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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

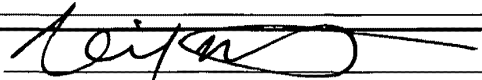
This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

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Additional inventors are being named on the _____ separately numbered sheets attached hereto		
TITLE OF THE INVENTION (500 characters max):		
METHOD AND APPARATUS FOR USE IN CAMERA AND SYSTEMS EMPLOYING SAME		
Direct all correspondence to: CORRESPONDENCE ADDRESS		
☒ The address corresponding to Customer Number: 37362		
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ENCLOSED APPLICATION PARTS (check all that apply)		
☒ Application Data Sheet. See 37 CFR 1.76	☐ CD(s), Number of CDs _____	
☒ Specification Number of Pages 107	☐ Other (specify) _____	
☒ Drawing(s) Number of Sheets 267		
Application Size Fee: If the specification and drawings exceed 100 sheets of paper, the application size fee due is \$250 (\$125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).		
METHOD OF PAYMENT OF FILING FEES AND APPLICATION SIZE FEE FOR THIS PROVISIONAL APPLICATION FOR PATENT		
☒ Applicant claims small entity status. See 37 CFR 1.27.	TOTAL FEE AMOUNT (\$)	
☒ A check or money order is enclosed to cover the filing fee and application size fee (if applicable).	\$1,700.00	
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☒ The Director is hereby authorized to charge the filing fee and application size fee (if applicable) or credit any overpayment to Deposit Account Number: 50-0763 . A duplicative copy of this form is enclosed for fee processing.		
The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.		
☒ No.		
☐ Yes, the name of the U.S. Government agency and the Government contract number are: _____		

SIGNATURE

Date **July 1, 2005**TYPED or PRINTED NAME **Neil A. Steinberg**REGISTRATION NO. **34,735**TELEPHONE **650-968-8079**

(if appropriate)

Docket Number: **301.001-P2****USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT**

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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First Named Inventor	Olsen	Docket Number	301.001-P2
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

(Case No. 301.001-P2)

In the Application of: **Olsen et al.**

Filed: **July 1, 2005**

Serial No: **To Be Assigned**

Title: **Method and Apparatus for Use in Camera and Systems Employing Same**

Commissioner for Patents
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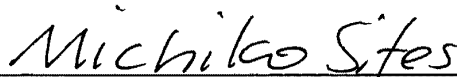
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I hereby certify that the attached: **1)** Provisional Application for Patent Cover Sheet (2 pages + 1 copy), **2)** Provisional Application (109 pages of text and 267 pages of drawings), and **3)** Check (\$1,700.00) is/are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" Service under 37 C.F.R. 1.10 on the date indicated above and is addressed to the Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.



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TITLE: Method and Apparatus for Use in Camera and Systems Employing Same

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PROVISIONAL PATENT APPLICATION

NEWPORT IMAGING CORPORATION

METHOD AND APPARATUS FOR USE IN CAMERA AND SYSTEMS EMPLOYING SAME

Field of the Invention

The field of the invention is digital imaging.

Background of the Invention

The recent technology transition from film to “electronic media” has spurred the rapid growth of the imaging industry with applications including still and video cameras, cell phones, other personal communications devices, surveillance equipment, automotive applications, computers, manufacturing and inspection devices, medical appliances, toys, plus a wide range of other and continuously expanding applications. The lower cost and size of digital cameras (whether as stand-alone products or imbedded in other appliances) is a primary driver for this growth and market expansion.

Most applications are continuously looking for all or some combination of higher performance (image quality), features, smaller size and/or lower cost. These market needs can often be in conflict: higher performance often requires larger size, improved features can require higher cost as well as a larger size, and conversely, reduced cost and/or size can come at a penalty in performance and/or features. As an example, consumers look for higher quality images from their cell phones, but are unwilling to accept the size or cost associated with putting stand-alone digital camera quality into their pocket sized phones.

One driver to this challenge is the lens system for digital cameras. As the number of photo detectors (pixels) increases, which increases image resolution, the lenses must become larger to span the increased size of the image sensor which carries the photo detectors. Also, the desirable “zoom lens” feature adds additional components, size and cost to a lens system. Zoom, as performed by the lens system, known as “optical zoom”, is a highly desired feature. Both these attributes, although benefiting image quality and features, add a penalty in camera size and cost. In some cases, such as cell phones or

other appliances where size and/or cost are critical, these negatives can be a major negative to users.

Digital camera suppliers have one advantage over traditional film providers in the area of zoom capability. Through electronic processing, digital cameras can provide “electronic zoom” which provides the zoom capability by cropping the outer regions of an image and then electronically enlarging the center region to the original size of the image. In a manner similar to traditional enlargements, a degree of resolution is lost when performing this process. Further, since digital cameras capture discrete input to form a picture rather than the ubiquitous process of film, the lost resolution is more pronounced. As such, although “electronic zoom” is a desired feature, it is not a direct substitute for “optical zoom.”

Summary of Invention

It should be understood that there are many inventions described and illustrated herein.

Indeed, the present invention is not limited to any single aspect or embodiment thereof nor to any combinations and/or permutations of such aspects and/or embodiments.

Moreover, each of the aspects of the present invention, and/or embodiments thereof, may be employed alone or in combination with one or more of the other aspects of the present invention and/or embodiments thereof. For the sake of brevity, many of those permutations and combinations will not be discussed separately herein.

Detailed Description

Figure 1 shows a prior art digital camera 100 that includes a lens assembly 110, a color filter sheet 112, an image sensor 116, an electronic image storage media 120, a power supply 124, a peripheral user interface (represented as a shutter button) 132, a circuit board 136 (which supports and electrically interconnects the aforementioned components), a housing 140 (including housing portions 141, 142, 143, 144, 145 and 146) and a shutter assembly (not shown), which controls an aperture 150 and passage of light into the digital camera 100. A mechanical frame 164 is used to hold the various

parts of the lens assembly 110 together. The lens assembly 110 includes lenses 161, 162 and one or more electro-mechanical devices 163 to move the lenses 161, 162 along a center axis 165. The lenses 161, 162 may be made up of multiple elements bonded together to form an integral optical component. Additional lenses may be employed if necessary. The electro-mechanical device 163 portion of the lens assembly 110 and the mechanical frame 164 portion of the lens assembly 110 may be made up of numerous components and/or complex assemblies.

The color filter 112 sheet has an array of color filters arranged in a Bayer pattern (e.g., a 2x2 matrix of colors with alternating red and green in one row and alternating green and blue in the other row, although other colors may be used). The Bayer pattern is repeated throughout the color filter sheet.

The image sensor 116 contains a plurality of identical photo detectors (sometimes referred to as “picture elements” or “pixels”) arranged in a matrix. The number of photo detectors is usually in range of hundreds of thousands to millions. The lens assembly 110 spans the diagonal of the array.

Each of the color filters in the color filter sheet 112 is disposed above a respective one of the photo detectors in the image sensor 116, such that each photo detector in the image sensor receives a specific band of visible light (e.g., red, green or blue) and provides a signal indicative of the color intensity thereof. Signal processing circuitry (not shown) receives signals from the photo detectors, processes them, and ultimately outputs a color image.

The peripheral user interface 132, which includes the shutter button, may further include one or more additional input devices (e.g., for settings, controls and/or input of other information), one or more output devices, (e.g., a display for output of images or other information) and associated electronics.

Figure 2A shows the operation of the lens assembly 110 in a retracted mode (sometimes referred to as normal mode or a near focus setting). The lens assembly 110 is shown focused on a distant object (represented as a lightning bolt) 180. A representation of the image sensor 116 is included for reference purposes. A field of view is defined between reference lines 182, 184. The width of the field of view may be for example, 50 millimeters (mm). To achieve this field of view 182, 184, electro-mechanical devices

163 have positioned lenses 161 and 162 relatively close together. The lens assembly 110 passes the field of view through the lenses 161, 162 and onto the image sensor 116 as indicated by reference lines 186, 188. An image of the object (indicated at 190) is presented onto the image sensor 116 in the same ratio as the width of the actual image 180 relative to the actual field of view 182, 184.

Figure 2B shows the operation of the lens assembly 110 in a zoom mode (sometimes referred to as a far focus setting). In this mode, the electro-mechanical devices 163 of the lens assembly 110 re-position the lens 161, 162 so as to reduce the field of view 182, 184 over the same image area, thus making the object 180 appear closer (i.e., larger). One benefit of the lens assembly 110 is that the resolution with the lens assembly 110 in zoom mode is typically equal to the resolution with the lens assembly 110 in retracted mode. One drawback, however, is that the lens assembly 110 can be costly and complex. Moreover, providing a lens with zoom capability results in less light sensitivity and thus increases the F-stop of the lens, thereby making the lens less effective in low light conditions.

Listed below are some of the other drawbacks that are associated with one or more traditional digital cameras.

Traditional digital cameras, employing one large array on an image sensor, also employ one lens that must span the entire array. That creates two physical size related issues: 1) a lens that spans a large array (e.g. 3 Meg pixels) will be physically larger than a lens that spans a smaller array (e.g., 1 Meg pixels) in both diameter and thickness; and 2) a larger Lens/array combination will likely have a longer focal length which will increase the height of the lens.

Also, since the traditional lens must resolve the entire spectrum of visible light wavelengths, they are complex, usually with 3 – 8 separate elements. This also adds height and cost.

Further, since the traditional lens must pass all bandwidths of color, it must be a clear lens (no color filtering). The needed color filtering previously described is accomplished by depositing a sheet of tiny color filters beneath the lens and on top of the image sensor. For example, an image sensor with one million pixels will require a sheet of one million individual color filters. This technique is costly (parts and assembly),

presents a limiting factor in shrinking the size of the pixels, plus attenuates the photon stream passing through it (i.e., reduces light sensitivity or dynamic range).

Further, since the lens must be moved forward and backwards with respect to the image sensor, additional time and power are required. This is an undesirable aspect of digital cameras as it creates long delays in capture response time as well as diminished battery capacity. One or more of the above drawbacks associated with traditional digital cameras may be addressed by one or more embodiments of one or more aspects of the present invention.

Figure 3 shows an example of a digital camera 200 in accordance with one embodiment of the present invention. The digital camera 200 includes a digital camera subsystem 210, an electronic image storage media 220, a power supply 224, a peripheral user interface (represented as a shutter button) 232, a circuit board 236 (which supports and electrically interconnects the aforementioned components), a housing 240 (including housing portions 241, 242, 243, 244, 245 and 246) and a shutter assembly (not shown), which controls an aperture 250 and passage of light into the digital camera 200.

The digital camera subsystem (sometimes referred to herein as the “DCS”) 210 includes one or more camera channels, e.g., four camera channels 260A-260D, and replaces (and/or fulfills one, some or all of the roles fulfilled by) the lens assembly 110, the color filter 112 and the image sensor 116 of the digital camera 100 described above.

The peripheral user interface 232, which includes the shutter button, may further include one or more additional input devices (e.g., for settings, controls and/or input of other information), one or more output devices, (e.g., a display for output of images or other information) and associated electronics.

The electronic image storage media 220, power supply 224, peripheral user interface 232, circuit board 236, housing 240, shutter assembly (not shown), and aperture 250, may be, for example, similar to the electronic image storage media 120, power supply 124, peripheral user interface 132, circuit board 136, housing 140, shutter assembly (not shown), and aperture 150 of the digital camera 100 described above.

Figures 4 show one embodiment of the digital camera system 210, which as stated above includes one or more camera channels (e.g., four camera channels 260A-260D). Each of the camera channels 260A-260D includes an optics portion and a sensor portion.

For example, camera channel 260A includes an optics portion 290A and a sensor portion 292A. Camera channel B includes an optics portion 290B and a sensor portion 292B. Camera channel C includes an optics portion 290C and a sensor portion 292C. Camera channel D includes an optics portion 290D and a sensor portion 292D. The optics portions of the one or more camera channels are collectively referred to herein as an optics subsystem. The sensor portions of the one or more camera channels are collectively referred to herein as a sensor subsystem.

If the digital camera subsystem 210 includes more than one camera channel, the channels may or may not be identical to one another. For example, in some embodiments, the camera channels are identical to one another. In some other embodiments, one or more of the camera channels are different, in one or more respects, from one or more of the other camera channels. In some of the latter embodiments, each camera channel may be used to detect a different color (or band of colors) and/or band of light than that detected by the other camera channels. For example, in some embodiments, one of the camera channels, e.g., camera channel 260A, detects red light, one of the camera channels, e.g., camera channel 260B, detects green light, one of the camera channels, e.g., camera channel 260C, detects blue light and one of the camera channels, e.g., camera channel 260D, detects infrared light. In some other embodiments, one of the camera channels, e.g., camera channel 260A, detects cyan light, one of the camera channels, e.g., camera channel 260B, detects yellow light, one of the camera channels, e.g., camera channel 260C, detects magenta light and one of the camera channels, e.g., camera channel 260D, detects clear light (black and white). In some other embodiments, one of the camera channels, e.g., camera channel 260A, detects red light, one of the camera channels, e.g., camera channel 260B, detects green light, one of the camera channels, e.g., camera channel 260C, detects blue light and one of the camera channels, e.g., camera channel 260D, detects cyan light. Any other color combinations can also be used.

Thus, if the subsystem includes more than one optics portion, the optics portions may or may not be identical to one another. In some embodiments, the optics portions are identical to one another. In some other embodiments, one or more of the optics portions are different, in one or more respects, from one or more of the other optics

portions. For example, in some embodiments, one or more of the characteristics (for example, but not limited to, its type of element(s), size, and/or performance) of one or more of the optics portions is tailored to the respective sensor portion and/or to help achieve a desired result. For example, if a particular camera channel is dedicated to a particular color (or band of colors) or wavelength (or band of wavelengths) then the optics portion for that camera channel may be adapted to transmit only that particular color (or band of colors) or wavelength (or band of wavelengths) to the sensor portion of the particular camera channel and/or to filter out one or more other colors or wavelengths.

Likewise, if the digital camera subsystem 210 includes more than one sensor portion, the sensor portions may or may not be identical to one another. In some embodiments, the sensor portions are identical to one another. In some other embodiments, one or more of the sensor portions are different, in one or more respects, from one or more of the other sensor portions. For example, in some embodiments, one or more of the characteristics (for example, but not limited to, its type of element(s), size, and/or performance) of one or more of the sensor portions is tailored to the respective optics portion and/or to help achieve a desired result. For example, if a particular camera channel is dedicated to a particular color (or band of colors) or wavelength (or band of wavelengths) then the sensor portion for that camera channel may be adapted to have a sensitivity that is higher to that particular color (or band of colors) or wavelength (or band of wavelengths) than other colors or wavelengths and/or to sense only that particular color (or band of colors) or wavelength (or band of wavelengths).

The digital camera system 210 further includes a processor. The processor includes an image processor portion 270 (hereafter image processor 270) and a controller portion 300 (hereafter controller 300). The controller portion is part of a positioning system 280. The processor 270 is connected to the one or more sensor portions, e.g., sensor portions 292A-292D, via one or more communication links, represented by a signal line 330.

The positioning system 280 includes the controller 300 and one or more positioners, e.g., positioners 310, 320. The controller 300 is connected (e.g., electrically connected) to the image processor 270 via one or more communication links, represented

by a signal line 340. The controller 300 is connected (e.g., electrically connected) to the one or more positioners, e.g., positioners 310, 320, via one or more communication links (for example, but not limited to, a plurality of signal lines) represented by signal lines 350, 360.

A communication link may be any kind of communication link including but not limited to, for example, wired (e.g., conductors, fiber optic cables) or wireless (e.g., acoustic links, electromagnetic links or any combination thereof including but not limited to microwave links, satellite links, infrared links), and combinations thereof, each of which may be public or private, dedicated and/or shared (e.g., a network). A communication link may employ for example circuit switching or packet switching or combinations thereof. Other examples of communication links include dedicated point-to-point systems, wired networks, and cellular telephone systems. A communication link may employ any protocol or combination of protocols including but not limited to the Internet Protocol.

The communication link may transmit any type of information. The information may have any form, including, for example, but not limited to, analog and/or digital (a sequence of binary values, i.e. a bit string). The information may or may not be divided into blocks. If divided into blocks, the amount of information in a block may be predetermined (e.g., specified and/or agreed upon in advance) or determined dynamically, and may be fixed (e.g., uniform) or variable.

The one or more positioners, e.g., positioners 310, 320, are adapted to support and/or position each of the one or more optics portions, e.g., optics portions 290A-290D, above and/or in registration with a respective one of the one or more sensor portions, e.g., sensor portions 292A-292D. In this embodiment, for example, the positioner 310 supports and positions the one or more optics portions e.g., optics portions 290A-290D, at least in part. The positioner 320 supports and positions the one or more sensor portions, e.g., sensor portions 292A-292D, at least in part.

The positioner 310 may be affixed, directly or indirectly, to the positioner 320. Thus, for example, the positioner 310 may be affixed directly to the positioner 320 (e.g., using adhesive) or the positioner 310 may be affixed to a support (not shown) that is, in turn, affixed to the positioner 320.

The size of the positioner 310 may be, for example, approximately the same size (in one or more dimensions) as the positioner 320, approximately the same size (in one or more dimensions) as the arrangement of the optics portions 290A-290D and/or approximately the same size (in one or more dimensions) as the arrangement of the sensor portions 292A-292D. One advantage of such dimensioning is that it helps keep the dimensions of the digital camera subsystem as small as possible.

The positioners 310, 320 may comprise any type of material(s) and may have any configuration and/or construction. For example, the positioner 310 may comprise silicon, glass, plastic, or metallic materials and/or any combination thereof. The positioner 320 may comprise, for example, silicon, glass, plastic or metallic materials and/or any combination thereof. Further, each of the positioners 310, 320 may comprise one or more portions that are fabricated separate from one another, integral with one another and/or any combination thereof.

One or more of the positioners 310, 320 may also be adapted to provide or help provide relative movement between one or more of the optics portions 290A-290D and one or more of the respective sensor portions 292A-292D. In that regard, and as will be further described below, one or more of the positioners 310, 320 may include one or more actuators to provide or help provide movement of one or more of the optics portions and/or one or more of the sensor portions. In some embodiments, one or more of the positioners 310, 320 include one or more position sensors to be used in providing one or more movements.

The operation of the digital camera subsystem is as follows. An optics portion of a camera channel receives light from within a field of view and transmits one or more portions of such light. The sensor portion receives one or more portion of the light transmitted by the optics portion and provides an output signal indicative thereof. The output signal from the sensor portion is supplied to the image processor, which as is further described below, may generate an image based thereon, at least in part. If the digital camera system includes more than one camera channels, the image processor may generate a combined image based at the images from two or more of the camera channels, at least in part. For example, in some embodiments, each of the camera channels is dedicated to a different color (or band of colors) or wavelength (or band of

wavelengths) than the other camera channels and the image processor combines the images from the two or more camera channels to provide a full color image. The positioning system may provide movement of the optics portion (or portions thereof) and/or the sensor portion (or portions thereof) to provide a relative positioning desired there between with respect to one or operating modes of the digital camera system.

Referring to Figure 5A-5W, an optics portion, such as for example, optics portions 290A, may include, for example, any number of lenses, filters, prisms, masks and/or combination thereof. Figure 5A is a schematic representation of one embodiment of optics portion 290A in which the optics portion 290A comprises a single lens. Figure 5B is a schematic representation of another embodiment of the optics portion 290A in which the optics portion 290A includes two or more lenses. The portions of may be separate from one another, integral with one another, and/or any combination thereof. Thus, for example, the two lenses represented in Figure 5B may be separate from one another or integral with one another.

Figures 5C-5G show schematic representations of example embodiments of optics portion 290A in which the optics portion 290A has one or more lenses and one or more filters. The one or more lenses and one or more filters may be separate from one another, integral with one another, and/or any combination thereof. Moreover, the one or more lenses and one or more filters may be disposed in any configuration and/or sequence, for example, a lens-filter sequence (see for example Figure 5C), a filter-lens sequence (see for example Figure 5G), a lens-lens-filter-filter sequence (see for example Figure 5D, which shows two or more lenses and two or more filters), a lens-filter-lens-filter sequence (see for example Figure 5E), a lens-filter-filter-lens sequence (see for example Figure 5F) and combinations and/or variations thereof.

Figures 5H-5L show schematic representations of example embodiments of optics portion 290A in which the optics portion 290A has one or more lenses and one or more prisms. The one or more lenses and one or more prisms may be separate from one another, integral with one another, and/or any combination thereof. Moreover, the one or more lenses and one or more prisms may be disposed in any configuration and/or sequence, for example, a lens-prism sequence (see for example Figure 5H), a prism-lens sequence (see for example Figure 5L), a lens-lens-prism-prism sequence (see for example

Figure 5I, which shows two or more lenses and two or more prisms), a lens–prism–lens–prism sequence (see for example Figure 5J), a lens–prism–prism–lens sequence (see for example Figure 5K) and combinations and/or variations thereof.

Figures 5M-5Q show schematic representations of example embodiments of optics portion 290A in which the optics portion 290A has one or more lenses and one or more masks. The one or more lenses and one or more masks may be separate from one another, integral with one another, and/or any combination thereof. Moreover, the one or more lenses and one or more masks may be disposed in any configuration and/or sequence, for example, a lens-mask sequence (see for example Figure 5M), a mask-lens sequence (see for example Figure 5Q), a lens-lens-mask-mask sequence (see for example Figure 5N, which shows two or more lenses and two or more masks), a lens–mask–lens–mask sequence (see for example Figure 5O), a lens–mask–mask–lens sequence (see for example Figure 5P) and combinations and/or variations thereof.

