(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification:
H04N 5/235 (2006.01)

(21) International Application Number:
PCT/US2006/036793

(22) International Filing Date:
21 September 2006 (21.09.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/719,304	21 September 2005 (21.09.2005)	US
60/719,305	21 September 2005 (21.09.2005)	US
60/719,306	21 September 2005 (21.09.2005)	US
60/727,897	18 October 2005 (18.10.2005)	US

(71) Applicant and
(72) Inventor: DAVIDOVICI, Sorin [US/US]; 160 Main Street, Oceanport, NJ 07757 (US).

(74) Agent: MCGUINNESS, Lindsay; McGuinness & Manaras LLP, 125 Nagog Park, Acton, MA 01720 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: SYSTEM AND METHOD FOR IMAGE SENSOR ELEMENT OR ARRAY WITH PHOTOMETRIC AND REAL-TIME REPORTING CAPABILITIES

(57) Abstract: A solid-state pixel structure or pixel array includes integrated exposure control provided within the pixel structure and/or pixel array. Including exposure control within the pixel structure and/or array allows optimal exposure to be achieved in real time. Optimal exposure is achieved by measuring the response of pixel structures to received electromagnetic radiation, and using the response information, in conjunction with knowledge regarding the pixel structure capabilities and photometric thresholds, to determine when the pixel structure is operating optimally. Tight control of the exposure of the pixel structure to the electromagnetic radiation allows the pixel structure to operate optimally in order to provide an optimal captured image.

SYSTEM AND METHOD FOR AN IMAGE SENSOR ELEMENT OR ARRAY WITH

PHOTOMETRIC AND REALTIME REPORTING CAPABILITIES

[001]   Field of the Invention

[002]   This invention relates generally to the field of electronic imaging and more particularly to

a method and apparatus for enhanced image capture using photometric measurement and

reporting.

[003]   Background of the Invention

[004]   Photography is the process of making pictures by means of the action of light. Light is

the commonly used term for electromagnetic radiation in a frequency range that is visible to the

human eye. Light patterns reflected or emitted from objects are recorded by an image sensor

through a timed exposure. Image sensors can be chemical in nature, such as photographic film,

or solid state in nature, such as the CCD and CMOS image sensors employed by digital still and

video cameras.

[005]   Digital cameras have a series of lenses that focus light to create an image of a scene. But

instead of focusing this light onto a piece of photographic film, as in traditional cameras, it

focuses it onto the solid state image sensor which converts the electromagnetic radiation of the

light into an electrical charge. The atomic element of an image sensor is said to be a picture

element, or a 'pixel' and practical image sensors for digital photography typically have a large

number of pixels. The electrical charge indicates a relative intensity of the electromagnetic

radiation as perceived by the image sensor, and generally is used to associate a light intensity

value with the pixel.

[006]   One goal of photography is to provide an image that accurately represents the image

viewed by the human eye. However, the human eye is not equally sensitive to all wavelengths of

light. As a result, the response of the image sensors to the electromagnetic radiation that

impinges upon them must be adjusted in accordance with the sensitivities of human vision. The

adjustment is typically done by the adjusting the exposure of the image sensor to the

electromagnetic radiation to compensate for human sensitivities to different wavelengths.

[007]   However it is often difficult to determine the correct level of exposure to provide to the

image sensor; the failure to determine and apply the correct level of exposure of electromagnetic

radiation to the light sensitive image sensor component results in degradation of the captured

image. Such degradation is often referred to as 'overexposed' or 'underexposed.' Overexposure

occurs when the level of electromagnetic radiation that is exposed to the light sensitive

component is greater than the optimal level for the light wavelength. Overexposure often results

in lack of highlight detail in the captured image.

[008]   Figure 1A illustrates the response characteristic of an image sensor to overexposure. The

abscissa represents the intensity of the electromagnetic radiation impinging upon the sensor. The

ordinate represents the corresponding output voltage of the image sensor. For low intensity

radiation, the voltage of the image sensitive component increases linearly with the intensity of

the electromagnetic radiation. However, as the intensity of the electromagnetic radiation

increases beyond a threshold T_o (as indicated by the dashed line of Figure 1a), the image

sensitive component output voltage does not change accordingly, but rather levels out at some

maximum voltage. Thus, the image sensitive device cannot accurately represent images having

electromagnetic radiation intensity levels that exceed the threshold T_o and the recorded image is

said to be overexposed.

[009]   Figure 1B illustrates the response characteristic of an image sensor to underexposure.

Underexposure occurs when the level of exposure of the image sensitive component to the

electromagnetic radiation is less than the optimal level. Underexposure often results in lack of

shadow detail in the captured image. As can be seen in Figure 1B, for low intensity values the

voltage of the image sensitive component does not change in response to changes in the intensity

of the electromagnetic radiation. Only after the light intensity is past a minimum light intensity

level threshold *Tu* does the voltage of the image sensitive component increase linearly with the intensity of the electromagnetic radiation. Thus, the image sensitive device cannot accurately represent image details or colors having electromagnetic radiation intensity levels that do not exceed the threshold T_U and the recorded image is said to be underexposed.

[0010]   Figure 1C illustrates a transfer function that reflects the correct exposure of an image sensor to electromagnetic radiation. Correct exposure occurs when an image is captured optimally with full detail in the segments of low electromagnetic radiation intensity levels as well as in the segments of high electromagnetic radiation intensity levels. Correct exposure allows both highlights and shadows sections of the original image to be accurately represented in the captured electronic representation of the image.

[0011]   Figures 2A-2C illustrates histograms of pixel intensities of exposed images, wherein the exposed images each have a range of potential pixel intensities from 0 through 255. Figure 2A is a histogram of pixel intensities that may be found in an image that has been overexposed, for example using an exposure process having a transfer function such as that illustrated in 1A. Figure 2B is a histogram of pixel intensities that may be found in an underexposed image, such as an image captured using the transfer function of Figure 1B. Figure 2C is a histogram of pixel intensities that may be found in an image that has been correctly exposed, for example using the transfer function of Figure 1C. While the histogram of Figure 2C illustrates a normalized distribution of pixel intensities, Figure 2A illustrates that an overexposed image has pixel intensities that are compressed at the maximum image sensor output value ('255'), while an underexposed image has pixel intensities that are compressed at the minimum image sensor output value ('0'),.

[0012]   An image reaching the pixel array contains dark and light areas that can differ drastically in intensity and thus cause the image to have high dynamic range. Although the dynamic range of the image might fit within the dynamic range of the pixel array the exposure calculation must

be extremely accurate. The limited dynamic range of realistic pixel arrays and the high dynamic range of typical images combine to make accurate exposure calculation a very difficult task.

[0013] The current art recognizes a number of methods of calculating the exposure time. One known method is to capture the image using an estimated exposure time setting, observe the pixel output histogram, arrive at a new exposure time estimate and acquire the image using this new exposure time estimate. This method is wasteful of power as it captures each image twice. It is also inaccurate as the second exposure time estimate, although better than the first value, is still an approximation and numerous pixels will be exposed to light intensities that are outside of their dynamic range.

[0014] Another method is to examine the entire image, measure the average light image intensity value and calculate an exposure time based on this value. However, such a method is inaccurate as it does not take into account the actual distribution of light intensities within the image. Here too numerous pixels will be exposed to light intensities that are outside of their dynamic range.

[0015] Identifying the correct amount of exposure is further complicated by photometry. Photometry is the science of measurement of visible light, especially its intensity and it can be used to describe the image intensity in terms of its perceived brightness to human vision. Photometry can be used to account for the different sensitivities of human vision to light wavelengths by weighting the measured intensity of a wavelength with a factor that is a function of how sensitive the eye is at that wavelength.

[0016] Photometric measurements are typically made and reported using electromagnetic radiation sensitive devices that are designed for the specific photometric measurement function. The electromagnetic sensitive device may be, for example, a charge coupled device (CCD) or a complementary metal oxide semiconductor (CMOS) device. Figure 3 illustrates a pixel array 10 which includes pixel structures such as pixel structure 12 and photometric measurement structures such as photometric measurement structure 14. Typical pixel structures using such photometric measurements devices take photometric measurements in one or more sub-areas of

the image to be captured. The measurements of the various sub-images are then processed to determine a level which the image sensitive material should be exposed to electromagnetic radiation. The image undergoes a second processing stage where the image is then captured by exposing the solid-state image sensor device, to the incoming electromagnetic radiation for the pre-calculated exposure time.

[0017]   However, because the photometric measurements are taken from a generally small subset of points within the image to be captured it is often sub-optimal; any visual attributes and/or artifacts of the sampling points are used to calculate an exposure level that is applied across the image. As a result, exposure times derived from such measurements are often inaccurate and the resulting processed image generally suffers. Another disadvantage of the described method is that it does not consider properties of the image sensor. For example, image sensors may react differently to different intensities of electromagnetic radiation. Blindly applying a weighting factor to the image sensors that does not take into account the gain characteristics of the image sensors may exacerbate the problem of providing an optimal output image.

[0018]   Summary of the Invention

[0019]   A solid-state pixel structure of the present invention includes an image sensor, means for measuring a response of the image sensor to a received electromagnetic radiation and means for reporting a state of the response of the image sensor to an exposure controller.

[0020]   According to another aspect of the invention, a pixel array includes an exposure controller and at least one group of pixel structures coupled to the exposure controller. Each group of pixel structures includes at least one pixel structure. The pixel structure includes an image sensor, means for measuring a response of the image sensor to received electromagnetic radiation; and means for reporting a state of the response to the exposure controller. The exposure controller analyzes the state of the response(s) to determine whether the state of the response(s) indicates that an exposure termination triggering event has occurred.

