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(54) **Title**: DETECTION SYSTEM AND DETECTOR ARRAY INTERCONNECT ASSEMBLIES

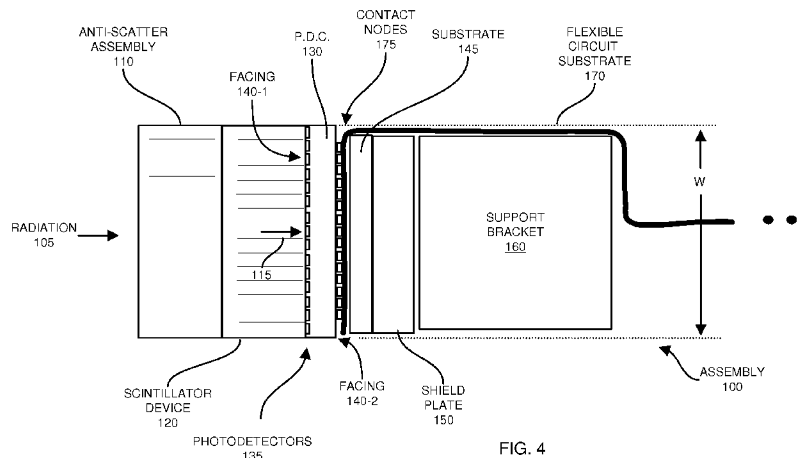


FIG. 4

(57) **Abstract**: The present disclosure includes multiple ways of providing photo-detector interconnectivity using, for example: a) single-layered thick or thin film ceramic substrate to change a node pitch from one facing to another, and/or b) direct bonding of photodiode circuit to a flex cable interconnect.

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# DETECTION SYSTEM AND DETECTOR ARRAY INTERCONNECT ASSEMBLIES

## BACKGROUND

The current trend in x-ray Computed Tomography (CT) imaging is toward high-
15 speed volume imaging, which requires that a large number of slices of image information be acquired simultaneously. Detector measurement systems (DMS) for these purposes present many challenges, as the number of channels quickly moves from ten thousand to hundreds of thousands and beyond.

The advent of high integration measurement integrated circuits (ICs), which
20 include upwards of 64 to 256 or more channels per chip, allows the design of smaller self-contained modules that can be assembled in yet larger arrays in both the X- and the Z-directions. The challenges presented by such modules include: transferring the regular connections of the photo-detector circuit array to the different connections required by the remaining components of the electronic circuitry, protecting nearby electronic
25 components from x-ray damage, preventing the heat generated by the electronic components from affecting the detectors, and so on. Further challenges include building in the requisite mechanical accuracy, and designing a module that can easily be constructed.

CT (Computed Tomography) detectors requiring large slice counts use
30 photodiodes with so-called back-contacts in order to overcome limitations of high density interconnects. For example, the current state-of-the-art CT detectors use a multi-layered ceramic substrate for electrically coupling the photodetectors to corresponding data acquisition electronics. Although the conventional multi-layered ceramic substrate

provides interconnectivity as well as provides a change in node density from one side of the ceramic substrate to the other, it is difficult and expensive to manufacture.

BRIEF DESCRIPTION OF EMBODIMENTS

5 In contrast to conventional applications, embodiments herein include multiple independent cost effective ways of providing photo-detector interconnectivity. For example, a first embodiment includes use of a single-layered thick or thin-film ceramic substrate to change a node pitch from one facing to another. A second embodiment includes direct bonding of a photodiode circuit to a flexible circuit substrate.

10 More specifically, one embodiment herein includes an assembly. The assembly comprises a photo-detector circuit and a flexible circuit substrate. The photo-detector circuit such as a p-i-n (a.k.a., a PIN photo diode array) photo-diode array includes an array of photo-detectors disposed on a circuit substrate. Additionally, the photo-detector circuit includes a first facing and a second facing. In one embodiment, each of the photo-
15 detectors of the photo-detector circuit includes a respective active region disposed on or near the first facing of the circuit substrate to detect optical energy. A corresponding facing of the flexible circuit substrate includes contact nodes. The second facing (opposite the first facing) of the photo-detector circuit is directly bonded to the contact nodes disposed on the facing of the flexible circuit substrate.

20 In accordance with another embodiment, an assembly comprises a photo-detector circuit, a flexible circuit substrate, and an interconnect substrate. The photo-detector circuit includes an array of photo-detectors disposed on a circuit substrate. A facing of the flexible circuit substrate includes an array of contact nodes. The interconnect substrate includes a first facing and a second facing. The first facing of the interconnect
25 substrate contacts the photo-detector circuit. The second facing of the interconnect substrate contacts the array of contact nodes on the flexible circuit substrate. The interconnect substrate includes conductive paths extending from the first facing to the second facing to provide interconnectivity between the array of photo-detectors on the photo-detector circuit and the array of contact nodes disposed on the flexible circuit

substrate. In contrast to conventional applications implementing a multi-layer substrate, in one embodiment, the interconnect substrate is a single layer substrate.

In yet further embodiments, an assembly as discussed herein comprises an array of active areas of a photo-detector circuit operable to detect presence of respective optical signals. Each active area of a photo-detector includes at least one contact element. The assembly further includes a flexible circuit substrate having a first end including an array of surface nodes disposed thereon. A single layer of material such as an interconnect substrate provides connectivity between the array of active areas on the photo-detector circuit and the array of surface nodes on the flexible circuit substrate. By way of a non-limiting example, the array of surface nodes (i.e., contact nodes) disposed on the flexible circuit substrate is more densely packed than corresponding a density of contact elements disposed on the photo-detector circuit. The single layer of material (e.g., interconnect substrate) provides a respective electrically conductive path between a contact element associated with an active area in the photo-detector circuit to a respective surface node of the flexible circuit substrate. In accordance with further embodiments, the single layer of material provides a change in pitch of nodes from one facing of the layer of material (e.g., interconnect substrate) to another.

Embodiments herein include methods implemented by one or more resources. A computed tomography detector includes a front-illuminated photodiode array and a flexible circuit substrate. A method as discussed herein comprises: Via a front-illuminated detection circuit, receive optical energy indicative of radiation that has traversed an examination region of interest in a computed tomography system. The front-illuminated detection circuit converts the received energy into electrical signals. The front-illuminated detection circuit transmits the electrical signals to a facing of a flexible circuit substrate. The front-illuminated detection circuit is directly bonded to a facing of the flexible circuit.

In accordance with yet further embodiments, the front-illuminated detection circuit receives the energy from a scintillator disposed in optical communication with the front-illuminated detection circuit. The front-illuminated detection circuit can be

disposed between the scintillator and the flexible circuit substrate. The scintillator converts received radiation into the energy.

The front-illuminated photo-detector circuit can be configured to transmit the electrical signals on multiple conductive paths fabricated on a substrate of the front-illuminated detection circuit. The multiple conductive paths can be configured to extend through the detection circuit from photodiodes detecting the energy to respective contact nodes disposed on the flexible circuit substrate.

In accordance with yet further embodiments, a respective pitch of photodiodes disposed in the front-illuminated detection circuit can be greater than a respective pitch of the contact nodes disposed on the flexible circuit substrate. The conductive paths through the detection circuit facilitate a change in pitch between the photodiodes and the respective contact nodes on the flexible circuit substrate.

The flexible circuit substrate conveys the electrical signals on the flexible circuit substrate to a remote circuit board. The flexible circuit substrate can include at least one bend greater than 45 degrees to provide connectivity between the remote circuit substrate and the photo-detector circuit.

Another embodiment includes a method comprising: receiving optical energy; converting the received optical energy into electrical signals; and transmitting the electrical signals through an interconnect substrate to a flexible circuit substrate, the interconnect substrate being a single layer substrate of material disposed between the photo-detector circuit and the flexible circuit substrate. The method can be implemented via a resource such as a photo-detector circuit coupled to the interconnect substrate.

The interconnect substrate conveys the electrical signals in the interconnect substrate on conductive paths extending from a first facing of the interconnect substrate to a second facing of the interconnect substrate. In such an embodiment, the conductive paths provide interconnectivity between an array of photo-detectors that receives the optical energy and an array of contact nodes disposed on the flexible circuit substrate.

In accordance with yet another embodiment, the interconnect substrate conveys the electrical signals on portions of substantially orthogonal electrically conductive paths extending through the single layer substrate from the first facing to the second facing.

In accordance with another embodiment, the photo-detector circuit receives the optical energy from a scintillator device. The scintillator device can be disposed adjacent to the photo-detector circuit. The photo-detector circuit receiving the optical energy can be sandwiched between the scintillator and the interconnect substrate.

5 In yet further embodiments, the photo-detector circuit or optical detector circuit transmits the electrical signals through at least one layer of conductive paths disposed on a surface of the interconnect substrate. The at least one layer of conductive paths electrically couple the photo-detector circuit to the flexible circuit substrate.

Further embodiments herein include a photo-detector circuit (e.g., optical detector 10 circuit) that transmits the electrical signals on conductive paths disposed in the interconnect substrate. A respective spatial density of first terminal ends of the conductive paths per unit of area on a first facing of the interconnect substrate is less than a spatial density of second terminal ends of the conductive paths per unit of area on a second facing. The second facing of the interconnect substrate can be coupled directly to 15 the flexible circuit substrate.

In accordance with one embodiment, the photo-detector circuit is a back-illuminated photo-detector circuit. The back-illuminated photo-detector circuit receives the optical energy and subsequently transmits the electrical signals from the back-illuminated photo-detector circuit through the interconnect substrate to the flexible circuit 20 substrate.

These and other more specific embodiments are disclosed in more detail below.

As discussed herein, techniques herein are well suited for use in applications such as photo-detector applications. However, it should be noted that embodiments herein are not limited to use in such applications and that the techniques discussed herein are well 25 suited for other applications as well.

Additionally, note that although each of the different features, techniques, configurations, etc., herein may be discussed in different places of this disclosure, it is intended, where suitable, that each of the concepts can optionally be executed independently of each other or in combination with each other. Accordingly, the one or

more present inventions as described herein can be embodied and viewed in many different ways.

Also, note that this preliminary discussion of embodiments herein purposefully does not specify every embodiment and/or incrementally novel aspect of the present disclosure or claimed invention(s). Instead, this brief description only presents general embodiments and corresponding points of novelty over conventional techniques. For additional details and/or possible perspectives (permutations, elements, aspects, etc.) of the invention(s), the reader is directed to the textual Detailed Description section and corresponding figures of the present disclosure as further discussed below. The following Detailed Description, in addition to providing an intricate description of details of the invention, also provides a further summary of aspects of the invention or inventions.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features, and advantages of the invention will be apparent from the following more particular description of preferred embodiments herein, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, with emphasis instead being placed upon illustrating the embodiments, principles, concepts, etc.

FIG. 1 is an example diagram of a conventional multi-row detector array used in a CT imaging system according to conventional techniques.

FIG. 2 is a schematic functional diagram of a helical CT scanner according to conventional techniques.

FIG. 3 is an example diagram illustrating a multi-row DMS array that is modular in both the X- and the Z-directions according to conventional techniques.

FIG. 4 is an example diagram illustrating a cross-sectional view of a photo-detector assembly including an optical detector circuit according to embodiments herein.

FIG. 5A is an example diagram illustrating a view of a first facing of a photo-detector circuit according to embodiments herein.

FIG. 5B is an example diagram illustrating a cross-sectional view of a photo-detector circuit according to embodiments herein.

FIG. 5C is an example diagram illustrating a view of a second facing associated with a photo-detector circuit according to embodiments herein.

5 FIG. 6 is an example side view diagram of a photo-detector circuit according to embodiments herein.

FIG. 7 is an example diagram illustrating a cross-sectional view of a photo-detector assembly coupled to a circuit board according to embodiments herein.

FIG. 8 is an example diagram illustrating an exploded view of a photo-detector

10 assembly according to embodiments herein.

FIG. 9 is an example diagram illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein.

FIG. 10 is an example diagram illustrating a method of fabricating a photo-detector circuit assembly including an optical detector circuit according to embodiments

15 herein.

FIG. 11 is an example diagram illustrating an assembly including an interconnect substrate that provides connectivity according to embodiments herein.

FIG. 12A is an example diagram illustrating a view of a first facing of an interconnect substrate according to embodiments herein.

20 FIG. 12B is an example diagram illustrating a cross-sectional view of an interconnect substrate according to embodiments herein.

FIG. 12C is an example diagram illustrating a view of a second facing of an interconnect substrate according to embodiments herein.

FIG. 13 is a more detailed cross-sectional view of a interconnect substrate

25 according to embodiments herein.

FIG. 14 is an example diagram illustrating an exploded view of a photo-detector assembly according to embodiments herein.

FIG. 15 is an example diagram illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein.

FIGS. 16 and 17 combine to form a flowchart illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein.

DETAILED DESCRIPTION

5 The use of conventional multi-layered interconnect substrates increases the cost of CT detectors and in general reduces their reliability, because of possibility of open connections in multiple conductive layers. The CT detector contributes significantly to the cost of CT scanners, and detector failures due to failed interconnections may contribute significantly to down time of medical or security CT scanners.

10 As previously discussed, embodiments herein include a novel detector assembly using more economical and reliable single layer substrate with thick or thin film contacts. Another embodiment herein includes direct bonding of the back-contact photo-detector to flex cable, completely eliminating the use of substrate.

FIG. 1 is a schematic functional diagram of a conventional multi-row detector 15 array for a CT imaging system 10. A CT imaging system 10 allows an image of the internal structure of a target object 11 to be generated, one cross-sectional slice at a time, or in helical mode of data acquisition by irradiating the slices of the target object 11 with radiation such as X-rays, from one or more directions.

In overview, the CT imaging system 10 includes an X-ray source 12, a multi-row 20 X-ray detector array 14, a signal acquisition system 16, and an image reconstruction system 18. The X-ray source 12 generates X-rays which pass through the target object 11, which may typically be an anatomical region of a patient. In other words, the X-ray radiation traverses an examination region of interest of a computed tomography system such as object 111.

25 The X-ray detector array 14 (i.e., array of photo-detectors, optical detector circuit, etc.) detects X-rays that have passed through the target object 11, and generates detection signals indicative of the attenuated intensities of the X-rays that have traversed an examination region including the target object 11. In one embodiment, the X-rays traverse the examination region of a computed tomgraphy apparatus (e.g., CT imaging 30 system 10).

The signal acquisition system 16 digitizes and processes these detection signals. The processed signals are then sent to the image reconstruction system 18, which implements image processing techniques to reconstruct a tomographic image of the target object 11.

5 The X-ray source 12 may be a conventional X-ray tube (XRT), for example. The X-ray source 12 generates X-rays from a focal spot of the XRT. These X-rays are typically collimated before the X-rays irradiate the target object 11. The X-ray detector array 14 is an array of individual X-ray detector elements, for example solid-state detectors consisting of scintillators and photodetectors.