Figures 5R-5V show schematic representations of example embodiments of optics portion 290A in which the optics portion 290A has one or more lenses, filters, prisms, and/or masks. The one or more lenses, filters, prisms and/or masks may be separate from one another, integral with one another, and/or any combination thereof. Moreover, the one or more lenses, filters, prisms and/or masks may be disposed in any configuration and/or sequence, for example, a lens-filter-prism sequence (see for example Figure 5R), a lens-filter-mask sequence (see for example Figure 5S), a lens-prism-mask sequence (see for example Figure 5T), a lens–filter–prism–mask sequence (see for example Figure 5U and Figure 5V, which shows two or more lenses, two or more filters, two or more prisms and two or more masks) and combinations and/or variations thereof.

Figure 5W is a representation of one embodiment of optics portion 290A in which the optics portion 290A includes two or more lenses, two or more filters, two or more prisms and two or more masks.

Figures 6A-6B are a representation of one embodiment of a sensor portion, e.g., sensor portion 292A, the purpose of which is to capture light and convert it into one or more signals (e.g., electrical signals) indicative thereof. Referring to Figure 6A, the sensor portion includes a plurality of sensor elements such as for example, a plurality of identical photo detectors (sometimes referred to as “picture elements” or “pixels”). The

photo detectors are arranged in an array, for example a matrix type array. The number of pixels in the array may be, for example, in a range from hundreds of thousands to millions. The pixels may be arranged for example, in a 2 dimensional array configuration, for example, having a plurality of rows and a plurality of columns, e.g., 640x480, 1280x1024, etc.

In some embodiments, the sensor elements are disposed in a plane, referred to herein as a sensor plane. The sensor may have orthogonal sensor reference axes, including for example, an x axis, Xs, a y axis, Ys, and a z axis, Zs, and may be configured so as to have the sensor plane parallel to the xy plane XY and directed toward the optics portion of the camera channel. Each camera channel has a field of view corresponding to an expanse viewable by the sensor portion. Each of the sensor elements may be, for example, associated with a respective portion of the field of view.

The sensor portion may employ any type of technology, for example, but not limited to MOS pixel technologies (meaning that one or more portions of the sensor are implemented in "Metal Oxide Semiconductor" technology), charge coupled device (CCD) pixel technologies or combination of both (hybrid).

In operation, the sensor portion is exposed to light by either sequentially line per line basis (similar to scanner) or globally (similar to conventional film camera exposure). After being exposed to light for certain period of time (exposure time), the pixels will be read out sequentially line per line and they will be delivered to the image processor(s).

Circuitry sometimes referred to as column logic is used to read the signals from the pixels. More particularly, data is passed into and out of the sensor elements via signal lines, referred to as bit lines, which run vertically through the sensor array XX. The sensor elements may be accessed one row at a time by asserting one of the word lines, which run horizontally through the sensor array XX.

As will be further described below, each sensor array may, for example, focus on a specific band of light (visible and/or invisible), for example, one color or band of colors. If so, each sensor array may be tuned so as to be more efficient in capturing and/or processing an image or images in its particular band of light.

In this embodiment, the well depth of the photo detectors across each individual array is the same, although in some other embodiments, the well depth may vary. For

example, the well depth of any given array can readily be manufactured to be different from that of other arrays on the image sensor. Selection of an appropriate well depth could depend on many factors, including most likely the targeted band of visible spectrum. Since each entire array is likely to be targeted at one band of visible spectrum (e.g., red) the well depth can be designed to capture that wavelength and ignore others (e.g., blue, green).

Doping of the semiconductor material in the color specific arrays can further be used to enhance the selectivity of the photon absorption for color specific wavelengths.

Figures 7A-7B depict an image being captured by a sensor of the type shown in Figure 6. More particularly, Figure 7A shows an image of an object (a lightning bolt) striking a sensor. Figure 7B shows the captured image. In Figure 7A, sensor elements are represented by circles XX. Photons that form the image are represented by shading. For purposes of this example, photons that strike the sensor elements (e.g., photons that strike within the circles XX) are sensed and/or captured thereby. Photons that do not strike the sensor elements (e.g., photons that strike outside the circles XX) are not sensed and/or captured. Notably, portions of the image that do not strike the sensor elements do not appear in the captured image.

The configuration of the sensor (e.g., number, shape, size type and arrangement of sensor elements) can have an effect on the characteristics of the sensed images. Figures 8A-8B depict an image being captured by a sensor that has more sensor elements and closer spacing of the sensor elements than in the sensor shown in Figures 6 and 7A. Figure 8A shows an image of an object (a lightning bolt) striking the sensor. Figure 8B shows the captured image. Notably, the image captured by the sensor of Figure 8A has greater detail than the image captured by the sensor of Figures 6 and 7A.

The positioning system provides relative movement between the optics portion (or portion(s) thereof) and the sensor portion (or portion(s) thereof). The positioning system may accomplish this by moving the optics portion relative to the sensor portion and/or by moving the sensor portion relative to the optics portion. For example, the optics portion may be moved and the sensor portion may be left stationary, the sensor portion may be moved and the optics portion may be left stationary, or the optics portion and the sensor

portions may each be moved to produce a net change in the position of the optics portion relative to the sensor portion.

Figures 9A-9I, 10A-10Y and 11A-11E are block diagram representations showing examples of various types of relative movement that may be employed between an optics portion and a sensor portion. More particularly, Figure 9A depicts an example of an optics portion and a sensor portion prior to relative movement there between. In that regard, it should be understood that although Figure 9A shows the optics portion having an axis aligned with an axis of the sensor portion, which may be desirable and/or advantageous, such a configuration is not required. Figures 9B-9C depict the optics portion and the sensor portion after relative movement in the x direction (or in a similar manner in the y direction). Figures 9D-9E depict the optics portion and the sensor portion after relative movement in the z direction. Figures 9F-9G depict the optics portion and the sensor portion during rotation of the optics portion relative to the sensor portion. Figures 9H-9I depict the optics portion and the sensor portion after tilting of the optics portion relative to the sensor portion.

Figures 9J-9T are further representations of the various types of relative movement that may be employed between an optics portion and a sensor portion. The relative positioning shown in Figure 9J is an example of an initial positioning. This initial positioning is shown in Figures 9K-9T by dotted lines. Although Figures 9J-9T show movement of only the optics portion, some other embodiments may move the sensor portion instead of or in addition to the optics portion. Although the initial positioning shows an axis of the optics portion aligned with an axis of the sensor portion, some embodiments may employ an initial positioning without such alignment and/or optics portions and sensor portions without axes.

If an optics portion comprises more than one portion (e.g., if the optics portion is a combination of one or more lenses, filters, prisms, and/or masks, see, for example, Figures 5A) one, some or all of the portions may be moved by the positioning system. For example, in some embodiments all of the portions may be moved. In some other embodiments, one or more of the portions may be moved and the other portions may be left stationary. In some other embodiments, two or more portions may be moved in different ways (e.g., one portion may be moved in a first manner and another portion may

be moved in a second manner) such that there is a net change in the position of one portion of the optics portion relative to another portion of the optics portion.

Likewise, if a sensor portion has more than one portion, one, some or all of the portions may be moved by the positioning system. For example, in some embodiments all of the portions may be moved. In some other embodiments, one or more of the portions may be moved and the other portions may be left stationary. In some other embodiments, two or more portions may be moved (such that there is a net change in the position of one portion of the sensor portion relative to another portion of the sensor portion).

Figures 10A-10Y and 11A-11E show examples of various types of relative movement that may be employed between an optics portion and a sensor portion when the optics portion comprises more than one portion. More particularly, Figures 10A-10E show examples of relative movement between a sensor portion and all portions of the optics portion. Figures 10F-10J show examples of relative movement between a sensor portion and one portion of the optics portion without relative movement between the sensor portion and another portion of the optics portion. Figures 10K-10Y show examples having relative movement between a sensor portion and one portion of the optics portion and different relative movement between the sensor portion and another portion of the optics portion. Figures 11A-11E show examples having relative movement between a sensor portion and one portion of the optics portion without relative movement between the sensor portion and two other portions of the optics portion.

It should be understood that there is no requirement that a positioning system employ all types of movement described herein. For example, some positioning systems may employ only one type of movement, some other positioning systems may employ two or more types of movement, and some other positioning systems may employ all types of movement. It should also be understood that the present invention is not limited to the types of movement described herein. Thus, a positioning system may employ other type(s) of movement with or without one or more of the types of movement described herein.

Figures 12A-12Q are block diagram representations showings example configurations of an optics portion and the positioning system in accordance with various

embodiments of the present invention. Figures 12A-12C each show an optics portion (e.g., optics portion 290A) having two lens (e.g., two lenslets arranged in a stack). Also shown is a portion of a positioning system 280 that moves one or more portions of the optics portion 290A. In Figure 12A, a first one of the lenses is movable by the positioning system 280. In Figure 12B, a second one of the lenses is movable by the positioning system. In Figure 12C, each of the lenses is movable by the positioning system 280.

Figures 12D-12F each show an optics portion (e.g., optics portion 290A) having one lens and one mask. Also shown is a portion of a positioning system 280 that moves one or more portions of the optics portion 290A. In Figure 12D, the lens is movable by the positioning system 280. In Figure 12E, the mask is movable by the positioning system. In Figure 12F, the lens and the mask are each movable by the positioning system 280.

Figures 12G-12I each show an optics portion (e.g., optics portion 290A) having one lens and two masks. Also shown is a portion of a positioning system 280 that moves one or more portions of the optics portion 290A. In Figure 12G, the lens is movable by the positioning system 280. In Figure 12H, the first mask is movable by the positioning system. In Figure 12I, the second mask is movable by the positioning system. In Figure 12J, the lens and the two masks are each movable by the positioning system 280.

Figures 12K-12M each show an optics portion (e.g., optics portion 290A) having one lens and a mask. Also shown is a portion of a positioning system 280 that moves one or more portions of the optics portion 290A. In Figure 12K, the lens is movable by the positioning system 280. In Figure 12L, the mask is movable by the positioning system. In Figure 12M, the lens and the prism are each movable by the positioning system.

Figures 12N-12Q each show an optics portion (e.g., optics portion 290A) having one lens, one filter and one mask. Also shown is a portion of a positioning system 280 that moves one or more portions of the optics portion 290A. In Figure 12N, the lens is movable by the positioning system 280. In Figure 12O, the filter is movable by the positioning system. In Figure 12P, the mask is movable by the positioning system. In Figure 12Q, the lens, the filter and the mask are each movable by the positioning system 280.

Figures 12Q-12AA are block diagram representations showing examples of other configurations of the optics, sensor and positioning system, in accordance with various aspects of the present invention.

Figures 13A-13D are block diagram representations showing example configurations of a system having four optics portions (each of which may have one or more portions), in accordance with various embodiments of the present invention. In Figure 13A, the first optics portion is movable by the positioning system 280. In Figure 13B, the second optics portion is movable by the positioning system 280. In Figure 13C, the first and second optics portions are movable by the positioning system 280. In Figure 13D, all of the optics portions are movable by the positioning system 280.

Figures 13E-13O depicts four optics portions, e.g., optics portions 290A-290D, in various positions relative to four sensor portions 292A-292D. More particularly, Figure 13E shows an example of a first relative positioning of the optic portions 290A-290D and the sensor portions 2902A-292D. Figure 13F shows an example of a relative positioning in which the optics portions 290A-290D have been moved in a direction parallel to the sensor portions (i.e., a direction that is referred to herein as a positive y direction) compared to their positions in the first relative positioning. Figure 13F shows an example of a relative positioning in which each of the optics portions 290A-290D has been moved in a positive y direction compared to their positions in the first relative positioning. Figure 13G shows an example of a relative positioning in which optics portions 290A-290B have been moved in a positive y direction compared to their positions in the first relative positioning and optics portions 290C-290D have been moved in a negative y direction compared to their positions in the first relative positioning. Figure 13H shows an example of a relative positioning in which each of the optics portions 290A-290D have been moved in a z direction compared to their positions in the first relative positioning. Figure 13I shows an example of a relative positioning in which each of the optics portions 290A-290D have been tilted in a first direction compared to their positions in the first relative positioning. Figure 13J shows an example of a relative positioning in which one optics portion, optics portion 290D, has been tilted in a first direction compared to its position in the first relative positioning. Figure 13K shows an example of a relative positioning in which optics portion 290D has been tilted

in a first direction compared to its position in the first relative positioning and optics portion 290B has been tilted in a second direction (opposite to the first direction) compared to its position in the first relative positioning. Figure 13L shows an example of a relative positioning in which one optics portion, optics portion 290D, has been moved in a negative y direction compared to its position in the first relative positioning. Figure 13M shows an example of a relative positioning in which one optics portion, optics portion 290D, has been moved in a positive x direction compared to its position in the first relative positioning. Figure 13N shows an example of a relative positioning in which one optics portion, optics portion 290B, has been rotated around an axis compared to their position in the first relative positioning. Figure 13O shows an example of a relative positioning in which each of the optics portions 290A-290D have been rotated around an axis compared to their positions in the first relative positioning. Other types of movement may also be employed.

Figures 14A-14D are block diagram representations showing example configurations of a system having four sensor portions, in accordance with various embodiments of the present invention. In Figure 14A, the first sensor portion is movable by the positioning system 280. In Figure 14B, the second sensor portion is movable by the positioning system 280. In Figure 14C, the first and second sensor portions are movable by the positioning system 280. In Figure 14D, all of the sensor portions are movable by the positioning system 280.

As stated above, and as will be further described below, relative movement between an optics portion (or one or more portions thereof) and a sensor portion (or one or more portions thereof), including, for example, but not limited to relative movement in the x and/or y direction, z direction, tilting, rotation (e.g., rotation of less than, greater than and/or equal to 360 degrees) and/or combinations thereof, may be used in providing various features and/or in the various applications disclosed herein, including, for example, but not limited to, increasing resolution (e.g., increasing detail), zoom, 3D enhancement, image stabilization, image alignment, lens alignment, masking, image discrimination, auto focus, mechanical shutter, mechanical iris, hyperspectral imaging, a snapshot mode, range finding and/or combinations thereof.

Figures 15A-15I show one embodiment of the digital camera subsystem 210. In this embodiment, the positioner 310 is adapted to support four optics portions, e.g., the optics portions 290A-290D, at least in part, and to move each of the optics portions 290A-290D in the x direction and/or the y direction. Positioner 320 is for example, a stationary positioner that supports the one or more sensor portions 292A-292D, at least in part.

The positioner 310 and positioner 320 may be affixed to one another, directly or indirectly. Thus, for example, the positioner 310 may be affixed directly to the positioner 320 (e.g., using bonding) or the positioner 310 may be affixed to a support (not shown) that is in turn affixed to the positioner 320.

The size of the positioner 310 may be, for example, approximately the same size (in one or more dimensions) as the positioner 320, approximately the same size (in one or more dimensions) as the arrangement of the optics portions 290A-290D and/or approximately the same size (in one or more dimensions) as the arrangement of the sensor portions 292A-292D. One advantage of such dimensioning is that it helps keep the dimensions of the digital camera subsystem as small as possible.

Referring to Figure 15C, in this embodiment, each of the optics portions 290A-290D comprises a lens or a stack of lenses (or lenslets), although, as stated above, the present invention is not limited to such. For example, in some embodiments, a single lens, multiple lenses and/or compound lenses, with or without one or more filters, prisms and/or masks are employed. Moreover, one or more of the optics portions shown in the digital camera subsystem of Figures 15A-15I may be replaced with one or more optics portions having one or more other optics portions having a configurations (see for example, Figures 5A-5V) that is/are different than those shown in Figures 15A-15I.

Moreover, as stated above, if the digital camera subsystem 210 includes more than one camera channel, the channels may or may not be identical to one another. For example, in some embodiments, the camera channels are identical to one another. In some other embodiments, one or more of the camera channels are different from one or more of the other camera channels in one or more respects. For example, in some embodiments, each camera channel may detect a different color and/or band of light. For example, one of the camera channels may detect red light, one of the camera channels

may detect green light, one of the camera channels may detect blue light and camera channel D detects infrared light.

Thus, if the subsystem includes more than one optics portion, the optics portions may or may not be identical to one another. For example, in some embodiments, the optics portions are identical to one another. In some other embodiments, one or more of the optics portions are different from one or more of the other optics portions in one or more respects. Moreover, in some embodiments, one or more of the characteristics of each of the optics portions (including but not limited to its type of element(s), size, and/or performance) is tailored (e.g., specifically adapted) to the respective sensor portion and/or to help achieve a desired result.

Referring to Figures 15B-15E, the positioner 310 defines one or more inner frame portions (e.g., four inner frame portions 400A-400D) and one or more outer frame portions (e.g., outer frame portions 404, 406, 408, 410, 412, 414). The one or more inner frame portions 400A-400D support and/or assist in positioning the one or more optics portions 290A-290D.

The one or more outer frame portions (e.g., outer frame portions 404, 406, 408, 410, 412, 414), may include, for example, one or more portions (e.g., outer frame portions 404, 406, 408, 410) that collectively define a frame around the one or more inner frame portions and/or may include one or more portions (e.g., outer frame portions 412, 414) that separate the one or more inner frame portions (e.g., 400A-400D). In this embodiment, for example, outer frame portions 404, 406, 408, 410, collectively define a frame around the one or more inner frame members 400A-400D and outer frame portions 412, 414 separate the one or more inner frame portions 400A-400D from one another.

Referring to Figures 15D-15E, in this embodiment, each inner frame portion defines an aperture 416 and a seat 418. The aperture 416 provides an optical path for the transmission of light. The seat 418 is adapted to receive a respective one of the one or more optical portions 290A-290. In this regard, the seat 418 may include one or more surfaces (e.g., surfaces 420, 422) adapted to abut one or more surfaces of the optics portion to support and/or assist in positioning the optics portion relative to the inner frame portion 400A of the positioner 310, the positioner 320 and/or one or more of the sensor portions 292A-292D. In this embodiment, surface 420 is disposed about the

perimeter of the optics portion to support and help position the optics portion in the x direction and the y direction). Surface 422 (sometimes referred to herein as “stop” surface) positions helps position the optics portion in the z direction.

The seat 418 may have dimensions adapted to provide a press fit for the respective optics portions. The position and/or orientation of the stop surface 422 may be adapted to position the optics portion at a specific distance (or range of distance) and/or orientation with respect to the respective sensor portion.

Each inner frame portion (e.g., 400A-400D) is coupled to one or more other portions of the positioner 310 by one or more MEMS actuator and/or position sensor portions. For example, actuator portions 430A-430D couple the inner frame 400A to the outer frame of the positioner 310. Actuator portions 434A-434D couple the inner frame 430B to the outer frame of the positioner 310. Actuator portions 438A-438D couple the inner frame 430C to the outer frame of the positioner 310. Actuator portions 442A-444D couple the inner frame 430D to the outer frame of the positioner 310.

The positioner 310 may further define clearances or spaces that isolate the one or more inner frame portions, in part, from the rest of the positioner 310. For example, the positioner 310 defines clearances 450, 452, 454, 456, 458, 460, 462, 464 that isolate the inner frame portion 400A, in part, in one or more directions, from the rest of the positioner 310.

In some embodiments, less than four actuator portions (e.g., one, two or three actuator portions) are used to couple an inner frame A to one or more other portions of the positioner 310. In some other embodiments more than four actuator portions are used to couple an inner frame to one or more other portions of the positioner 310.

Although the actuator portions, 430A-430D, 434A-434D, 438A-438D and 442A-442D are shown as being identical to one another, this is not required. Moreover, although the actuator portions 430A-430D, 434A-434D, 438A-438D and 442A-442D are shown having a dimension in the z direction that is smaller than the z dimension of other portions of the positioner 310, some other embodiments may employ one or more actuator portions that have a z dimension that is equal to or greater than the z dimension of other portions of the positioner 310.

The positioner 310 and/or actuator portions may comprise any type of material(s) including, for example, but not limited to, silicon, semiconductor, glass, ceramic, metal, plastic and combinations thereof. If the positioner 310 is a single integral component, each portion of the positioner 310 (e.g., the inner frame portions, the outer frame portions, the actuator portions), may comprise one or more regions of such integral component.

As will be further described below, applying appropriate control signal(s) to one or more of the MEMS actuator portions causes the one or more MEMS actuator portions to expand and/or contract to thereby move the associated optics portion. It may be advantageous to make the amount of movement equal to a small distance, e.g., 2 microns (2 μm), which may be sufficient for many applications. In some embodiments, for example, the amount of movement may be as small as about $\frac{1}{2}$ of the width of one sensor element (e.g., $\frac{1}{2}$ of the width of one pixel) on one of the sensor portions. In some embodiments, for example, the magnitude of movement may be equal to the magnitude of the width of one sensor element or two times the magnitude of the width of one sensor element.

