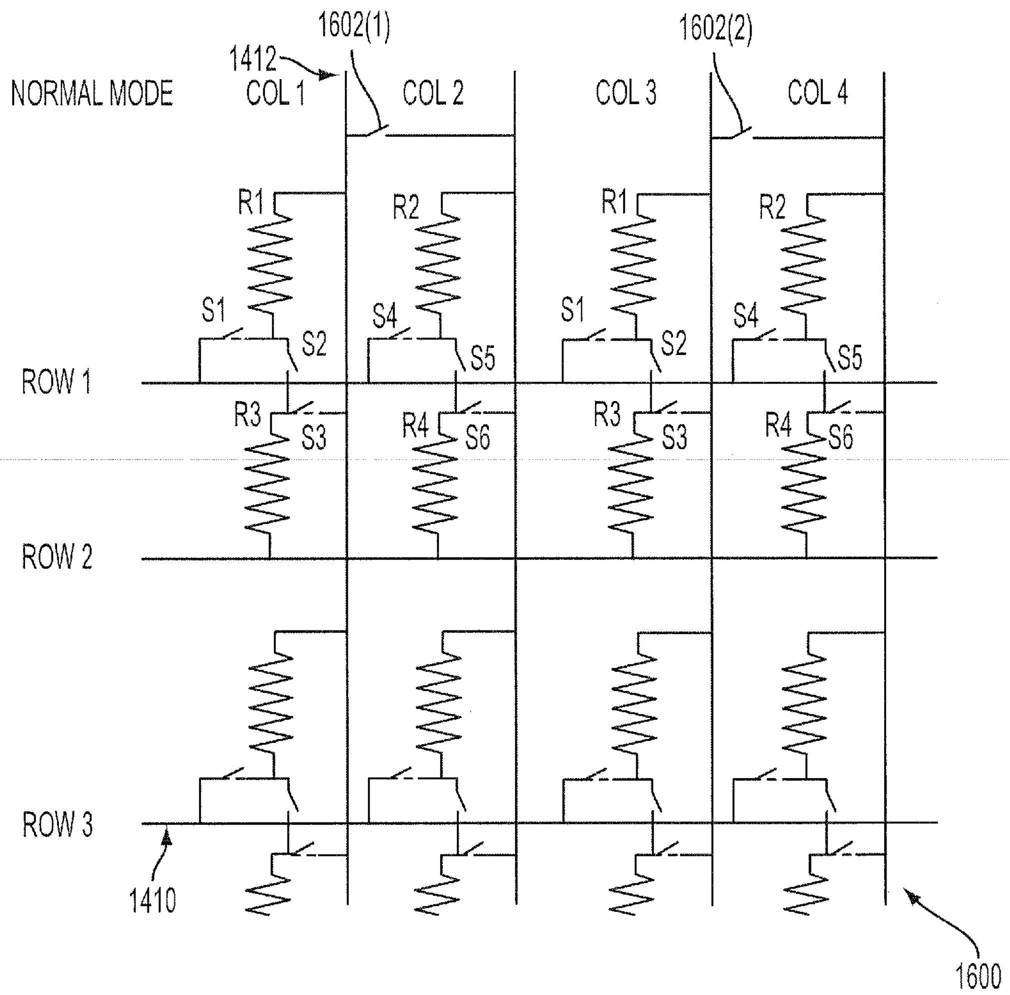

FIG. 17

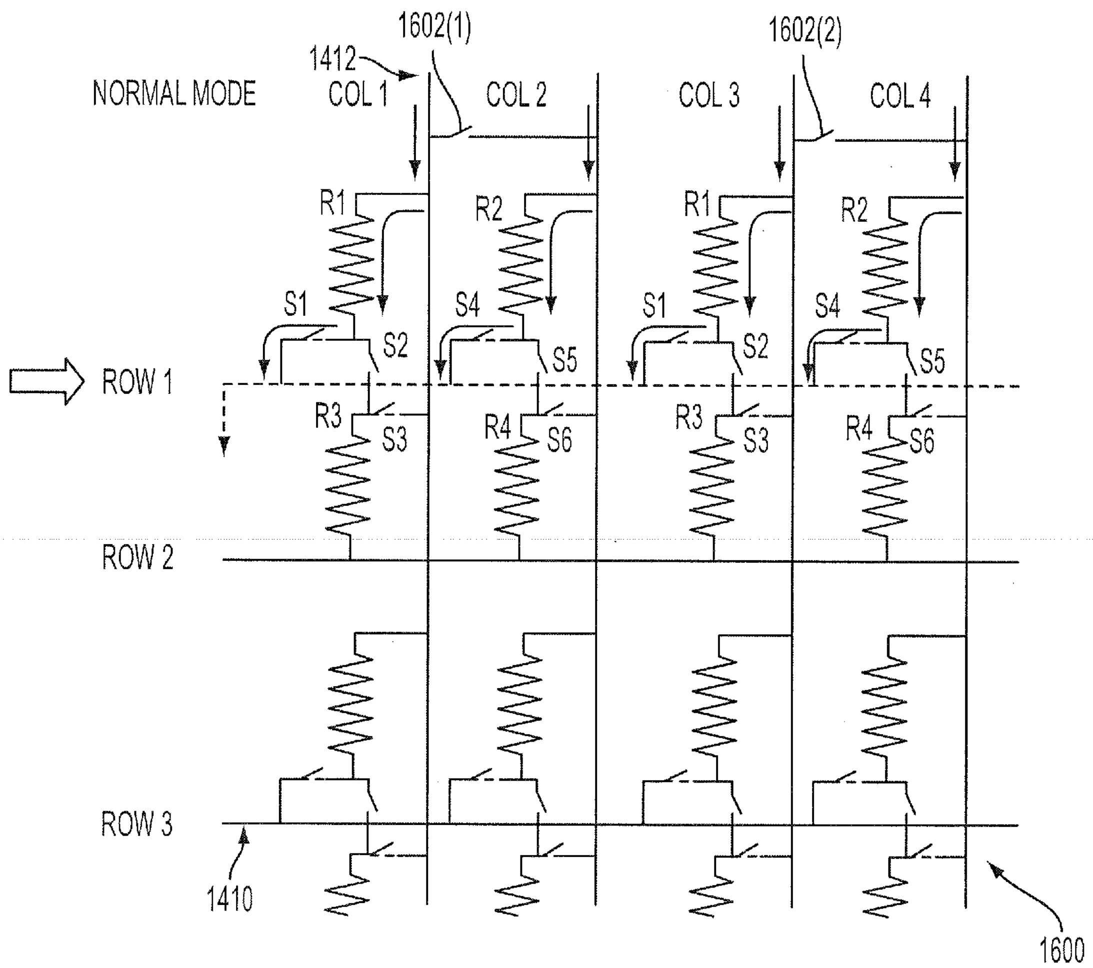

FIG. 18

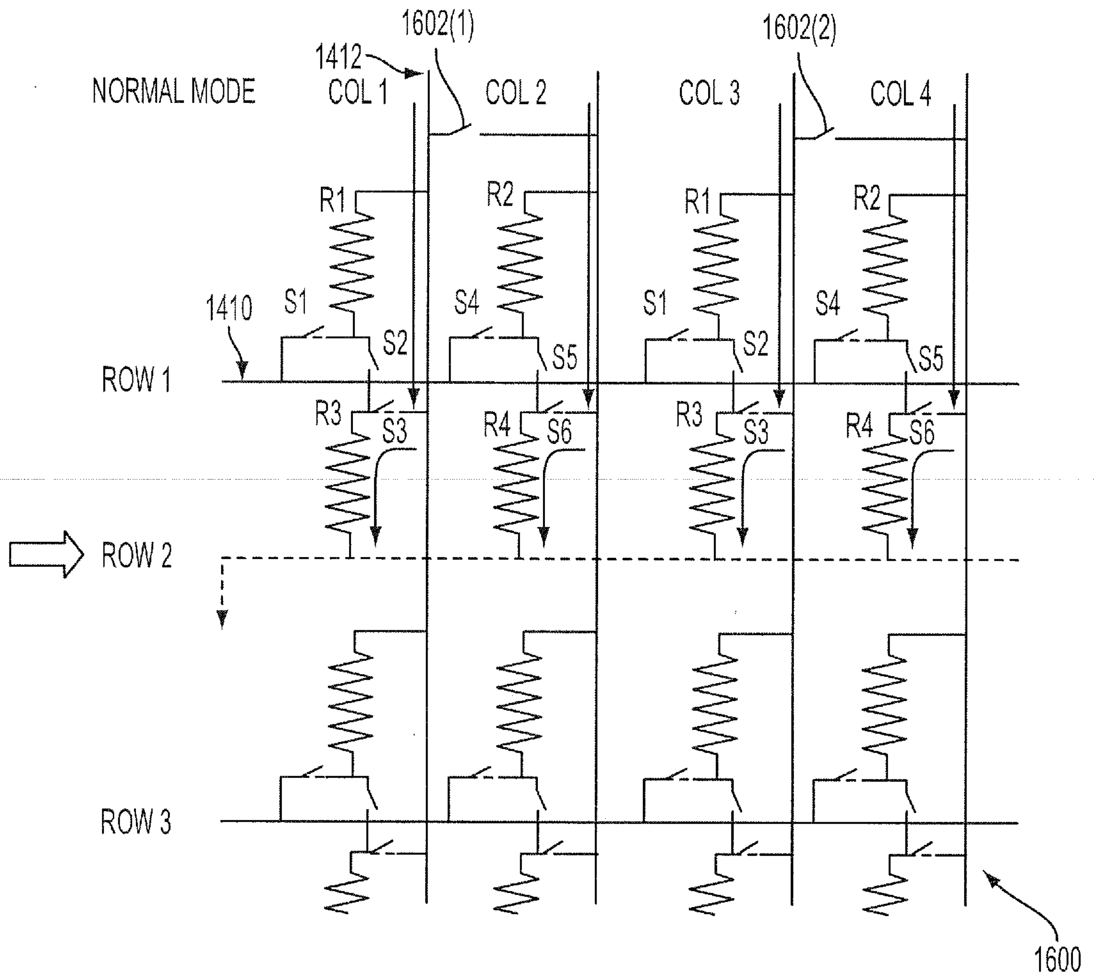

FIG. 19

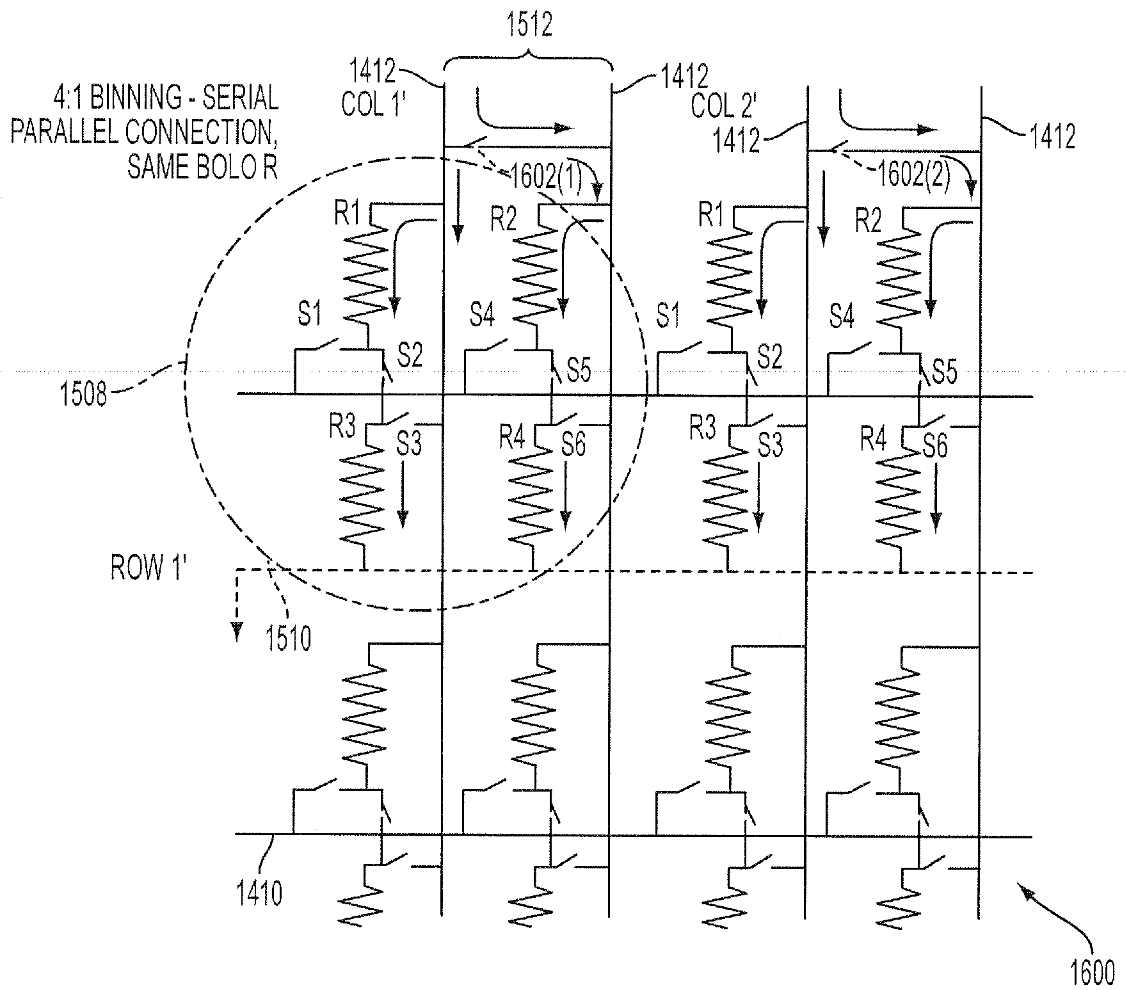

FIG. 20

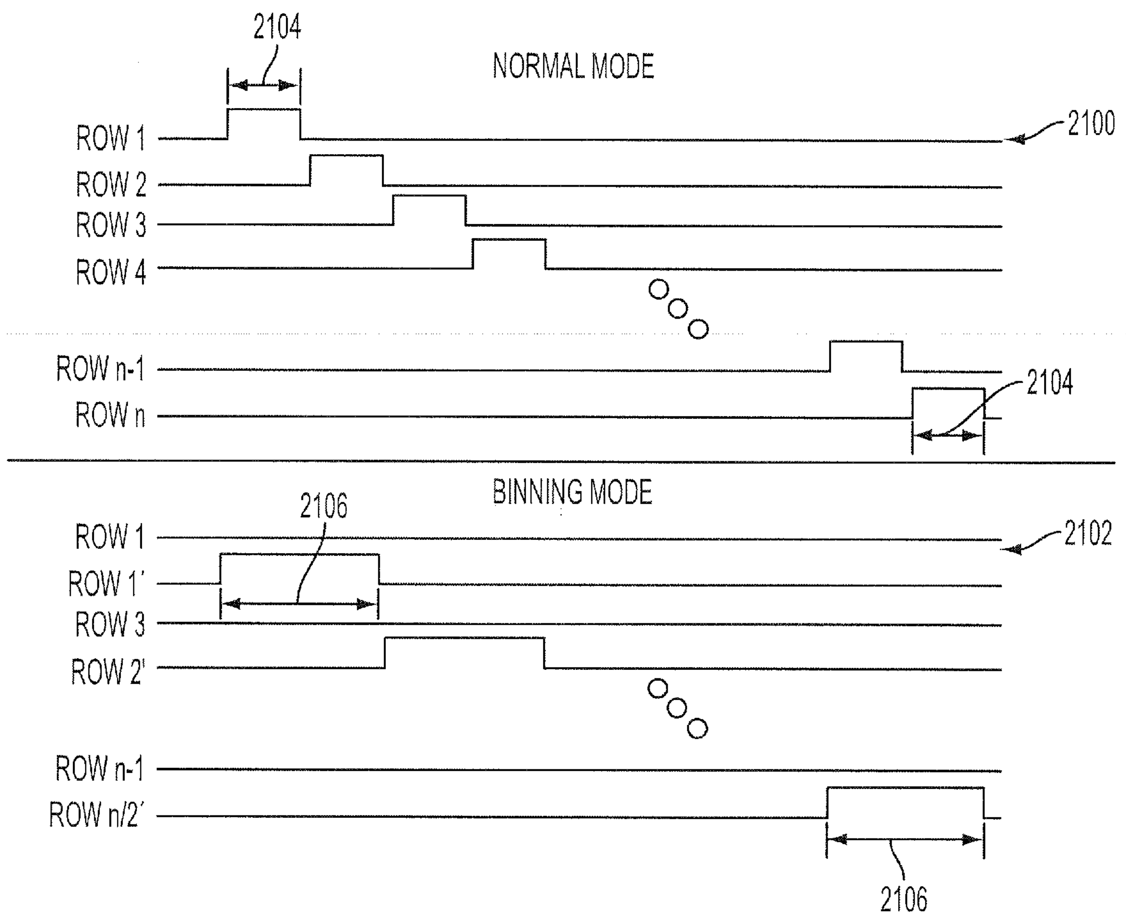

FIG. 21

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/077681

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N5/33 H04N5/347
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/115877 A1 (VERDANT ARNAUD [FR]) 7 May 2009 (2009-05-07)	1-3,5, 10,11, 13,14
A	paragraphs [0049] - [0051]; figure 1	4,12