10 When photodetectors are used, the X-rays that have traversed the target object 11 first interact with scintillators, which convert the incident X-rays into visible light. The photodetectors receive the visible light generated by the scintillators, and generate electrical signals responsive to the visible light received from the scintillators. X-ray detector elements other than scintillators and photodetectors may also be used in different 15 embodiments of the present disclosure. Typically, the photodetectors are photodiodes.

Note that embodiments herein are not limited to medical applications. That is, the techniques as discussed herein can be applied to any application configured to analyze objects using radiation.

FIG. 2 is a schematic functional diagram of a helical CT scanner according to 20 conventional techniques.

In a helical CT scanner, the patient 25 is translated (typically at a constant speed), while the X-ray source and the detector array 14 rotate around the patient. As the patient is moving, the data for a prescribed number of axial slices of the target object is acquired. As seen from FIG. 1B, the trajectory 22 of the X-ray tube focal spot 19 maps out a helix.

25 In FIGS. 1 and 2, the z-axis indicates the axial direction along which the multiple slices of the target object 11 are taken, while the x-axis is one of the coordinates of the plane in which the array of X-ray detector elements are disposed. As seen from FIGS. 1 and 2, a conventional multi-row detector array has x-ray detector elements that are modularized along the x-direction. Typically, a module may include 16, 24, 32 or more 30 pixels, and 2 or more dozen modules may be contained per arc.

When the number of slices in CT systems is on the order of 16, 32, 64, etc., modularity in the z-direction may not be necessary. As the number of slices approaches several hundred, however, with four or five thousand pixels per module, modularizing along the z-direction as well as along the x-direction may be required.

5 FIG. 3 illustrates an array of multiple photo-detector circuits according to conventional techniques. As discussed above, each of the photo-detectors 135 disposed on the photo-detector circuit 130 detects a presence of radiation in a corresponding region of coverage. In this front view diagram, the bracket 160 resides behind the photo-detector circuit 130 and provides support to corresponding processing circuitry as will be 10 discussed later in this specification.

In one embodiment, the photo-detector circuit 130 includes a planar array of multiple semiconductor chips disposed in the x and/or y direction to form a sufficiently large array of photo-detectors 135.

As an alternative to using multiple chips to form an array of photo-detectors, the 15 photo-detector circuit 130 can be a single semiconductor chip including the multiple photo-detectors 135.

Note that multiple arrays of photo-detector arrays can be mounted side by side to provide a large area of detector coverage as shown by array 14 in FIG. 1.

FIG. 4 is an example diagram illustrating a cross-sectional view of a photo-20 detector assembly according to embodiments herein.

As shown, photo-detector assembly 100 includes anti-scatter assembly 110 that receives radiation 105. In one embodiment, the anti-scatter assembly 110 reduces the amount of scattered radiation received by scintillator array 120. .

At least a portion of the radiation 105 passing through the anti-scatter assembly 25 105 is received by scintillator array. The scintillator device 120 converts received radiation 105 into a respective optical signal 115 detected by an optical detector circuit such as photo-detectors 135. By way of a non-limiting example, the scintillator device 120 is disposed adjacent to and in contact with the first facing 140-1 of the photo-detector circuit 135. The photo-detector circuit 130 is sandwiched between the scintillator device 30 120 and the flexible circuit substrate 170.

In this non-limiting example, facing 140-1 of photo-detector circuit 130 includes photo-detectors 135. The photo-detector circuit 130 can include an array of so-called front illuminated photo-detectors. For example, the photo-detector circuit 130 can include an array of photo-detectors 135 disposed on a corresponding circuit substrate
5 such as a semiconductor device.

The photo-detector circuit 130 includes a first facing 140-1 and a second facing 140-2. In one embodiment, the photo-detector circuit 130 is a front-illuminated detector circuit.

Each of the photo-detectors 135 of the photo-detector circuit 130 have a
10 respective active region disposed and/or formed on or near the first facing 140-1 of photo-detector circuit 130 in which to detect a presence of optical energy produced by the scintillator device 120. By way of a non-limiting example, each of the photo-detectors 135 of the photo-detector circuit 130 receives at least a portion of the optical energy through the facing 140-1. Thus, the photo-detectors 135 can be front-illuminated photo-
15 detectors.

Based on a received optical signal 115, each of the photo-detectors 135 produces a corresponding electrical signal representative of a degree to which the photo-detector detects presence of radiation in a respective area of coverage.

The flexible circuit substrate 170 includes contact nodes 175 on a respective
20 facing in contact with the facing 140-2 of the photo-detector circuit 130. In one embodiment, the second facing 140-2 of the photo-detector circuit 130 (and/or nodes thereon) is directly bonded to the contact nodes 175 disposed on the facing of the flexible circuit substrate 170. A suitable material such as solder may provide connectivity between a respective contact node 175 on the flexible circuit substrate and a
25 corresponding node disposed on facing 140-2 of the photo-detector circuit 130.

Conductive paths extending from photo-detectors 135 on facing 140-1 through the photo-detector circuit 130 carry the respective electrical signals produced by photo-detectors 135 to contact nodes 175 of the flexible circuit substrate 170. Flexible circuit substrate 170, in turn, conveys the electrical signals (as produced by the respective photo-
30 detectors 135) to remotely located image processing circuitry that reproduces an image

based on the electrical signals produced by photo-detectors 135 in the photo-detector circuit 130.

As mentioned, in one embodiment, each of the photo-detectors 135 disposed on the photo-detector circuit 130 includes an active region in which to detect received optical energy from scintillator device 120. In one non-limiting example, each respective active region is a doped region including an impurity diffused through the first facing 140-1 during fabrication of the photo-detector circuit 130. Detection of an optical signal via the active region (disposed on and/or near a front facing 140-1 of the photo-detector circuit 130) results in generation of a corresponding electrical signal indicating a degree to which radiation is present in the corresponding region of coverage.

In one embodiment, the flexible circuit substrate 170 is any suitable thickness such as 0.2 millimeter thick.

FIG. 5B is an example diagram illustrating a side view of the photo-detector circuit according to embodiments herein.

As shown, the facing 140-1 of circuit substrate (e.g., photo-detector circuit 130) on which the photo-detectors 135 reside can include multiple conductive paths 550 extending through the circuit substrate from the first facing 140-1 to the second facing 140-2. For example, the conductive paths 550 through the photo-detector circuit 130 provide electrical connectivity between photo-detector contact elements disposed on or near the first facing 140-1 and contact nodes 175 disposed on the flexible circuit substrate 170.

More specifically, photo-detector circuit 130 includes photo-detector 135-1, photo-detector 135-2, photo-detector 135-3, photo-detector 135-4, etc., as shown in front view of FIG. 5A.

Each photo-detector 135 disposed on facing 140-1 can include one or more contact nodes (also on or near facing 140-1) that are electrically connected to respective nodes 575 (e.g., photodiode contact nodes) on facing 140-2 via a respective conductive path 550.

FIG. 5C illustrates a view of nodes 575 disposed on facing 140-2 of photo-detector circuit 130. Each photo-detector 135 disposed on facing 140-1 of photo-detector circuit 130 includes one or more circuit nodes from which to output an electrical signal.

As previously discussed, the paths 550 through the photo-detector circuit 130 provide connectivity of the one or more circuit nodes on facing 140-1 to nodes 575 disposed on facing 140-2 of photo-detector circuit 130. For example, as shown, a first conductive path of conductive paths 550 provides connectivity from a node of photo-detector 135-1 on facing 140-1 to node 575-1 disposed on facing 140-2; a second conductive path of conductive paths 550 provides connectivity from photo-detector 135-2 on facing 140-1 to node 575-2 disposed on facing 140-2; a third conductive path of conductive paths 550 provides connectivity from photo-detector 135-3 on facing 140-1 to node 575-3; a fourth conductive path of conductive paths 550 provides connectivity from photo-detector 135-4 on facing 140-1 to node 575-4 disposed on facing 140-2; and so on. Accordingly, via the conductive paths 550 through the photo-detector circuit 130, the node associated with the photo-detectors 135 of photo-detector circuit 130 are accessible from facing 140-2.

As shown, the nodes of photo-detectors (e.g., one node per photo-detector) on facing 140-1 are more densely packed than corresponding nodes 575 associated with photo-detectors 135 on facing 140-2. Accordingly, facing 140-2 can include a pattern of nodes associated with the photo-detectors 135 that are reduced compared to a respective smaller pattern of nodes 575 disposed on facing 140-2.

Thus, in one non-limiting example, a respective spacing between adjacent output contact elements associated with the photo-detectors 135 on the first facing 140-1 is greater than a respective spacing between corresponding contact nodes 575 disposed on a facing of 140-2 of the photo-detector circuit 130.

Note that the pattern of nodes 575 on the facing 140-2 can be configured to substantially match the pattern of contact nodes 175 on the flexible circuit substrate 170. Via solder or other suitable joints, the contact nodes 575 can be electrically and fixedly coupled to the respective contact nodes 175 on the flexible circuit substrate 170. In accordance with such embodiments, the conductive paths 550 and configuration of the

photo-detector circuit 130 facilitates a change in pitch between the photo-detectors 135 on facing 140-1 and the corresponding contact nodes 175 on the flexible circuit substrate 170.

As shown, the conductive paths 550 can be configured to extend through the photo-detector circuit 130 in any suitable manner. In one non-limiting example, at least a portion of each conductive path 550 can be configured to extend substantially perpendicular from the facing 140-1 to the facing 140-2 to accommodate the change in pitch from facing 140-1 to facing 140-2 as discussed above. Additionally, a portion of each of one or more of the conductive paths 550 can be disposed in parallel or substantially in a plane of facing 140-1 and/or facing 140-2 to provide a fan-in or fan-out. Thus, a first portion of a respective conductive path can extend substantially in a plane of facing 140-1 and/or facing 140-2. A second portion of a respective conductive path can extend substantially orthogonal through the photo-detector circuit 130 from facing 140-1 and facing 140-2. Accordingly, one embodiment herein includes a photo-detector circuit 130 configured to include nodes on a back-side (i.e., facing 140-2) that are more densely packed than corresponding nodes of photo-detectors 135 disposed on a front-side (i.e., facing 140-1).

FIG. 6 is an example diagram illustrating a photo-detector circuit according to embodiments herein.

As shown, conductive path 550-1 provides an electrical connection from a node of photo-detector 135-1 (such as a front-illuminated photo-detector) to corresponding contact node 575-1 disposed on or adjacent to facing 140-2. The conductive path 550-1 can include multiple portions along different axis. For example, at least one portion of the conductive path 550-1 extends orthogonal with respect to a plane of facings 140 (e.g., substantially parallel to the z-axis) through the substrate of photo-detector circuit 130. One or more other portions of the conductive path 550-1 can extend in the x-axis and/or y-axis as well to provide connectivity.

In one embodiment, the optical signal 115 detected by the photo-detector 135-1 produces a corresponding charge value in an active region of the photo-detector 135-1. The charge is carried as output current from the active area of the corresponding photo-

detector through conductive path 550-1 to contact node 575-1. The output current is proportional to the number of light photons received. Thus, upon detection of an optical signal, the photo-detector 135-1 outputs an electrical signal over conductive path 550-1 to contact node 575-1.

5 In accordance with further embodiments, remotely located processing circuitry converts the electrical signal (conveyed over the conductive path 550-1) into a digital value indicative of the amount of radiation 105 received in the region monitored by the photo-detector 135-1.

In a similar manner, conductive path 550-2 provides an electrical connection from 10 a node of photo-detector 135-2 to corresponding contact node 575-2 disposed on or adjacent to facing 140-2. For example, the conductive path 550-2 also can include multiple segments disposed in one or more axis to provide the connectivity between the photo-detector 135-2 and the contact node 575-2. Upon detection of an optical signal in an active region of the photo-detector 135-2, the photo-detector 135-2 outputs an 15 electrical signal over conductive path 550-2 to contact node 575-2.

Each of the photo-detectors 135 can be configured to operate in a similar manner.

FIG. 7 is an example diagram illustrating a cross-sectional view of a photo-detector assembly coupled to a circuit board according to embodiments herein.

In one embodiment, the flexible circuit substrate 170 of assembly 100 includes 20 one or more layers of conductive paths to electrically couple the contact nodes 175 to corresponding detection circuitry (i.e., processing circuitry) located on a circuit board 650.

As shown, a planar surface of the circuit board 650 (e.g., substrate) on which the processing circuit 640 resides is substantially orthogonal with respect to a plane of the 25 photo-detector circuit 130 (e.g., circuit substrate) on which the array of photo-detectors 135 resides.

Moreover, as shown, the flexible circuit 170 can include one or more bends that are each greater than 45 degrees to provide connectivity between the photo-detector circuit 130 and the (remote) circuit board 650.

To facilitate connectivity between the flexible circuit substrate 170 and the circuit board 650, an intermediate connector 220 can be configured to provide connectivity of the conductive paths in the flexible circuit substrate 170 to the circuit board 650. Traces in circuit board 650 provide further connectivity to processing circuit 640. Accordingly,
5 processing circuit receives an electrical signal produced by each of the photo-detectors 135.

The assembly 100 including anti-scatter assembly 110, scintillator device 120, ..., circuit board 650 can be duplicated and stacked as shown.

FIG. 8 is an example diagram illustrating an exploded view of a photo-detector
10 assembly according to embodiments herein.

As previously discussed, assembly 100 includes anti-scatter assembly 110 coupled to scintillator device 120. Scintillator device 120 is sandwiched between anti-scatter assembly 110 and facing 140-1 of photo-detector circuit 130. Facing 140-2 of photo-detector circuit 130 couples to contact nodes 175 disposed on flexible circuit
15 substrate 170.

A combination of substrate 145 (e.g., made from ceramic or other suitable material), shield plate 150 (e.g., made from tungsten or other suitable radiation blocking material), and bracket 160 resides in cavity 750 formed by bends in the flexible circuit substrate 170.

20 In one embodiment, the substrate 150 prevents the circuit board 650, processing circuit 640, etc., from being exposed to any portion of radiation 105 that is not converted into a respective optical signal via the scintillator device 120.

FIG. 9 is an example flowchart 800 illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein. In general, the steps can be
25 executed in any suitable order.

In step 810, an assembler receives a photo-detector circuit 130. The photo-detector circuit 130 includes an array of photo-detectors 135 disposed on a circuit substrate. The photo-detector circuit 130 includes a first facing 140-1 and a second facing 140-2. Each of the photo-detectors 135 of the photo-detector circuit 135 has a

respective active region on the first facing 140-1 to detect presence of optical energy produced by the scintillator device 120.

In step 820, the assembler receives a flexible circuit substrate 170. A facing of the flexible circuit substrate 170 includes contact nodes 175.

5 In step 830, the assembler bonds the second facing 140-2 of the photo-detector circuit 135 to the contact nodes 175 disposed on the facing of the flexible circuit substrate 170.

FIG. 10 is an example flowchart 900 illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein. In general, the steps can be 10 executed in any suitable order.