Figures 15F-15I show examples of the operation of the positioner 310. More particularly Figure 15F shows an example of the inner frame portion at a first (e.g., rest) position. Referring to Figure 15G, the controller may provide one or more control signals to cause one or more of the actuator portions to expand (see, for example, actuator portion 430D) and cause one or more of the actuator portions to contract (see, for example, actuator portion 430B) and thereby cause the associated inner frame portion and the associated optics portion to move in the positive y direction (see, for example, inner frame portion 400A and optics portion 290A). The control signals may be, for example, in the form of electrical stimuli that are applied to the actuators (e.g., actuators 430B, 430D) themselves. Referring to Figure 15H, the controller may provide one or more control signals to cause one or more of the actuator portions to expand (see, for example, actuator portion 430A) and cause one or more of the actuator portions to contract (see, for example, actuator portion 430C) and thereby cause the associated inner frame portion and the associated optics portion to move in the positive x direction (see, for example, inner frame portion 400A and optics portion 290A). The control signals may be, for example,

in the form of electrical stimuli that are applied to the actuators (e.g., actuators 430A, 430C) themselves. Referring to Figure 15I, the controller may provide one or more control signals to cause two or more of the actuator portions to expand (see, for example, actuator portions 430A, 430D) and cause two of the actuator portions to contract (see, for example, actuator portions 430B, 430C) and thereby cause the associated inner frame portion and the associated optics portion to move in the positive y direction and positive x direction (i.e., in a direction that includes a positive y direction component and a positive x direction component)(see, for example, inner frame portion 400A and optics portion 290A). The control signals may be, for example, in the form of electrical stimuli that are applied to the all of the actuators (e.g., actuators 430A-430D) themselves.

Figure 15J is a schematic diagram of one embodiment of the inner frame portion (e.g., 400A), the associated actuator portions 430A-430D and portions of one embodiment of the controller 300 (e.g., two position control circuits) employed in some embodiments of the digital camera subsystem of Figures 15A-15I. In this embodiment, each of the MEMS actuators portions 430A-430D comprises a comb type MEMS actuator.

Figure 15K is a schematic diagram of another embodiment of the inner frame portion (e.g., 400A), the associated actuator portions 430A-430D and portions of one embodiment of the controller 300 (e.g., two position control circuits) employed in some embodiments of the digital camera subsystem of Figures 15A-15I. In this embodiment, each of the MEMS actuators portions 430A-430D comprises a comb type MEMS actuator.

Figure 15L is a schematic diagram of another embodiment of the inner frame portion (e.g., 400A), the associated actuator portions 430A-430D and portions of one embodiment of the controller 300 (e.g., two position control circuits) employed in some embodiments of the digital camera subsystem of Figures 15A-15I. In this embodiment, each of the MEMS actuators portions 430A-430D comprises a comb type MEMS actuator.

Figures 16A-16E depict another embodiment of the positioner 310 of the digital camera subsystem 210. In this embodiment, MEMS actuator portions 430A-430D are adapted to move and/or tilt in the z direction. For example, one or more of the MEMS

actuator portions (e.g., 430A-430D, 434A-434D, 438A-438D, 442A-442D) may be provided with torsional characteristics that cause the actuators to move and/or tilt upward (or move and/or tilt downward) in response to appropriate control signals (e.g., stimuli from the controller). In such embodiments one or more of the inner frame portions (e.g., 400A-400D) may be raised, lowered and/or tilted. Referring to Figure 16A, in one embodiment, for example, the controller provides a first control signal (e.g., stimuli) to all of the MEMS actuator portions (e.g., 430A-430D, 434A-434D, 438A-438D, 442A-442D) to cause all of the inner frame portions 400A-400D, to be moved upward. Referring to Figure 16B, a second control signal (e.g., stimuli) may be provided to all of the actuators (e.g., 430A-430D, 434A-434D, 438A-438D, 442A-442D) to cause all of the inner frame portions 400A-400D, to be moved downward. Referring to Figure 16C, in some embodiments, the controller 300 may provide one or more control signals to cause all of the inner frame portions 400A-400D, to be tilted inward (toward the center of the positioner). Referring to Figure 16D in some embodiments, the controller 300 may provide one or more control signals to cause all of the inner frame portions 400A-400D to be tilted outward (away from the center of the positioner). Referring to Figure 16E in some embodiments, the controller 300 may provide one or more control signals to cause one or more of the inner frame portions, e.g., frame portion 400A, to be tilted outward and one or more of the inner frame portions, e.g., frame portion 400B, to be tilted inward.

Referring to Figures 17A-17I and 18A-18E in another aspect of the present invention, the actuator portions 430A-430D, 434A-434D, 438A-438D, 442A-442D are not limited to MEMS actuators. Rather, the positioner 310 and/or actuator portions 430A-430D, 434A-434D, 438A-438D, 442A-442D comprise any type or types of actuators and/or actuator technology or technologies and employ any type of motion including, for example, but not limited to, linear and/or rotary, analog and/or discrete, and any type of actuator technology, including, for example, but not limited to, microelectromechanical systems (MEMS) actuators, electro-static actuators, diaphragm actuators, magnetic actuators, bi-metal actuators, thermal actuators, ferroelectric actuators, piezo-electric actuators, motors (e.g., linear or rotary), solenoids (e.g., micro-solenoids) and/or combinations thereof (see, for example, Figures 19A-19J). Referring to Figure 18A-18C in some embodiments, actuator portions 430A-430D are adapted to

move and/or tilt in the z direction. In such embodiments one or more of the inner frame portions (e.g., 400A-400D) may be raised, lowered and/or tilted.

Figures 17F-17I show examples of the operation of the positioner 310. More particularly Figure 17F shows an example of the inner frame portion at a first (e.g., rest) position. Referring to Figure 17G, the controller may provide one or more control signals to cause one or more of the actuator portions (see, for example, actuator portions 430B, 430D) to move the inner frame portion and the associated optics portion in the positive y direction. In some embodiments, for example, the control signals cause one of the actuator portions to expand and one of the actuator portions to contract, although this is not required. Referring to Figure 17H, the controller may provide one or more control signals to cause one or more of the actuator portions (see, for example, actuator portions 430A, 430C) to move the inner frame portion and the associated optics portion in the positive x direction. In some embodiments, for example, the control signals cause one of the actuator portions to expand and one of the actuator portions to contract, although this is not required. Referring to Figure 17I, the controller may provide one or more control signals to cause one or more of the actuator portions (see for example, actuator portions 430A-430D) to move the inner frame portion and the associated optics portion in the positive y and positive x directions (i.e., in a direction that includes a positive y direction component and a positive x direction component. In some embodiments, for example, the control signals cause two of the actuator portions to expand and two of the actuator portions to contract, although this is not required.

Referring to Figures 18A-18E, in some embodiments, actuator portions 430A-430D are adapted to move and/or tilt in the z direction. For example, one or more of the actuator portions (e.g., 430A-430D, 434A-434D, 438A-438D, 442A-442D) may be provided with torsional characteristics that cause the actuators to move and/or tilt upward (or move and/or tilt downward) in response to appropriate control signals (e.g., stimuli from the controller). In such embodiments one or more of the inner frame portions (e.g., 400A-400D) may be raised, lowered and/or tilted. Referring to Figure 18A, in one embodiment, for example, the controller provides a first control signal (e.g., stimuli) to all of the actuator portions (e.g., 430A-430D, 434A-434D, 438A-438D, 442A-442D) to cause all of the inner frame portions 400A-400D, to be moved upward. Referring to

Figure 18B, a second control signal (e.g., stimuli) may be provided to all of the actuators (e.g., 430A-430D, 434A-434D, 438A-438D, 442A-442D) to cause all of the inner frame portions 400A-400D, to be moved downward. Referring to Figure 18C, in some embodiments, the controller 300 may provide one or more control signals to cause all of the inner frame portions 400A-400D, to be tilted inward (toward the center of the positioner). Referring to Figure 18D in some embodiments, the controller 300 may provide one or more control signals to cause all of the inner frame portions 400A-400D to be tilted outward (away from the center of the positioner). Referring to Figure 18E in some embodiments, the controller 300 may provide one or more control signals to cause one or more of the inner frame portions, e.g., frame portion 400A, to be tilted outward and one or more of the inner frame portions, e.g., frame portion 400B, to be tilted inward.

Figure 19A is a schematic diagram of one of an inner frame portion (e.g., 400A), the associated actuator portions 430A-430D and portions of one embodiment of the controller 300 (e.g., a position control circuit) employed in some embodiments of the digital camera subsystem of Figures 17A-17I. In this embodiment, the positioner 310 and/or actuator portions 430A-430D comprise any type or types of actuators and/or actuator technology or technologies and employ any type of motion including, for example, but not limited to, linear and/or rotary, analog and/or discrete, and any type of actuator technology, including, for example, but not limited to, microelectromechanical systems (MEMS) actuators, electro-static actuators, diaphragm actuators, magnetic actuators, bi-metal actuators, thermal actuators, ferroelectric actuators, piezo-electric actuators, motors (e.g., linear or rotary), solenoids (e.g., micro-solenoids) and/or combinations thereof (see, for example, Figures 19B-19M).

In another aspect of the present invention, two actuator portions (e.g., 430A-430B), rather than four actuator portions, are associated with each inner frame portion (e.g., 400A) and/or optics portion (e.g., optics portion 290A). Figure 20A is a schematic diagram of such one embodiment of the inner frame portion (e.g., 400A), the associated actuator portions 430A-430D and portions of one embodiment of the controller 300 (e.g., two position control circuits). The actuator portions may comprise any type of actuator(s), for example, but not limited to, MEMS actuators, such as for example, similar to those described above with respect to Figures 15A-15H and 16A-16E. If

MEMS actuators are employed, the MEMS actuators may be of the comb type, such as for example, as shown in Figures 20B-20D.

Other types of actuators may also be employed, for example, electro-static actuators, diaphragm actuators, magnetic actuators, bi-metal actuators, thermal actuators, ferroelectric actuators, piezo-electric actuators, motors (e.g., linear or rotary), solenoids (e.g., micro-solenoids) and/or combinations, such as for example, similar to those described above with respect to Figures 17A-17H and 18A-18E. The actuators may be of a comb type (see for example, Figures 20B-20D), a linear type and/or combinations thereof, but are not limited to such.

Referring to Figures 21A-21B, in another aspect of the present invention, one or more outer frame portions are provided for each of the one or more of the inner frame portions (e.g., inner frames 400A-400D) such that the one or more inner frame portions and/or the one or more optics portions 290A-290D are isolated from one another. In this aspect, two or more optics portions may be moved independently of one another. In this embodiment, outer frame portion 500A is associated with inner frame portion 400A, outer frame portion 500B is associated with inner frame portion 400B, outer frame portion 500C is associated with inner frame portion 400C, outer frame portion 500D is associated with inner frame portion 400D. Clearances or spaces isolate the outer frame portions from one another. The actuators may be MEMS actuators, for example, similar to those described hereinabove with respect to Figures 15A-15H, 16A-16E and/or 20A-20D.

Referring to Figures 21C-21D, in another aspect of the present invention, one or more outer frame portions are provided for each of the one or more of the inner frame portions (e.g., inner frames 400A-400D) such that the one or more inner frame portions and/or the one or more optics portions 290A-290D are isolated from one another. In this aspect, two or more optics portions may be moved independently of one another. In this embodiment, outer frame portion 500A is associated with inner frame portion 400A, outer frame portion 500B is associated with inner frame portion 400B, outer frame portion 500C is associated with inner frame portion 400C, outer frame portion 500D is associated with inner frame portion 400D. Clearances or spaces isolate the outer frame portions from one another. The actuators may be any type of actuators, for example,

similar to those described hereinabove with respect to Figures 17A-17H, 18A-18E and/or 20A-20D.

Referring to Figure 22, in another aspect of the present invention, the optics portion 290A has two or more portions and the positioner 310 comprises two or more positioners, e.g., 310A-310B, adapted to be moved independently of one another, e.g., one for each of the two or more portions of the optics portion. In this aspect, the two or more portions of the optics portion may be moved independently of one another. The positioners 310A, 310B may each be, for example, similar or identical to the positioner of Figures 15A-15I and/or, for example, similar or identical to the positioner of Figures 17A-17I.

Referring to Figures 23A-23D, in another aspect of the present invention, the positioner 510 includes one or more upper frame portions 514, one or more lower frame portions 518, and one or more actuator portions 522. The lower frame portion may be, for example, affixed to a positioner such as for example, positioner 320 (see for example Figure 15A), which supports the one or more sensor portions 292A-292D. The upper frame portions support the one or more optics portions e.g., 290A-290D. The actuator portions are adapted to move the one or more upper frame portions in the z direction and/or tilt the upper frame portions. One or more of the actuator portions 522 may comprise for example a diaphragm type of actuator (e.g., an actuator similar to a small woofer type audio speaker), but is not limited to such. Rather the actuator portions 522 may comprise any type or types of actuators and/or actuator technology or technologies and may employ any type of motion including, for example, but not limited to, linear and/or rotary, analog and/or discrete, and any type of actuator technology, including, for example, but not limited to, microelectromechanical systems (MEMS) actuators, electrostatic actuators, diaphragm actuators, magnetic actuators, bi-metal actuators, thermal actuators, ferroelectric actuators, piezo-electric actuators, motors (e.g., linear or rotary), solenoids (e.g., micro-solenoids) and/or combinations thereof.

Referring to Figures 24A-24D, in another aspect of the present invention, the upper frame portion of the positioner 510 of Figures 23A-23D is similar or identical to the positioner 310 of Figures 15A-15I so that the positioner is also able to move the one or more optics portions in the x direction and/or the y direction.

Referring to Figures 25A-25D, in another aspect of the present invention, the upper frame portion of the positioner 510 of Figures 23A-23D is similar or identical to the positioner 310 of Figures 17A-17I so that the positioner is also able to move the one or more optics portions in the x direction and/or the y direction.

Referring to Figures 26A-26D, in another aspect of the present invention, the upper frame portion of the positioner 510 of Figures 24A-24D is similar or identical to the upper frame portion of the positioner 510 of Figures 21A-21B such that the one or more inner frame portions and/or the one or more optics portions 290A-290D are isolated from one another, which may further enhance the ability to move two or more optics portions independently of one another.

Referring to Figures 27A-27D, in another aspect of the present invention, the upper frame portion of the positioner 510 of Figures 25A-25D is similar or identical to the upper frame portion of the positioner 510 of Figure 21C-21D such that the one or more inner frame portions and/or the one or more optics portions 290A-290D are isolated from one another, which may further enhance the ability to move two or more optics portions independently of one another.

Referring to Figure 28A, in another aspect of the present invention, the one or more actuators of the positioner 510 of Figures 24A-24D comprises a single actuator 522 disposed between the one or more upper frame portions 514 and the one or more lower frame portions 518, thereby enhancing the ability to rotate the one or more upper frame portions 514.

Referring to Figure 28D, in another aspect of the present invention, the positioner 510 of Figures 24A-24D comprises a single actuator 522 between each of the one or more upper frame portions 514 and the one or more lower frame portions 518, thereby enhancing the ability to independently rotate each of the one or more upper frame portions 514.

Referring to Figure 28C, in another aspect of the present invention, the one or more actuators of the positioner 510 of Figures 25A-25D comprises a single actuator 522 disposed between the one or more upper frame portions 514 and the one or more lower frame portions 518, thereby enhancing the ability to rotate the one or more upper frame portions 514.

Referring to Figure 28D, in another aspect of the present invention, the positioner 510 of Figures 25A-25D comprises a single actuator 522 between each of the one or more upper frame portions 514 and the one or more lower frame portions 518, thereby enhancing the ability to independently rotate each of the one or more upper frame portions 514.

Referring to Figure 29, in another aspect of the present invention, the optics portion 290A has two or more portions and the positioner 510 comprises two or more positioners, e.g., 510A-510B, adapted to be moved independently of one another, e.g., one for each of the two or more portions of the optics portion. In this aspect, the two or more portions of the optics portion may be moved independently of one another. The positioners 510A, 510B may each be, for example, similar or identical to the positioner of Figures 24A-24D.

Referring to Figure 30, in another aspect of the present invention, the optics portion 290A has two or more portions and the positioner 510 comprises two or more positioners, e.g., 510A-510B, adapted to be moved independently of one another, e.g., one for each of the two or more portions of the optics portion. In this aspect, the two or more portions of the optics portion may be moved independently of one another. The positioners 510A, 510B may each be, for example, similar or identical to the positioner of Figures 25A-25D.

Referring to Figures 31A-31D, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 has a first frame and/or actuator configuration for one or more of the optics portions and a different frame and/or actuator configuration for one or more of the other optics portions.

Referring to Figures 31E-31H, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 defines a first seat at a first height or first depth (e.g., positioning in z direction) for one or more of the optics portions and further defines a second seat at a second height or second depth that is different than the first height or first depth for one

or more of the other optics portions. As stated above, the depth may be different for each lens and is based, at least in part, on the focal length of the lens. Thus, if a camera channel is dedicated to a specific color (or band of colors), the lens or lenses for that camera channel may have focal length that is adapted to the color (or band of colors) to which the camera channel is dedicated and different than the focal length of one or more of the other optics portions for the other camera channels.

Referring to Figures 31I-31J, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 is adapted to receive only three optics portions (e.g., corresponding to only three camera channels). For example, in some embodiments, there are only three camera channels in the digital camera subsystem, e.g., one camera channel for red, one camera channel for green, and one camera channel for blue. It should be understood that in some other embodiments, there are more than four camera channels in the digital camera subsystem.

Referring to Figures 31K-31L, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 is adapted to receive only two optics portions (e.g., corresponding to only two camera channels). For example, in some embodiments, there are only two camera channels in the digital camera subsystem, e.g., one camera channel for red and one camera channel for green or one camera channel for red and one camera channel for blue.

Referring to Figures 31M-31N, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 is adapted to receive only one optics portion (e.g., corresponding to only one camera channels). For example, in some embodiments, there is only one camera channel in the digital camera subsystem, e.g., dedicated to a single color (or band of colors) or wavelength (or band of wavelengths), infrared light, black and white imaging, or full color using a traditional bayer pattern configuration.

Referring to Figure 31O-31T, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 is adapted to receive one or more optics portions of a first size and one or more optics portions of a second size that is different than the first size. For example, in some embodiments, the digital camera subsystem comprises three camera channels, e.g., one camera channel for red, one camera channel for blue, and one camera channel for green, wherein the sensor portion of one of the camera channels, e.g., the green camera channel, has a sensor portion that is larger than the sensor portions of one or more of the other camera channels, e.g., the red and blue camera channels. The camera channel with the larger sensor portion may also employ an optics portion (e.g., lens) that is adapted to the larger sensor and wider than the other optics portions, to thereby help the camera channel with the larger sensor to collect more light. In some embodiments, optics portions of further sizes may also be received, e.g., a third size, a fourth size, a fifth size.

Referring to Figure 32A-32P in another aspect, the positioner 320 is adapted to move one or more of the sensor portions, e.g., 292A-292D. In this aspect, the positioner 320 may have, for example, a configuration similar to the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 has one or more portions curved portions. Such aspect may be advantageous, for example, in some embodiments in which it is desired to reduce or minimize the dimensions of the digital camera subsystem.

Referring to Figure 33A-33H, in another aspect, the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30 may be employed to move one or more other portions of the optics portions, e.g., filter(s) and/or masks of any configuration.

Referring to Figure 33I-33J in another aspect, the positioner 320 is adapted to move one or more of the sensor portions, e.g., 292A-292D. In this aspect, the positioner 320 may have, for example, a configuration similar to the positioner 310 of any of

Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30, 31A-31N.

Referring to Figure 33K-33L in another aspect, the positioner 310 is adapted to move one or more of the optics, e.g., 290A-290D, as a single group. In this aspect, the positioner 310 may have, for example, one or more features similar to the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30, 31A-31N.

Referring to Figure 33M-33N in another aspect, the positioner 320 is adapted to move one or more of the sensor portions, e.g., 292A-292D, as a single group. In this aspect, the positioner 320 may have, for example, one or more features similar to the positioner 310 of any of Figures 15A-15L, 16A-16E, 17A-17I, 18A-18E, 19A-19J, 20A-20D, 21A-21D, 22 and/or the positioner 510 of any of Figures 23A-23D, 24A-24D, 25A-25D, 26A-26D, 27A-27D, 28A-28D, 29, 30, 31A-31N.

Figure 35A is a block diagram of one embodiment of the controller. In this embodiment, the controller includes a position scheduler that receives one or more input signals, e.g., input1, input2, input3, indicative of one or more operating modes desired for one or more of the camera channels, e.g., camera channels 260A-260D, of the digital camera subsystem. The position scheduler generates one or more output signals, e.g., desired position camera channel A, desired position camera channel B, desired position camera channel C, desired position camera channel D, indicative of the desired positioning and/or relative positioning for the one or more camera channels or portions thereof.

The output signals from the position scheduler are based at least in part on one or more of the one or more input signals and a position schedule, which includes data indicative of the relationship between the one or more operating modes and the desired positioning and/or relative positioning of the one or more camera channels or portions thereof. As used herein, an operating mode can be anything having to do with the digital camera subsystem and/or information (e.g., images) generated thereby, for example, but not limited to, a condition (lighting) or performance characteristic (resolution, zoom

window, type of image). An operating mode may have a relationship (or relationships) to a desired positioning or positionings of one or more of the camera channels (or portions thereof) of the digital camera subsystem.