[0021]   According to another aspect of the invention, a method of controlling exposure of a group

of pixel structures to electromagnetic radiation is provided. The group of pixel structures

comprising at least one pixel structure and each pixel structure having an image sensor. The

method includes the steps of at least one pixel structure in the group of pixels measuring a

response of an associated image sensor to received electromagnetic radiation and analyzing a

state received from at least one pixel structure in the group, the state associated with a measured

response to the image sensor of at least one pixel structure, the step of analyzing to determine

whether the state of the response indicates that an exposure termination triggering event has

occurred, and terminating exposure of the group of pixels structures to the electromagnetic

radiation in response to the exposure termination event.

[0022]   With such an arrangement, pixel structure exposure can be controlled in real-time to

allow for optimal image capture. These and other advantages of the invention will become

evident upon reading the description below, in conjunction with the attached figures, which

describe:

[0023]   Brief Description of the Figures

[0024]   Figures 1A-1C illustrate transfer curves of pixel structure response in respective

overexposed, underexposed and correctly exposed conditions;

[0025]   Figures 2A-2C are histograms provided to illustrate the distribution of pixel intensities of

respective overexposed, underexposed and correctly exposed captured images;

[0026]   Figure 3 illustrates an exemplary pixel array structure of the prior art;

[0027]   Figure 4 is a exemplary functionally equivalent block diagram of a typical pixel structure

followed by an ADC and a DSP;

[0028]   Figure 5 is a exemplary functionally equivalent circuit diagram of a typical pixel

structure;

[0029]   Figure 6 is a diagram of a solid state pixel array of the present invention, with integrated

exposure control;

[0030]   Figure 7 is a exemplary block diagram illustrating exemplary components and

communication buses that may be included in a solid state pixel structure of the present

invention;

[0031]   Figure 8 is an exemplary circuit and block circuit diagram of one embodiment of the

solid state pixel structure of Figure 7;

[0032]   Figure 9 is a functional flow diagram provided to illustrate exemplary steps that may be

taken in the exposure control process of the present invention;

[0033]   Figure 10 illustrates a second embodiment of a solid state pixel array incorporating

integrated exposure control of the present invention;

[0034]   Figure 11 illustrates a third embodiment of a solid state pixel array incorporating

integrated exposure control of the present invention; and

[0035]   Figure 12 illustrates a fourth embodiment of a solid state pixel array incorporating

integrated exposure control of the present invention.

[0036]   Detailed Description

[0037]   According to one aspect of the invention, a solid-state pixel structure or pixel array

includes integrated exposure control provided within the pixel structure and/or pixel array.

Including exposure control within the pixel structure and/or array allows optimal exposure to be

achieved in real time.   Optimal exposure is achieved by measuring the response of pixel

structures to received electromagnetic radiation, and using the response information, in

conjunction with knowledge regarding the pixel structure capabilities and photometric

thresholds, to determine when the pixel structure is operating optimally.

[0038]   In one embodiment, each solid state pixel structure is capable of photometric

measurement. The measurements characterize the response of the pixel structure to the

electromagnetic radiation. By including photometric measurement capability within the solid-

state pixel structure, pixel exposure may be monitored and tightly controlled during image

capture. The solid state pixel structure includes reporting logic for reporting exposure response

characteristics to an exposure controller. The exposure controller terminates exposure when the

exposure response characteristics indicate that an image with optimal exposure has been

captured. The measurement and reporting logic of the solid state pixel structure provide

dynamic feedback to the exposure controller logic to ensure that the pixel structure is optimally

exposed to the electromagnetic radiation, taking into account the real time response of the pixel

structure. Exposure complexity and power consumption is reduced because exposure

measurements can be handled during image capture, rather than as a separate process.

[0039]   The advantages of the present invention can best be described by comparison with typical

solid state pixel structure operation as described in Figures 4 and 5. For example, Figure 4 is a

block diagram illustrating several components that are included in a typical digital image capture

device. A signal source 20 is coupled to a signal processing chain that includes an integrator 21,

analog to digital converter (ADC) 22 and digital signal processor (DSP) 23. Signal source 20 is a

light intensity sensor that generates an electrical response in response to electromagnetic

radiation, such as light impinging upon it then sensor 20 and integrator 21 from the core of a

typical CMOS pixel structure. Sensor 20 may be used in timed applications, such as in digital

camera applications where the sensor is exposed to light for a specific duration of time,

commonly referred to as the exposure time. The integrator 21 serves to integrate the response of

sensor 20 caused by all photons received during the exposure time into one value, such as for

example a voltage, to be read-out at the end of the exposure time.

[0040]   Figure 5 illustrates in more detail a typical image sensor assembly circuit. Signal source

30 is a light sensor that by way of example can be said to be a photodiode. Capacitor 34 is a

simple integrator. The input to the integrator is the output of signal source 30. Capacitor 34 is

reset by switch 35 which is in the closed position prior to starting the integration process. At the

start of the integration process switch 35 opens and the voltage across capacitor 34 begins to

change in response to the input signal originating from signal source 30. At the end of the integration process switch 33 closes and integrator output 36, V_{OUT}, is sampled.

[0041]   Integrator output 36, V_{OUT}, cannot in general exceed the upper limit imposed by the available power supply voltage. Power supply voltages are decreasing in state-of-the-art equipment due to stringent power consumption requirements. Integrator output 36 cannot exceed the power supply voltage and will saturate if the integrator output signal continues to build after reaching the power supply voltage level. Saturation occurs when the output voltage reaches the available power supply voltage and is unable to respond to further changes in the input signal.

[0042]   The pixel dynamic range, as limited by the integrator, requires careful consideration when setting the exposure time. An exposure time that is too small will prohibit the output of one or more pixels from rising sufficiently high and above the noise floor. An exposure time that is too large will cause the output of one or more pixels to saturate.

[0043]   As mentioned with regard to Figures 1C and 2C, optimal array operation is obtained when all array pixels operate in their linear output range (do not saturate) and generate an output voltage that is above the electronic noise floor. In order to generate an output voltage that is above the electronic noise floor the gain of the pixel structure should be sufficiently high to generate a sufficient output voltage when illuminated by the minimum value of the operational range specified for the electromagnetic radiation intensity. This determines the sensitivity of the pixel structure. The dynamic range of the pixel structure should be sufficiently high in order to always operate in the linear region and not saturate its output when illuminated by electromagnetic radiation intensity having the maximum value of the operational range for the structure.

[0044]   The present invention recognizes the value of integrating exposure control within the pixel structure, pixel array, or combination thereof. As will be seen below, the integration of exposure control into the pixel structure and/or pixel array allows for optimal image capture with minimal complexity and power consumption. The present invention may be embodied in many

different forms, at many different granularities. The embodiments are representative of a subset

of equivalent embodiments of the present invention, and the invention is not limited to the

disclosed embodiments.

[0045]   Figure 6 illustrates one embodiment of the present invention, in which each pixel such as

for example pixel 101 incorporates additional logic capable of reporting when the pixel output

has reached specific reportable states. The reportable states that are indicated by the logic are a

matter of design choice, and may include, but are not limited to, such states as: the pixel output

level has reached the minimum required level, the pixel output level has reached saturation level,

the pixel output level has reached a first specific state higher than the minimum required level

and lower than saturation, the pixel output level has reached a second specific state that is higher

than the minimum required level, lower than saturation and different than the first specific state,

the pixel output level has reached a first combination of the above states, and/or the pixel output

level has reached a second combination of the above states.

[0046]   The state information is forwarded to Function Block 102. Function block 102, in one

embodiment, communicates with system components external to the pixel array 100 via interface

bus 103. The function block 102 is advantageously dynamically programmable, although this is

not a requirement. In one embodiment, the function block may be programmed to detect

exposure termination trigger conditions. The exposure termination trigger conditions can be

selected a priori to the image capture process, or alternatively can be adaptively selected in

response to incoming information from the image capture process. By way of example potential

preset exposure termination conditions include but are not limited to: an indication that the

maximum exposure time that has been set a priori has been reached, an indication that all pixels

reported that minimum output voltage has been reached and one pixel reported that its output

voltage saturation value has been reached, an indication that a preset number of pixels reported

that output saturation voltage has been reached, an indication that a preset number of pixels

reported that minimum output voltage has been reached, an indication that a number of pixels

larger than a first preset threshold reported that output saturation voltage has been reached and a

number of pixels larger than a second preset threshold reported that minimum output voltage has

been reached, and an indication that a combination of exposure termination conditions has

occurred.

[0047]   Figure 7 is a block diagram illustrating components that may be included in a solid-state

pixel structure of the invention. As illustrated in Figure 7, the pixel structure includes a means,

responsive to signal source 50 and integrator 51 that contains the means necessary to generate a

status report for forwarding to function block 102. The status report may take any variety of

forms depending upon the information that is desired to be communicated between the pixel

structure and the function block. For example, in a simplest embodiment, the status report may

comprise a trigger signal which when asserted indicates that the pixel has reached a specific state

that might in turn indicate the existence of the exposure termination triggering condition. In

more complex embodiments, the signal may be encoded, on a serial or multi-bit bus based on a

pre-determined communication protocol. Other techniques of communicating data between

points in an array may be substituted herein without affecting the scope of the present invention.

[0048]   Figure 8 provides a more detailed diagram of one embodiment of a solid state pixel

structure 62 of the present invention. The structure 62 is similar to that described with regard to

Figure 5, but includes photometric measurement and reporting logic 63 of the present invention.