In step 910, the assembler receives a photo-detector circuit 130. The photo-detector circuit 130 includes an array of photo-detectors 135 disposed on a respective semiconductor substrate. The photo-detector circuit 130 further includes a first facing 140-1 and a second facing 140-2. Each of the photo-detectors 135 of the photo-detector 15 circuit 130 has a respective active region on or near the first facing 140-1 to detect a presence of optical energy produced by the scintillator device 120.

In step 920, the assembler receives a flexible circuit substrate 170. A facing of the flexible circuit substrate 170 includes contact nodes 175.

In step 930, the assembler bonds the second facing 140-2 of the photo-detector 20 circuit 130 to the contact nodes 175 disposed on the facing of the flexible circuit substrate 170.

In step 940, the assembler receives a scintillator device 120.

In step 950, the assembler disposes the scintillator device 120 adjacent to the first facing 140-1 of the photo-detector circuit 130. The photo-detector circuit 130 is 25 sandwiched between the scintillator device 120 and the flexible circuit substrate 170. The scintillator device 120 converts received radiation 105 into optical energy.

In step 960, the assembler provides connectivity between circuit 650 (e.g., a remote circuit substrate) and the circuit substrate on which the array of photo-detectors 135 resides based on one or more bends in the flexible circuit substrate 170. As 30 previously discussed, each of the one or more bends can be greater than 45 degrees.

FIG. 11 is an example diagram illustrating an assembly including an interconnect substrate according to embodiments herein. Assembly 1000 can be used as an alternative to use of assembly 100 in FIG. 7 to fabricate a respective radiation detection system including circuit board 650 and processing circuit 640.

5 As shown in FIG. 11, assembly 1000 includes anti-scatter assembly 110. In one embodiment, the anti-scatter assembly 110reduces the amount of scattered radiation received by scintillator array 120.

At least a portion of the radiation 105 passing through the anti-scatter assembly 105 is received by scintillator device 120. By way of a non-limiting example, the

10 scintillator device 120 can be partitioned such that pixilated portions of the scintillator device 120 align with corresponding photo-detectors circuits disposed on a facing of the photo-detectors 135.

During scanning, the scintillator device 120 converts received radiation into a respective optical signal 115.

15 By way of a non-limiting example, the scintillator device 120 is disposed adjacent to and in contact with the photo-detector circuit 1300. The photo-detector circuit 1300 is sandwiched between the scintillator device 120 and the interconnect substrate 143.

Photo-detectors 1350 reside on a surface of the photo-detector circuit 1300 in contact with facing 1040-1 of the interconnect substrate 143.

20 By way of a non-limiting example, the photo-detector circuit 1300 can include an array of so-called back illuminated photo-detectors. For example, the photo-detector circuit 1300 can include an array of photo-detectors 1350 disposed on a corresponding circuit substrate such as a semiconductor device. The photo-detector circuit 1300 includes a first facing in contact with the scintillator device 120 as previously discussed.

25 The photo-detector circuit 1300 also includes an array of photo-detectors 1350 disposed on a second facing in contact with interconnect substrate 143.

By way of a non-limiting example, each of the photo-detectors 1350 of the photo-detector circuit 1300 has a respective active region (on the back facing of photo-detector circuit 1300 in contact with the interconnect substrate 143) in which to detect a presence

30 of optical energy produced by the scintillator device 120. By way of a non-limiting

example, each of the photo-detectors 1350 of the photo-detector circuit 1300 receives at least a portion of the optical energy through the backside of the photo-detector circuit 1350.

Based on a received optical signal 115 in a region of coverage, each of the photo-
5 detectors 1350 produces a corresponding electrical signal representative of a degree to which the photo-detector detects presence of radiation in a respective area of coverage.

As discussed in the following figures, the interconnect substrate 143 conveys electrical signals outputted from nodes on the photo-detector circuit 1300 to the contact nodes 175 on flexible circuit substrate 170. In other words, for each of the photo-
10 detectors 1350, the interconnect substrate 143 includes a respective conductive path extending from facing 1040-1 to facing 1040-2 to provide connectivity between the photo-detectors 1350 and contact nodes 175 on the flexible circuit substrate 170.

Flexible circuit substrate 170, in turn, conveys the electrical signals to a remote image processing circuit that reproduces an image based on the electrical signals
15 produced by the photo-detector circuit 130. The flexible circuit substrate 170 can include one or more trace layers to provide connectivity to a remote processing circuit.

In one embodiment, each of the photo-detectors 1350 disposed on the photo-detector circuit 1300 includes an active region. Each respective active region is a doped region including an impurity diffused during fabrication of the photo-detector circuit
20 1300. Thus, in one embodiment, respective active regions in the photo-detector circuit 1300 are semiconductor doped regions disposed on a facing of the photo-detector circuit 1300 in contact with the first facing 1040-1 of the interconnect substrate 143.

In accordance with further embodiments, the first facing 1040-1 of the interconnect substrate 143 is fixedly attached to photo-detector contact elements (e.g.,
25 output pads associated with the photo-detectors 1350) disposed on a respective surface of the photo-detector circuit 1300. The second facing 1040-2 of the interconnect substrate 143 is fixedly attached to the contact nodes 175 disposed on the flexible circuit substrate 170.

Detection of the optical signal 115 in the active region associated with a photo-detector 1350 results in generation of a corresponding electrical signal indicating a degree to which radiation is present in the corresponding region of coverage.

In one embodiment, conductive paths in the interconnect substrate 143 include
5 first terminal ends and second terminal ends. The first terminal ends of the conductive paths of the interconnect substrate 143 disposed on the first facing 1040-1 are fixedly attached to corresponding photo-detector contact elements disposed on a respective surface of the photo-detector circuit 1300. Second terminal ends of the conductive paths of the interconnect substrate 143 disposed on a second facing 1040-2 are fixedly attached
10 to the contact nodes 175 disposed on the flexible circuit substrate 175.

In accordance with embodiments herein, a respective spatial density of the first terminal ends of the conductive paths per unit of area on the first facing 1040-1 is less than a spatial density of the second terminal ends of the conductive paths per unit of area on the second facing 1040-2.

15 Reducing a pitch between adjacent electrical nodes from facing 1040-1 to facing 1040-2 renders it possible to keep a thickness of a portion of the assembly 1000 including flexible circuit substrate 170, substrate 145, support bracket 160, etc., less than width, W, as shown. In accordance with such an embodiment, the multiple circuit boards can be easily stacked such that respective photo-detectors provide continuous detector coverage.

20 FIG. 12A is an example diagram illustrating a view of a first facing 1040-1 of interconnect substrate 143 according to embodiments herein.

FIG. 12B is an example diagram illustrating a cross-sectional view of interconnect substrate 143 according to embodiments herein.

FIG. 12C is an example diagram illustrating a view of a second facing 1040-2 of
25 interconnect substrate 143 according to embodiments herein.

As shown in FIG. 12B, the interconnect substrate 143 includes contact nodes 235 disposed on facing 1040-1. For example, facing 1040-1 includes contact node 235-1, contact node 235-2, contact node 235-3, contact node 235-4, and so on.

The interconnect substrate 143 includes contact nodes 275 on facing 1040-2. For example, facing 1040-2 includes contact node 275-1, contact node 275-2, contact node 275-3, contact node 275-4, and so on.

As shown, in one embodiment, the number of contact nodes 275 per unit of area on facing 1040-2 is smaller than the number of contact nodes 235 per unit of area on facing 1040-1.

Conductive paths 1180 in interconnect substrate 143 provide connectivity between the contact nodes 235 on facing 1040-1 and contact nodes 275 on facing 1040-2.

FIG. 13 is a more detailed cross-sectional, exploded view of an assembly including a photo-detector circuit, interconnect substrate, and flexible circuit substrate according to embodiments herein.

As shown, photo-detector circuit 1300 includes multiple photo-detectors 1350 on a back facing. Each photo-detector includes at least one corresponding contact node 225 (e.g., an anode). For example, photo-detector 1350-1 includes contact node 225-1; photo-detector 1350-2 includes contact node 225-2; photo-detector 1350-3 includes contact node 225-3; and so on.

As previously discussed, each of the photo-detectors 1350 includes an active region in which to detect a presence of an optical signal (from scintillator device) that varies depending on how much radiation 105 is converted into the detected optical signal 115 produced by the scintillator device 120. During scanning, the optical signal is detected on the front surface of the photo-detector circuit 1350, but the charge is collected in the active area of photodetectors 1350. In one embodiment, the total thickness of the photo-detector circuit 1300 is 0.120 millimeters in order to efficiently collect all optically created charges in the active areas 1350. The thickness can vary depending on the embodiment.

Each of the photo-detectors 1350 outputs a respective electrical signal whose magnitude varies depending on the received optical signal. For example, the photo-detector 1350-1 outputs a respective electrical signal from contact node 225-1; the photo-detector 1350-2 outputs a respective electrical signal from contact node 225-2; the photo-detector 1350-3 outputs a respective electrical signal from contact node 225-3; and so on.

By way of a non-limiting example, interconnect substrate 143 includes contact nodes 235, a trace layer 1210, and a substrate layer 1220. The trace layer 1210 resides on facing 1040-1 substrate layer 1220 and provides connectivity between the contact nodes 235 on exposed facing 1040-1 and contact nodes 275. For example, a first conductive
5 path extends from contact node 235-1 through trace layer 1210 to element 245-1; a second conductive path extends from contact node 235-2 through trace layer 1210 to element 245-2; a third conductive path extends from contact node 235-3 through trace layer 1210 to element 245-3; and so on. A terminal end of a respective end the elements 245 serve as contact nodes 275 expose on facing 1040-2. The traces disposed in trace
10 layer 1210 can be metallization disposed on the surface (e.g., facing 1040-1) of the single layered ceramic substrate layer 1220. Traces can be created using thin or thick film deposition processes.

Each of the conductive paths in the trace layer 1210 can be electrically isolated from each other. Each of the elements 245 is made from electrically conductive material
15 such as metal.

As shown, the contact nodes 225 disposed on a back facing of the photo-detector circuit 1300 align with the contact nodes disposed on facing 1040-1 of the interconnect substrate 143. Thus, subsequent to assembly, after the photo-detector circuit 1300 is bonded to the facing 1040-1 of the interconnect substrate 143, contact node 225-1 is
20 electrically connected to contact node 235-1; contact node 225-2 is electrically connected to contact node 235-2; contact node 225-3 is electrically connected to contact node 235-3; and so on.

Electrical connectivity can be provided via any suitable manner such as soldering contact nodes 225 to corresponding contact nodes 235.

25 Further as shown, the contact nodes 275 disposed on facing 1040-2 (e.g., at terminal ends of elements 245) of the interconnect substrate 143 align with the contact nodes 175 disposed on the flexible circuit substrate 170. By way of a non-limiting example, subsequent to assembly, such as after facing 1040-2 of the interconnect substrate 143 is bonded to the flexible circuit substrate 170, contact node 275-1 (e.g., at
30 the terminal end of element 245-1 on facing 1040-2) is electrically connected to contact

node 175-1; contact node 275-2 (e.g., at the terminal end of element 245-2 on facing 1040-2) is electrically connected to contact node 175-2; contact node 275-3 (e.g., at the terminal end of element 245-3 on facing 1040-2) is electrically connected to contact node 175-3; and so on.

5 Electrical connectivity can be provided via any suitable manner such as soldering contact nodes 275 to corresponding contact nodes 175.

In accordance with further embodiments, substrate layer 1220 can be a single layer of any type of suitable electrically non-conductive material. Substrate layer can be rigid to reduce flexing of the photo-detector circuit 1300.

10 In one non-limiting example embodiment, the interconnect substrate 143 includes a single layer of material such as ceramic. In other words, the substrate layer 1220 can be a ceramic substrate through which holes are drilled or etched to produce the elements 245. Trace layer 1210 provides further connectivity as previously discussed.

Each element 245 and/or contact node 275 can be made from electrically
15 conductive material such as a copper alloy. By way of a non-limiting example, each of the elements 245 disposed in the substrate layer 1220 can be formed to any suitable shape such as a pillar, cylinder, etc.

As shown, and as previously discussed, the conductive paths such as elements 245 extending through the single layer of material (e.g., substrate layer 1220) are disposed
20 substantially orthogonal with respect to facing 1040-2.

Portions of conductive paths in trace layer 1210 from the contact node 235 to the elements 245 can be disposed substantially orthogonal with respect to a lengthwise axis of elements 245 disposed in the substrate layer 1220. For example, in accordance with one embodiment, each of the conductive paths extending from a contact node 235 to a
25 corresponding contact node 275 can include a first portion and a second portion. The first portions of the conductive paths extending through the interconnect substrate 143 in trace layer 1210 can reside in a plane associated with facing 1040-1. The first portions of the conductive paths include terminal ends (e.g., contact nodes 235) disposed on or near facing 1040-1; the second portions of the conductive paths can include terminal ends
30 (e.g., contact nodes 275) disposed on facing 1040-2.

FIG. 14 is an example diagram illustrating an exploded view of a photo-detector assembly according to embodiments herein.

As previously discussed, assembly 1000 includes anti-scatter assembly 110 coupled to scintillator device 120. Scintillator device 120 is sandwiched between anti-scatter assembly 110 and photo-detector circuit 1300. Interconnect substrate 143 provides connectivity between the photo-detector circuit 1300 and the flexible circuit substrate 170.

A combination of substrate 145 (e.g., ceramic or other suitable material), shield plate 150 (e.g., tungsten or other suitable radiation blocking material), and bracket 160 reside in cavity 1370 formed by bends in the flexible circuit substrate 170. In one embodiment, the substrate 150 substantially prevents the circuit board 650, processing circuit 640, etc., from being exposed to any portion of radiation 105 that is not converted into a respective optical signal by the scintillator device 120. In other words, a portion of radiation 105 may pass through scintillator device 120, photo-detector circuit 1300, flexible circuit substrate 1370, and substrate 145. As its name suggests, shield plate 150 prevents all of a portion of the passing radiation from striking circuit board 650 or corresponding circuitry thereon.

FIG. 15 is an example diagram illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein. In general, the steps can be executed in any suitable order.

In step 1410, an assembler receives a photo-detector circuit 1300. The photo-detector circuit 1300 includes an array of photo-detectors 1350 disposed on a respective circuit substrate.

In step 1420, the assembler receives a flexible circuit substrate 170. A facing of the flexible circuit substrate 170 includes an array of contact nodes 175.

In step 1430, the assembler receives interconnect substrate 143.

In step 1440, the assembler disposes the interconnect substrate 143 between the photo-detector circuit 1300 and the flexible circuit substrate 175. The interconnect substrate 143 provides interconnectivity between the array of photo-detectors 1350 and the array of contact nodes 175 disposed on the flexible circuit substrate 170.

FIGS. 16 and 17 combine to form a flowchart illustrating a method of fabricating a photo-detector circuit assembly according to embodiments herein. In general, the steps can be executed in any suitable order.

In step 1510, an assembler receives a photo-detector circuit 1300; the photo-
5 detector circuit 1300 includes an array of photo-detectors 1350 disposed on a circuit substrate.