The input signal may have any form and may be supplied from any source, for example, but not limited to, one or more sources within the processor, the user peripheral interface and/or the controller itself. For example, in some embodiments, the peripheral user interface includes one or more input devices by which a user can indicate one or more preferences in regard to one or more desired operating modes (e.g., resolution, manual exposure control) and the peripheral user interface generates one or more signals indicative of such preference or preferences. In some embodiments, one or more portions of the processor generates one or more signals indicative of one or more desired operating mode (e.g., resolution, auto exposure control, parallax, absolute positioning of one or more camera channels or portions thereof, relative positioning of one or more channels or portions thereof, change in absolute or relative positioning of one or more camera channels or portions thereof). In some embodiments, the one or more portions of the processor generates one or more of such signals in response to one or more inputs from the peripheral user interface. For example, in some embodiments, one or more signals from the peripheral user interface are supplied to one or more portions of the processor, which in turn processes such signals and generates one or more signals to be supplied to the controller to carry out the user's preference or preferences. In some embodiments, the one or more portions of the processor generates one or more of the signals in response to one or more outputs generated within the processor. For example, in some embodiments, the image processor captures one or more images and processes such images to make a determination as to one or more operating modes (e.g., whether a desired amount of light is being transmitted to the sensor and if not, whether the amount of light should be increased or decreased) and generates one or more signals indicative thereof (e.g., to indicate a desired positioning and/or a change desired in the positioning of one or more of the camera channels or portions thereof), which are in turn supplied to the controller.

The one or more output signals generated by the position scheduler are supplied to one or more driver banks, e.g., driver bank A, driver bank B, driver bank C and driver

bank D, each of which generates one or more signals to control the positioning and/or relative positioning of a respective one of the camera channels, e.g., camera channels 260A-260D, or portions thereof. In this embodiment, for example, driver bank A generates a plurality of control signals to control the relative positioning of the portions of camera channel A. Driver bank B generates a plurality of control signals to control the relative positioning of the portions of camera channel B. Driver bank C generates a plurality of control signals to control the relative positioning of the portions of camera channel C. Driver bank D generates a plurality of control signals to control the relative positioning of the portions of camera channel D.

In this embodiment, the position schedule comprises a mapping of a relationship between the one or more operating modes and the desired positioning and/or relative positioning of the one or more camera channels or portions thereof. The mapping may be predetermined or adaptively determined. The mapping may have any of various forms known to those skilled in the art, for example, but not limited to, a look-up table, a “curve read”, a formula, hardwired logic, fuzzy logic, neural networks, and/or any combination thereof. The mapping may be embodied in any form, for example, software, hardware, firmware or any combination thereof.

Figure 35B shows a representation of one embodiment of the position scheduler. In this embodiment, the position scheduler is in the form of a look-up table. The look up table includes data indicative of the relationship between one or more operating modes and a positioning or positionings desired for the one or more camera channels or portions thereof to provide or help provide such operating mode. The look-up table comprises a plurality of entries. Each entry indicates the output values to be generated if a particular operating mode is desired. For example, the first entry in the look-up table specifies that if one or more of the input signals indicate that a normal operating mode is desired, then each of the outputs will have a value corresponding to a 0 logic state, which in this embodiment, causes a positioning desired for the normal operating mode. The second entry in the look-up table specifies that if one or more of the input signals indicate that a 2x resolution operating mode is desired, then each of the A outputs will have a value corresponding to a 1 logic state, and all of the other outputs will have a value

corresponding to a 0 logic state, which in this embodiment, causes a positioning desired for the 2x resolution operating mode.

It should also be recognized that the makeup of the look-up table may depend on the configuration of the rest of the positioning system, for example, the drivers and the actuators. It should also be recognized that a look-up table may have many forms including but not limited to a programmable read only memory (PROM).

It should also be understood that the look-up table could be replaced by a programmable logic array (PLA) and/or hardwired logic.

Figure 35C shows one embodiment of one of the driver banks, e.g., driver bank A. In this embodiment, driver bank A comprises a plurality of drivers. The first driver has an input that receives the input signal, Desired Position Channel A Actuator A, and an output that provides an output signal, Control Channel A Actuator A. The second driver has an input that receives the input signal, Desired Position Channel A Actuator B, and an output that provides an output signal, Control Channel A Actuator B. The third driver has an input that receives the input signal, Desired Position Channel A Actuator C, and an output that provides an output signal, Control Channel A Actuator C. The fourth driver has an input that receives the input signal, Desired Position Channel A Actuator D, and an output that provides an output signal, Control Channel A Actuator D.

It should be understood that although the input signals are shown supplied on a single signal line, the input signals may have any form including for example but not limited to, a single ended digital signal, a differential digital signal, a single ended analog signal and/or a differential analog signal.

Each of the drivers further includes first and second power supply First and second supply voltage, e.g., V+, V-, are supplied to first and second power supply inputs, respectively, of each of the drivers.

In this embodiment, the output signal Control Channel A Actuator A is supplied to one of the contacts of actuator 430A. The output signal Control Channel A Actuator B is supplied to one of the contacts of actuator 430B. The output signal Control Channel A Actuator C is supplied to one of the contacts of actuator 430C. The output signal Control Channel A Actuator D is supplied to one of the contacts of actuator 430D.

The operation of driver A is now described. If the Desired Position Channel A Actuator A signal has a first logic state (e.g., a logic low state or “0”), then the Control Channel A Actuator A output signal has a first magnitude (e.g., approximately equal to V-) adapted to drive the Actuator A into a first actuation state (e.g., not actuated). If the Desired Position Channel A Actuator A signal has a second logic state (e.g., a logic high state or “1”), then the Control Channel A Actuator A output signal has a magnitude (approximately equal to V+) to drive the Actuator A into a second actuation state (e.g., fully actuated).

The other driver banks, i.e., driver bank B, driver bank C and driver bank D are configured similar or identical to driver bank A and operate in a manner that is similar or identical to driver bank A.

Because the drive described above is either “on” or “off” such drive can be characterized as a binary drive (i.e., the drive is one of two magnitudes). In a binary drive system, it may be advantageous to provide a power supply voltage V+ having a magnitude that provides the desired amount of movement when the V+ signal (minus any voltage drops) is supplied to the actuators.

Notwithstanding the above, it should be understood that the present invention is not limited to such type of drive (i.e., binary drive) and/or drive voltages of such magnitudes. For example, in some other embodiments, more than two discrete levels of drive and/or an analog type of drive may be employed.

Although an embodiment has been shown in which the asserted logic state is a high logic state (e.g., “1”), it should be understood that in some embodiments, the asserted logic state for one or more signals may be the low logic state (e.g., “0”).

Figure 35D shows another embodiment of a driver bank. In this embodiment, the driver is supplied with one or more position feedback signals indicative of the positioning and/or relative positioning. In such embodiment, the driver bank may adjust the magnitude of its output signals so as to cause the sensed positioning and/or relative positioning to correspond to the desired positioning and/or relative positioning.

Figure 46 shows a flowchart of steps that may be employed in generating a mapping for the position scheduler and/or in calibrating the positioning system. In this

embodiment, the mapping or calibration is performed prior to use of the digital camera system.

At a step __, the digital camera subsystem is installed on a tester that provides one or more objects of known configuration and positioning. In some embodiments, the one or more objects includes an object defining one or more interference patterns.

At a step __, an image of the interference pattern is captured from one or more of the camera channels, without stimulation of any of the actuators in the positioning system. Thereafter, each of the actuators is provided with a stimulus, e.g., a stimulus having a magnitude selected to result in maximum (or near maximum) movement of the actuators. Another image of the interference pattern is then captured from the one or more camera channels.

At a step __, an offset and a scale factor are determined based on the data gathered on the tester. In some embodiments, the offset and scale factor are used to select one or more of the power supply voltages $V+$, $V-$ that are supplied to the driver banks. If desired, the offset and scale factor may be stored in one or more memory locations within the digital camera subsystem for subsequent retrieval.

As stated above, if the drive is a binary drive, then it may be advantageous to provide a power supply voltage $V+$ having a magnitude that provides the desired amount of movement when the $V+$ signal (minus any voltage drops) is supplied to the actuators, although this is not required.

If the drive employs more than two discrete levels of drive and/or an analog drive, it may be advantageous to gather data for various levels of drive (i.e., stimulus) within a range of interest, and to thereafter generate a mapping that characterizes the relationship (e.g., scale factor) between drive and actuation (e.g., movement) at various points within the range of interest. If the relationship is not linear, it may be advantageous to employ a piecewise linear mapping.

In some embodiments, one piecewise linear mapping is employed for an entire production run. In such embodiments, the piecewise linear mapping is stored in the memory of each digital camera subsystem. A particular digital camera subsystem may thereafter be calibrated by performing a single point calibration and generating a correction factor which in combination with the piecewise linear mapping, sufficiently

characterizes the relationship between drive (e.g., stimulus) and movement (or positioning) provided the actuators.

Another embodiment that may be employed in calibrating the positioning system to help the positioning system provide the desired movements with a desired degree of accuracy is set forth below.

At a step __, one or more calibration objects having one or more features of known size(s), shape(s), and/or color(s) are positioned at one or more predetermined positions within the field of view of the digital camera subsystem.

At a step __, an image is captured and examined for the presence of the one or more features. If the features are present, the position(s) of such features within the first image are determined at a step __.

At a step __, one or more movements of one or more portions of the optics portion and/or sensor portion are initiated. The one or more movements may be, for example, movement(s) in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

At a step __, a second image is captured and examined for the presence of the one or more features. If the features are present, the position(s) of such features within the second image are determined at a step __.

At a step __, the positions of the features within the second image are compared to one or more expected positions, i.e., the position(s), within the second image, at which the features would be expected to appear based on the positioning of the one or more calibration objects within the field of view and/or the first image and the expected effect of the one or more movements initiated by the position system.

If the position(s) within the second image are not the same as the expected position(s), the system determines the difference in position at a step __. The difference in position may be, for example, a vector, represented, for example, as multiple components (e.g., an x direction component and a y direction component) and/or as a magnitude component and a direction component.

The above steps may be performed twice for each type of movement to be calibrated to help generate gain and offset data for each such type of movement.

At a step __, the system stores data indicative of the gain and offset of each type of movement to be calibrated.

The steps set forth above may be performed, for example, during manufacture and/or test of digital camera subsystem and/or the digital camera. Thereafter, the stored data may be used in initiating any calibrated movements.

The controller 300 may be any kind of controller. For example, the controller may be programmable or non programmable, general purpose or special purpose, dedicated or non dedicated, distributed or non distributed, shared or not shared, and/or any combination thereof. A controller may include, for example, but is not limited to, hardware, software, firmware, hardwired circuits and/or any combination thereof. The controller may or may not execute one or more computer programs that have one or more subroutines, or modules, each of which may include a plurality of instructions, and may or may not perform tasks in addition to those described herein. In some embodiments, the controller comprises at least one processing unit connected to a memory system via an interconnection mechanism (e.g., a data bus). If the controller executes one or more computer programs, the one or more computer programs may be implemented as a computer program product tangibly embodied in a machine-readable storage medium or device for execution by a computer. Further, if the controller is a computer, such computer is not limited to a particular computer platform, particular processor, or programming language.

Example output devices include, but are not limited to, displays(e.g., cathode ray tube (CRT) devices, liquid crystal displays (LCD), plasma displays and other video output devices), printers, communication devices for example modems, storage devices such as a disk or tape and audio output, and devices that produce output on light transmitting films or similar substrates.

Example input devices include but are not limited to buttons, knobs, switches, keyboards, keypads, track ball, mouse, pen and tablet, light pen, touch screens, and data input devices such as audio and video capture devices.

In addition, as stated above, it should be understood that the features disclosed herein can be used in any combination.

In some embodiments, the image processor and controller are combined into a single unit.

Figure 36A shows a block diagram representation of the image processor in accordance with one embodiment of aspects of the present invention. In this embodiment, the image processor includes one or more channel processors, one or more image pipelines, and/or one or more image post processors. Each of the channel processors is coupled to a respective one of the camera channels and generates an image based at least in part on the signal(s) received from the respective camera channel. In some embodiments, one or more of the channel processors are tailored to its respective camera channel. For example, as further described below, if one of the camera channels is dedicated to a specific wavelength or color (or band of wavelengths or colors), the respective channel processor may also be adapted to such wavelength or color (or band of wavelengths or colors). Tailoring the channel processing to the respective camera channel may help to make it possible to generate an image of a quality that is higher than the quality of images resulting from traditional image sensors of like pixel count. In such embodiments, providing each camera channel with a dedicated channel processor may help to reduce or simplify the amount of logic in the channel processors as the channel processor may not need to accommodate extreme shifts in color or wavelength, e.g., from a color (or band of colors) or wavelength (or band of wavelengths) at one extreme to a color (or band of colors) or wavelength (or band of wavelengths) at another extreme.

The images generated by the channel processors are supplied to the image pipeline, which may combine the images to form a full color or black/white image. The output of the image pipeline is supplied to the post processor, which generates output data in accordance with one or more output formats.

Figure 36B shows one embodiment of a channel processor. In this embodiment, the channel processor includes column logic, analog signal logic, black level control and exposure control. The column logic is coupled to the sensor and reads the signals from the pixels. If the channel processor is coupled to a camera channel that is dedicated to a specific wavelength (or band of wavelengths), it may be advantageous for the column

logic to be adapted to such wavelength (or band of wavelengths). For example, the column logic may employ an integration time or integration times adapted to provide a particular dynamic range in response to the wavelength (or band of wavelengths) to which the color channel is dedicated. Thus, it may be advantageous for the column logic in one of the channel processors to employ an integration time or times that is different than the integration time or times employed by the column logic in one or more of the other channel processors.

The analog signal logic receives the output from the column logic. If the channel processor is coupled to a camera channel dedicated to a specific wavelength or color (or band of wavelengths or colors), it may be advantageous for the analog signal logic to be specifically adapted to such wavelength or color (or band of wavelengths or colors). As such, the analog signal logic can be optimized, if desired, for gain, noise, dynamic range and/or linearity, etc. For example, if the camera channel is dedicated to a specific wavelength or color (or band of wavelengths or colors), dramatic shifts in the logic and settling time may not be required as each of the sensor elements in the camera channel are dedicated to the same wavelength or color (or band of wavelengths or colors). By contrast, such optimization may not be possible if the camera channel must handle all wavelength and colors and employs a Bayer arrangement in which adjacent sensor elements are dedicated to different colors, e.g., red-blue, red-green or blue-green.

The output of the analog signal logic is supplied to the black level logic, which determines the level of noise within the signal, and filters out some or all of such noise. If the sensor coupled to the channel processor is focused upon a narrower band of visible spectrum than traditional image sensors, the black level logic can be more finely tuned to eliminate noise. If the channel processor is coupled to a camera channel that is dedicated to a specific wavelength or color (or band of wavelengths or colors), it may be advantageous for the analog signal logic to be specifically adapted to such wavelength or color (or band of wavelengths or colors).

The output of the black level logic is supplied to the exposure control, which measures the overall volume of light being captured by the array and adjusts the capture time for image quality. Traditional cameras must make this determination on a global basis (for all colors). If the sensor coupled to the channel processor is dedicated to a

specific color (or band of colors, the exposure control can be specifically adapted to the wavelength (or band of wavelengths) to which the sensor is targeted. Each channel processor is thus able to provide a capture time that is specifically adapted to the sensor and/or specific color (or band of colors) targeted thereby and different than the capture time provided by one or more of the other channel processors for one or more of the other camera channels.

Figure 36C shows one embodiment of the image pipeline. In this embodiment, the image pipeline includes two portions. The first portion includes a color plane integrator and an image adjustor. The color plane integrator receives an output from each of the channel processors and integrates the multiple color planes into a single color image. The output of the color plane integrator, which is indicative of the single color image, is supplied to the image adjustor, which adjusts the single color image for saturation, sharpness, intensity and hue. The adjustor also adjusts the image to remove artifacts and any undesired effects related to bad pixels in the one or more color channels. The output of the image adjustor is supplied to the second portion of the pipeline, which provides auto focus, zoom, windowing, pixel binning and camera functions.

Figure 36D shows one embodiment of the image post processor. In this embodiment, the image post processor includes an encoder and an output interface. The encoder receives the output signal from the image pipeline and provides encoding to supply an output signal in accordance with one or more standard protocols (e.g., MPEG and/or JPEG). The output of the encoder is supplied to the output interface, which provides encoding to supply an output signal in accordance with a standard output interface, e.g., universal serial bus (USB) interface.

Figure 36E shows one embodiment of the system control.

It should be understood that the processor is not limited to the stages and/or steps set forth above. For example, the processor may comprise any type of stages and/or may carry out any steps. It should also be understood that the processor 270 may be implemented in any manner. For example, the processor may be programmable or non programmable, general purpose or special purpose, dedicated or non dedicated, distributed or non distributed, shared or not shared, and/or any combination thereof. If the processor has two or more distributed portions, the two or more portions may

communicate via one or more communication links. A processor may include, for example, but is not limited to, hardware, software, firmware, hardwired circuits and/or any combination thereof. The processor may or may not execute one or more computer programs that have one or more subroutines, or modules, each of which may include a plurality of instructions, and may or may not perform tasks in addition to those described herein. If a computer program includes more than one module, the modules may be parts of one computer program, or may be parts of separate computer programs. As used herein, the term module is not limited to a subroutine but rather may include, for example, hardware, software, firmware, hardwired circuits and/or any combination thereof.

In some embodiments, the processor comprises at least one processing unit connected to a memory system via an interconnection mechanism (e.g., a data bus). A memory system may include a computer-readable and writeable recording medium. The medium may or may not be non-volatile. Examples of non-volatile medium include, but are not limited to, magnetic disk, magnetic tape, non-volatile optical media and non-volatile integrated circuits (e.g., read only memory and flash memory). A disk may be removable, e.g., known as a floppy disk, or permanent, e.g., known as a hard drive. Examples of volatile memory include but are not limited to random access memory, e.g., dynamic random access memory (DRAM) or static random access memory (SRAM), which may or may not be of a type that uses one or more integrated circuits to store information.

If the processor executes one or more computer programs, the one or more computer programs may be implemented as a computer program product tangibly embodied in a machine-readable storage medium or device for execution by a computer. Further, if the processor is a computer, such computer is not limited to a particular computer platform, particular processor, or programming language. Computer programming languages may include but are not limited to procedural programming languages, object oriented programming languages, and combinations thereof.

A computer may or may not execute a program called an operating system, which may or may not control the execution of other computer programs and provides scheduling, debugging, input/output control, accounting, compilation, storage

assignment, data management, communication control, and/or related services. A computer may for example be programmable using a computer language such as C, C++, Java or other language, such as a scripting language or even assembly language. The computer system may also be specially programmed, special purpose hardware, or an application specific integrated circuit (ASIC).

Figure 37A shows another embodiment of the channel processor. In this embodiment, the channel processor includes a double sampler, an analog to digital converter, a black level clamp and a deviant pixel correction.

The double sampler provides an estimate of the amount of light received by each pixel during an exposure period. To accomplish this, the double sampler determines the amount by which the value of each pixel changes during the exposure period. For example, a pixel may have a first value, V_{start} , prior to an exposure period. The first value, V_{start} , may or may not be equal to zero. The same pixel may have a second value, V_{end} , after the exposure period. The difference between the first and second values, i.e., $V_{end} - V_{start}$, is indicative of the amount of light received by the pixel.

An image may be represented as a plurality of picture element (pixel) magnitudes. Each pixel magnitude indicates the picture intensity (relative darkness or relative lightness) at an associated location of the image. A relatively low pixel magnitude indicates a relatively low picture intensity (i.e., relatively dark location). Conversely, a relatively high pixel magnitude indicates a relatively high picture intensity (i.e., relatively light location). The pixel magnitudes are selected from a range that depends on the resolution of the sensor.

Figure 37B is a graphical representation of a neighborhood of pixel values. Figure 37B further illustrates a plurality of prescribed spatial directions, namely, a first prescribed spatial direction (e.g., the horizontal direction), a second prescribed spatial direction (e.g., the vertical direction), a third prescribed spatial direction (e.g., a first diagonal direction), and a fourth prescribed spatial direction (e.g., a second diagonal direction). The pixel P22 is adjacent to pixels P12, P21, P32 and P23. The pixel P22 is offset in the horizontal direction from the pixel P32. The pixel P22 is offset in the vertical direction from the pixel P23. The pixel P22 is offset in the first diagonal direction

from the pixel P11. The pixel P22 is offset in the second diagonal direction from the pixel P31.

Figure 37C shows a flowchart of steps employed in this embodiment of the double sampler. As indicated at a step __, the value of each pixel is sampled at the time of, or prior to, the start of an exposure period and signals indicative thereof are supplied to the double sampler. Referring to step __, the value of each pixel is sampled at the time of, or subsequent to, the end of the exposure period and signals indicative thereof are supplied to the double sampler. At a step __, the double sampler generates a signal for each pixel, indicative of the difference between the start and end values for such pixel.

As stated above, the magnitude of each difference signal is indicative of the amount of light received at a respective location of the sensor portion. A difference signal with a relatively low magnitude indicates that a relatively low amount of light is received at the respective location of the sensor portion. A difference signal with a relatively high magnitude indicates that a relatively high amount of light is received at the respective location of the sensor portion.

Referring again to Figure 37A, the difference signals generated by the double sampler are supplied to an analog to digital converter, which samples each of such signals and generates a sequence of multi-bit digital signals in response thereto, each multi-bit digital signal being indicative of a respective one of the difference signals.