The photometric measurement and reporting logic in one embodiment is dynamically

programmable, with the function block including the capability to customize the end of exposure

criteria and exposure triggering thresholds of the logic 63 via external input 55. The

measurement and reporting logic 63 can be dedicated to one pixel or can serve more than one

pixel. When the measurement and reporting logic 63 serves more than one pixel the additional

data indicative of the state of the additional pixels is input to the measurement and reporting

logic 63 via additional connections. Connectors 68 and 69 are exemplary connectors that bring

additional pixel state data to the measurement and reporting logic 63. When the measurement

and reporting logic 63 serves more than one pixel the number of additional connections varies according to the implementation specifics. The photometric measurement and reporting logic 63 can operate according to preset or adaptive algorithms. When cost and simplicity of operation is are major considerations the operation of the measurement and reporting logic 63 can be preset and not subject to change. When superior image sensor performance is a major consideration the operation of the measurement and reporting logic 63 can be adaptive and subject to change in response to external commands. Input 55 serves to change the operation of the measurement and reporting logic 63 in response to external commands. The mode of operation of the measurement and reporting logic 63 can be changed via selection among a number of previously programmed modes of operation or via programming a new mode of operation. In an exemplary embodiment, the measurement and reporting logic 63 monitors one or both of the pixel output signal voltage and the Reset/Enable command. Based on either or the combination of the two, and on the programmed trigger conditions for the structure, the measurement and reporting logic 63 provides status signals to the function block 102 to indicate the presence of certain characteristics at the solid-state structure, wherein the characteristics may be the voltage level, voltage level to saturation level ratio, etc. The programmed trigger conditions may take into consideration photometric data when determining trigger thresholds.

[0049]   Figure 8 thus illustrates how measurement and reporting capabilities may be incorporated in a CMOS image sensor such as that of Figure 5. However, the present invention is not limited to use with only CMOS image sensors, or for that matter to digital image sensors. Rather, the concept of measuring responses to electromagnetic radiation, and using the measurements in conjunction with knowledge including knowledge regarding sensor behavior to control exposure can be used in conjunction with any image sensitive device. In one embodiment of the invention, a pixel structure includes a sensor device comprising a high resolution and wide dynamic range such as that described in patent application serial number _____ (attorney docket number 680-008U), entitled "SYSTEM AND METHOD

FOR A HIGH DYNAMIC RANGE SENSITIVE SENSOR ELEMENT OR ARRAY" by

Davidovici, incorporated herein by reference. In an alternate embodiment, a pixel structure

includes a sensor device such as that disclosed in patent serial number

(attorney docket number 680-010) entitled "SYSTEM AND METHOD FOR A HIGH

DYNAMIC RANGE SENSITIVE SENSOR ELEMENT OR ARRAY WITH GAIN

CONTROL" filed on even date herewith by Davidovici, incorporated herein by reference.

[0050]   Figure 9 includes a pair of functional flow diagrams that are provided to illustrate steps

that may be performed by the function block 102 and measurement and reporting logic of pixel

101, as well as exemplary communications that may occur between the components. Process 70

includes steps that may be performed by the function block 102, while process 80 illustrates

steps that may be performed by the measurement and reporting logic 80. It should be noted that

Figure 9 is meant as an illustrative, not limiting, example which in its equivalents may take many

different forms, and have portions of which are controlled by hardware, software, or a

combination thereof.

[0051]   The function block process initiates at step 72 when pixel structure exposure is initiated,

for example when the camera trigger is depressed. The function block proceeds to step 73,

where it gathers status reports from groups of pixels, each group including one or more pixels.

[0052]   The measurement and reporting block initiates processing when the image sensor

becomes active at step 82. For example, it may detect a voltage from the image sensor. At step

84, sensor measurements are monitored or collected to determine when the pixel structure is at a

reportable state. When it is determined that the pixel structure is at a reportable state, the state is

reported, and step 88 to the function block.

[0053]   The function block 102, 240, 340, 440 analyzes the status reports, received from one or

more pixel structures to determine when an exposure termination trigger event has occurred.

When the triggering event has occurred, the function block terminates the exposure at step 76.

The function block may terminate exposure for one or more pixels in the pixel array based on the

triggering conditions, and thus the present invention is not limited to any exposure termination granularity. At step 78, the captured image is recorded in a storage medium.

[0054]   The above described approach to exposure time determination has the major benefit that the exposure time setting is performed while the image is captured (or acquired) thus attaining maximum accuracy. The flexibility to determine the exposure termination condition as the image capture process is on-going has the benefit of allowing the exposure time to be adaptive and matched to the characteristics of the image to be captured.

[0055]   The embodiment described with regard to Figure 6, which includes photometric measuring and reporting in each pixel structure is relatively complex due to the large number of pixels contained within commercially available pixel arrays. Meaningful images that are commonly the object of image capture such as might be the case in digital still photography or video cameras exhibit a high correlation between adjacent pixels. The high adjacent pixel correlation renders much of the reported pixel output data redundant.

[0056]   Figure 10 illustrates another embodiment of the present invention, wherein a pixel array 200 is arranged with fewer than all pixels reporting the state of their output. The reporting pixels exemplified by pixels 230, 210 and 220 can be arranged in a regular or in a random pattern throughout the pixel array. High correlation between adjacent pixels is used to limit the number of reporting pixels with minimal degradation of the image capture process. Thus, the lower limit of the number of reporting pixels can be one and the upper limit of the number of reporting pixels can equal the size of the array.

[0057]   Figure 11 illustrates yet another embodiment of the invention, having reduced the complexity as compared to the embodiments of Figures 6 and 10. In Figure 11, a pixel array 300 is apportioned into pixel groups so that the pixels that are capable of reporting the state of their output are grouped together. A group of pixels capable of output state reporting can contain as few as two pixels and as many as the number of pixels contained in the array, however all groups contain an identical number of pixels. The reporting pixel groups exemplified by pixel groups

330, 310 and 320 that contain four pixels can be arranged in a regular or in a random pattern throughout the pixel array. The lower limit of the number of reporting pixels can be one and the upper limit of the number of reporting pixels can equal the size of the array divided by two.

[0058]   Figure 12 illustrates yet another embodiment of the invention, wherein the pixels that are capable of reporting the state of their output are grouped together. A group of pixels capable of output state reporting can contain as few as one pixel and as many as the number of pixels contained in the array. The embodiment of Figure 12 differs from that of Figure 11, as groups may vary in size. The reporting pixel groups exemplified by pixel groups 430, 410 and 420 contain one, four and a number larger than four pixels, respectively, and can be arranged in a regular or in a random pattern throughout the pixel array. The lower limit of the number of reporting pixel groups can be one and the upper limit of the number of reporting pixel groups can equal the size of the array.

[0059]   Accordingly, a method and apparatus for controlling pixel array exposure time using pixel structures and arrays having integrated exposure control has been shown and described in various embodiments. Accordingly, the present invention overcomes the problems of the prior art by providing an improved image sensor which includes photometric measuring and reporting capability. The measuring and reporting capability can be used to control the exposure of the image sensor to the electromagnetic radiation, thereby enabling exposure to be terminated when the image sensor has reached an optimum exposure point or some other triggering threshold level. In addition, it allows exposure to be controlled in real-time, rather than as a secondary process performed on the image after capture.

[0060]   There are numerous benefits of the present invention. The first benefit is the inherent accuracy of the approach described herein where the data used to determine the pixel array exposure is extracted from the image being captured in real time simultaneously with the capture process. A second benefit is that incorporating the photometric measurement capability into the pixel structure itself ensures that any gain characteristics of the solid-state image sensor are

considered when determining appropriate exposure levels. Reduced power consumption due to

the elimination of the double capture process required to determine the exposure time in one

commonly used approach is a third benefit. These and other benefits of the present invention are

obvious to one conversant with the art.

[0061]   Having described various embodiments of the invention, it will be appreciated that many

of the above figures are flowchart illustrations of methods, apparatus (systems) and computer

program products according to an embodiment of the invention. It will be understood that each

block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations, can

be implemented by computer program instructions. These computer program instructions may be

loaded onto a computer or other programmable data processing apparatus to produce a machine,

such that the instructions which execute on the computer or other programmable data processing

apparatus create means for implementing the functions specified in the flowchart block or

blocks. These computer program instructions may also be stored in a computer-readable memory

that can direct a computer or other programmable data processing apparatus to function in a

particular manner, such that the instructions stored in the computer-readable memory produce an

article of manufacture including instruction means which implement the function specified in the

flowchart block or blocks. The computer program instructions may also be loaded onto a

computer or other programmable data processing apparatus to cause a series of operational steps

to be performed on the computer or other programmable apparatus to produce a computer

implemented process such that the instructions which execute on the computer or other

programmable apparatus provide steps for implementing the functions specified in the flowchart

block or blocks.

[0062]   Those skilled in the art should readily appreciate that programs defining the functions of

the present invention can be delivered to a computer in many forms; including, but not limited

to: (a) information permanently stored on non-writable storage media (e.g. read only memory

devices within a computer such as ROM or CD-ROM disks readable by a computer I/O

attachment); (b) information alterably stored on writable storage media (e.g. floppy disks and hard drives); or (c) information conveyed to a computer through communication media for example using baseband signaling or broadband signaling techniques, including carrier wave signaling techniques, such as over computer or telephone networks via a modem

[0063]   The above description and figures have included various process steps and components that are illustrative of operations that are performed by the present invention. However, although certain components and steps have been described, it is understood that the descriptions are representative only, other functional delineations or additional steps and components can be added by one of skill in the art, and thus the present invention should not be limited to the specific embodiments disclosed. In addition it is understood that the various representational elements may be implemented in hardware, software running on a computer, or a combination thereof.

[0064]   While the invention is described through the above exemplary embodiments, it will be understood by those of ordinary skill in the art that modification to and variation of the illustrated embodiments may be made without departing from the inventive concepts herein disclosed. Accordingly, the invention should not be viewed as limited except by the scope and spirit of the appended claims.

CLAIMS:

1.   A reporting pixel structure comprising:

an image sensor;

means for measuring a response of the image sensor to a received electromagnetic radiation; and

means for providing a report of the response of the image sensor to an exposure controller.

2.   A pixel array comprising:

at least one reporting group of pixel structures   including at least one pixel structure comprising:

an image sensor,

means for measuring a response of the image sensor to received electromagnetic radiation; and

means for providing a report of the response to an exposure controller.