In step 1520, the assembler receives a flexible circuit substrate 170. A facing of the flexible circuit substrate 170 includes an array of contact nodes 175.

In step 1530, an assembler receives (a single-layer) interconnect substrate 143, the
10 interconnect substrate 143 includes a first facing 1040-1 and a second facing 1040-2.

In step 1540, an assembler disposes the interconnect substrate 143 between the photo-detector circuit 1300 and the flexible circuit substrate 170. The interconnect substrate 143 provides interconnectivity between the array of photo-detectors 1350 and the array of contact nodes 175 disposed on the flexible circuit substrate 170.

15 In sub-step 1550, an assembler fixedly attaches the first facing 1040-1 of the interconnect substrate 143 to photo-detector contact elements (e.g., contact nodes 225 disposed on a respective surface of the photo-detector circuit 1350.

In sub-step 1560, an assembler fixedly attaches the second facing 1040-2 of the interconnect substrate 143 to the contact nodes 175 disposed on the flexible circuit
20 substrate 170.

In step 1610 of FIG. 17, an assembler receives a scintillator device 120.

In step 1620, an assembler disposes the scintillator device 120 adjacent to the photo-detector circuit 1300. In one embodiment, the photo-detector circuit 1300 is sandwiched between the scintillator device 120 and the interconnect substrate 143.
25 During operation, the scintillator device 120 converts received radiation 105 into an optical signal 115. The photo-detector circuit 1300 detects the optical signal 115.

In step 1630, via one or more layers of conductive paths in the flexible circuit substrate 170, an assembler electrically couples the contact nodes 175 on the flexible circuit substrate to remotely located circuitry (e.g., processing circuitry 640) disposed on
30 circuit board 650.

In step 1640, an assembler disposes the planar surface of the remote circuit board 650 to be substantially orthogonal to a plane of the photo-detector circuit 1300 on which the photo-detectors 1350 reside.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present application as defined by the appended claims. Such variations are intended to be covered by the scope of this present application. As such, the foregoing description of embodiments of the present application is not intended to be limiting. Rather, any limitations to the invention are presented in the following claims.

We claim:

1. A computed tomography detector comprising:

a front-illuminated photodiode array including a first facing configured to receive optical energy indicative of X-radiation that has traversed an examination region of a computed tomography apparatus, a substrate, and a second facing including a plurality of photodiode contact nodes in electrical communication with corresponding photodiodes in the array;

a flexible circuit substrate, a facing of the flexible circuit substrate including contact nodes; and

wherein the photodiode contact nodes of the front-illuminated photodiode array are directly bonded to the contact nodes disposed on the facing of the flexible circuit.

2. The computed tomography detector as in claim 1 further comprising:

a scintillator disposed in optical communication with the first facing of the photodiode array, the photo-diode array disposed between the scintillator and the flexible circuit substrate, the scintillator converting received X-radiation into the optical energy.

3. The computed tomography detector as in claim 1, wherein the substrate of the front-illuminated photodiode array includes multiple conductive paths extending through the substrate from photodiodes to the second facing, the conductive paths through the substrate providing electrical connectivity between the photodiodes and the contact nodes disposed on the flexible circuit substrate.

4. The computed tomography detector as in claim 3, wherein a respective pitch of corresponding photodiodes in the array is greater than a respective pitch of the contact nodes disposed on the flexible circuit substrate, the conductive paths

through the substrate facilitating a change in pitch between the photodiode contact nodes and the corresponding contact nodes on the flexible circuit substrate.

5. The computed tomography detector as in claim 1, wherein the flexible circuit substrate includes multiple layers of conductive paths to electrically couple the contact nodes to detection circuitry located on a remote circuit substrate, a planar surface of the remote circuit substrate on which the detection circuitry resides being substantially orthogonal with respect to a plane of the substrate on which the array of photodiodes reside.

6. The computed tomography detector as in claim 5, wherein the flexible circuit includes at least one bend greater than 45 degrees to provide connectivity between the remote circuit substrate and the circuit substrate on which the array of corresponding photodiodes reside.

7. The computed tomography detector of claim 1, wherein the detector forms part of a computed tomography imaging apparatus.

8. The computed tomography detector of claim 1, wherein the detector is disposed in an array of multiple detectors.

9. A method comprising:

via a front-illuminated detection circuit in a computed tomography system, detecting energy indicative of radiation that has traversed an examination region of interest;

utilizing the front-illuminated detection circuit to convert the received energy into electrical signals; and

transmitting the electrical signals from the front-illuminated detection circuit to a flexible circuit substrate, the front-illuminated detection circuit directly bonded to a facing of the flexible circuit.

10. The method as in claim 9 further comprising:

receiving the energy from a scintillator disposed in communication with the front-illuminated detection circuit, the front-illuminated detection circuit disposed between the scintillator and the flexible circuit, the scintillator converting received radiation into the energy.

11. The method as in claim 9 further comprising:

transmitting the electrical signals on multiple conductive paths fabricated in a substrate of the front-illuminated detection circuit, the multiple conductive paths extending through the substrate of the front-illuminated detection circuit from photo-detectors of the front-illuminated detection circuit detecting the energy to respective contact nodes disposed on the facing of the flexible circuit.

12. The method as in claim 11, wherein a respective pitch of the photo-detectors in the front-illuminated detection circuit is greater than a respective pitch of the contact nodes disposed on the flexible circuit, the conductive paths through the substrate of the front-illuminated detection circuit facilitating a change in pitch between the photo-detectors and the respective contact nodes.

13. The method as in claim 9 further comprising:

conveying the electrical signals on the flexible circuit, the flexible circuit including multiple layers of conductive paths to electrically couple the front-illuminated detection circuit to processing circuitry located on a remote circuit substrate, a planar surface of the remote circuit substrate on which the processing circuitry resides being substantially orthogonal with respect to a plane of the front-illuminated detection circuit.

14. The method as in claim 9 further comprising:

conveying the electrical signals on the flexible circuit, the flexible circuit including at least one bend greater than 45 degrees to provide connectivity between a remote circuit substrate and the front-illuminated detection circuit.

5 15. An assembly comprising:

a photo-detector circuit including an array of photo-detectors disposed on a circuit substrate to receive optical energy indicative of radiation that has traversed the examination region of a computed tomgraphy apparatus;

a flexible circuit substrate, a facing of the flexible circuit substrate
10 including an array of contact nodes; and

an interconnect substrate including a first facing and a second facing, the interconnect substrate being a single substrate of material, the first facing in contact with the photo-detector circuit, the second facing in contact with the array of contact nodes, the interconnect substrate including conductive paths extending
15 from the first facing to the second facing to provide interconnectivity between the array of photo-detectors and the array of contact nodes disposed on the flexible circuit substrate.

16. The assembly as in claim 15, wherein at least a portion of each of the conductive
20 paths extending through the single layer of material is disposed substantially orthogonal with respect to both the first facing and the second facing.

17. The assembly as in claim 16, wherein the first facing of the interconnect substrate is fixedly attached to photo-detector contact elements disposed on a respective
25 surface of the photo-detector circuit; and

wherein the second facing of the interconnect substrate is fixedly attached to the contact nodes disposed on the flexible circuit substrate.

18. The assembly as in claim 17, wherein the interconnect substrate includes a single
30 layer of ceramic.

19. The assembly as in claim 15, wherein each of the conductive paths includes a first portion and a second portion; and

wherein the first portions of the conductive paths include terminal ends
5 disposed on the first facing; and

wherein the terminal ends of the conductive paths on the first facing align with the photo-detector contact elements.

20. The assembly as in claim 19, wherein the second portions of the conductive paths
10 extending through the interconnect substrate are disposed substantially orthogonal with respect to both the first facing and the second facing; and

wherein the second portions of the conductive paths include terminal ends disposed on the second facing;

15 21. The assembly as in claim 20, wherein the contact nodes disposed on the facing of the flexible circuit substrate are more densely populated per unit of area than a density per unit area of the photo-detector contact elements disposed on a respective surface of the photo-detector circuit.

20 22. The assembly as in claim 15, wherein respective active regions in the photo-detector circuit are semiconductor doped regions disposed in the photo-detector circuit adjacent a facing of the photo-detector circuit in contact with the first facing of the interconnect substrate.

25 23. The assembly as in claim 15 further comprising:

a scintillator disposed adjacent to the photo-detector circuit, the photo-detector circuit sandwiched between the scintillator and the interconnect substrate, the scintillator converting received radiation into an optical signal, the photo-detector circuit detecting the optical signal.

30

24. The assembly as in claim 15, wherein the flexible circuit substrate includes at least one layer of conductive paths that electrically couple the contact nodes on the flexible circuit substrate to remotely located circuitry disposed on a planar surface of a remote circuit substrate, the planar surface of the remote circuit substrate being substantially orthogonal to a plane of the photo-detector circuit on which the array of photo-detectors reside.

25. The assembly as in claim 15, wherein the flexible circuit substrate disposed between the substrate and the remote circuit substrate includes multiple bends, each of which is greater than 45 degrees.

26. The assembly as in claim 15, wherein first terminal ends of the conductive paths on the first facing of the interconnect substrate are fixedly attached to corresponding photo-detector contact elements disposed on a respective surface of the photo-detector circuit, second terminal ends of the conductive paths being disposed on a second facing of the interconnect substrate fixedly attached to the contact nodes disposed on the flexible circuit substrate; and

wherein a respective spatial density of the first terminal ends of the conductive paths per unit of area on the first facing is less than a spatial density of the second terminal ends of the conductive paths per unit of area on the second facing.

27. The assembly as in claim 15, wherein the photo-detectors are back-illuminated photo-detectors.

28. The assembly as in claim 15, wherein the interconnect substrate includes traces fabricated on only the first facing.

29. The assembly as in claim 15, wherein the interconnect substrate includes traces fabricated on both the first facing and the second facing.

30. A method comprising:

receiving optical energy indicative of X-ray radiation traversing an examination region of interest;

5 converting the received optical energy into electrical signals; and

transmitting the electrical signals through an interconnect substrate to a flexible circuit, the interconnect substrate being a single layer substrate of material sandwiched between an optical detector circuit that receives the optical energy and a flexible circuit substrate.

10

31. The method as in claim 30 further comprising:

conveying the electrical signals through the interconnect substrate on conductive paths extending from a first facing of the interconnect substrate to a second facing of the interconnect substrate, the conductive paths providing

15 interconnectivity between an array of photo-detectors in the optical detector circuit that receives the optical energy and an array of contact nodes disposed on the flexible circuit.

32. The method as in claim 31 further comprising:

20 conveying the electrical signals on substantially orthogonal electrically conductive paths extending through the single layer substrate from the first facing of the interconnect substrate to the second facing of the interconnect substrate.

33. The method as in claim 30 further comprising:

25 receiving the optical energy from a scintillator, the scintillator disposed adjacent to the optical detector circuit that generates the electrical signals, the optical detector circuit sandwiched between the scintillator and the interconnect substrate, the scintillator converting the X-ray radiation into the optical energy.

30 34. The method as in claim 30 further comprising:

transmitting the electrical signals through at least one trace layer disposed on a facing of the interconnect substrate to which the optical detector circuit is attached, the at least one trace layer electrically coupling the optical detector circuit to the flexible circuit.

5

35. The method as in claim 30 further comprising:

transmitting the electrical signals on conductive paths disposed in the interconnect substrate, a respective spatial density of first terminal ends of the conductive paths per unit of area on a first facing of the interconnect substrate

10 being less than a spatial density of second terminal ends of the conductive paths per unit of area on a second facing, the second facing of the interconnect substrate coupled to the flexible circuit.

36. The method as in claim 30, wherein the optical detector circuit that generates the

15 electrical signals is a back-illuminated photo-detector circuit, the method further comprising:

receiving the optical energy at the back-illuminated photo-detector circuit; and

transmitting the electrical signals from detectors on the back-illuminated

20 photo-detector circuit through the interconnect substrate to the flexible circuit.

37. An apparatus comprising:

means for receiving optical energy;

means for converting the received optical energy into electrical signals;

25 and

means for transmitting the electrical signals through an interconnect substrate to a flexible circuit substrate, the interconnect substrate being a single layer substrate of material disposed between the photo-detector circuit and the flexible circuit substrate.

30

38. An apparatus comprising:

means for receiving optical energy indicative of X-ray radiation that has traversed an examination region of a computed tomography apparatus;

means for converting the received optical energy into electrical signals via
5 the front-illuminated photo-detector circuit; and

means for transmitting the electrical signals from the front-illuminated photo-detector circuit to contact nodes disposed on a facing of a flexible circuit substrate, the photo-detector circuit directly bonded to a facing of the flexible circuit.