The multi-bit digital signals are supplied to a black level clamp, which compensates for drift in the sensor portion of the camera channel. The difference signals should have a magnitude equal to zero unless the pixels are exposed to light. However, due to imperfection in the sensor (e.g., leakage currents) the value of the pixels may change (e.g., increase) even without exposure to light. For example, a pixel may have a first value, V_{start} , prior to an exposure period. The same pixel may have a second value, V_{end} , after the exposure period. If drift is present, the second value may not be equal to the first value, even if the pixel was not exposed to light. The black level clamp compensates for such drift.

To accomplish this, in some embodiments, a permanent cover is applied over one or more portions (e.g., one or more rows) of the sensor portion to prevent light from reaching such portions. The cover is applied, for example, during manufacture of the

sensor portion. The difference signals for the pixels in the covered portion(s) can be used in estimating the magnitude (and direction) of the drift in the sensor portion.

In this embodiment, the black level clamp generates a reference value (which represents an estimate of the drift within the sensor portion) having a magnitude equal to the average of the difference signals for the pixels in the covered portion(s). The black level clamp thereafter compensates for the estimated drift by generating a compensated difference signal for each of the pixels in the uncovered portions, each compensated difference signal having a magnitude equal to the magnitude of the respective uncompensated difference signal reduced by the magnitude of the reference value (which as stated above, represents an estimate of the drift).

The output of the black level clamp is supplied to the deviant pixel identifier, which seeks to identify defective pixels and help reduce the effects thereof. In this embodiment, a defective pixel is defined as pixel for which one or more values, difference signal and/or compensated difference signal fails to meet one or more criteria, in which case one or more actions are then taken to help reduce the effects of such pixel. In this embodiment, for example, a pixel is defective if the magnitude of the compensated difference signal for the pixel is outside of a range of reference values (i.e., less than a first reference value or greater than a second reference value). The range of reference values may be a predetermined, adaptively determined and/or any combination thereof.

If the magnitude of the compensated difference signal is outside such range, then the magnitude of the compensated difference signal is set equal to a value that is based, at least in part, on the compensated difference signals for one or more pixels adjacent to the defective pixel, for example, an average of the pixel offset in the positive x direction and the pixel offset in the negative x direction.

Figure 37D shows a flowchart of steps employed in this embodiment of the defective pixel identifier. As indicated at a step __, the magnitude of each compensated difference signal is compared to a range of reference values. If a magnitude of a compensated difference signal is outside of the range of reference values, then the pixel is defective and at a step __, the magnitude of difference signal is set to a value in accordance with the methodology set forth above.

Figure 37E shows another embodiment of the image pipeline. In this embodiment, the image pipeline includes an image plane integrator, image plane alignment and stitching, exposure control, focus control, zoom control, gamma correction, color correction, edge enhancement, chroma noise reduction, white balance, color enhancement, image scaling and color space conversion.

The output of a channel processor is a data set that represents a compensated version of the image captured by the camera channel. The data set may be output as a data stream. For example, the output from the channel processor for camera channel A represents a compensated version of the image captured by camera channel A and may be in the form of a data stream $P_{A1}, P_{A2}, \dots P_{An}$. The output from the channel processor for camera channel B represents a compensated version of the image captured by camera channel B and may be in the form of a data stream $P_{B1}, P_{B2}, \dots P_{Bn}$. The output from the channel processor for camera channel C represents a compensated version of the image captured by camera channel C and is in the form of a data stream $P_{C1}, P_{C2}, \dots P_{Cn}$. The output from the channel processor for camera channel D represents a compensated version of the image captured by camera channel D and is in the form of a data stream $P_{D1}, P_{D2}, \dots P_{Dn}$.

The image plane integrator receives the data from each of the two or more channel processors and combines such data into a single data set, e.g., $P_{A1}, P_{B1}, P_{C1}, P_{D1}, P_{A2}, P_{B2}, P_{C2}, P_{D2}, P_{A3}, P_{B3}, P_{C3}, P_{D3}, P_{An}, P_{Bn}, P_{Cn}, P_{Dn}$. Figure 37F shows one embodiment of the image plane integrator. In this embodiment, the image plane integrator includes a multiplexer and a multi-phase phase clock.

The multiplexer has a plurality of inputs in_0, in_1, in_2, in_3 , each of which is adapted to receive a stream (or sequence) of multi-bit digital signals. The data stream of multi-bit signals, $P_{A1}, P_{A2}, \dots P_{An}$, from the channel processor for camera channel A is supplied to input in_0 via signal lines ___. The data stream $P_{B1}, P_{B2}, \dots P_{Bn}$ from the channel processor for camera channel B is supplied to input in_1 via signal lines ___. The data stream $P_{C1}, P_{C2}, \dots P_{Cn}$ from the channel processor for camera channel C is supplied to input in_2 via signal lines ___. The data stream $P_{D1}, P_{D2}, \dots P_{Dn}$ from the channel processor for camera channel D is supplied to the input in_3 on signal lines ___. The multiplexer has an output, out, that supplies a multi-bit output signal on signal lines

____. Note that in some embodiments, the multiplexer comprises of a plurality of four input multiplexers each of which is one bit wide.

The multi-phase clock has an input, enable, that receives a signal via signal line _____. The multi-phase clock has outputs, c0, c1, which are supplied to the inputs s0, s1 of the multiplexer via signal lines ___, _____. In this embodiment, the multi-phase clock has four phases, shown in Figure 37G.

The operation of the image plane integrator is as follows. The integrator has two states. One state is a wait state. The other state is a multiplexing state. Selection of the operating state is controlled by the logic state of the enable signal supplied to the multi-phase clock. The multiplexing state has four phases, which correspond to the four phases of the multi-phase clock. In phase 0, neither of the clock signals c1, c0 are asserted causing the multiplexer to output one of the multi-bit signals from the A camera channel, e.g., P_{A1}. In phase 1, clock signals c0, is asserted causing the multiplexer to output one of the multi-bit signals from the B camera channel, e.g., P_{B1}. In phase 2, clock signal c1, is asserted causing the multiplexer to output one of the multi-bit signals from the C camera channel, e.g., P_{C1}. In phase 0, both of the clock signals c1, c0 are asserted causing the multiplexer to output one of the multi-bit signals from the D camera channel, e.g., P_{D1}.

Thereafter, the clock returns to phase 0, causing the multiplexer to output another one of the multi-bit signals from the A camera channel, e.g., P_{A2}. Thereafter, in phase 1, the multiplexer outputs another one of the multi-bit signals from the B camera channel, e.g., P_{B2}. In phase 2, the multiplexer outputs another one of the multi-bit signals from the C camera channel, e.g., P_{C2}. In phase 3, the multiplexer outputs another one of the multi-bit signals from the D camera channel, e.g., P_{D2}.

This operation is repeated until the multiplexer has output the last multi-bit signal from each of the camera channels, e.g., P_{An}, P_{Bn}, P_{Cn}, and P_{Dn}.

The output of the image plane integrator is supplied to the image planes alignment and stitching stage. The purpose of this stage is to make sure that a target captured by different camera channels is aligned at the same position within the respective images e.g., to make sure that a target captured by different camera channels appears at the same place within each of the camera channel images). For example, our eyes are good example of 2 channel image plane system. When we hold a pencil about 1 ft in front of

our eyes, close our left eye and use our right eye to see the pencil, we will see the pencil at a particular location that is different than when we close our right eye and use the left eye to see the pencil. This is because our brain only receives 1 image at a time and couldn't correlate it with the other image from the other eye that was received at different time. When we open both of our eyes and try to see the pencil again (hold it at the same location as previous experiment), our brain will receive the 2 images of the pencil at the same time. In this case, our brain will automatically try to align the 2 images of the same pencil and we will perceive a single image of a pencil in front of us, except this one becomes a stereo image. The automatic image planes alignment and stitching also does the same thing as our brain (the vision part) except in this particular case, it does image alignment on 3, 4, 5 or more image channels instead just from 2 image channels.

The output of the image planes alignment and stitching is supplied to the exposure control. The purpose of the exposure control is to help make sure that the captured images are not over exposed or under exposed. An over exposed image is too bright. An under exposed image is too dark. In this embodiment, it is expected that a user will supply a number that represent the brightness of a picture that user feel comfortable (not too bright or not too dark). The auto exposure control will use this brightness number and will automatically adjust the exposure time of the image pickup array during preview mode accordingly. When user press the capture button (capture mode), then the captured picture will have an exposure time that will give the brightness level the user preferred on the captured image. User can also manually adjust the exposure time of image pick up array directly, similar to adjusting the iris of a conventional film camera.

Figure 37H shows one embodiment of the automatic exposure control.

The output of the exposure control is supplied to the Auto/Manual focus control, the purpose of which is to sure that the lens is focused to targets all the time. For example, when an image is over or under focus, the objects in this image will be blurred. The image will have peak sharpness when the lens is in focus point. In one embodiment, the auto focus control detects the amount of blurriness of an image in preview mode, will move the lens back and forth accordingly to find the focus point. Today's digital still cameras utilize this type of mechanism. Other embodiments may also be employed. For example, consider a situation where we want to take a picture of a person. We adjust the

focus of the lens so the person is in focus. Then the person moves forward or backward and the image become out of focus. This phenomenon is due to Depth of Focus number of the lens we are using. In layman term, Depth of Focus is a measure on how much a person can move forward or backward in front of the lens before the person become out of focus. The advance auto focus mechanism basically increases the Depth of Focus number by 10, 20 or more times, so that the camera focus is insensitive of target location. So practically, the target is in focus most of the time, which is another way of auto focus mechanism implementation. Depth of Focus can be increased by putting an optical filter (available off the shelves) with certain pattern on the top of lens in conjunction with wave front encoding algorithm (available in public domain).

The output of the focus control is supplied to the zoom controller. The purpose of the zoom controller is similar to a that of a zoom feature found in traditional digital cameras. For example, when a television anchor in the news channels was wearing a striped tie, sometimes we saw colorful lines phenomena within these striped ties. This phenomenon is called aliasing. This is due to the fact that camera at that time doesn't have enough resolution anymore to dissolve the stripes pattern detail on the tie. By moving the lens 0.5 pixel (A pixel is a physical cell inside image pick up array) distance in both X and Y direction and take a picture for each direction and combining every pictures taken on each direction, we can remove or substantially reduce the aliasing. When the aliasing is removed or reduced, we basically can see more resolution beyond the original resolution of the camera. This resolution can be enhanced by 2 times which means our camera now has doubled the resolution. With double resolution, we now can zoom in into the target 2 more times. Lens movement by 0.5 pixel distance can be done using MEMS actuator sitting underneath the lens structure.

The output of the zoom controller is supplied to the gamma correction stage, which helps to map the values received from the camera channels into values that more closely match the dynamic range characteristics of a display device (e.g., a liquid crystal display or cathode ray tube device). The values from the camera channels are based, at least in part, on the dynamic range characteristics of the sensor, which often does not match the dynamic range characteristics of the display device. The mapping provided by

gamma correction stage helps to compensate for the mismatch between the dynamic ranges.

Figure 37I is a graphical representation showing an example of the operation of the gamma correction stage

Figure 37J shows one embodiment of the gamma correction stage.

The transfer function may be any type of transfer function including a linear transfer function, a non-linear transfer function and/or combinations thereof. The transfer function may have any suitable form including but not limited to one or more equations, lookup tables and/or combinations thereof. The transfer function may be predetermined, adaptively determined and/or combinations thereof.

The output of the gamma correction stage is supplied to the color correction stage, which helps to map the output of the camera into a form that matches the color preferences of a user. In this embodiment, the color correction stage generates corrected color values using a correction matrix that contains a plurality of reference values to implement color preferences as follows (The correction matrix contains sets of parameters that are defined, for example, by the user and/or the manufacturer of the digital camera):

$$\begin{bmatrix} R_c \\ G_c \\ B_c \end{bmatrix} = \begin{bmatrix} R_r & G_r & B_r \\ R_g & G_g & B_g \\ R_b & G_b & B_b \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad \begin{bmatrix} \\ \\ 1 \end{bmatrix}$$

such that

$$R \text{ corrected} = (R_r \times R \text{ un-corrected}) + (G_r \times G \text{ un-corrected}) + (B_r \times B \text{ un-corrected}),$$

$$G \text{ corrected} = (R_g \times R \text{ un-corrected}) + (G_g \times G \text{ un-corrected}) + (B_g \times B \text{ un-corrected})$$

and

$$B \text{ corrected} = (R_b \times R \text{ un-corrected}) + (G_b \times G \text{ un-corrected}) + (B_b \times B \text{ un-corrected})$$

where

R_r is a value indicating the relationship between the output values from the red camera channel and the amount of red light desired from the display device in response thereto,

G_r is a value indicating the relationship between the output values from the green camera channel and the amount of red light desired from the display device in response thereto,

B_r is a value indicating the relationship between the output values from the blue camera channel and the amount of red light desired from the display device in response thereto,

R_g is a value indicating the relationship between the output values from the red camera channel and the amount of green light desired from the display device in response thereto,

G_g is a value indicating the relationship between the output values from the green camera channel and the amount of green light desired from the display device in response thereto,

B_g is a value indicating the relationship between the output values from the blue camera channel and the amount of green light desired from the display device in response thereto,

R_b is a value indicating the relationship between the output values from the red camera channel and the amount of blue light desired from the display device in response thereto,

G_b is a value indicating the relationship between the output values from the green camera channel and the amount of blue light desired from the display device in response thereto,

and

B_b is a value indicating the relationship between the output values from the blue camera channel and the amount of blue light desired from the display device in response thereto,

Figure 37K shows one embodiment of the color correction stage. In this embodiment, the color correction stage includes a red color correction circuit, a green color correction circuit and a blue color correction circuit.

The red color correction circuit includes three multipliers. The first multiplier receives the red value (e.g., P_{An}) and the transfer characteristic R_r and generates a first signal indicative of the product thereof. The second multiplier receives the green value (e.g., P_{Bn}) and the transfer characteristic G_r and generates a second signal indicative of the product thereof. The third multiplier receives the green value (e.g., P_{Cn}) and the transfer characteristic B_r and generates a third signal indicative of the product thereof. The first, second and third signals are supplied to an adder which produces a sum that is indicative of a corrected red value (e.g., $P_{An \text{ corrected}}$).

The green color correction circuit includes three multipliers. The first multiplier receives the red value (e.g., P_{An}) and the transfer characteristic R_g and generates a first signal indicative of the product thereof. The second multiplier receives the green value (e.g., P_{Bn}) and the transfer characteristic G_g and generates a second signal indicative of the product thereof. The third multiplier receives the green value (e.g., P_{Cn}) and the transfer characteristic B_g and generates a third signal indicative of the product thereof. The first, second and third signals are supplied to an adder which produces a sum indicative of a corrected green value (e.g., $P_{Bn \text{ corrected}}$).

The blue color correction circuit includes three multipliers. The first multiplier receives the red value (e.g., P_{An}) and the transfer characteristic R_b and generates a first signal indicative of the product thereof. The second multiplier receives the green value (e.g., P_{Bn}) and the transfer characteristic G_b and generates a second signal indicative of the product thereof. The third multiplier receives the green value (e.g., P_{Cn}) and the transfer characteristic B_b and generates a third signal indicative of the product thereof. The first, second and third signals are supplied to an adder which produces a sum indicative of a corrected blue value (e.g., $P_{Cn \text{ corrected}}$).

The output of the color corrector is supplied to the edge enhancer/sharpener, the purpose of which is to help enhance features that may appear in an image. Figure 37L

shows one embodiment of the edge enhancer/sharpener. In this embodiment, the edge enhancer/sharpener comprises a high pass filter that is applied to extract the details and edges and apply the extraction information back to the original image.

The purpose of the chroma noise reduction stage is to reduce the appearance of aliasing. The mechanism is similar to that of the zoom controller. When the details in a scene are beyond the camera enhanced resolution, aliasing phenomenon will appear again. Aliasing phenomenon manifests itself in the form of false color (chroma noise) in pixel per pixel basis in an image. Therefore, by filtering high frequency component of color information in an image, aliasing appearance effect can be reduced.

The output of the chroma noise reduction portion is supplied to the Auto/Manual white balance portion, the purpose of which is to make sure that a white colored target is captured as a white colored target, not slightly reddish/greenish/bluish colored target. In this embodiment, the auto white balance stage performs a statistical calculation on an image to detect the presence of white objects. If a white objects is found, the algorithm will measure the color of this white object. If the color is not pure white, then the algorithm will apply color correction to make the white object white. Auto white balance can have manual override to let user manually enter the correction values.

The output of the white balance portion is supplied to the Auto/Manual color enhancement portion, the purpose of which is to further enhance the color appearance in an image in term of contrast, saturation, brightness and hue. This is similar in some respects to adjusting color settings in a TV or computer monitor. In this embodiment, auto/manual color enhancement is carried out by manually entering the settings level. The user can give preference level and let the algorithm to automatically adjust the settings based on user supplied settings level.

The output of the Auto/Manual color enhancement portion is supplied to the image scaling portion, the purpose of which is to reduce or enlarge the image. This is carried out by removing or adding pixels to adjust the size of an image.

The output of the image scaling portion is supplied to the color space conversion portion, the purpose of which is to convert color format from RGB to YCrCB or YUV for

compression. In this embodiment, the conversion is accomplished using the following equations:

$$Y = (0.257 * R) + (0.504 * G) + (0.098 * B) + 16$$

$$Cr = V = (0.439 * R) - (0.368 * G) - (0.071 * B) + 128$$

$$Cb = U = -(0.148 * R) - (0.291 * G) + (0.439 * B) + 128$$

The output of the color space conversion portion is supplied to the image compression portion of the post processor. The purpose of the image compression portion is to reduce the size of image file. This may be accomplished using an off the shelf JPEG, MPEG or WMV compression algorithm.

The output of the image compression portion is supplied to the image transmission formatter, the purpose of which is to format the image data stream to comply with YUV422, RGB565, etc format both in bi-directional parallel or serial 8-16 bit interface.

Figure 38 shows another embodiment of the channel processor. In this embodiment, the double sampler receives the output of the analog to digital converter instead of the output of the sensor portion

Figures 39-40 show another embodiment of the channel processor and image pipeline respectively. In this embodiment, the deviant pixel corrector is disposed in the image pipeline rather than the channel processor. In this embodiment, the deviant pixel corrector receives the output of the image plane alignment and stitching rather than the output of the black level clamp.

It should be understood that the channel processor, the image pipeline and/or the post processor may have any configuration. For example, in some other embodiments, the image pipeline employs fewer than all of the blocks shown in Figures 36C, 37E and/or Figure 40, with or without other blocks and in any suitable order.

As stated above, relative movement between one or more optics portions (or portions thereof) and one or more sensor portions (or portions thereof) may be used in

providing various features and/or in various applications, including for example, but not limited to, increasing resolution (e.g., increasing detail), zoom, 3D enhancement, image stabilization, image alignment, lens alignment, masking, image discrimination, auto focus, mechanical shutter, mechanical iris, hyperspectral imaging, snapshot mode , range finding and/or combinations thereof.

Increasing resolution

Figures 41A-41J show an example of how movement in the x direction and/or y direction may be used to increase the resolution (e.g., detail) of images provided by the digital camera subsystem. In this example, a first image is captured with the optics and sensor in a first relative positioning (e.g., an image captured with the lens positioning system in a rest position). In that regard, Figure 41A shows an image of an object (a lightning bolt) striking a sensor with the optics and the sensor in a first relative positioning. The first captured image is shown in Figure 41B. This is the image that could be displayed based upon the information in the first captured image. In Figure 41A, sensor elements are represented by circles XX and photons that form the image of the object are represented by shading. In this example, photons that strike the sensor elements (e.g., photons that strike within the circles XX) are sensed and/or captured by the sensor elements. Photons that do not strike the sensor elements (e.g., photons that strike outside the circles XX) are not sensed and/or captured by the sensor elements. Notably, portions of the image of the object that do not strike the sensor elements do not appear in the captured image. .

The optics and/or the sensor are thereafter moved (e.g., shifted) in the x direction and/or y direction to provide a second relative positioning of the optics and the sensor, and a second image is captured with the optics and the sensor in such positioning. For example, an electronic stimuli may be applied to actuators in the lens positioning system thus shifting the lenses (in this example, eastward) by a small distance. A new image is captured which is represented by the solid circles.

In that regard, Figure 41C shows an image of the object striking the sensor with the optics and the sensor in a second relative positioning. Figure 41D shows the second captured image. This second image represents a second set of data that, in effect, doubles

the number of pixel signals. Figure 41E shows the relationship between the first relative positioning and the second relative positioning. In Figure 41E, the first relative positioning of the sensor elements is represented by dashed circles. The second relative positioning is represented by solid circles.

As with the first relative positioning, some photons do not strike the sensor elements and are therefore not sensed and/or captured. Portions of the image of the object that do not strike the sensor elements do not appear in the second captured image. Notably, however, in the second relative positioning, the sensor elements sense and/or capture some of the photons that were not sensed and/or captured by the first relative positioning. Consequently, the first and second images may be “combined” to produce an image that has greater detail than either the first or second captured images, taken individually, and thereby increase the effective resolution of the digital camera subsystem. Figure 41F shows an example of an image that is a combination of the first and second captured images. A comparison of Figure 41F to Figure 41B reveals the enhanced detail that may be displayed as a result thereof.

If desired, the optics and/or the sensor may thereafter be moved (e.g., shifted) in the x direction and/or y direction to provide a third relative positioning of the optics and the sensor, and a third image may be captured with the optics and the sensor in such positioning. For example, an electronic stimuli may be applied to actuators in the lens positioning system thus shifting the lenses (in this example, southward) by a small distance.