3.   The method according to claim 2 wherein the exposure controller is integrated in the pixel array and processes the report to determine whether an exposure termination triggering event has occurred.

4.   The method according to claim 2 wherein the exposure controller is coupled to the pixel array and processes the report to determine whether an exposure termination triggering event has occurred.

5.   The pixel array of claim 2, wherein each reporting group of pixels provides one report to the exposure controller.

6.   The pixel array of claim 5 wherein the exposure controller processes one report forwarded from one selected group of pixels in the pixel array to determine exposure for the pixel array.

7.   The pixel array of claim 6, wherein the one report reports a response of one of the pixels in the group of pixels.

8.   The pixel array of claim 6 wherein the one report reports a response of more than one of the pixels in the group of pixels.

9.   The pixel array of claim 5 wherein the exposure controller processes multiple reports to determine exposure for the pixel array, the multiple reports comprising one report provided by each pixel group of a plurality of pixel groups in the pixel array.

10.   The pixel array of claim 9, wherein at least one report reports a response of one of the pixels in the group of pixels associated with the at least one report.

11.   The pixel array of claim 9 wherein at least one report reports a response of more than one of the pixels in the group of pixels associated with the at least one report.

12.   The pixel array of claim 9, wherein at least two reports provided by an associated at least two groups report responses from different numbers of pixels in the associated at least two groups.

13.   The pixel array of claim 2, wherein a plurality of reporting group of pixels each provide a set of multiple reports to the exposure controller.

14.   The pixel array of claim 13 wherein the exposure controller processes one set of multiple reports to determine exposure for the pixel array.

15.   The pixel array of claim 14, wherein the one set of multiple reports includes a report for a response of one of the pixels in the associated group of pixels.

16.   The pixel array of claim 14 wherein the one set of multiple reports includes a report of a response of more than one of the pixels in the associated group of pixels.

17.   The pixel array of claim 13 the exposure controller processes multiple sets of multiple reports to determine exposure for the pixel array.

18.   The pixel array of claim 17, wherein one of the multiple reports includes a report of a response of one of the pixels in an associated group of pixels.

19.   The pixel array of claim 17 wherein one of the multiple reports includes a report of a response of more than one of the pixels in the associated group of pixels.

20.   The pixel array of claim 17, wherein at least two of the multiple reports provided by an associated at least two groups report responses from different numbers of pixels in the associated at least two groups.

21.   The pixel array of claim 2, wherein the exposure termination triggering event includes at least one of an indication that a maximum exposure time set a priori has been reached, an indication that all pixels in the pixel array have reported that a minimum output signal has been reached, an indication that at least one pixel has reported that its output saturation value has been reached, an indication that a preset number of pixels reported that output signal saturation value has been reached, an indication that a preset number of pixels reported that minimum output signal has been reached, an indication that a number of pixels larger than a first preset threshold reported that output signal saturation value has been reached and a number of pixels larger than a second preset threshold reported that minimum output signal has been reached, and an indication that a combination of exposure termination conditions has occurred.

22.   A method of controlling exposure of a pixel array comprising a plurality of groups of pixel structures, at least one of the groups including at least one reporting pixel structure, the method including the step of:

    processing a report received from a group of pixel structures including a reporting pixel structure to determine whether an exposure termination triggering event has occurred, and

    terminating exposure of the pixel array in response to the occurrence of the exposure termination event.

23. The method of claim 22, wherein each group of pixels that includes a reporting pixel generates one report for processing.

24.   The method of claim 23 wherein the step of terminating exposure is responsive to only one of the reports.

25.   The method of claim 24, wherein the one report reports a response of one of the pixels in the group of pixels.

26.   The method of claim 24 wherein the one report reports a response of more than one of the pixels in the group of pixels.

27.   The method of 23 wherein the step of terminating exposure is responsive to more than one report received from groups of pixels that include a reporting pixel structure.

28.   The method of claim 27, wherein at least one report reports a response of one of the pixels in the group of pixels associated with the at least one report.

29.   The method of claim 27 wherein at least one report reports a response of more than one of the pixels in the group of pixels associated with the at least one report.

30.   The method of claim 27, wherein at least two reports provided by an associated at least two groups report responses from different numbers of pixels in the associated at least two groups.

31.   The method of claim 22, wherein at least one of the groups includes a plurality of reporting pixels, and wherein the step of terminating exposure operates in response to one or more sets of multiple reports received from one or more group of pixels.

32.   The method of claim 31 wherein the step of terminating exposure operates in response to only one set of multiple reports from one group of pixels.

33.   The method of claim 32 wherein the one set of multiple reports includes a report for a response of one of the pixels in the associated group of pixels.

34.   The method of claim 32 wherein the one set of multiple reports includes a report of a response of more than one of the pixels in the associated group of pixels.

35.   The method of claim 30 wherein the step of terminating exposure operates in response to multiple sets of multiple reports to determine exposure for the pixel array.

36.   The method of claim 35, wherein one set of the multiple reports includes a report of a response of one of the pixels in an associated group of pixels.

37.   The method of claim 35 wherein one set of the multiple reports includes a report of a response of more than one of the pixels in the associated group of pixels.

38.   The method of claim 35, wherein at least two sets of the multiple reports provided by an associated at least two groups report responses from different numbers of pixels in the associated at least two groups.

39.   The method of claim 22, wherein the exposure termination triggering event includes at least one of an indication that a maximum exposure time set a priori has been reached, an indication that all pixels in the pixel array have reported that a minimum output signal value has been reached, an indication that at least one pixel has reported that its output signal saturation value has been reached, an indication that a preset number of pixels reported that output signal saturation value has been reached, an indication that a preset number of pixels reported that minimum output signal value has been reached, an indication that a number of pixels larger than a first preset threshold reported that output signal saturation value has been reached and a number of pixels larger than a second preset threshold reported that minimum output signal value has been reached, and an indication that a combination of exposure termination conditions has occurred.