10

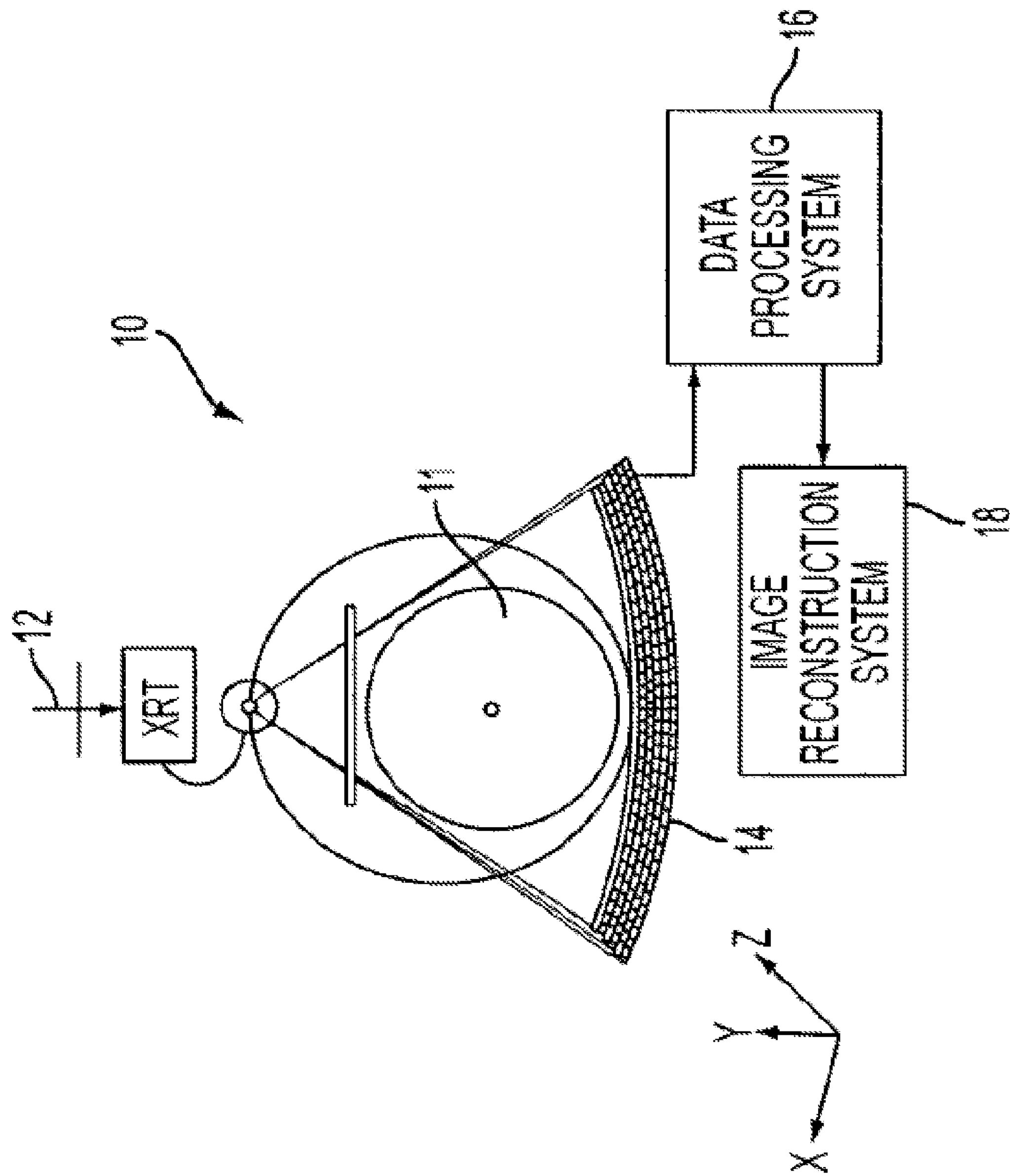


FIG. 1

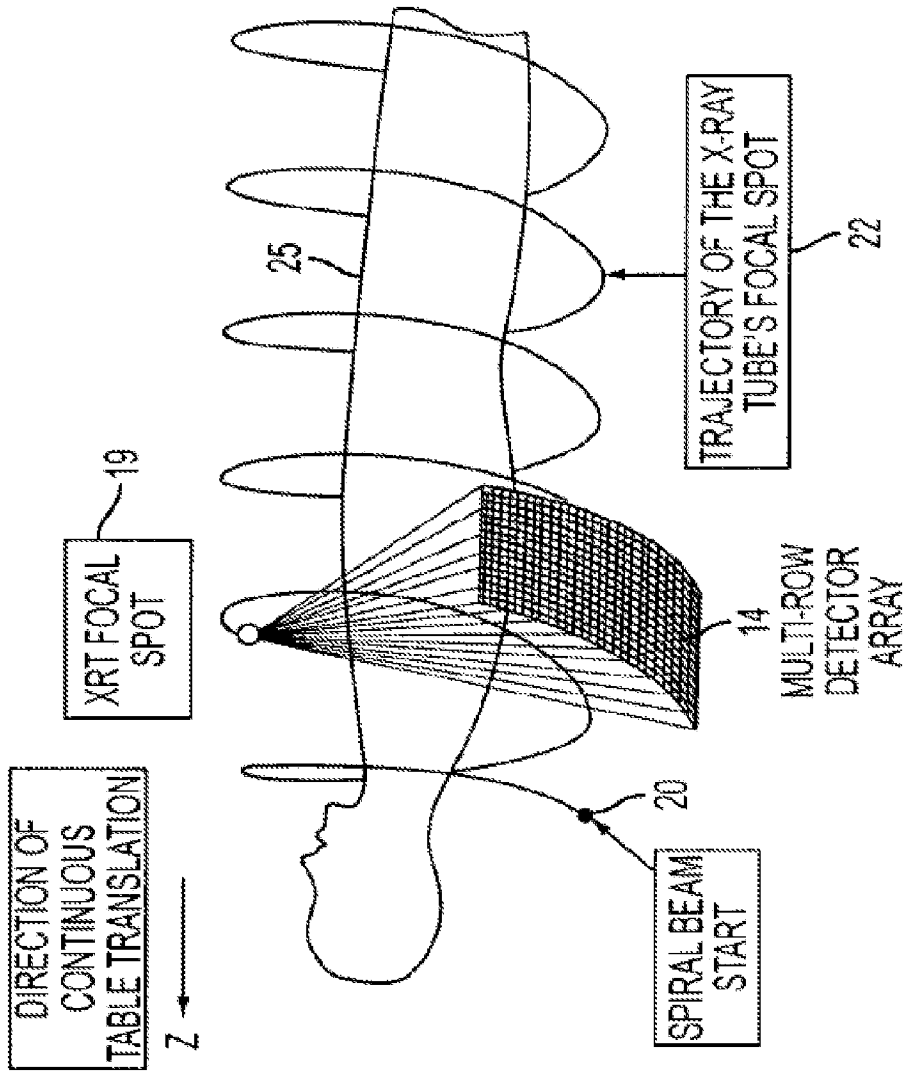


FIG. 2

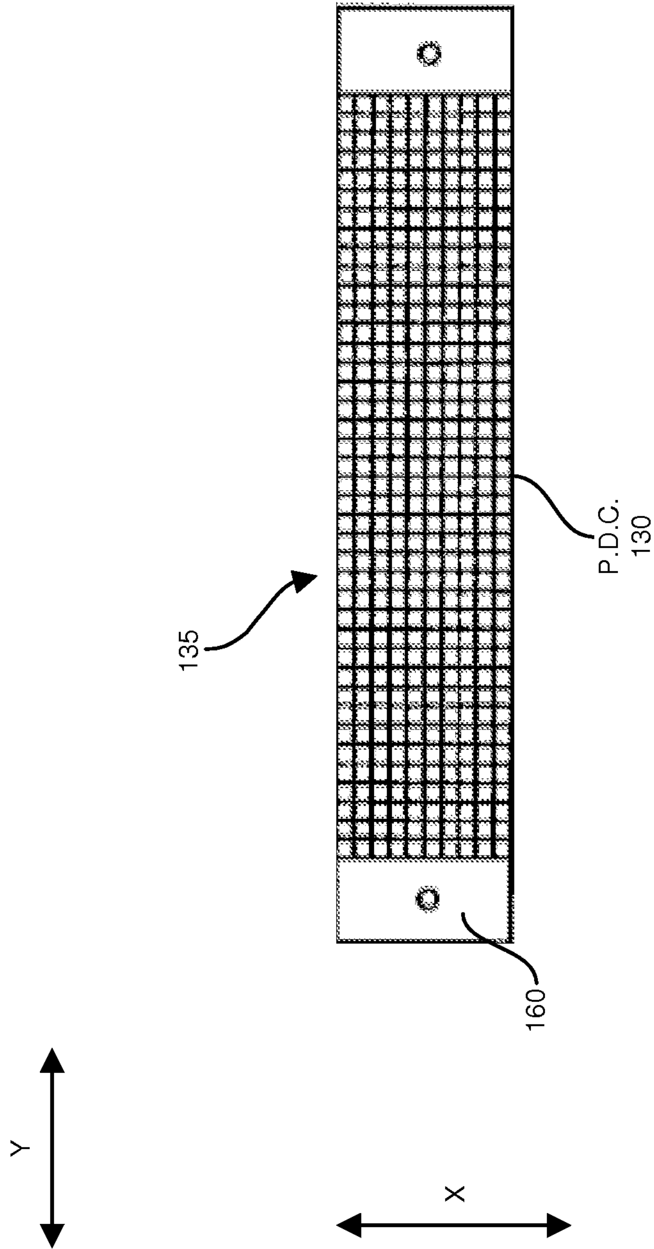


FIG. 3

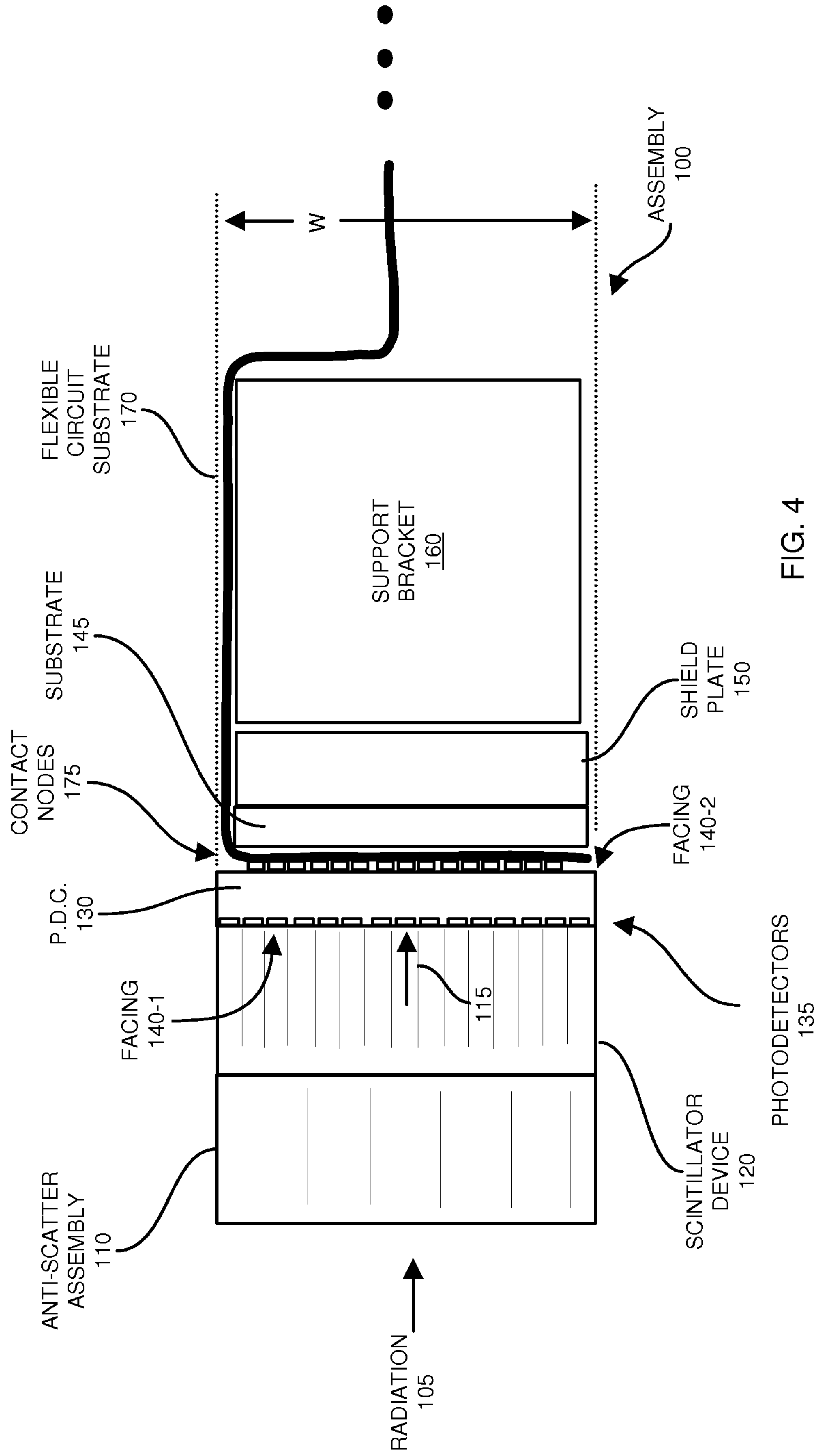


FIG. 4

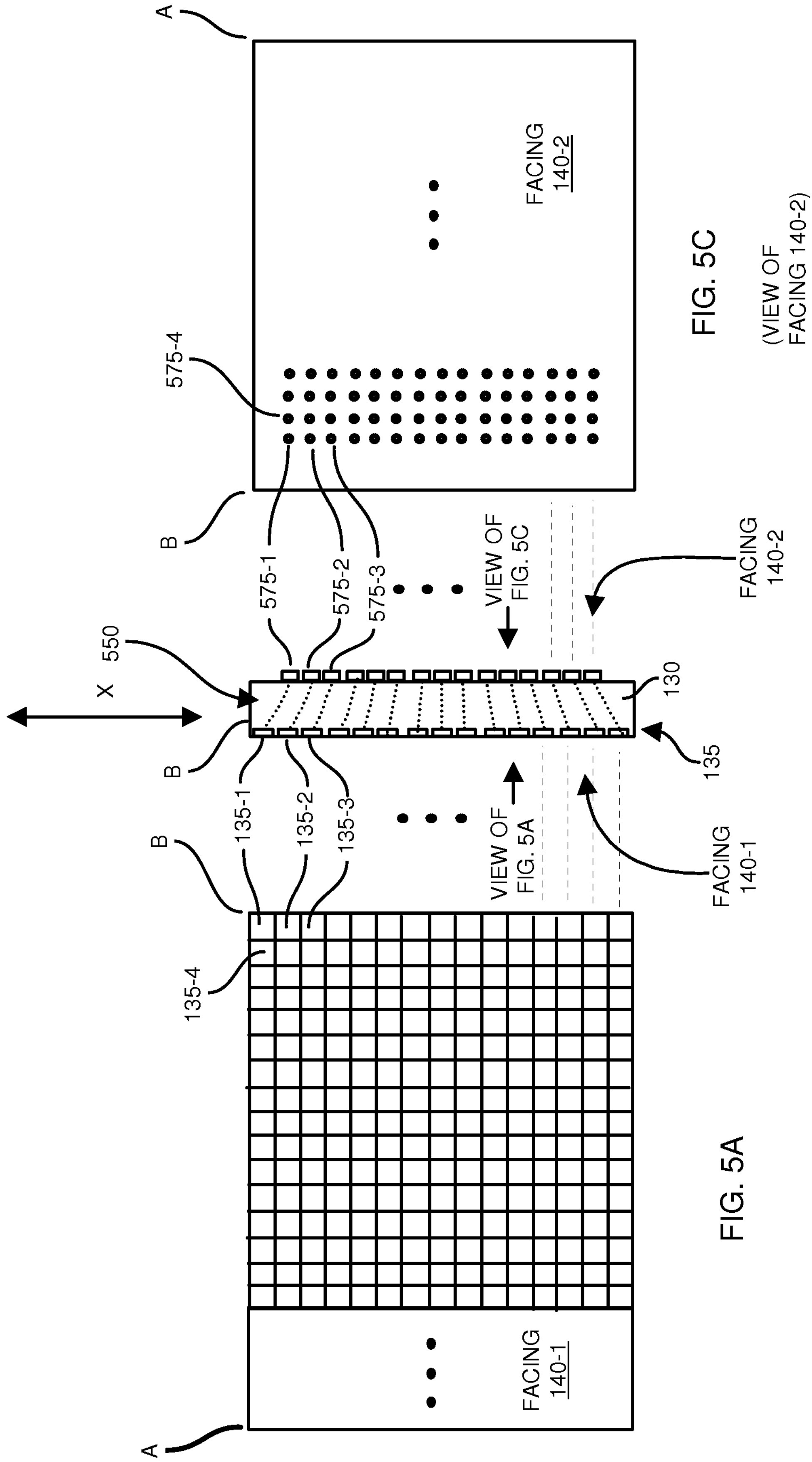


FIG. 5C
(VIEW OF FACING 140-2)