A	US 2004/200961 A1 (PARRISH WILLIAM J [US] ET AL) 14 October 2004 (2004-10-14) paragraph [0062]; figures 9,10a	1-6, 10-14
A	US 2011/234864 A1 (INOKUMA KAZUYUKI [JP]) 29 September 2011 (2011-09-29) paragraph [0021]	6,14
X	US 2012/140881 A1 (YOSHIMATSU AKINA [JP] ET AL) 7 June 2012 (2012-06-07) abstract	7,8,15, 16

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 May 2014	21/05/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Zakharian, Andre

International application No
PCT/US2013/077681

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 444 983 B1 (MCMANUS TIMOTHY J [US] ET AL) 3 September 2002 (2002-09-03) column 1, line 49 - column 2, line 21 -----	7,8,15, 16

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2009115877	A1	07-05-2009	CN	101431597	A	13-05-2009
			EP	2056590	A1	06-05-2009
			FR	2923339	A1	08-05-2009
			JP	5264407	B2	14-08-2013
			JP	2009118476	A	28-05-2009
			US	2009115877	A1	07-05-2009
US 2004200961	A1	14-10-2004	US	2004200961	A1	14-10-2004
			WO	2005073684	A1	11-08-2005
US 2011234864	A1	29-09-2011	CN	102224736	A	19-10-2011
			US	2011234864	A1	29-09-2011
			WO	2010089830	A1	12-08-2010
US 2012140881	A1	07-06-2012	CN	102590844	A	18-07-2012
			JP	2012120030	A	21-06-2012
			US	2012140881	A1	07-06-2012
US 6444983	B1	03-09-2002	US	6444983	B1	03-09-2002
			US	2002185601	A1	12-12-2002

International application No.
PCT/US2013/077681

INTERNATIONAL SEARCH REPORT

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [X] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

7, 8, 15, 16

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-6, 10-14

   Prevention of drop of signal due to impedance mismatch of between the binned macro-bolometer and the ROIC readout circuitry and handling of the frame rate in a known bolometer array when binning is applied.

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2. claims: 7, 8, 15, 16

   Improving of sensitivity of the known bolometer array when binning is applied.

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3. claims: 9, 17

   Providing for a non-uniformity correction in a known bolometer array when binning is applied.