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
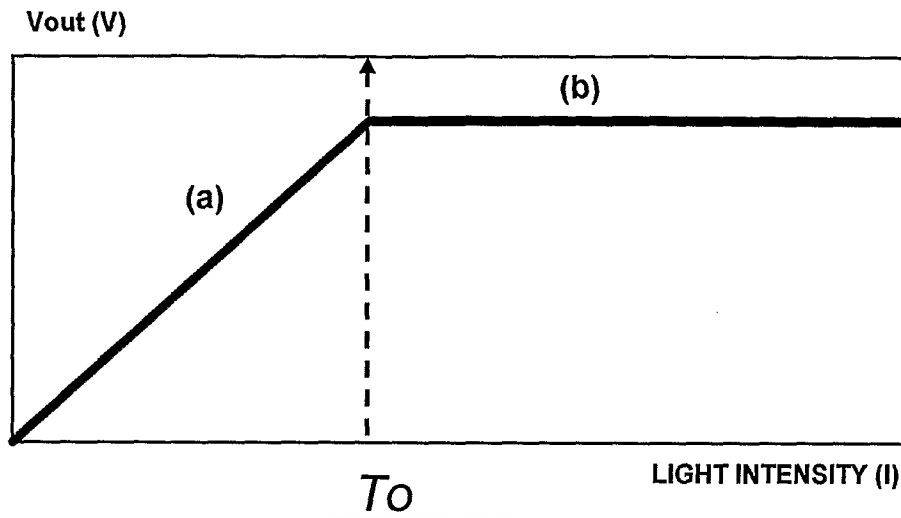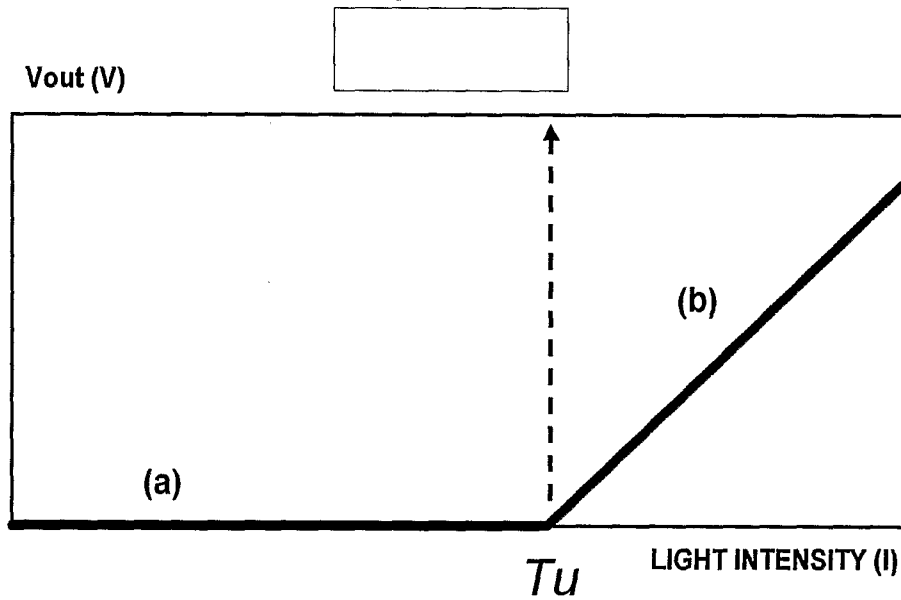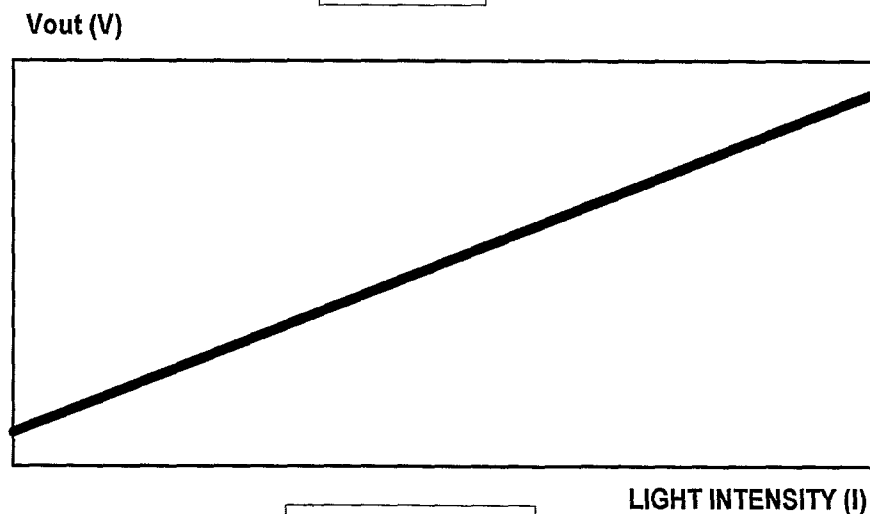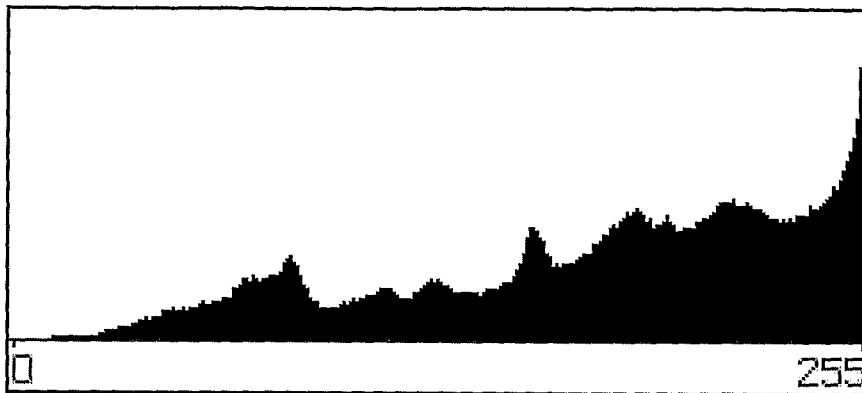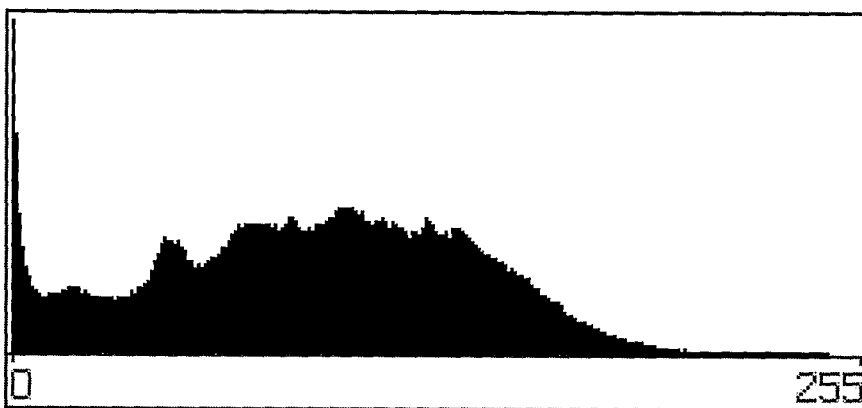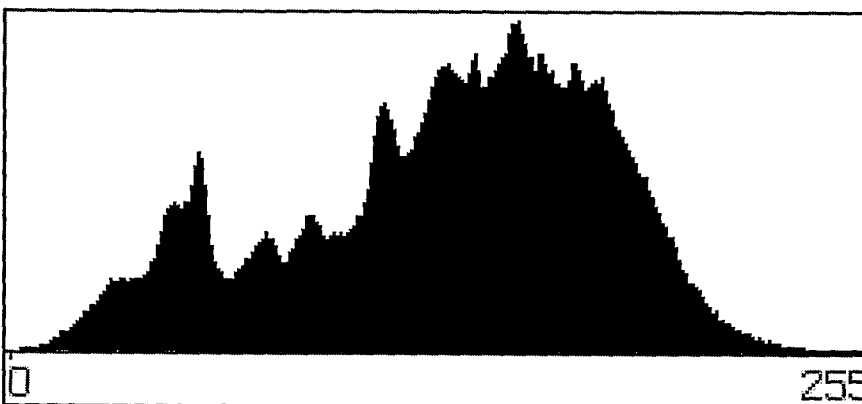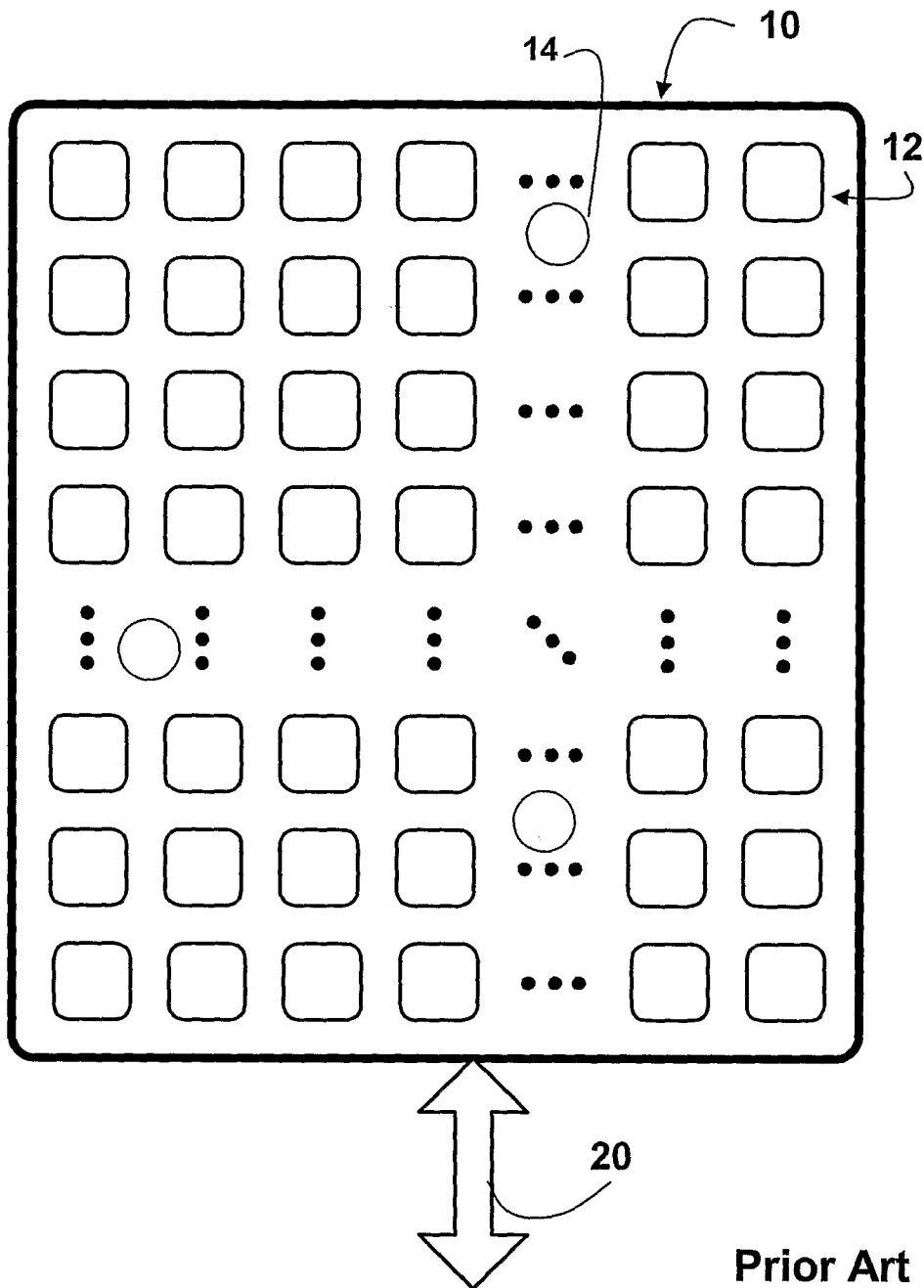Attorney Docket No.: 680-001
Sheet 1 of 12

Vout (V)

(b)

(a)

Figure 1A

To

LIGHT INTENSITY (I)

Vout (V)

(b)

(a)

Figure 1B

Tu   LIGHT INTENSITY (I)

Vout (V)

Figure 1C

LIGHT INTENSITY (I)

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
Attorney Docket No.: 680-001
Sheet 2 of 12