FIG. 5B

FIG. 5A

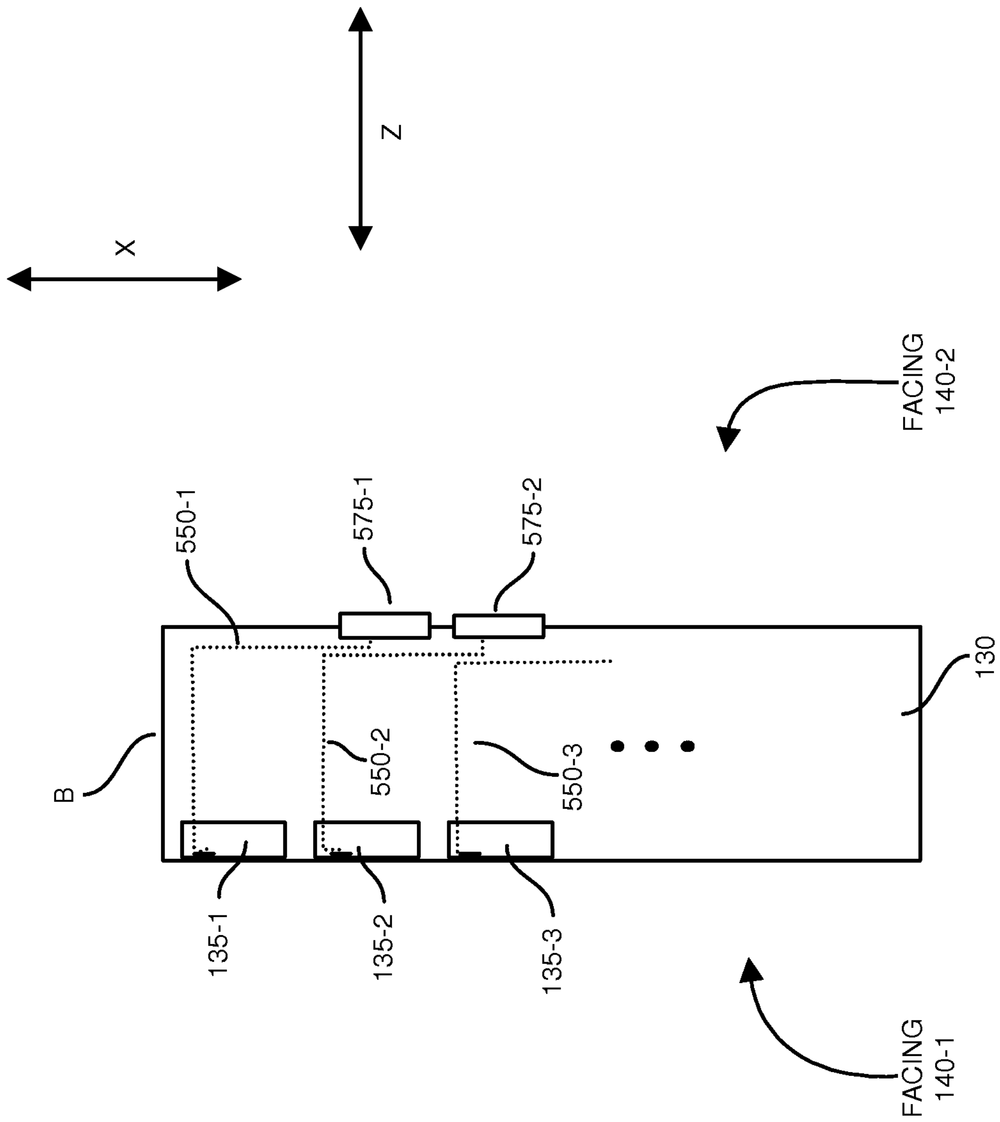


FIG. 6

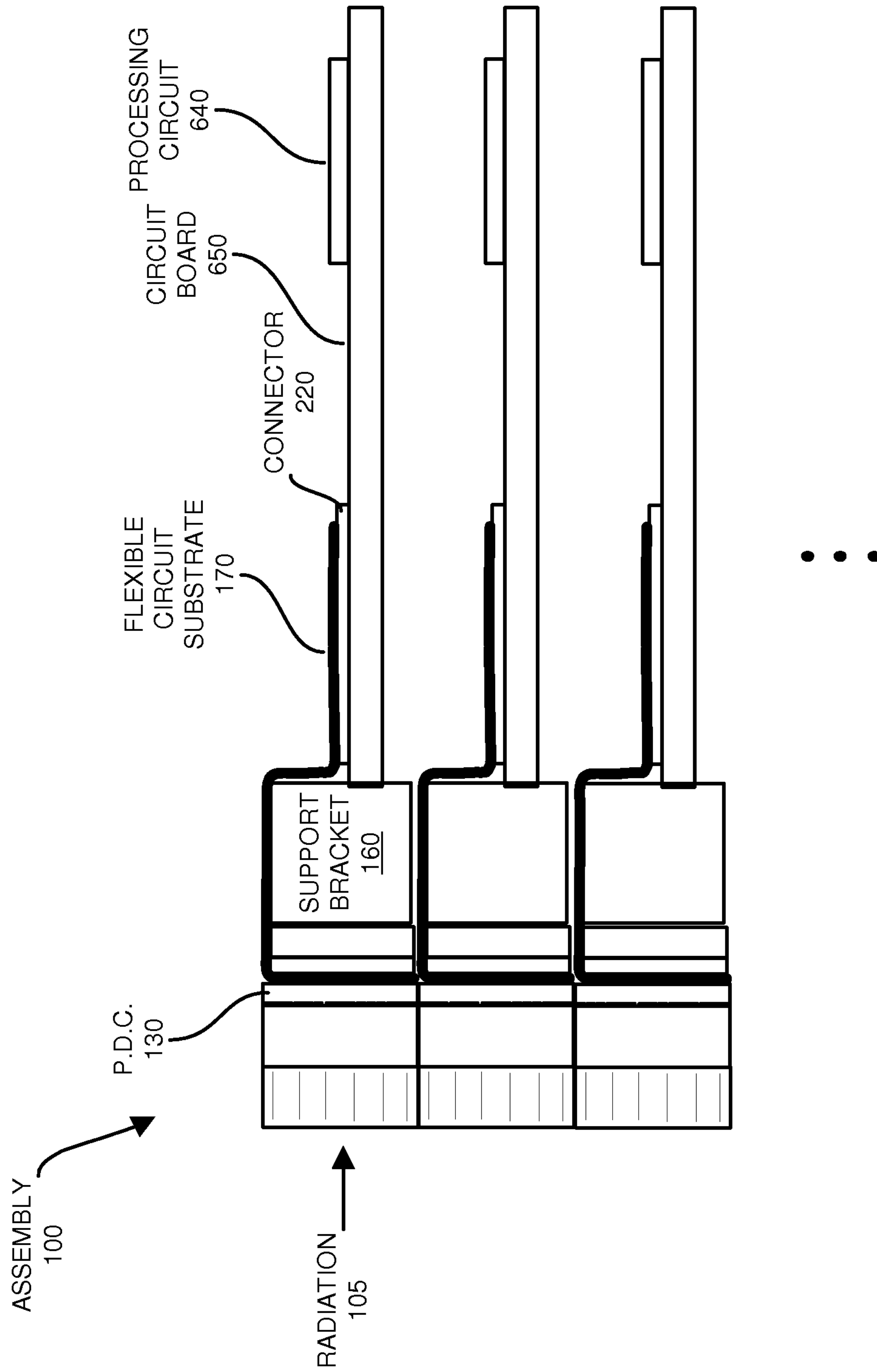


FIG. 7

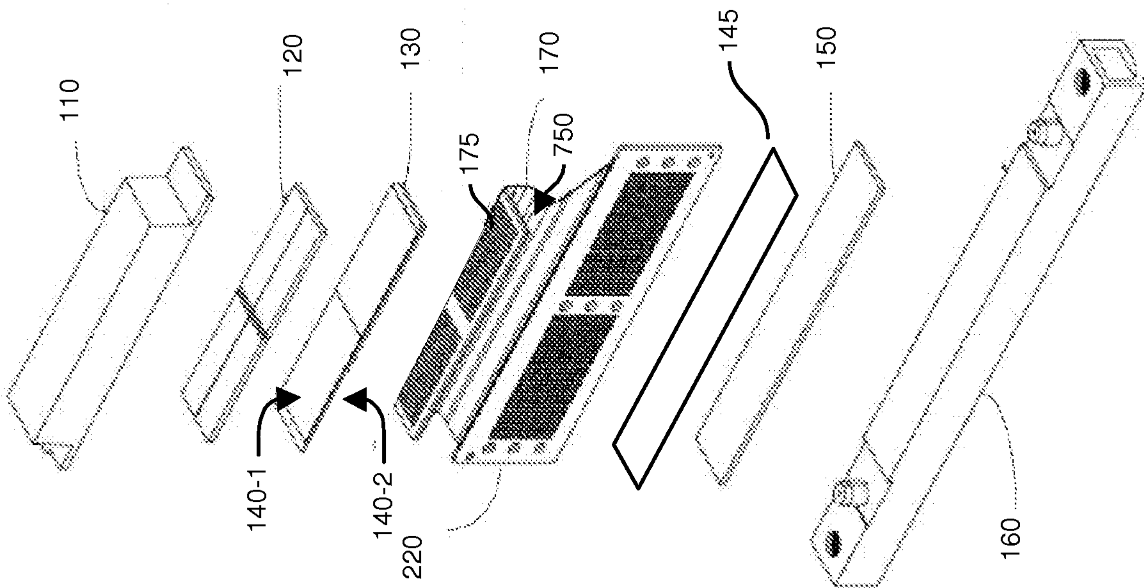


FIG. 8

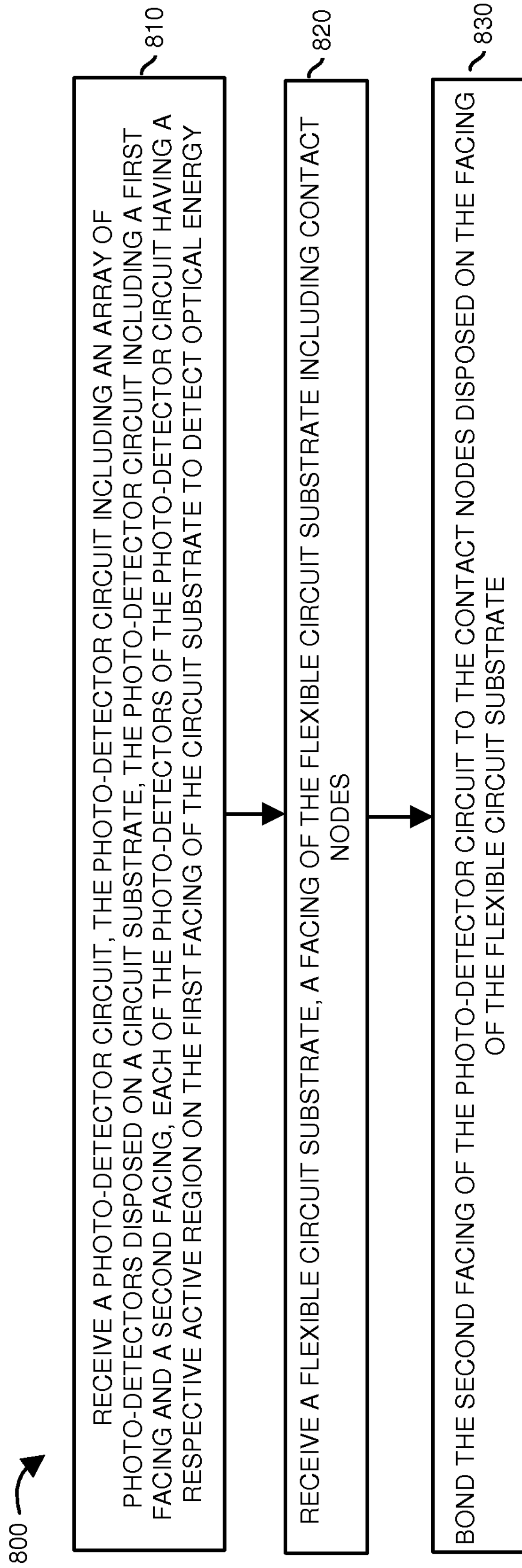


FIG. 9

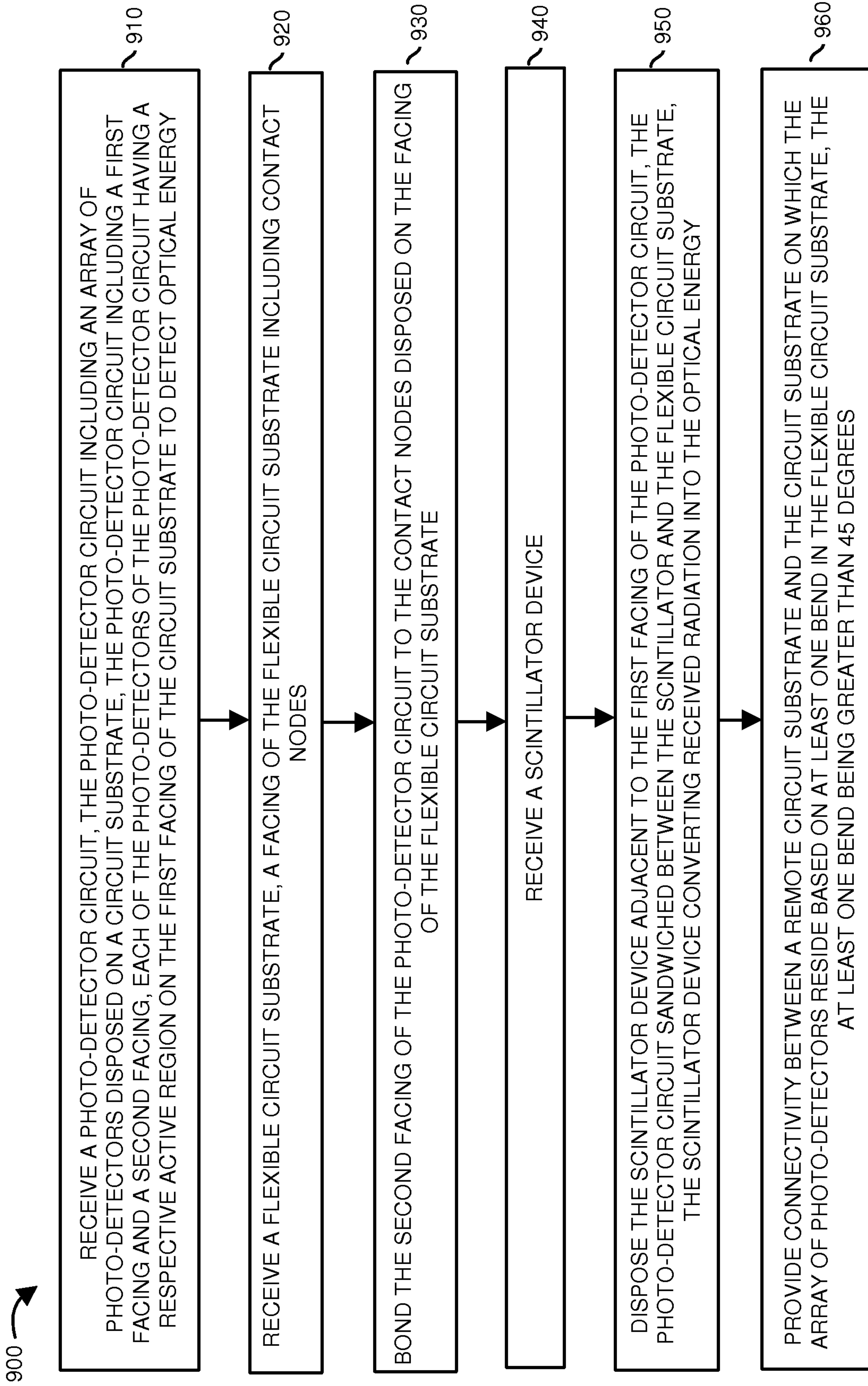


FIG. 10

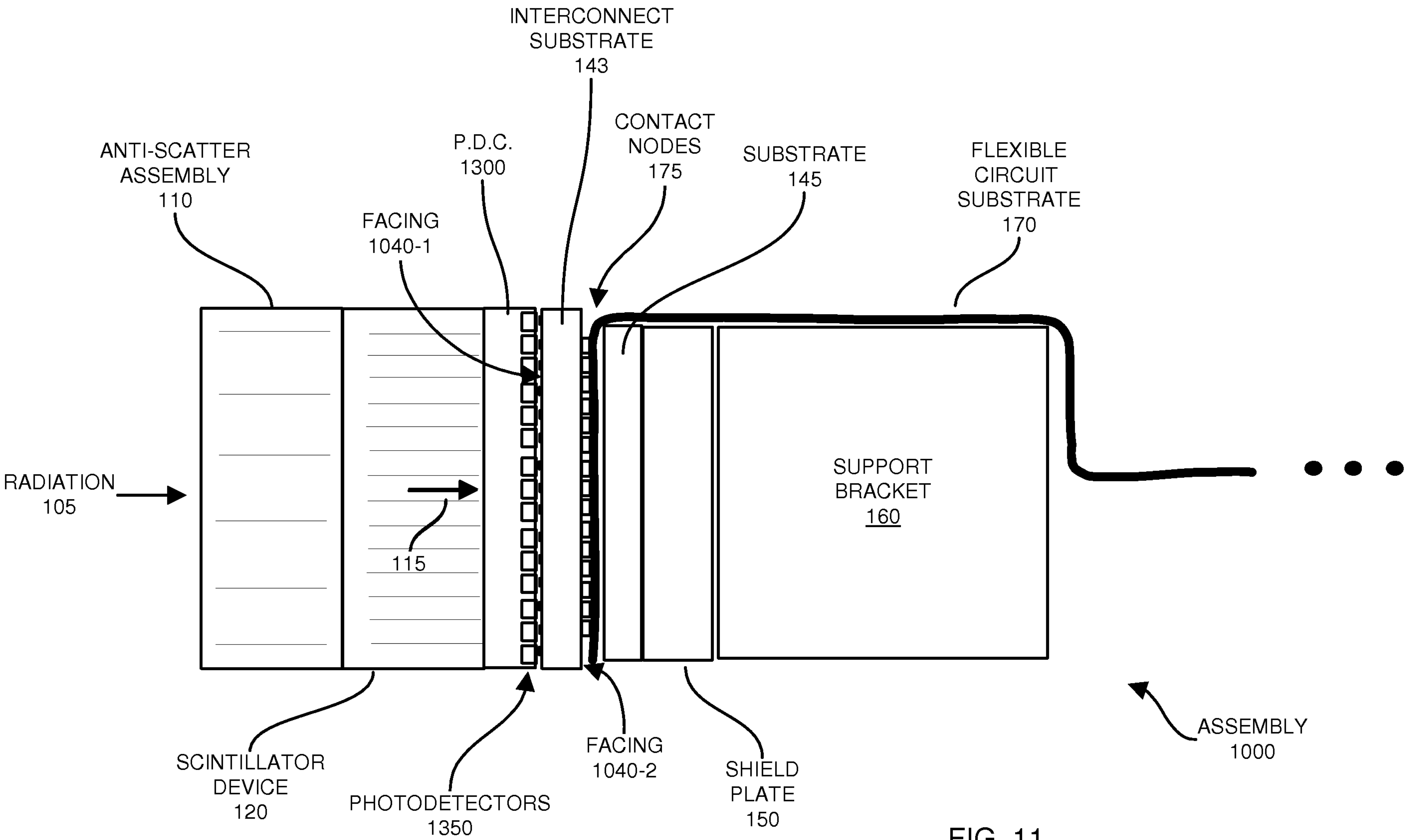


FIG. 11

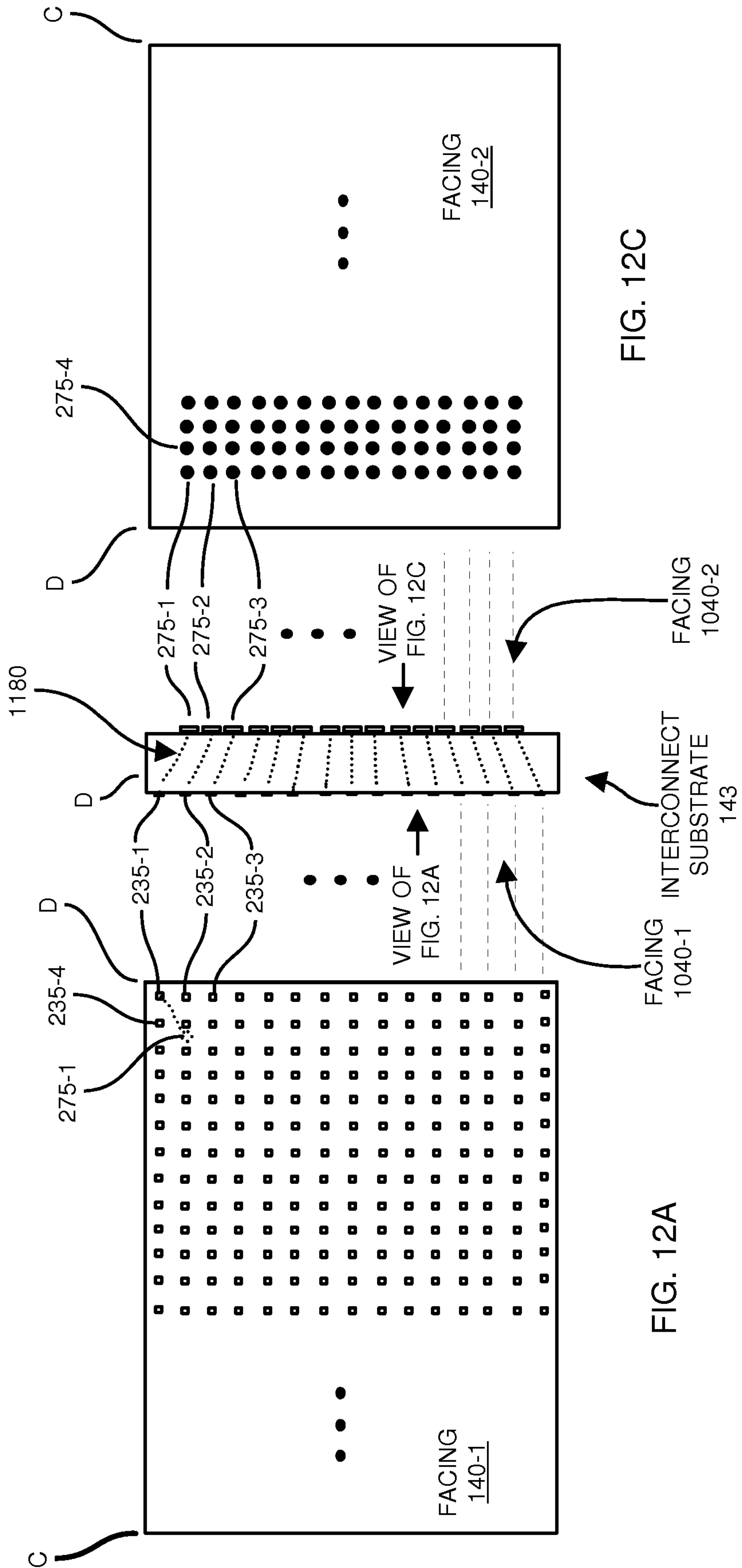


FIG. 12C

FIG. 12B

FIG. 12A

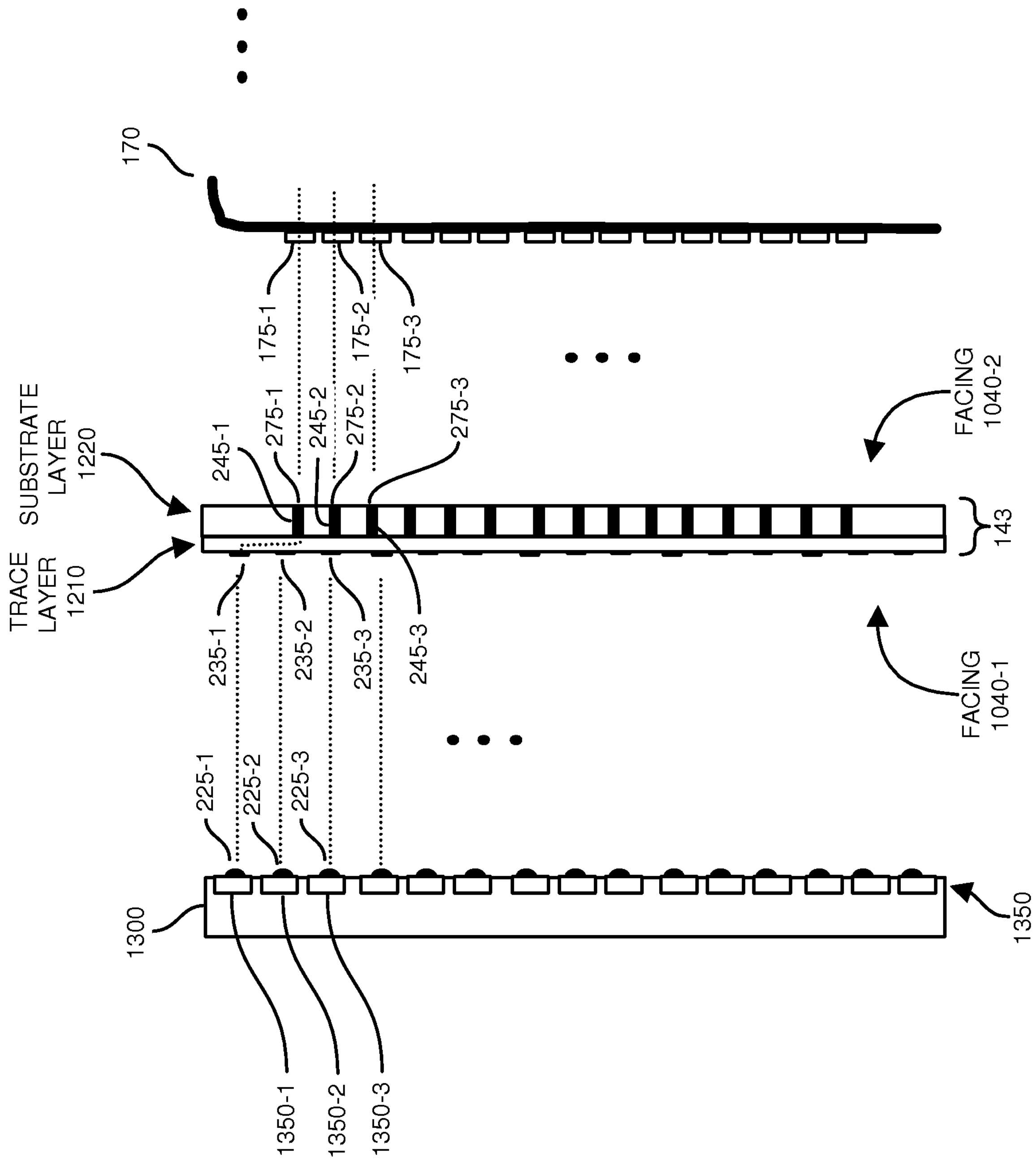


FIG. 13

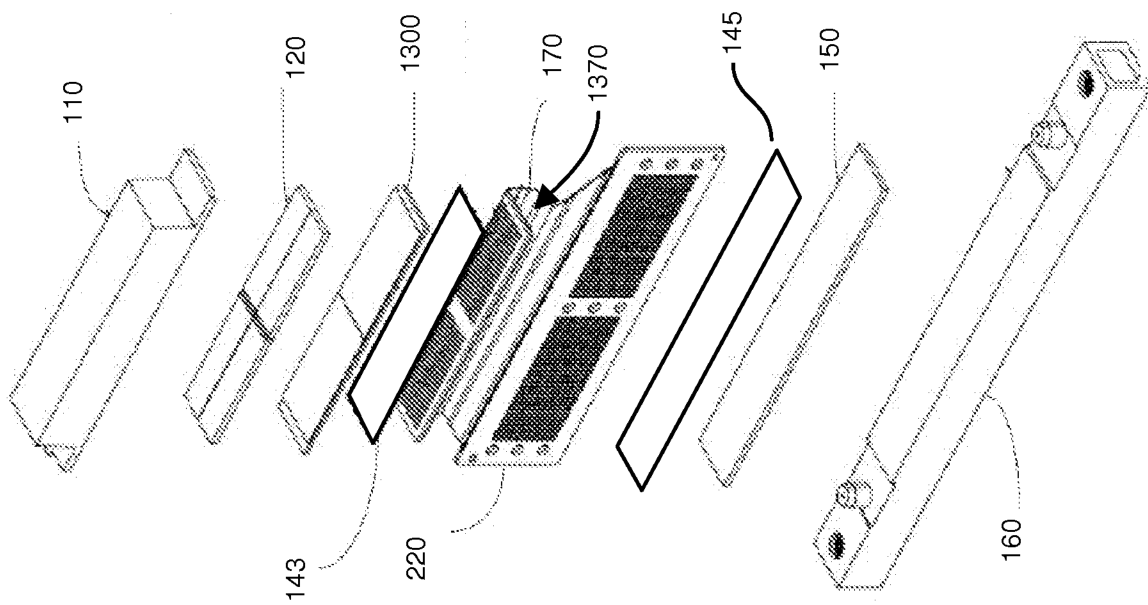


FIG. 14

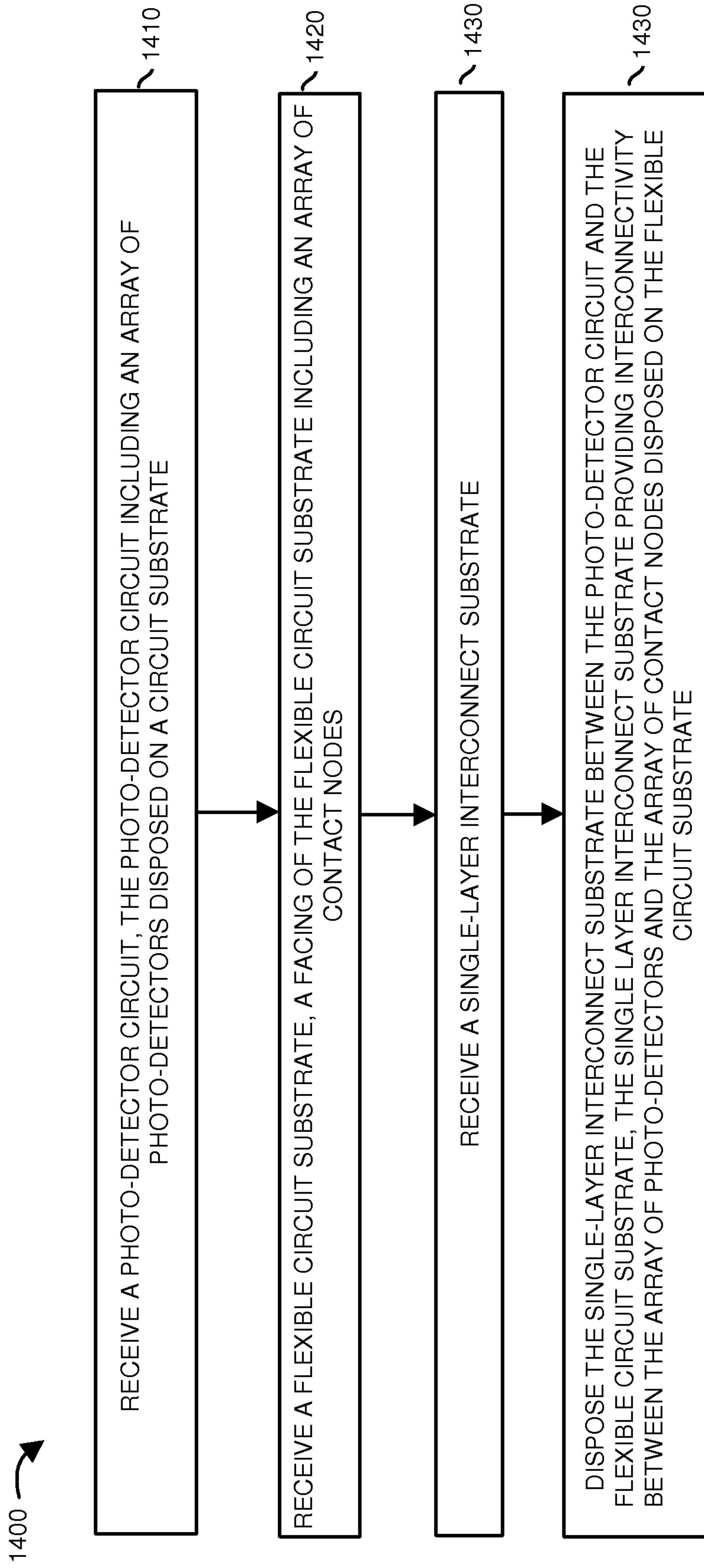


FIG. 15

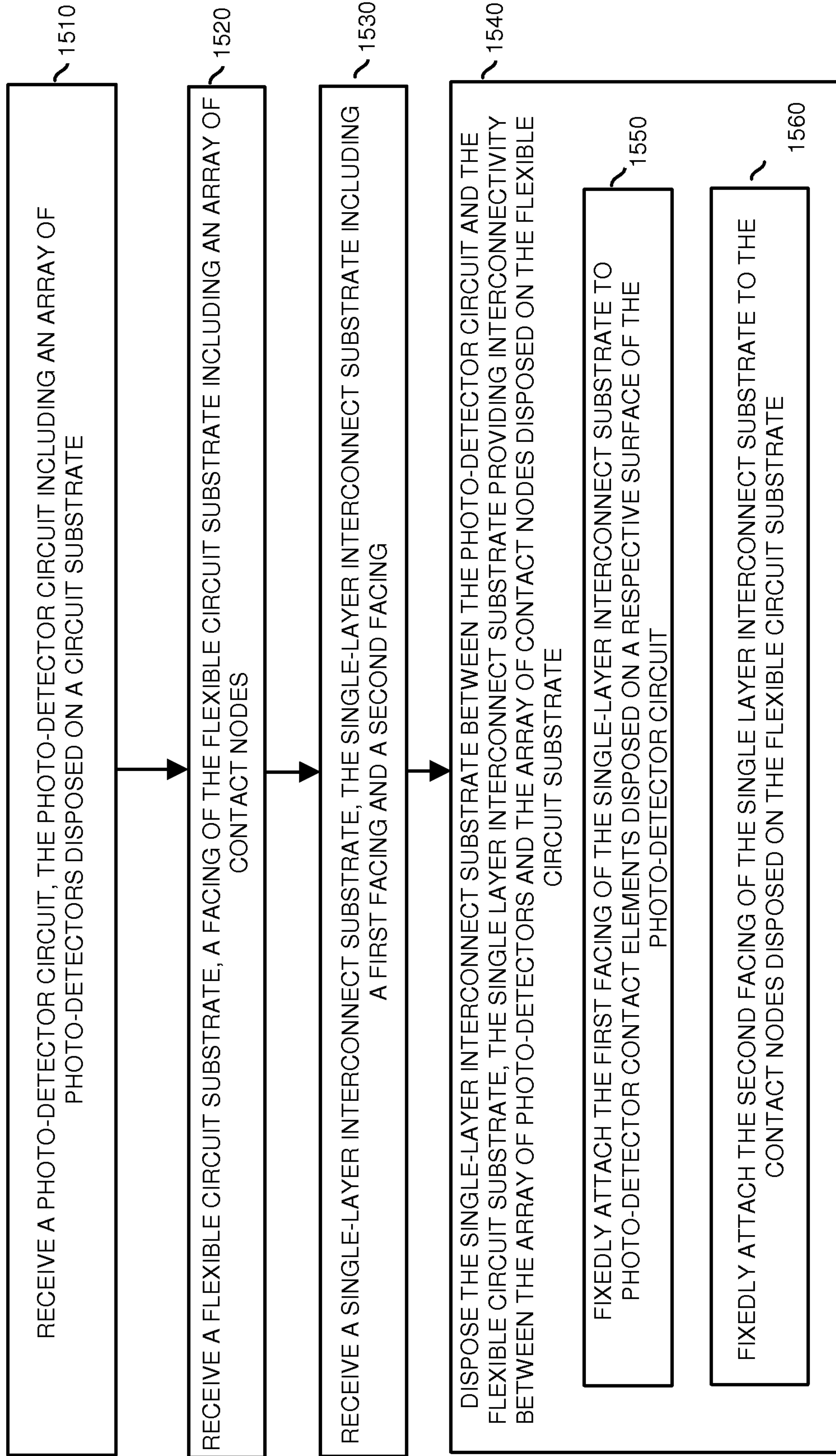


FIG. 16

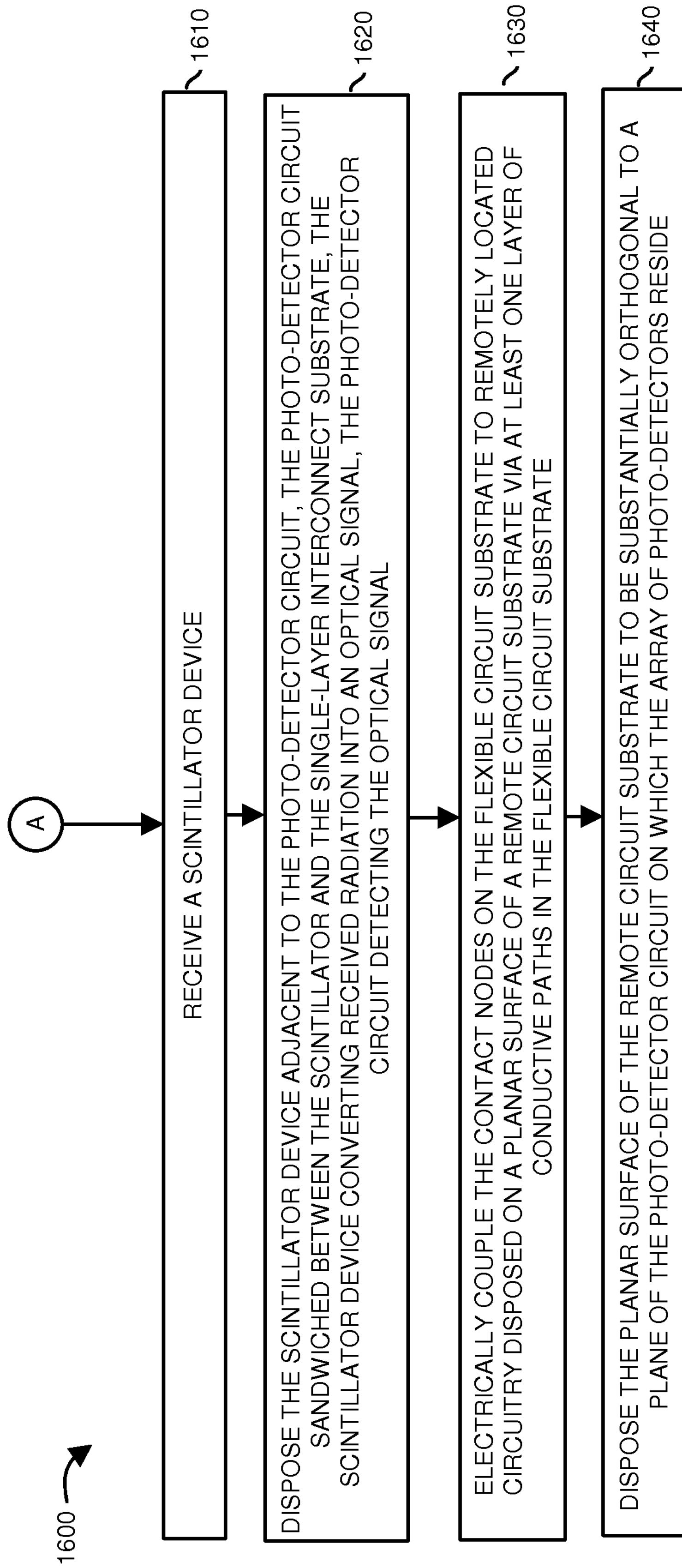


FIG. 17

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2012/039006

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. G01T1/20 H01L27/146
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)
G01T H01L

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, INSPEC, COMPENDEX

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>Y | US 2009/129538 A1 (TKACZYK JOHN ERIC [US] ET AL) 21 May 2009 (2009-05-21)<br>paragraph [0037] - paragraph [0041]; figures<br>----- | 1-3, 7-11,38<br>4,12 |
| X<br>Y | US 2004/120448 A1 (RATZMANN PAUL MICHAEL [US]) 24 June 2004 (2004-06-24)<br>paragraph [0019] - paragraph [0022]; figures<br>----- | 1-3, 7-11,38<br>4,12 |
| X<br>Y | US 2005/018810 A1 (NARAYANASWAMY MAHESH RAMAN [US] ET AL) 27 January 2005 (2005-01-27)<br>paragraph [0004]<br>paragraph [0031] - paragraph [0033]<br>paragraph [0038]; figures<br>----- | 1-3, 7-11,38<br>4,12 |

-/--

[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 |
|---|---|
| 8 February 2013 | 19/04/2013 |

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