In that regard, Figure 41G shows an image of the object striking the sensor with the optics and the sensor in a third relative positioning. Figure 41H shows a third captured image. This third image represents a third set of data that, in effect, triples the number of pixel signals. Figure 41I shows the relationship between the first, second and third relative positioning. In Figure 41I, the first and second relative positioning of the sensor elements is represented by dashed circles. The third relative positioning is represented by solid circles.

In the third relative positioning, as with the first and second relative positioning, some photons do not strike the sensor elements and are therefore not sensed and/or

captured. Portions of the image of the object that do not strike the sensor elements do not appear in the third captured image. However, in the third relative positioning, the sensor elements sense and/or capture some of the photons that were not sensed and/or captured by the first or second relative positioning. Consequently, if the first, second and third images are “combined”, the resulting image has greater detail than either of the first, second or third captured images, taken individually, which can be viewed as an increase in the effective resolution of the digital camera subsystem. Figure 41J shows an example of a combination of the first, second and third captured images. A comparison of Figure 41J to Figures 41B and 41F reveals the enhanced detail that may be displayed as a result thereof.

It should be understood that any number of steps may be employed in any direction. In some embodiments, movements are divided into $\frac{1}{2}$ pixel increments. In some embodiments, the movements are divided into two or more steps in the x direction and two or more steps in the y direction.

It should be understood that although Figures 41A-41J show only nine pixels a digital camera may have for example, hundreds of thousands to millions of pixels. However, the result is still the same. Thus, it is possible to increase the resolution of the digital camera subsystem without increasing the pixel count.

In view of the above, it should be understood that an increase in resolution can be achieved using relative movement in the x direction, relative movement in the y direction and/or any combination thereof. Thus, for example, relative movement in the x direction may be used without relative movement in the y direction and relative movement in the y direction may be used without relative movement in the x direction. In addition, it should also be understood that a shift of the optics and/or sensor portions need not be purely in the x direction or purely in the y direction. Thus, for example, a shift may have a component in the x direction, a component in the y direction and/or one or more components in one or more other directions.

It should also be understood that similar results may be obtain using other types of relative movement, including, for example, but not limited to relative movement in the z direction, tilting, and/or rotation. For example, each of these types of relative movement

can be used to cause an image of an object to strike different sensor elements on a sensor portion.

Figure 42A shows a flowchart of steps that may be employed in increasing resolution, in accordance with one embodiment of the present invention.

Figure 42B is a diagrammatic representation of the manner in which images may be combined.

Figures 42C-42E show one embodiment of an image combiner.

Figure 43 shows a flowchart of steps that may be employed in increasing resolution, in accordance with one embodiment of the present invention.

Zoom

Figures 44A-44G show two ways that a traditional digital camera can provide zooming. More particularly, Figure 12A shows an image of an object (a lightning bolt) striking a sensor having 144 sensor elements XX arranged in a 12x12 array. Note that although a 144 pixel camera is employed for illustrative purposes, any number of pixels, including up into the millions, can be used. The captured image, without zooming, is shown in Figure 44B. In this example, with the lens in its normal (un-zoomed) setting approximately 9 pixels capture photons from the object.

As in the examples above, photons that strike the sensor elements (e.g., photons that strike within the circles XX) are sensed and/or captured thereby. Photons that do not strike the sensor elements (e.g., photons that strike outside the circles XX) are not sensed and/or captured.

Figures 44C-44E show an example of traditional digital or electronic zooming (enlarging the target object by electronic processing techniques). With digital zooming, a portion of a captured image is enlarged to thereby produce a new image. Figure 44C shows a window around the portion of the image that is to be enlarged. Figure 44D is an enlarged representation of the sensor elements and the portion of the image within the window. Figure 44E shows an image produced by enlarging the portion of the image within the window.

Notably, digital zooming does not improve resolution. To make the object appear larger relative to the overall field of view, the outer portions of the image are cropped out

(e.g., the signals from the outer pixels are discarded). The remaining image is then enlarged (magnified) to refill the total frame, which is shown in view 2B. The object in 2B still has only 9 pixels worth of data. As such, electronic zoom yields an object within the image as the same size as optical zoom, but does so at a sacrifice in resolution.

Thus while the object appears larger, imperfections found in the original captured image also appear larger.

Figures 44F-44G show an example of optical zooming (i.e., enlarging the image of the object through the use of optics). With optical zooming, one or more optical components are moved along a z axis so as to increase the size of the image striking the sensor. Figure 44FC shows an image of the object striking the sensor after optical zooming. With the lens in the zoom position, the field of view is narrowed and the object fills a greater portion of the pixel array. In this example, the image of the object now strikes approximately thirty four of the sensor elements rather than only nine of the sensor elements as in Figure 44A. This improves the resolution of the captured image. Figure 44G shows the image produced by the optical zooming. Notably, while the object appears larger, the size of the imperfections in the original captured image are not correspondingly enlarged.

As illustrated in Figure 44F-44G, a traditional zoom camera makes an object appear closer by reducing the field of view. Its advantage is that it maintains the same resolution. Its disadvantages are that the lens system is costly and complex. Further, the nature of zoom lenses are that they reduce the light sensitivity and thus increase the F-stop of the lens. This means that the lens is less effective in low light conditions.

Figures 45A-45L show an example of how movement in the x direction and/or y direction may be used in zooming. In this example, a first image is captured with the optics and sensor in a first relative positioning. In that regard, Figure 45A shows an image of an object (a lightning bolt) striking a sensor with the optics and the sensor in a first relative positioning. A window is shown around the portion of the image that is to be enlarged (sometimes referred to herein as the window portion of the image). Figure 45B shows the captured image without zooming. Figure 45C is an enlarged representation of the sensor elements and the window portion of the image. Figure 45D shows the first image captured for the window portion. Notably, portions of the image

that do not strike the sensor elements do not appear in the first captured image. Moreover, although the object appears larger in Figure 45D as compared to Figure 45B, imperfections also appear larger.

The optics and/or the sensor are thereafter moved (e.g., shifted) for example, in the x direction and/or y direction to provide a second relative positioning of the optics and the sensor, and a second image is captured with the optics and the sensor in such positioning. In that regard, Figure 45E is an enlarged representation of the sensor elements and the window portion of the image. Figure 45F shows the second captured image for the window portion. Figure 45G shows the relationship between the first relative positioning and the second relative positioning. In Figure 45G, the first relative positioning of the sensor elements is represented by dashed circles. The second relative positioning is represented by solid circles.

As with the first relative positioning, some photons do not strike the sensor elements and are therefore not sensed and/or captured. Portions of the image that do not strike the sensor elements do not appear in the second captured image. Notably, however, in the second relative positioning, the sensor elements sense and/or capture some of the photons that were not sensed and/or captured by the first relative positioning. Consequently, the first and second captured images may be “combined” to produce a zoom image that has greater detail than either the first or second captured images, taken individually. Figure 45H shows an example of a zoom image created by combining the first and second captured images.

If desired, the optics and/or the sensor may thereafter be moved (e.g., shifted) in the x direction and/or y direction to provide a third relative positioning of the optics and the sensor, and a third image may be captured with the optics and the sensor in such positioning. In that regard, Figure 45I is an enlarged representation of the sensor elements and the window portion of the image. Figure 45J shows the third captured image for the window portion. Figure 45K shows the relationship between the first relative positioning and the second relative positioning. In Figure 45K, the first and second relative positioning of the sensor elements is represented by dashed circles. The third relative positioning is represented by solid circles.

In the third relative positioning, as with the first and second relative positioning, some photons do not strike the sensor elements and are therefore not sensed and/or captured. Portions of the image that do not strike the sensor elements do not appear in the third captured image. However, in the third relative positioning, the sensor elements sense and/or capture some of the photons that were not sensed and/or captured by the first or second relative positioning. Consequently, the first, second and third captured images may be “combined” to produce a zoom image that has greater detail than either the first, second, or third captured images, taken individually. The image may be cropped however, in this case, the cropping results in an image with approximately the same resolution as the optical zoom.

Figure 45L shows an example of a zoom image created by combining the first, second and third captured images.

It should be understood that that any number of steps may be employed in any direction. In some embodiments, movements are divided into $\frac{1}{2}$ pixel increments. In some embodiments, the movements are divided into two or more steps in the x direction and two or more steps in the y direction.

The above example illustrates the ability to take “optically equivalent” zoom pictures without the need of a zoom lens.

In view of the above, it should be understood that zooming may be improved using relative movement in the x direction, relative movement in the y direction and/or any combination thereof. Thus, for example, relative movement in the x direction may be used without relative movement in the y direction and relative movement in the y direction may be used without relative movement in the x direction. In addition, it should also be understood that a shift of the optics and/or sensor portions need not be purely in the x direction or purely in the y direction. Thus, for example, a shift may have a component in the x direction, a component in the y direction and/or one or more components in one or more other directions.

It should also be understood that similar results may also be obtain using other types of relative movement, including, for example, but not limited to relative movement in the z direction, tilting, and/or rotation. For example, each of these types of relative

movement can be used to cause an image of an object to strike different sensor elements on a sensor portion.

It should also be recognized that the examples set forth herein are illustrative. For example, exact pixel counts in each case will depend, at least in part, on the optics, the sensor, the amount of cropping (e.g., the ratio of the size of the window relative to the size of the field of view), and the number/magnitude of shifts employed by the positioning system. Nonetheless, in at least some embodiments, results at least equivalent to optical zoom can be achieved if desired, given appropriate settings and sizes of each type of lens.

Figure 46A shows a flowchart of steps that may be employed in providing zoom, according to one embodiment of the present invention.

Figure 46B shows one embodiment that may be used to generate the zoomed image.

Figure 47A shows a flowchart of steps that may be employed in providing zoom, according to another embodiment of the present invention.

Figure 47BA shows a flowchart of steps that may be employed in providing zoom, according to another embodiment of the present invention.

Image stabilization

Users of digital cameras (e.g., still or video) often have difficulty holding a camera perfectly still, thereby resulting in inadvertent and undesired movements (e.g., jitter) that can in turn result in “blurriness” in a still image and/or undesired “shaking” or “bouncing” in a video image.

In some embodiments, it is desirable to have the ability to introduce relative movement between an optics portion (e.g., one or more portions thereof) and a sensor portion (e.g., one or more portions thereof) to compensate for some or all of such inadvertent and undesired movements on the part of the user and/or to reduce the effects of such inadvertent and undesired movements.

The positioning system may be used to introduce such movement.

Figures 48A-48G show steps used in providing image stabilization according to one embodiment of aspects of the present invention.

Figure 49 shows a flowchart of the steps used in providing image stabilization in one embodiment.

A first image is captured at a step _____. At a step _____, one or more features are identified in the first image and their position(s), within the first image, are determined. A second image is captured at a step _____. At a step _____, the second image is examined for the presence of the one or more features, and if the one or more features are present in the second image, their position(s) within the second image are determined.

At a step _____, the system determines whether the position(s) of the one or more features in the second image are the same as their position(s) in the first image. If the position(s) are not the same, the system computes a difference in position(s) at a step _____. The difference in position may be, for example, a vector, represented, for example, as multiple components (e.g., an x direction component and a y direction component) and/or as a magnitude component and a direction component.

At a step _____, the system identifies one or more movements that could be applied to the optics and/or sensor to counter the difference in position, at least in part, such that in subsequent images, the one or more features would appear at position(s) that are the same as, or reasonably close to, the position(s) at which they appeared in the first image. For example, movements that could be applied to the optics and/or sensor to cause the image to appear at a position, within the field of view of the sensor, that is the same as, or reasonably close to, the position, within the field of view of the sensor, at which the image appeared in the first image, so that the image will strike the sensor elements in the same way, or reasonably close thereto, that the first image struck the sensor elements.

The one or more movements may include movement in the x direction, y direction, z direction, tilting, rotation and/or combinations thereof. For example, the movement may comprises only an x direction component, only a y direction component, or a combination of an x direction component and a y direction component. In some other embodiments, one or more other types of movement or movements (e.g., z direction, tilting, rotation) are employed with or without one or more movements in the x direction and/or y direction.

At a step _____, the system initiates one, some or all of the one or more movements identified at step _____.

At a step __, the system determines whether it is desired to continue to provide image stabilization.

If further stabilization is desired, then a jump is made to step __. For example, a third image is captured at step __, and at step __, the third image is examined for the presence of the one or more features. If the one or more features are present in the third image, their position(s) within the third image are determined. At step __, the system determines whether the position(s) of the one or more features in the third image are the same as their position(s) in the first image. If the position(s) are not the same, the system computes a difference in position at a step __. At step __, the system identifies one or more movements that could be applied to the optics and/or sensor to counter the difference in position, at least in part, and at step __, the system initiates one, some or all of the one or more movements identified at step ____.

If further stabilization is not desired, then stabilization is halted at a step __.

Optics/sensor alignment

In some embodiments, it is desired to configure the digital camera such that a field of view for one or more camera channels matches a field of view for the digital camera. However, misalignments (e.g., as a result of manufacturing tolerances) may occur in the optics subsystem and/or the sensor subsystem thereby causing the field of view for the one or more camera channels to differ from the field of view of the digital camera.

In the event that the optics subsystem and/or the sensor subsystem are out of alignment with one another and/or one or more other parts of the digital camera, it may be desirable to introduce relative movement between an optics portion (e.g., one or more portions thereof) and a sensor portion (e.g., one or more portions thereof) to compensate for some or all of such misalignment and/or to reduce the effects of such misalignment. The positioning system may be used to introduce such movement.

Figures 50A-50N show examples of misalignment and movements that could be used to compensate for such.

Figure 51 shows a flowchart of steps that may be employed in providing optics/sensor alignment, according to one embodiment of the present invention.

At a step __, one or more calibration objects having one or more features of known size(s), shape(s), and/or color(s) are positioned at one or more predetermined positions within the field of view of the digital camera subsystem.

At a step __, an image is captured and examined for the presence of the one or more features. If the features are present, the position(s) of such features within the first image are determined at a step __. At a step __, the positions of the features within the first image are compared to one or more expected positions, i.e., the position(s), within the image, at which the features would be expected to appear based on the positioning of the one or more calibration objects and the one or more features within the field of view. If the position(s) within the first image are not the same as the expected position(s), the system determines the difference in position at a step __. The difference in position may be, for example, a vector, represented, for example, as multiple components (e.g., an x direction component and a y direction component) and/or as a magnitude component and a direction component.

At a step __, the system compares the magnitude of the difference to a reference magnitude. If the difference is greater than the reference magnitude, then at a step __, the system identifies one or more movements that could be applied to the optics and/or sensor to compensate for the difference in position, at least in part, so that in subsequent images, the features would appear at position(s) that are the same as, or reasonably close to, the expected position(s). The one or more movements may be, for example, movements that could be applied to the optics and/or sensor to cause the image to appear at the expected position within the field of view of the sensor. The one or more movements may be, for example, movement(s) in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof. At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

At a step __, data indicative of the misalignment and/or the movement used to compensate for the misalignment is stored.

In some embodiments, further steps may be performed to determine whether the movements had the desired effect, and if the desired effect is not achieved, to make further adjustments.

For example, Figure 52, shows a flowchart employed in another embodiment. Referring to Figure 52, steps ___ are similar to the steps ___ in the flowchart of Figure 51. A second image may be captured at a step ___. At a step ___, the second image is examined for the presence of the one or more features. The position(s) of the features are determined at a step ___.

The steps set forth in Figure 51 and/or Figure 52 may be performed, for example, during manufacture and/or test of digital camera subsystem and/or the digital camera. Thereafter, the stored data may be used in initiating the desired movement(s) each time that the digital camera is powered up.

Channel/channel alignment

In some embodiments, it is desired to configure the digital camera such that the field of view for one or more camera channels matches the field of view for one or more other camera channels.

In the event of misalignment between the camera channels, the positioning system may be used to introduce movement to compensate for (i.e., cancel some or all) such misalignment.

Figure ___ shows a flowchart of steps that may be employed in providing channel/channel alignment, according to one embodiment of the present invention.

At a step ___, one or more calibration objects having one or more features of known size(s), shape(s), and/or color(s) are positioned at one or more predetermined positions within the field of view of the digital camera subsystem.

At a step ___, an image is captured from each of the channels to be aligned. At a step ___, the position(s) of the one or more features, within each image, are determined. For example, if the digital camera has four camera channels, the system determines the position(s) of the one or more features within the image for the first channel, the position(s) of the one or more features within the image for the second channel, the position(s) of the one or more features within the image for the third channel and the position(s) of the one or more features within the image for the fourth channel.

If the position(s) within the images do not coincide, the system determines one or more difference(s) between the position(s) at a step ____.

At a step ____, the system compares the magnitude(s) of the difference(s) to one or more reference magnitude(s). If one or more of the difference(s) are greater than the reference magnitude(s), then at a step ____, the system identifies one or more movements that could be applied to the optics and/or sensor to compensate for one or more of the differences, at least in part, so that in subsequent images for the camera channels, the position(s) of the features in the image for one of the channels is the same as, or reasonably close to, the position(s) of the features in the images for the other channels.

The one or more movements may be, for example, movement(s) in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof. At a step ____, the system initiates one, some or all of the one or more movements identified at step ____.

At a step ____, data indicative of the misalignment and/or the movement used to compensate for the misalignment is stored.

In some embodiments, further steps may be performed to determine whether the movements had the desired effect, and if the desired effect is not achieved, to make further adjustments.

For example, Figure ____, shows a flowchart employed in another embodiment. Referring to Figure ____, steps ____ are similar to the steps performed in the flowchart of Figure ____.

The steps set forth in Figure ____ may be performed, for example, during manufacture and/or test of digital camera subsystem and/or the digital camera. Thereafter, the stored data may be used in initiating the desired movement(s) each time that the digital camera is powered up.

Figure ____, shows a flowchart of the steps that may be employed. Referring to Figure ____, the digital camera is powered up at a step _____. Data indicative of the misalignment and/or the movement to compensate is retrieved at a step ____, and at a step ____, the desired movement(s) are initiated.

Masking

In some embodiments, it is desired to employ one or more masks in the optical path to provide or help provide one or more masking effects (e.g., a visual effect or effects). For example, masks and/or mask techniques may be used in hiding portions of an image and/or field of view in whole or in part, in enhancing one or more features (e.g., fine details and/or edges (e.g., edges that extend in a vertical direction or have a vertical component)) in an image and/or within a field of view and/or in “bringing out” (i.e., to make more apparent) one or more features within an image and/or within a field of view.

Some masks and/or mask techniques employ and/or take advantage of the principles of interference.

Figures 53A-53C show a portion of a digital camera subsystem that includes an optics portion 290A having a mask in accordance with one embodiment of aspects of the present invention. The mask may be positioned anywhere, for example, between a lens and a sensor portion 292A. The mask includes a mask portion and a support portion. The mask portion is light blocking or filtering, at least in part. The support portion supports the mask portion, at least in part. The support portion may or may not transmit light. Thus, in some embodiments, the mask portion includes one or more portions of the support portion (i.e., one or more portions of the support portion are light blocking or filtering, at least in part, and help provide the masking effects, at least in part).

The mask portion may have any form and may be integral with the support portion and/or affixed thereto. In this embodiment, for example, the mask portion comprises a plurality of elements disposed on and/or within the support portion. The elements may have any shape and may be arranged in a pattern. In this embodiment, each of the plurality of elements is a linear element and the linear elements are arranged in a linear array. Light striking the mask portion is blocked, at least in part. Light striking between the elements is transmitted, at least in part. The pattern may be adapted to provide one or more effects and/or may have one or more characteristics selected to correspond to one or more characteristics of the sensor elements or arrangement thereof. The elements may also be arranged, for example, in a pattern that corresponds to the pattern of the sensor elements. For example, if the sensor elements are arranged in a grid pattern, the elements may be arranged in a grid pattern that corresponds therewith (e.g.,

the elements of the mask portion may be arranged in a grid pattern that is the same as, or a scaled version of, the grid pattern in which the sensor elements are arranged).

The positioning system may be employed to position and/or move the mask into, within and/or out of the optical path to provide a desired effect or effects.

For example, Figure 53A shows the lens, the mask and the sensor portion in a first relative positioning, wherein the mask portion blocks or filters portions of the light within the field of view. Figure 53B shows the lens, the mask and the sensor portion in a second relative positioning, wherein the mask portion blocks or filters a different portions of the light than that blocked or filtered by the mask portion in the first relative positioning. Figure 53C shows the lens, the mask and the sensor portion in a third relative positioning. In such positioning, the mask is out of the optical path.

Figures 53D-53F show a portion of a digital camera subsystem that includes an optics portion 290A having a mask in accordance with another embodiment of aspects of the present invention. In this embodiment, the mask includes a mask portion that comprises linear elements arranged in a grid. The pattern may be adapted to provide one or more effects and/or may have one or more characteristics selected to correspond to one or more characteristics of the sensor elements or arrangement thereof. If the sensor elements are arranged in a grid pattern, the elements of the mask portion may be arranged in a grid pattern that corresponds therewith (e.g., the elements of the mask portion may be arranged in a grid pattern that is the same as, or a scaled version of, the grid pattern in which the sensor elements are arranged).