Figure 2A

Figure 2B

Figure 2C

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
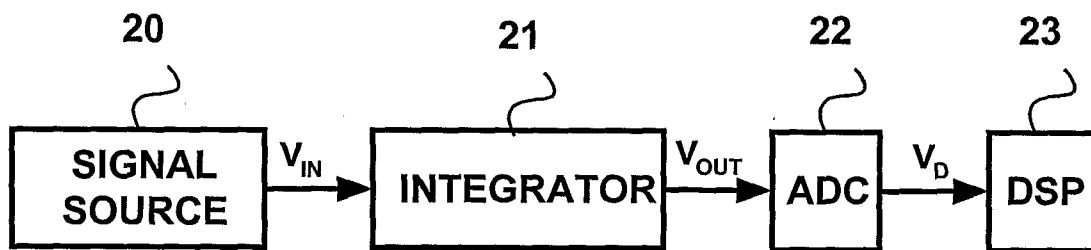Attorney Docket No.: 680-001
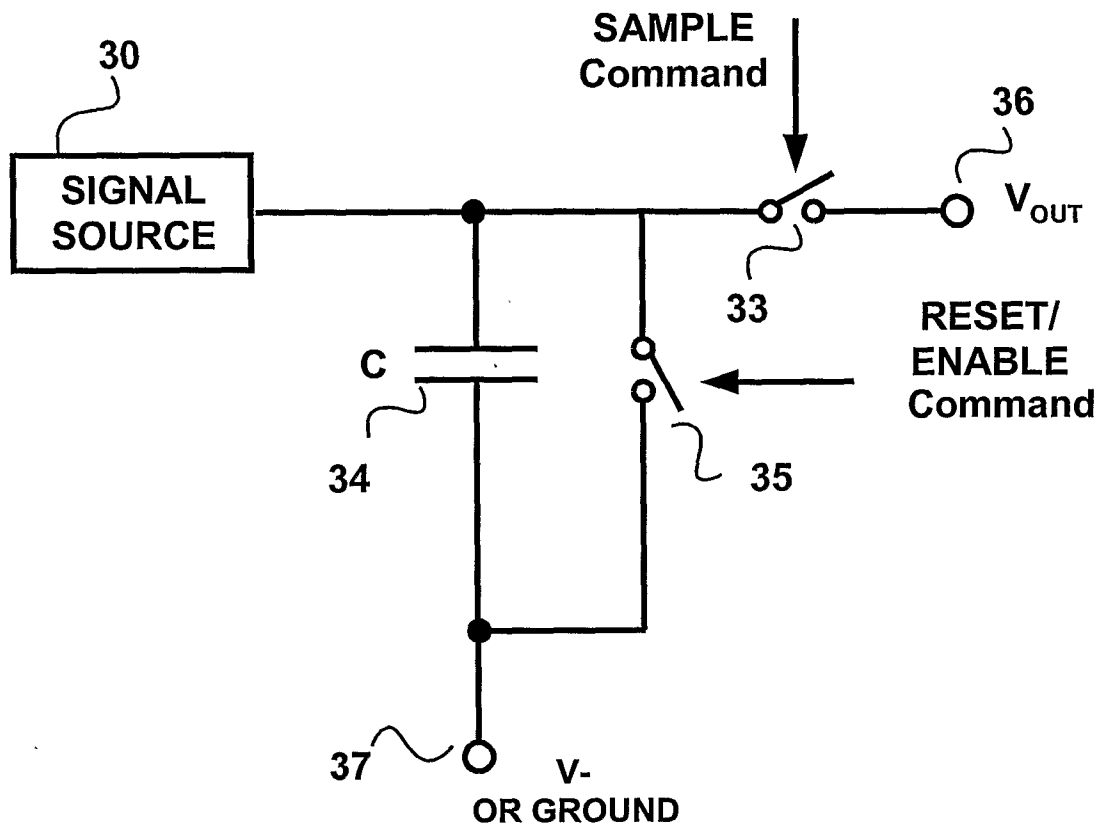Sheet 3 of 12

Prior Art

Figure 3

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
Attorney Docket No.: 680-001
Sheet 4 of 12

20 **21** **22** **23**

```
┌──────────┐        ┌──────────────┐        ┌──────┐       ┌──────┐
│  SIGNAL  │  V_IN  │              │  V_OUT │      │  V_D  │      │
│  SOURCE  │───────▶│  INTEGRATOR  │───────▶│ ADC  │──────▶│ DSP  │
│          │        │              │        │      │       │      │
└──────────┘        └──────────────┘        └──────┘       └──────┘
```

Figure 4

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
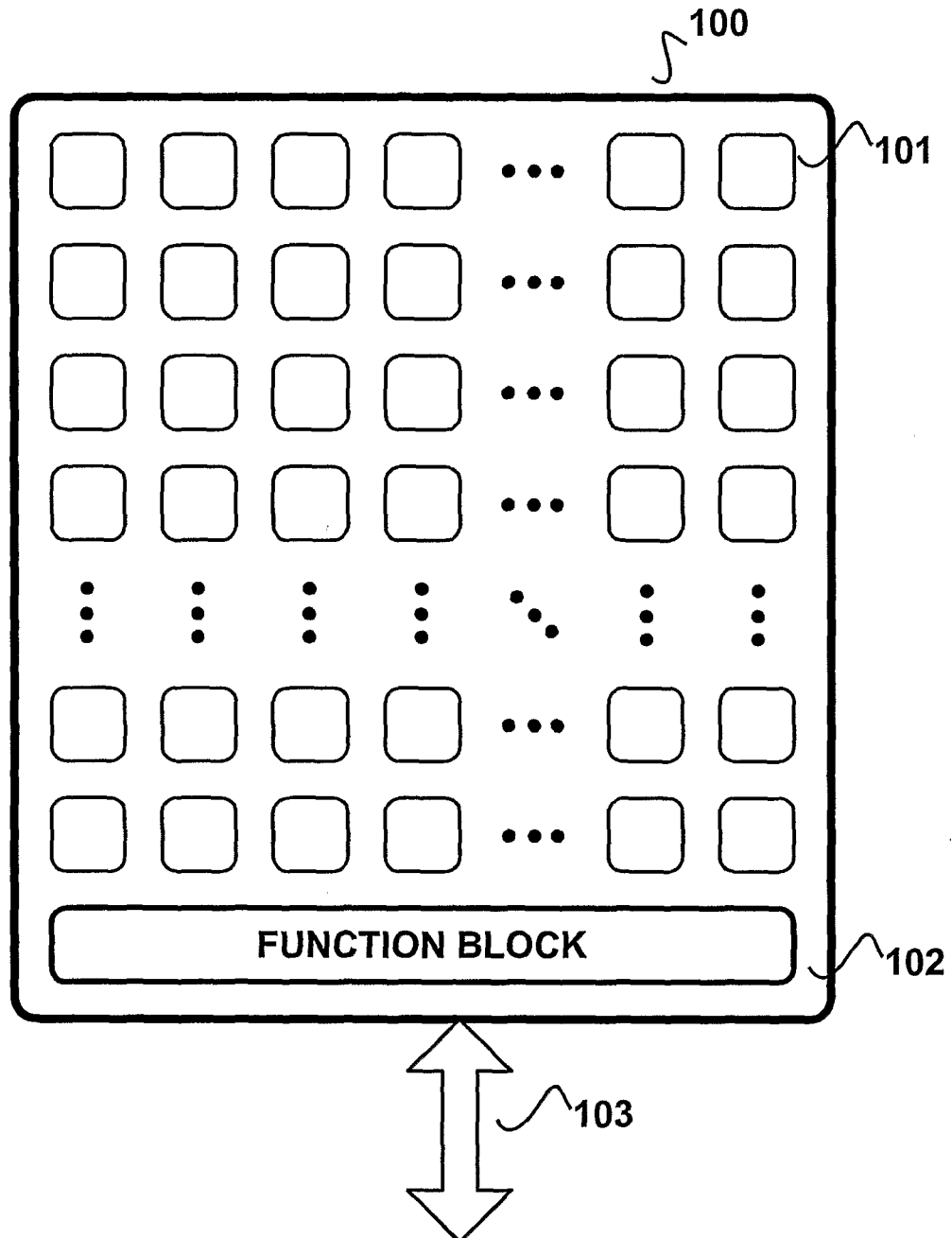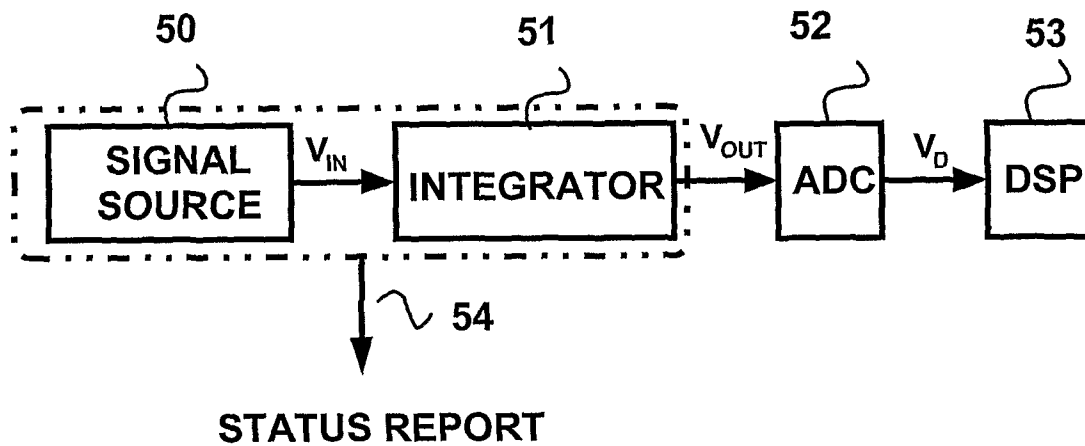PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
Attorney Docket No.: 680-001
Sheet 5 of 12

Figure 5

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
Attorney Docket No.: 680-001
Sheet 6 of 12

Figure 6

WO 2007/035860   PCT/US2006/036793

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
Attorney Docket No.: 680-001
Sheet 7 of 12