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2007/039840 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS CORP [US]; LEVENE SIMHA [) 12 April 2007 (2007-04-12) | 1-3, 5-11,13, 14,38 |
| Y | page 7, line 3 - line 9<br>page 8, line 8 - line 18 | 4,12 |
| Y | US 2007/221858 A1 (ABENAIM DANIEL [US] ET AL) 27 September 2007 (2007-09-27)<br>paragraph [0023] - paragraph [0034] | 4,12 |
| A | JP 2008 122116 A (GE MED SYS GLOBAL TECH CO LLC) 29 May 2008 (2008-05-29)<br>abstract; figures | 1 |

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2012/039006

**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. ☐ 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.:

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.:

1-14, 38

**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.

☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2012/039006

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| US 2009129538 A1 | 21-05-2009 | NONE | |
| US 2004120448 A1 | 24-06-2004 | DE 10358867 A1 | 02-09-2004 |
| | | JP 2004195236 A | 15-07-2004 |
| | | NL 1024913 A1 | 26-10-2004 |
| | | NL 1024913 C2 | 25-07-2005 |
| | | US 2004120448 A1 | 24-06-2004 |
| | | US 2007104312 A1 | 10-05-2007 |
| US 2005018810 A1 | 27-01-2005 | DE 102004035405 A1 | 10-02-2005 |
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| | | JP 4502736 B2 | 14-07-2010 |
| | | JP 2005040610 A | 17-02-2005 |
| | | US 2005018810 A1 | 27-01-2005 |
| WO 2007039840 A2 | 12-04-2007 | CN 101278208 A | 01-10-2008 |
| | | EP 1934633 A2 | 25-06-2008 |
| | | JP 2009511104 A | 19-03-2009 |
| | | US 2008253507 A1 | 16-10-2008 |
| | | WO 2007039840 A2 | 12-04-2007 |
| US 2007221858 A1 | 27-09-2007 | NONE | |
| JP 2008122116 A | 29-05-2008 | NONE | |

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1-14, 38

A computed tomography detector comprising a front-illuminated photodiode array including a first facing configured to receive optical energy indicative of X-radiation that has traversed an examination region of a computed tomography apparatus, a substrate, and a second facing including a plurality of photodiode contact nodes in electrical communication with corresponding photodiodes in the array; a flexible circuit substrate, a facing of the flexible circuit substrate including contact nodes; and wherein the photodiode contact nodes of the front-illuminated photodiode array are directly bonded to the contact nodes disposed on the facing of the flexible circuit and a corresponding method.

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2. claims: 15-37

An assembly comprising a photo-detector circuit including an array of photo-detectors disposed on a circuit substrate to receive optical energy indicative of radiation that has traversed the examination region of a computed tomography apparatus; a flexible circuit substrate, a facing of the flexible circuit substrate including an array of contact nodes; and an interconnect substrate including a first facing and a second facing, the interconnect substrate being a single substrate of material, the first facing in contact with the photo-detector circuit, the second facing in contact with the array of contact nodes, the interconnect substrate including conductive paths extending from the first facing to the second facing to provide interconnectivity between the array of photo-detectors and the array of contact nodes disposed on the flexible circuit substrate and a corresponding method

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