Figure 53D shows the lens, the mask and the sensor portion in a first relative positioning, wherein the mask portion blocks or filters portions of the light within the field of view. Figure 53E shows the lens, the mask and the sensor portion in a second relative positioning, wherein the mask portion blocks or filters a different portions of the light than that blocked or filtered by the mask portion in the first relative positioning. Figure 53F shows the lens, the mask and the sensor portion in a third relative positioning. In such positioning, the mask is out of the optical path.

Figures 53G-53I show a portion of a digital camera subsystem that includes an optics portion 290A having a mask in accordance with another embodiment of aspects of

the present invention. In this embodiment, the mask has first and second portions disposed, for example, between a lens and a sensor portion 292A. Each of the mask portions comprises a plurality of linear elements. The elements may have any shape and may be arranged in a pattern. In this embodiment, each of the mask portions comprises a plurality of linear elements arranged in a linear array, such that the mask portions collectively define a grid. The pattern may be adapted to provide one or more effects and/or may have one or more characteristics selected to correspond to one or more characteristics of the sensor elements or arrangement thereof.

Figure 53G shows the lens, the mask and the sensor portion in a first relative positioning, wherein the mask portion blocks or filters portions of the light within the field of view. Figure 53H shows the lens, the mask and the sensor portion in a second relative positioning, wherein the mask portion blocks or filters a different portions of the light than that blocked or filtered by the mask portion in the first relative positioning. Figure 53I shows the lens, the mask and the sensor portion in a third relative positioning. In such positioning, the mask is out of the optical path.

Figure 54 shows a flowchart of steps that may be employed in association with one or more masks to provide or help provide one or more masking effects, according to one embodiment of the present invention.

At a step __, the system receives a signal indicative of one or more desired masking effects.

At a step __, the system identifies one or more movements to provide or help provide the one or more masking effects.

The one or movements may be movements to be applied to the mask and/or any other components in the optical path (e.g., movement of one or more other portions of the optic portion and/or movement of the sensor portion).

The movement may be movement in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

A first masked image is captured at a step __. In some embodiments, the first masked image may itself provide the desired masking effect.

In some embodiments, the one or more portions of the first masked image may be combined with one or more portions of one or more other images (masked or unmasked) to provide or help provide the desired masking effect, as indicated at a step ____.

Mechanical shutter

In some embodiments, it is desired to configure the digital camera with a mechanical shutter for use in controlling transmission of light to the sensor portion.

Figures 55A-55C show a portion of a digital camera subsystem that includes an optics portion 290A having a mechanical shutter in accordance with one embodiment of aspects of the present invention. In this embodiment, the mechanical shutter comprises a mask that is disposed, for example, between a lens and a sensor portion 292A. The mask defines one or more openings, e.g., openings. The openings may be arranged, for example, in a pattern that corresponds with the pattern of the sensor elements. For example, if the sensor elements are arranged in a grid pattern, the openings of the mask may be arranged in a grid pattern that corresponds therewith (e.g., the openings of the mask may be arranged in a grid pattern that is the same as, or a scaled version of, the grid pattern in which the sensor elements are arranged).

The positioning system may be employed to position the mechanical shutter and/or some other portion of the optics portion and/or the sensor portion to facilitate control over the amount of light transmitted to one or more portions of the optics portion and/or the sensor portion.

For example, Figure 55A shows the lens, the mechanical shutter and the sensor portion in a first relative positioning (sometimes referred to herein as a “fully open positioning”). In such positioning, each opening in the mask is in register with a respective sensor element, such that a minimum amount of light, or no light, within the field of view is blocked by the mask and the balance of the light within the field of view passes through the openings and strikes the sensor elements.

Figure 55B shows the lens, the mechanical shutter and the sensor portion in a second relative positioning (sometimes referred to herein as a “closed positioning”). In such positioning, the openings in the mask are out of register, at least in part, with respective sensor elements such that a minimum amount of light, or no light, within the

field of view strikes the sensor elements, but rather strikes regions between the sensor elements.

Figure 55C shows the lens, the mechanical shutter and the sensor portion in a third relative positioning (sometimes also referred to herein as an “open positioning”). In such positioning, the mask is out of the optical path, such that a maximum amount of light within the field of view strikes the sensor elements.

Figures 55D-55F show a portion of a digital camera subsystem that includes an optics portion 290A having a mechanical shutter in accordance with another embodiment of aspects of the present invention. In this embodiment, the mechanical shutter has first and second masks disposed, for example, between a lens and a sensor portion 292A. Each mask defines one or more openings. For example, the first mask defines openings. The second mask defines openings. The openings may be arranged, for example, in a pattern that corresponds to the pattern of the sensor elements. For example, if the sensor elements are arranged in a grid pattern, the openings of the masks may be arranged in a grid pattern that corresponds therewith (e.g., the openings of the masks may be arranged in a grid pattern that is the same as, or a scaled version of, the grid pattern in which the sensor elements are arranged).

The positioning system may be employed to position one or more of the masks and/or some other portion of the optics portion and/or the sensor portion to facilitate control over the amount of light transmitted to one or more portions of the optics portion and/or the sensor portion.

Figure 55D shows the lens, the mechanical shutter and the sensor portion in a first relative positioning (sometimes referred to herein as a “fully open positioning”). In such positioning, each opening in the first mask is in register with a respective opening in the second mask and a respective sensor element, such that a minimum amount of light, or no light, within the field of view is blocked by the mechanical shutter and the balance of the light within the field of view passes through the openings and strikes the sensor elements.

Figure 55E shows the lens, the mechanical shutter and the sensor portion in a second relative positioning (sometimes referred to herein as a “partially closed positioning”). In such positioning, the openings in the first mask are out of register with respective openings in the second mask, such that a minimum amount of light, or no

light, within the field of view strikes the sensor elements. In such positioning, the light within the field of view strikes the second mask (rather than passing through the openings in the second mask) and is therefore not transmitted to the sensor elements of the sensor portion.

Figure 55F shows the lens, the mechanical shutter and the sensor portion in a third relative positioning (sometimes also referred to herein as an “open positioning”). In such positioning, the shutter is out of the optical path, such that a maximum amount of light within the field of view strikes the sensor elements.

Figure 56 shows a flowchart of steps that may be employed in association with a mechanical shutter, according to one embodiment of the present invention.

At a step __, the system receives a signal indicative of the amount of light to be transmitted and/or one or more movements to be applied to one or both of the masks and/or some other portion of the optics portion and/or the sensor portion to control the amount of light to be transmitted.

The signal may be supplied from any source, including, but not limited to, from the processor and/or the user peripheral interface. For example, in some embodiments, the peripheral user interface may include one or more input devices by which the user can indicate a preference in regard to the amount of light transmitted to the sensor portion, and the peripheral user interface may provide a signal that is indicative of such preference. The signal from the peripheral user interface may be supplied directly to the controller of the positioning system or to some other portion of the processor, which may in turn process the signal to generate one or more control signals to be provided to the controller of the positioning system to carry out the user’s preference. In some other embodiments, the processor may capture one or more images and may process such images and make a determination as to whether a desired amount of light is being transmitted to the sensor and if not, whether the amount of light should be increased or decreased. Some other embodiments may employ combinations thereof.

At a step __, the system identifies one or more movements to facilitate control over the amount of light transmitted to one or more portions of the optics portion and/or the sensor portion.

The movement may be movement in the x direction, y direction, z direction, tilting, rotation and/or combinations thereof.

Note that the movements need not be computed every time but rather the movement may be computed once, stored and accessed as needed.

The movements may be predetermined, adaptively determined and/or a combination thereof.

The signal may be indicative of absolute or relative positioning, the amount of movement, the amount of light to be transmitted or not transmitted and/or combinations thereof. The signal may have any form for example, a magnitude, a difference, a ratio, or any other suitable method.

An alternative embodiment comprises a mapping of an overall relationship between the inputs ___ and the output(s) ___. The mapping may have any of various forms known to those skilled in the art, including but not limited to, a formula, a look-up table, a "curve read", fuzzy logic, neural networks.

The mapping may be predetermined, adaptively determined and/or a combination thereof.

Once generated, use of a mapping embodiment may entail considerably less processing overhead than that required other embodiments.

A mapping may be generated "off-line" by providing one or more input output combinations. Each input/output combination includes one or more input values and one or more output values associated therewith.

Each combination of input values and the associated output value collectively represent one data point in the overall input output relation. The data points may be used to create a look-up table that provides one or more outputs values for each of a plurality of combinations of input(s), one or more input(s) and output(s). Or, instead of a look-up table, the data points may be input to a statistical package to produce a formula for calculating the output based on the inputs. A formula can typically provide an appropriate output for any input combination in the sensor input range of interest, including combinations for which data points were not generated.

A look-up table embodiment may be responsive to absolute magnitudes and/or relative differences. A look-up table embodiment may use interpolation to determine an appropriate output for any input combination not in the table.

A mapping embodiment may be implemented in software, hardware, firmware or any combination thereof.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

In some embodiments, further steps may be performed to determine whether the movements had the desired effect, and if the desired effect is not achieved, to make further adjustments.

For example, Figure 57 shows a flowchart of steps that may be employed in providing a mechanical shutter, according to another embodiment of the present invention.

A first image is captured at a step __. At a step __, the system processes the image and generates a measure of the amount of light transmitted by the mechanical shutter.

At a step __, the system determines whether the amount of light transmitted by the mechanical shutter is the same as the desired amount, and if not, the system determines a difference between the two amounts at a step __. At a step __, the system compares the difference to a reference magnitude.

If the difference is greater than the reference magnitude, then at a step __, the system identifies one or more movements that could be applied to one or more portions of the optics portion and/or to the sensor portion to compensate for the difference.

That is, one or more movements to cause the amount of light transmitted by the mechanical shutter and/or the amount of light received by the sensor elements to be equal to or less than the amount of light that is desired.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

At a step __, data indicative of the compensation and/or the movement used to compensate is stored.

Although the mechanical shutter in Figures 55A-55C is shown having one portion (e.g., one mask) and although the mechanical shutter in Figures 55D-55F is shown having two portions (e.g., two masks), it should be understood that a shutter may have any configuration. For example, some other embodiments employ a shutter having more than two portions (e.g., more than two masks).

Moreover, although the shutter is shown disposed between the lens and the sensor portion, the shutter or portions thereof may be disposed in any position or positions suitable to control or help control the amount of light transmitted to one or more portions of one or more optics portions and/or one or more portions of one or more sensor portions. In addition, although the two masks in Figures 55D-55F are shown disposed adjacent to one another, it should be understood that portions of a mechanical shutter may or may not be disposed adjacent to one another.

Mechanical iris

In some embodiments, it is desired to configure the digital camera with a mechanical iris for use in controlling the amount of light transmitted to the optics and/or sensor.

Figures 58A-58D show a portion of a digital camera subsystem that includes an optics portion 290A having a mechanical iris in accordance with one embodiment of aspects of the present invention. In this embodiment, the mechanical iris includes a mask, disposed, for example, between a lens and a sensor portion 292A. The mask defines one or more openings, e.g., openings. The openings may be arranged, for example, in a pattern that corresponds to the pattern of the sensor elements. For example, if the sensor elements are arranged in a grid pattern, the openings of the mask may be arranged in a grid pattern that corresponds therewith (e.g., the openings of the mask may be arranged in a grid pattern that is the same as, or a scaled version of, the grid pattern in which the sensor elements are arranged).

The positioning system may be employed to position the shutter and/or some other portion of the optics portion and/or the sensor portion to facilitate control over the amount of light transmitted to one or more portions of the optics portion and/or the sensor portion.

For example, Figure 58A shows the lens, the mechanical iris and the sensor portion in a first relative positioning (sometimes referred to herein as a “fully open positioning”). In such positioning, each opening in the mask is in register with a respective sensor element, such that a minimum amount of light, or no light, within the field of view is blocked by the mask and the balance of the light within the field of view passes through the openings and strikes the sensor elements.

Figure 58B shows the lens, the mechanical iris and the sensor portion in a second relative positioning (sometimes referred to herein as a “partially closed positioning”). In such positioning, the openings in the mask are partially out of register with respective sensor elements such that a portion of the light does not strike the sensor elements, but rather strikes regions between the sensor elements.

Figure 58C shows the lens, the mechanical iris and the sensor portion in a third relative positioning (sometimes referred to herein as a “closed positioning”). In such positioning, the openings in the mask are out of register, at least in part, with respective sensor elements such that a minimum amount of light, or no light, within the field of view strikes the sensor elements, but rather strikes regions between the sensor elements.

Figure 58D shows the lens, the mechanical iris and the sensor portion in a fourth relative positioning (sometimes also referred to herein as an “open positioning”). In such positioning, the mask is out of the optical path, such that a maximum amount of light within the field of view strikes the sensor elements.

The positioning system may be employed to position the mechanical iris and/or some other portion of the optics portion and/or the sensor portion to facilitate control over the amount of light transmitted to one or more portions of the optics portion and/or the sensor portion.

Figures 58E-58H show a portion of a digital camera subsystem that includes an optics portion having a mechanical iris in accordance with one embodiment of another aspect of the present invention. In this embodiment, the mechanical iris has first and second masks disposed, for example, between a lens and a sensor portion 292A. Each mask defines one or more openings. For example, the first mask defines openings. The second mask defines openings. The openings in the first and second masks may be arranged, for example, in a pattern that corresponds to the pattern of the sensor elements.

For example, if the sensor elements are arranged in a grid pattern, the openings may be arranged in a grid pattern that corresponds therewith (e.g., the openings of the masks may be arranged in a grid pattern that is the same as, or a scaled version of, the grid pattern in which the sensor elements are arranged).

Figure 58E shows the lens, the mechanical iris and the sensor portion in a first relative positioning (sometimes referred to herein as a “fully open positioning”). In such positioning, each opening in the first iris is in register with a respective opening in the second iris and a respective sensor element, such that a minimum amount of light, or no light, within the field of view is blocked by the mechanical iris and the balance of the light within the field of view passes through the openings and strikes the sensor elements.

Figure 58F shows the lens, the mechanical iris and the sensor portion in a second relative positioning (sometimes referred to herein as a “partially closed positioning”). In such positioning, the openings in the first mask are partially out of register with respective openings in the second mask, such that some of the light strikes the second mask (rather than passing through the openings in the second mask) and is therefore not transmitted to the sensor elements of the sensor portion.

Figure 58G shows the lens, the mechanical shutter and the sensor portion in a third relative positioning (sometimes referred to herein as a “partially closed positioning”). In such positioning, the openings in the first mask are out of register with respective openings in the second mask, such that a minimum amount of light, or no light, within the field of view strikes the sensor elements. In such positioning, the light within the field of view strikes the second mask (rather than passing through the openings in the second mask) and is therefore not transmitted to the sensor elements of the sensor portion.

Figure 58H shows the lens, the mechanical iris and the sensor portion in a fourth relative positioning (sometimes also referred to herein as an “open positioning”). In such positioning, the iris is out of the optical path, such that a maximum amount of light within the field of view strikes the sensor elements.

Figure 59 shows a flowchart of steps that may be employed in association with a mechanical iris, according to one embodiment of the present invention.

At a step __, the system receives a signal indicative of the amount of light to be transmitted and/or one or more movements to be applied to one or both of the masks and/or some other portion of the optics portion and/or the sensor portion to control the amount of light to be transmitted.

The signal may be supplied from any source, including, but not limited to, from the processor and/or the user peripheral interface. For example, in some embodiments, the peripheral user interface may include one or more input devices by which the user can indicate a preference in regard to the amount of light transmitted to the sensor portion, and the peripheral user interface may provide a signal that is indicative of such preference. The signal from the peripheral user interface may be supplied directly to the controller of the or to some other portion of the processor, which may in turn process the signal to generate one or more control signals to be provided to the controller to carry out the user's preference. In some other embodiments, the processor may capture one or more images and may process such images and make a determination as to whether a desired amount of light is being transmitted to the sensor and if not, whether the amount of light should be increased or decreased. Some other embodiments may employ combinations thereof.

At a step __, the system identifies one or more movements to facilitate control over the amount of light transmitted to one or more portions of the optics portion and/or the sensor portion.

The relative movement may be relative movement in the x direction and/or y direction, relative movement in the z direction, tilting, rotation and/or combinations thereof.

As used herein identifying, determining, and generating includes identifying, determining, and generating, respectively, in any way including but not limited to, computing, accessing stored data and/or mapping (e.g., in a look up table) and/or combinations thereof.

Note that the movements need not be computed every time but rather the movement may be computed once (or alternatively predetermined), stored and accessed as needed.

The signal may be indicative of absolute or relative positioning, the amount of movement, the amount of light to be transmitted or not transmitted and/or combinations thereof. The signal may have any form for example, a magnitude, a difference, a ratio, or any other suitable method.

An alternative embodiment comprises a mapping of an overall relationship between the inputs ___ and the output(s) __. The mapping may have any of various forms known to those skilled in the art, including but not limited to, a look-up table, a formula, a "curve read", fuzzy logic, neural networks. The mapping may be predetermined or adaptively . Once generated, use of a mapping embodiment may entail considerably less processing overhead than that required other embodiments.

A mapping may be generated "off-line". For example, different combinations of input magnitudes may be presented. For each combination, an output is produced. Each combination and its associated output together represent one data point in the overall input output relation. The data points may be used to create a look-up table that provides, for each of a plurality of combinations of inputs, an associated output. Or, instead of a look-up table, the data points may be input to a statistical package to produce a formula for calculating the output based on the inputs. Such a formula may be able to provide an output for any input combination in a range of interest, including combinations for which data points were not generated.

A look-up table embodiment may be responsive to absolute magnitudes or alternatively to relative differences (or some other indication) between the inputs. A look-up table embodiment may use interpolation to determine an appropriate output for any input combination that is not in the table.

A mapping embodiment may have any type of implementation, such as, for example, software, hardware, firmware or any combination thereof.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

In some embodiments, further steps may be performed to determine whether the movements had the desired effect, and if the desired effect is not achieved, to make further adjustments.

For example, Figure 60 shows a flowchart of steps that may be employed in providing mechanical iris.

A first image is captured at a step __. At a step __, the system processes the image and generates a measure of the amount of light transmitted by the mechanical iris.

At a step, the system determines whether the amount of light transmitted by the mechanical iris is the same as the desired amount, and if not, the system determines a difference between the two amounts at a step __. At a step, the system compares the difference to a reference magnitude.

If the difference is greater than the reference magnitude, then at a step __, the system identifies one or more movements that could be applied to one or more portions of the optics portion and/or to the sensor portion to compensate for the difference.

That is, one or more movements to cause the amount of light transmitted by the mechanical iris and/or the amount of light received by the sensor elements to be equal to the amount of light that is desired.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

At a step __, data indicative of the compensation and/or the movement used to compensate is stored.

Although the iris in Figures 58A-58C is shown having one portion (e.g., one mask), and the iris in Figures 58D-58F is shown having two portions (e.g., two masks), it should be understood that an iris may have any configuration. For example, some other embodiments employ an iris having more than two portions (e.g., more than two masks).

Moreover, although the iris is shown disposed between the lens and the sensor portion, the iris or portions thereof may be disposed in any position or positions suitable to control or help control the amount of light transmitted to one or more portions of one or more optics portions and/or one or more portions of one or more sensor portions. In addition, although the two masks in Figures 55D-55F are shown disposed adjacent to one another, it should be understood that portions of a mechanical iris may or may not be disposed adjacent to one another.

Hyperspectral imaging

In some embodiments, one or more filters are employed in the optical path of one or more of the camera channels. In such embodiments, it may be desirable to have the ability to change and/or move one or more filters into, within, and/or out of an optical path. The positioning system may be used to introduce movement to change and/or move one or more filters into, within and/or out of an optical path.

In some embodiments, one or more filters are employed in the optical path of one or more of the camera channels. In such embodiments, it may be desirable to have the ability to change one or more of the filtering characteristics of a filter in an optical path.

To this effect, it may be advantageous to employ a filter that is adapted to provide different sets of filtering characteristics.

Figures 61A-61C show a portion of a digital camera subsystem that includes an optics portion 290A having a hyperspectral filter in accordance with one embodiment of aspects of the present invention. The hyperspectral filter is adapted to provide different sets of filtering characteristics. The hyperspectral filter defines one or more filter portions, e.g., filter portions. Each filter portions provides one or more filtering characteristics different than the filtering characteristics provided by one, some or all of the other filter portions. For example, the first filter portion may transmit only green light, the second filter portion may transmit only red light and the third filter portion may transmit only blue light. The filter may further define one or more transition regions that separate the adjacent filter portions. The transition regions may be discrete (e.g., abrupt) transition regions, continuous (e.g., gradual) transition regions and/or any combination thereof.

The filter and filter portions may have any shape. In this embodiment, for example, the filter is cylindrical and each filter portion is a wedge shaped portion of the overall filter.

The filter may be positioned anywhere, for example, between a lens and a sensor portion 292A.

In this embodiment, however, only one of the filter portions is positioned in the optical path at any given time.

The positioning system may be used to introduce movement to one or more portions of the optics portion and/or to move the sensor portion so as to insert a filter portion into the optical path, move a filter portion within the optical path, and/or remove a filter portion from the optical path and/or any combination thereof. The movement may be movement in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

For example, Figure 61A shows the lens, the filter and the sensor portion in a first relative positioning. In such positioning, the first filter portion is in the optical path (e.g., in register with the lens and the sensor portion). The second and third filters are out of the optical path (e.g., out of register with the lens and the sensor portion).