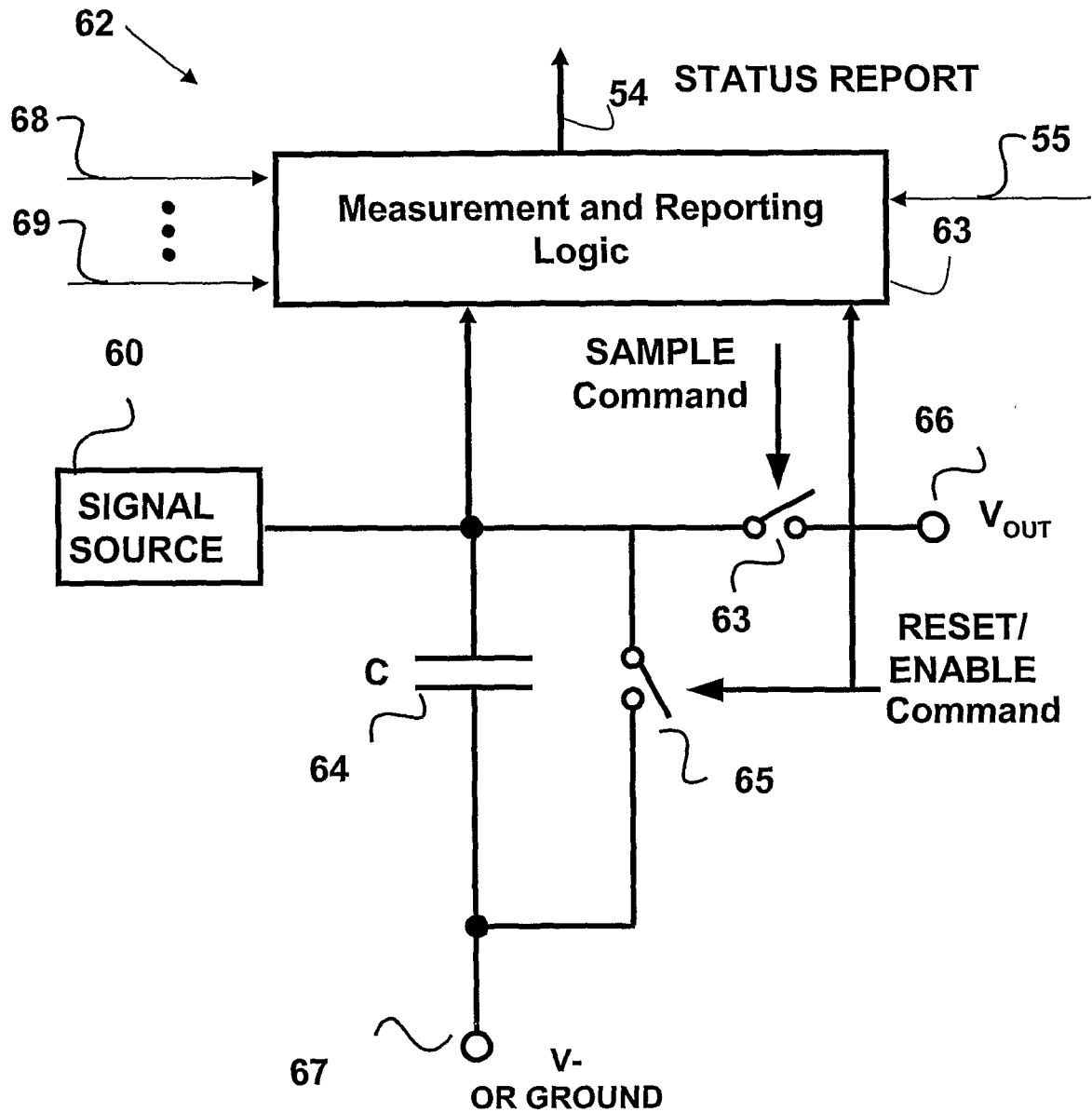50   51   52   53

SIGNAL SOURCE V_{IN} INTEGRATOR V_{OUT} ADC V_D DSP

54

STATUS REPORT

Figure 7

Figure 8

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
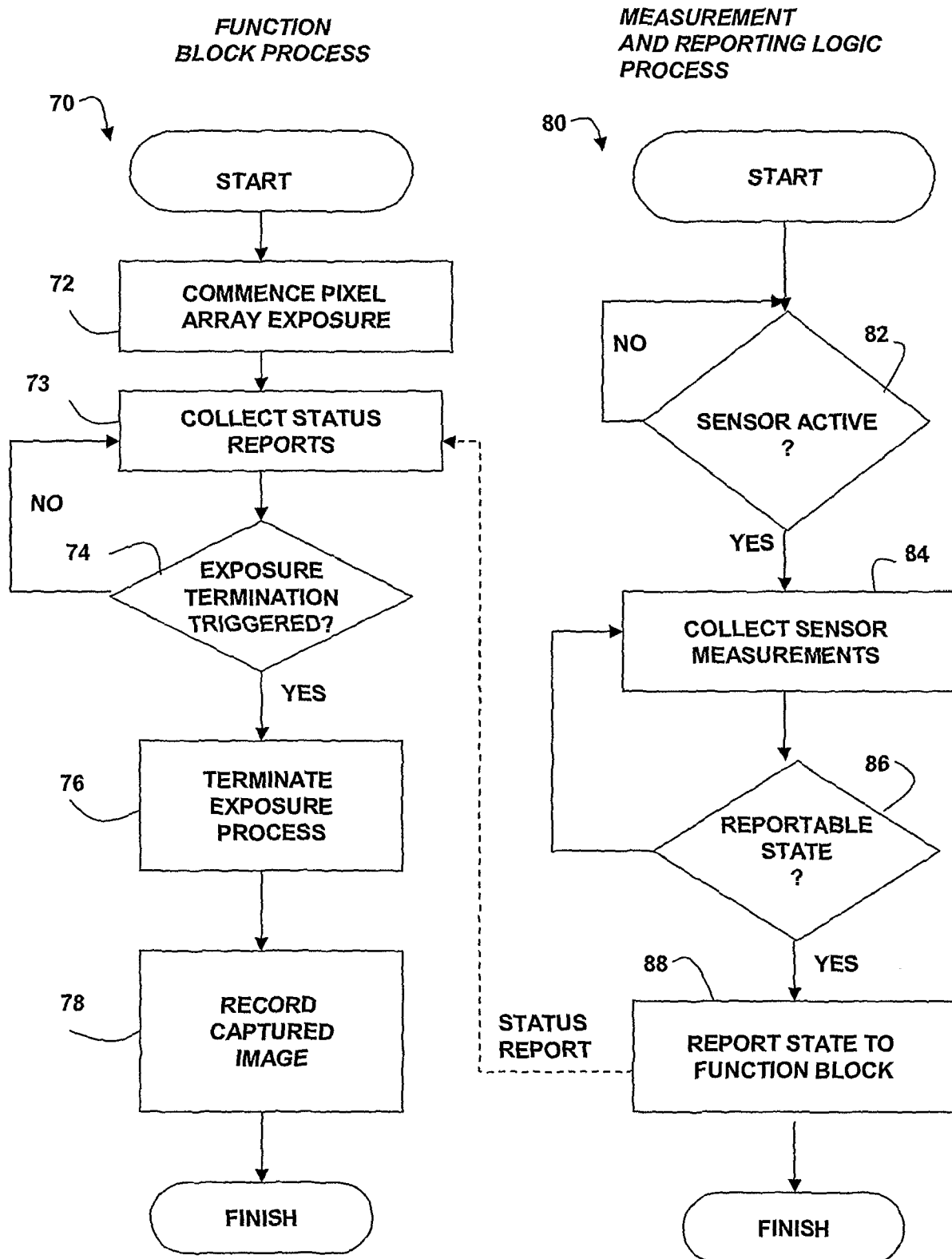Attorney Docket No.: 680-001
Sheet 9 of 12

FUNCTION
BLOCK PROCESS

MEASUREMENT
AND REPORTING LOGIC
PROCESS

70

START

72 — COMMENCE PIXEL
ARRAY EXPOSURE

73 — COLLECT STATUS
REPORTS

NO

74 — EXPOSURE
TERMINATION
TRIGGERED?

YES

76 — TERMINATE
EXPOSURE
PROCESS

78 — RECORD
CAPTURED
IMAGE

FINISH

80

START

NO

82 — SENSOR ACTIVE
?

YES

84 — COLLECT SENSOR
MEASUREMENTS

86 — REPORTABLE
STATE
?

YES

88 — REPORT STATE TO
FUNCTION BLOCK

STATUS
REPORT

FINISH

Figure 9

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
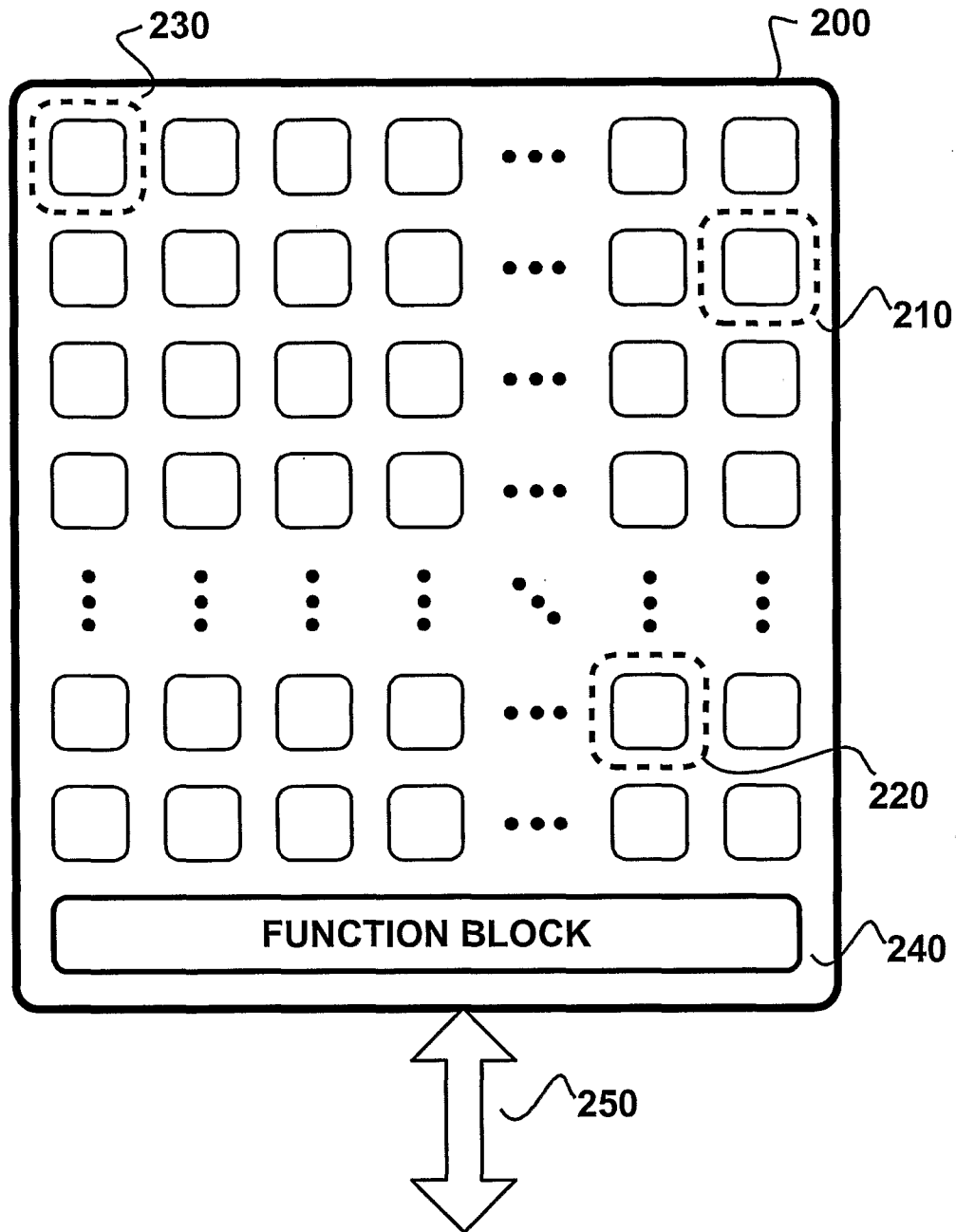Attorney Docket No.: 680-001
Sheet 10 of 12

Figure 10

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
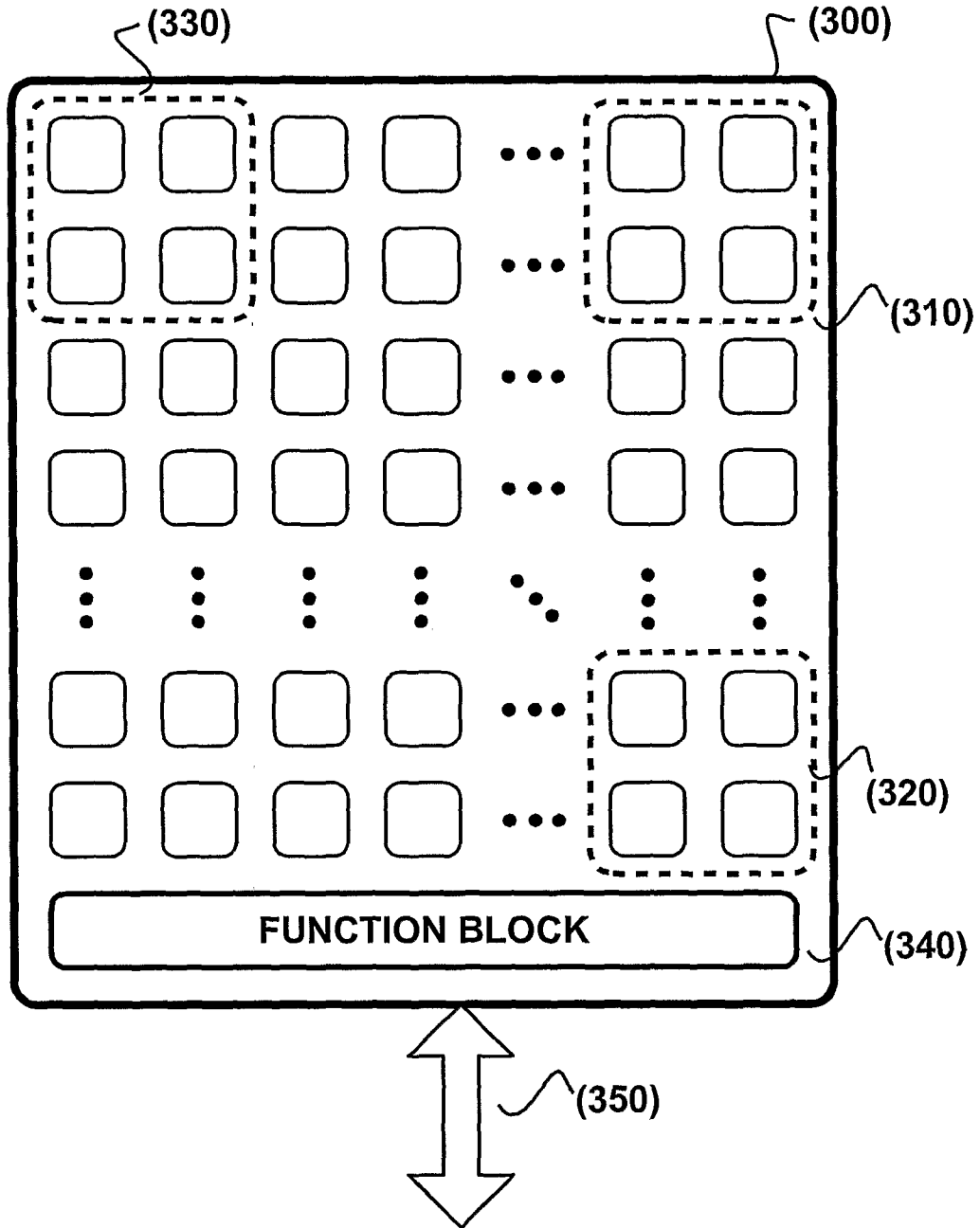Attorney Docket No.: 680-001
Sheet 11 of 12

FUNCTION BLOCK

Figure 11

SYSTEM AND METHOD FOR AN IMAGE SENSOR OR ARRAY WITH
PHOTOMETRIC AND REAL TIME REPORTING CAPABILITIES
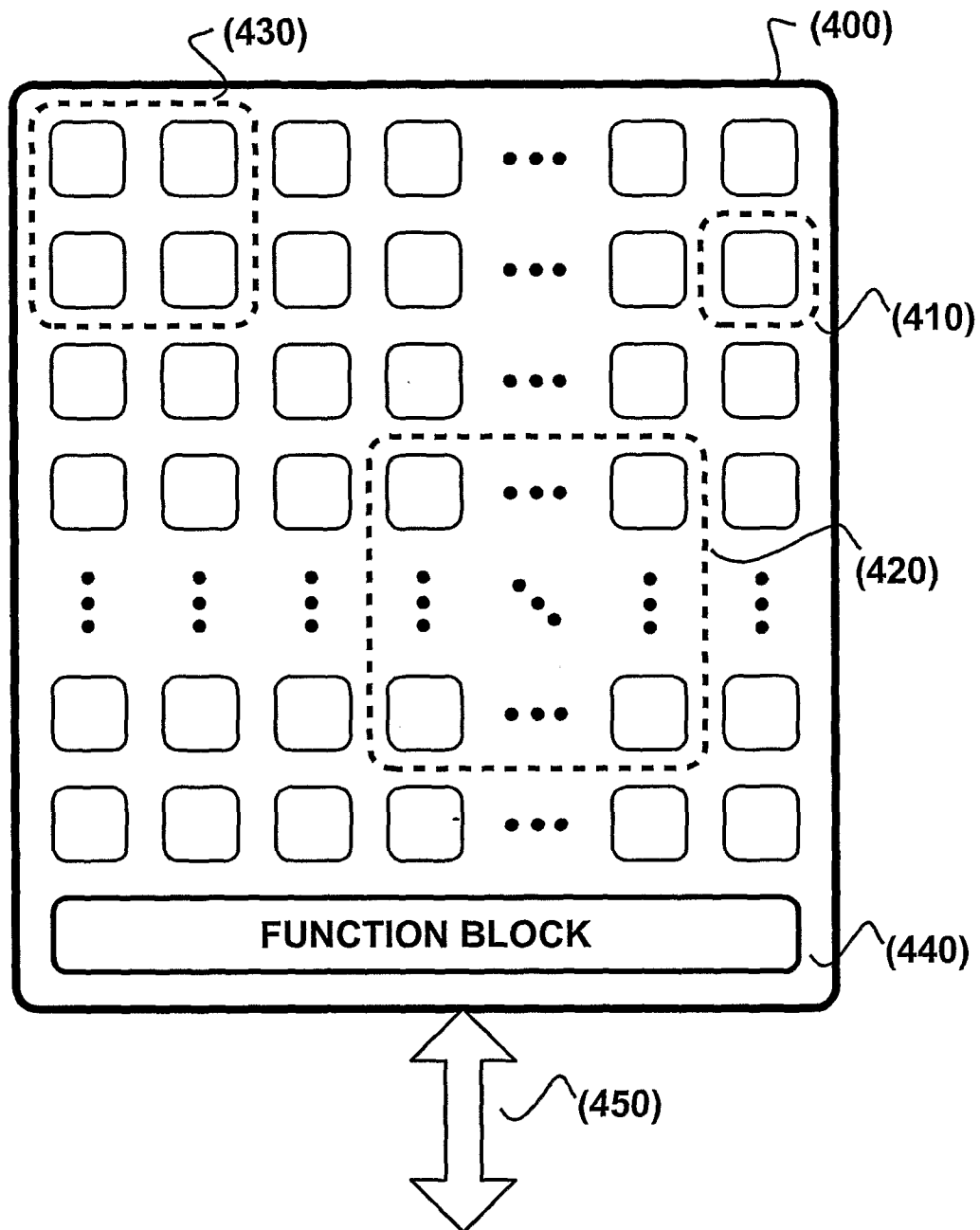Attorney Docket No.: 680-001
Sheet 12 of 12

Figure 12