Figure 61B shows the lens, the filter and the sensor portion in a second relative positioning. In such positioning, the second filter portion is in the optical path (e.g., in register with the lens and the sensor portion). The first and third filters are out of the optical path (e.g., out of register with the lens and the sensor portion).

Figure 61C shows the lens, the filter and the sensor portion in a third relative positioning. In such positioning, the third filter portion is in the optical path (e.g., in register with the lens and the sensor portion). The first and second filters are out of the optical path (e.g., out of register with the lens and the sensor portion).

In some embodiments, a digital camera subsystem includes an optics portion 290A having a filter in accordance with any other embodiments of any aspects of the present invention. Notably, in these embodiments, the filter may be any filter now known or later developed.

Figure 62A shows a flowchart of steps that may be employed in association with the filter according to one embodiment of the present invention.

A first image is captured at a step _____. In some embodiments, the first image may itself provide the desired filter effect.

At a step ___, the system identifies one or more movements to provide or help provide the desired hyperspectral imaging.

The one or more movements may be movement in the x direction, y direction, z direction, tilting, rotation and/or combinations thereof.

The one or movements may be movements to be applied to the filter and/or any other portions of the optic portion and/or movement of the sensor portion).

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

A second image is captured at a step __.

At a step __, the system combines the images to provided or help provide the desired hyperspectral imaging.

In some embodiments, the one or more portions of the first image may be combined with one or more portions of one or more other images (filtered or unfiltered) to provide or help provide the desired effect, as indicated at a step __.

Figure 62B is a block diagram representation of one embodiment of a combiner for generating a hyperspectral image.

Figure 63 shows a flowchart of steps that may be employed in providing hyperspectral imaging, according to another embodiment of the present invention.

Figure 64 shows some embodiments of filters that may be employed in hyperspectral imaging.

Figures 65A-65D show a portion of a digital camera subsystem that includes an optics portion 290A having a hyperspectral filter in accordance with another embodiment of aspects of the present invention.

Figures 66A-66D show a portion of a digital camera subsystem that includes an optics portion 290A having a hyperspectral filter in accordance with another embodiment of aspects of the present invention.

Figures 66E-66F show a portion of a digital camera subsystem that includes an optics portion 290A having a hyperspectral filter in accordance with another embodiment of aspects of the present invention.

Figures 67A-67D show a portion of a digital camera subsystem that includes an optics portion 290A having a hyperspectral filter in accordance with another embodiment of aspects of the present invention.

Increase/decrease parallax

If the digital camera subsystem has more than one camera channel, the camera channels will necessarily be spatially offset from one another (albeit, potentially by a small distance). This spatial offset can introduce a parallax between the camera channels, e.g., an apparent change in position of an object as a result of changing the position from which the object is viewed.

Figures 68A-68E show an example of parallax in a digital camera subsystem. More particularly, Figure 68A shows an object (i.e., a lightning bolt) and a digital camera subsystem having two camera channels spatially offset by a distance. The first camera channel has a sensor and a first field of view centered about a first axis. The second camera channel has a sensor and a second field of view that is centered about a second axis and spatially offset from the first field of view. The offset between the fields of view causes the position of the object within the first field of view to differ from the position of the object within the second field of view.

Figure 68B is a representation of an image of the object, as viewed by the first camera channel, striking the sensor in the first camera channel. The sensor has a plurality of sensor elements shown schematically as circles, for example, as indicated at ____.

Figure 68C is a representation of an image of the object, as viewed by the second camera channel, striking the sensor in the second camera channel. The sensor has a plurality of sensor elements shown schematically as circles, for example, as indicated at ____.

Figure 68D shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel. The difference between the position of the object in the first image and the position of the object in the second image is indicated at _____. In this embodiment, the parallax is in the x direction.

Figure 68E shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel if such parallax is eliminated.

Figures 68F-68H show an example of parallax in the y direction. Figure 68I shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel if such parallax is eliminated.

Figures 68J-68L show an example of parallax having an x component and a y component. Figure 68M shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel if such parallax is eliminated.

In some embodiments, it may be advantageous to increase and/or decrease the amount of parallax that is introduced between camera channels. For example, it may be advantageous to decrease the parallax so as to reduce differences between the images provided by two or more camera channels. It may be advantageous to increase the parallax, for example, if providing a 3-D effect and/or if determining an estimate of a distance to an object within the field of view.

In some embodiments, signal processing is used to increase (e.g., exaggerate the effects of) and/or decrease (e.g., compensate for the effects of) the parallax.

Movement of one or more portions of the optics portion and/or movement of the sensor portion may also be used to increase and/or decrease parallax. The movement may be, for example, movement(s) in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

The positioning system may be employed in providing such movement.

Figures 68N-68R show an example of the effect of using movement to help decrease parallax in the digital camera subsystem. More particularly, Figure 68N shows an object (i.e., a lightning bolt) and a digital camera subsystem having two camera channels spatially offset by a distance. The first camera channel has a sensor and a first field of view centered about a first axis. The second camera channel has a sensor and a second field of view that is centered about a second axis and spatially offset from the first field of view. The offset between the fields of view causes the position of the object within the first field of view to differ from the position of the object within the second field of view.

Figure 68O is a representation of an image of the object, as viewed by the first camera channel, striking the sensor in the first camera channel. The sensor has a plurality of sensor elements shown schematically as circles, for example, as indicated at ____.

Figure 68P is a representation of an image of the object, as viewed by the second camera channel, striking the sensor in the second camera channel. The sensor has a plurality of sensor elements shown schematically as circles, for example, as indicated at ____.

Figure 68Q shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel. The difference between the position of the object in the first image and the position of the object in the second image is indicated at _____. In this embodiment, the parallax is in the x direction.

Figure 68R shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel if such parallax is eliminated.

Figures 68S-56X show an example of the effect of using movement to help increase parallax in the digital camera subsystem. More particularly, Figure 68S shows an object (i.e., a lightning bolt) and a digital camera subsystem having two camera channels spatially offset by a distance. The first camera channel has a sensor and a first field of view centered about a first axis. The second camera channel has a sensor and a second field of view that is centered about a second axis and spatially offset from the first field of view. The offset between the fields of view causes the position of the object within the first field of view to differ from the position of the object within the second field of view.

Figure 68R is a representation of an image of the object, as viewed by the first camera channel, striking the sensor in the first camera channel. The sensor has a plurality of sensor elements shown schematically as circles, for example, as indicated at ____.

Figure 68P is a representation of an image of the object, as viewed by the second camera channel, striking the sensor in the second camera channel. The sensor has a plurality of sensor elements shown schematically as circles, for example, as indicated at ____.

Figure 68Q shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel. The difference between the position of the object in the first image and the position of the object in the second image is indicated at _____. In this embodiment, the parallax is in the x direction.

Figure 68R shows the image viewed by the first camera channel superimposed with the image viewed by the second camera channel if such parallax is eliminated.

Figure 70 shows a flowchart of steps that may be employed to increase and/or decrease parallax, according to one embodiment of the present invention.

At a step __, the system receives a signal indicative of a desired amount of parallax.

At a step __, the system identifies one or more movements to provide or help provide the desired amount of parallax. The one or movements may be movements to be applied to one or more portions of the optic portion and/or movement of the sensor portion. The one or more movement may be movement in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

In some embodiments, further steps may be performed to determine whether the movements had the desired effect, and if the desired effect is not achieved, to make further adjustments.

For example, Figures 71A-71B, shows a flowchart employed in another embodiment of the present invention.

Referring to Figures 71A-71B, images are captured at a step __, and at a step __, the images are processed to determine the amount of parallax, which is compared to the desired amount of parallax to determine the difference therebetween.

At a step __, the system compares the difference to a reference magnitude, and if the difference is less than or equal to the reference magnitude, then at step __, processing stops.

If the difference is greater than the reference magnitude, then processing returns to step __, where the system identifies one or more movements that could be applied to one or more portions of the optics portion and/or to the sensor portion to compensate for the difference, at least in part. At step __, the system initiates one, some or all of the one or more movements identified at step __. Images are captured at step __, and at a step __, the images are processed to determine the amount of parallax, which is compared to the desired amount of parallax to determine the difference therebetween. If the difference

is less than or equal to the reference magnitude, then processing stops at step ____.

Otherwise, steps ____ - ____ are repeated until the difference between the parallax and the desired parallax is less than or equal to the reference magnitude.

Range finding

In some embodiments, it is desirable to be able to generate an estimate of the distance to an object within the field of view. This capability is sometimes referred to as “range finding”.

One method for determining an estimate of a distance to an object is to employ parallax.

In this regard, it may be advantageous to have the ability to provide movement of one or more portions of the optic portion and/or movement of the sensor portion to increase the amount of parallax. Increasing the amount of parallax may help improve the accuracy of the estimate.

The movement may be movement in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

The positioning system may be employed in providing such movement.

Figure 72 shows a flowchart of steps that may be employed in generating an estimate of a distance to an object, or portion thereof, according to one embodiment of the present invention.

At a step ____, the system receives a signal indicative of a desired amount of parallax and/or one or movements

At a step ____, the system identifies one or more movements to provide or help provide the desired amount of parallax.

At a step ____, the system initiates one, some or all of the one or more movements identified at step ____.

At a step ____, an image is captured from each camera channel to be used in generating the estimate of the distance to the object (or portion thereof). For example, if two camera channels are to be used in generating the estimate, then an image is captured from the first camera channel and an image is captured from the second camera channel.

In some embodiments, at a step __, the system receives one or more signals indicative of the position of the object in the images or determines the position of the object within each image. For example, if two camera channels are to be used in generating the estimate of the distance to the object, the system may receive one or more signals indicative of the position of the object in the image from the first camera channel and the position of the object in the image from the second camera channel. In some other embodiments, the system determines the position of the object within each image, e.g., the position of the object within the image for the first channel and the position of the object within the image for the second channel.

At a step __, the system generates a signal indicative of the difference between the positions in the images. For example, if two camera channels are being used, the system generates a signal indicative of the difference between the position of the object in the image for the first camera channel and the position of the object in the image for the second camera channel.

At a step __, the system generates an estimate of the distance to the object (or portion thereof) based at least in part on (1) the signal indicative of the difference between the position of the object in the image for the first camera channel and the position of the object in the image for the second camera channel (2) the signal indicative of the relative positioning of the first camera channel and the second camera channel and (3) data indicative of a correlation between (a) the difference between the position of the object in the image for the first camera channel and the position of the object in the image for second camera channel, (b) the relative positioning of the first camera channel and the second camera channel and (c) the distance to an object.

Figure 73 is a block diagram showing a portion of one embodiment the range finder. In this embodiment, the range finder includes a differencer and an estimator. The differencer has one or more inputs that receive one or more signals indicative of the position of the object in a first image and the position of the object in a second image. The differencer further includes one or more outputs that supply a difference signal, Difference. The difference signal, Difference, is indicative of the difference between the position of the object in the first image and the position of the object in the second image.

The difference signal is supplied to the estimator, which also receives a signal indicative of the relative positioning between the camera channel that provided the first image and the camera channel that provided the second image. In response, the estimator provides an output signal, estimate, indicate of an estimate of the distance to the object (or portion thereof).

In order to accomplish this, the estimator includes data indicative of the relationship between (a) the difference between the position of the object in the first image and the position of the object in the second image, (b) the relative positioning of the camera channel generating the first image and the camera channel generating the second image and (c) the distance to an object.

This data may be in any form, including for example, but not limited to, a mapping of a relationship between inputs (e.g., (a) the difference between the position of the object in the first image and the position of the object in the second image and (b) the relative positioning of the camera channel generating the first image and the camera channel generating the second image) and the output (e.g., an estimate of the distance to the object).

The mapping may have any of various forms known to those skilled in the art, including but not limited to a formula and/or a look-up table. The mapping may be implemented in hardware, software, firmware or any combination thereof.

The mapping is preferably generated "off-line" by placing an object at a known distance from the digital camera subsystem, capturing two or more images with two or more camera channels having a known relative positioning and determining the difference between the position of the object in the image from the first camera channel and the position of the object in the image from the second camera channel.

This above process may be repeated so as to cover different combinations of known distance to the object and relative positioning of the camera channels. It may be advantageous to cover an entire range of interest (e.g. known distances and relative positioning), however, as explained below, it is generally not necessary to cover every conceivable combination. Each combination of known distance to object, relative positioning of camera channels and difference between the position of the object in the

image from the first camera channel and the position of the object in the image from the second camera channel represents one data point in the overall input output relation.

The data points may be used to create a look-up table that provides, for each of a plurality of combinations of input magnitudes, an associated output. Or, instead of a look-up table, the data points may be input to a statistical package to produce a formula for calculating the output based on the inputs. The formula can typically provide an appropriate output for any input combination in the sensor input range of interest, including combinations for which data points were not generated.

A look-up table embodiment may employ interpolation to determine an appropriate output for any input combination not in the look-up table.

The differencer may be any type of differencer that is adapted to provide one or more difference signals indicative of the difference between the position of the object in the first image and the position of the object in the second image. In this embodiment, for example, the differencer comprises an absolute value subtractor that generates a difference signal equal to the absolute value of the difference between the position of the object in the first image and the position of the object in the second image. In some other embodiments, the differencer may be a ratiometric type of differencer that generates a ratiometric difference signal indicative of the difference between the position of the object in the first image and the position of the object in the second image.

The signal indicative of the relative position of the camera channels may have any form. For example, the signal may be in the form of a single signal that is directly indicative of the difference in position between the camera channels. The signal may also be in the form of a plurality of signals, for example, two or more signals each of which indicates the position of a respective one of the camera channels such that the plurality of signals are indirectly indicative of the relative position of the camera channels.

Although the portion of range finder is shown having a differencer preceding the estimator, the range finder is not limited to such. For example, a differencer may be embodied within the estimator and/or a difference signal may be provided or generated in some other way. In some embodiments, the estimator may be responsive to absolute magnitudes rather than difference signals.

Furthermore, while the disclosed embodiment includes three inputs and one output, the range finder is not limited to such. The range finder may be employed with any number of inputs and outputs.

Range finding may also be carried out using only one camera channel. For example, one of the camera channels may be provided with a first view of an object and an image may be captured. Thereafter, one or more movements may be applied to one or more portions of the camera channel so as to provide the camera channel with a second view of the object (the second view being different than the first view). Such movements may be provided by the positioning system. A second image may be captured with the second view of the object. The first and second images may thereafter be processed by the range finder using the steps set forth above to generate an estimate of a distance to the object (or portion thereof).

Figure 74 is a block diagram representation of a locator portion of the range finder.

3D imaging

Referring to Figures 75A-75D, in some embodiments, it is desired to be able to produce images for use in providing one or more 3D effects, sometimes referred to herein as “3D imaging”.

One type of 3D imaging is referred to as stereovision. Stereovision is based, at least in part, on the ability to provide two views of an object, e.g., one to be provided to the right eye, one to be provided to the left eye. In some embodiment, the views are combined into a single stereo image. In one embodiment, for example, the view for the right eye may be blue and the view for the left eye may be red, in which case, a person wearing appropriate eyewear (e.g., blue eyepiece in front of left eye, red eyepiece in front of right eye) will see the appropriate view in the appropriate eye (i.e., right view in the right eye and the left view in the left eye). In another embodiment, the view for the right eye may be polarized in a first direction(s) and the view for the left eye may be polarized in a second direction(s) different than the first, in which case, a person wearing appropriate eyewear (e.g., eyepiece polarized in first direction(s) in front of left eye, eyepiece polarized in second direction(s) in front of left eye) will see the appropriate

view in the appropriate eye (i.e., right view in the right eye and the left view in the left eye).

Referring to Figure 76, another type of 3D imaging is referred to as 3D graphics, which is based, at least in part, on the ability to provide an image with an appearance of depth.

It is desirable to employ parallax when producing images for use in providing 3D effects.

Increasing the amount of parallax may help improve one or more characteristics of the 3D imaging.

In this regard, it is advantageous to have the ability to provide movement of one or more portions of the optic portion and/or movement of the sensor portion to increase the amount of parallax.

The movement may be movement in the x direction, y direction, z direction, tilting, rotation and/or any combination thereof.

The positioning system may be employed in providing such movement.

Figure 77A-77B shows a flowchart of steps that may be employed in providing 3D imaging, according to one embodiment of the present invention.

At a step __, the system receives a signal indicative of a desired amount of parallax and/or one or movements.

At a step __, the system identifies one or more movements to provide or help provide the desired amount of parallax.

At a step __, the system initiates one, some or all of the one or more movements identified at step ____.

At a step __, the system generates one or more images with the desired 3D effect.

At a step __, an image is captured from each camera channel to be used in the 3D imaging. For example, if two camera channels are to be used in the 3D imaging, then an image is captured from the first camera channel and an image is captured from the second camera channel.

At a step __, the system determines whether stereovision is desired or whether 3D graphics is desired. If stereovision is desired, then at a step __, the image captured from the first camera channel and the image captured from the second camera channel are each

supplied to a formatter, which generates two images, one suitable to be provided to one eye and one suitable to be provided to the other eye. For example, in one embodiment, for example, the view for the right eye may be blue and the view for the left eye may be red, in which case, a person wearing appropriate eyewear will see the appropriate view in the appropriate eye (i.e., right view in the right eye and the left view in the left eye). In another embodiment, the view for the right eye may be polarized in a first direction(s) and the view for the left eye may be polarized in a second direction(s) different than the first, in which case, a person wearing appropriate eyewear will see the appropriate view in the appropriate eye (i.e., right view in the right eye and the left view in the left eye).

The two images may be combined into a single stereo image at a step ____.

If 3D graphics is desired instead of stereovision, then at a step ____, the system characterizes the images using one or more characterization criteria. In one embodiment, for example, the characterization criteria includes identifying one or more features (e.g., edges) in the images and an estimate of the distance to one or more portions of such features. A range finder as set forth above may be used to generate estimates of distances to features or portions thereof. At a step ____, the system generates a 3D graphical image having the appearance of depth, at least in part, based, at least in part, on (1) the characterization data and (2) 3D rendering criteria.

The characterization criteria and the 3D graphical criteria may be predetermined, adaptively determined, and or combinations thereof.

It should be understood that 3D imaging may also be carried out using only one camera channel. For example, one of the camera channels may be provided with a first view of an object and an image may be captured. Thereafter, one or more movements may be applied to one or more portions of the camera channel so as to provide the camera channel with a second view of the object (the second view being different than the first view). Such movements may be provided by the positioning system. A second image may be captured with the second view of the object. The first and second images may thereafter be processed by the 3D imager using the steps set forth above to generate an estimate of a distance to the object (or portion thereof).

Figure 78 is a block diagram representation of one embodiment for generating an image with a 3D effect.

Figure 79 is a block diagram representation of one embodiment for generating an image with 3D graphics.

Image discrimination

Figure 80 shows a flowchart of steps that may be employed in providing image discrimination, according to one embodiment of the present invention.

Figures 81A-81B shows a flowchart of steps that may be employed in providing image discrimination, according to one embodiment of the present invention.

Auto focus

Figure 82 shows a flowchart of steps that may be employed in providing auto focus, according to one embodiment of the present invention.

Position sensors

In some embodiments, it is advantageous to incorporate position sensors within the positioning system, for example, to help the positioning system provide the desired movements with a desired degree of accuracy.

Some of the possible advantages of the positioning system are : 1) higher resolution image without increasing the number of pixels; 2), eliminate (or reduce) a need for a more complex and costly zoom lens assembly; 3) no requirement to move in the outward direction, thus increasing the thickness of the image capturing device; 4) maintains the same light sensitivity (F-stop) whereas a traditional zoom lens reduces sensitivity (increases F-stop) when in the zoom mode.

Notably, although various features, attributes and advantages of various embodiments have been described above, it should be understood that such features, attributes and advantages are not required in every embodiment of the present invention and thus need not be present in every embodiment of the present invention.

It should also be understood that there are many different types of digital cameras. The present inventions are not limited to use in association with any particular type of digital camera.

For example, as stated above, a digital camera subsystem may have one or more camera channels. Thus, although the digital camera subsystem 210 is shown having four camera channels, it should be understood that digital camera subsystems are not limited to such. Rather, a digital camera subsystem may have any number of camera channels, for example, but not limited to one camera channel, two camera channels, three camera channels, four camera, or more than four camera channels.

Figure 83A is a cross sectional view of another embodiment of the digital camera subsystem and a circuit board of the digital camera on which the digital camera subsystem may be mounted. In this embodiment, the digital camera subsystem includes a stack-up having a first integrated circuit die disposed superjacent the circuit board, a spacer disposed superjacent the integrated circuit die and a positioner disposed superjacent the spacer. A plurality of optics portions 290A-290D are seated in and/or affixed to the positioner.

Figure 83E is a plan view of the upper side (i.e., the major outer surface facing the spacer) of one embodiment of the first integrated circuit die. Figure 83F shows a cross section view of the first integrated circuit die. In this embodiment, the first integrated circuit die includes a plurality of portions. A first portion comprises sensor portion 292A. A second portion comprises sensor portion 292B. A third portion comprises 292C. A fourth portion comprises 292D. One or more other portions, e.g., 1000A-1000E, of the first integrated circuit die comprises one or more portions of the image processor 270. The first integrated circuit die further includes a plurality of electrically conductive pads disposed in one or more pad regions, e.g., 1002A-1002D (e.g., for example on one two three or four sides). Some of the pads are used in supplying one or more output signals from the image processor to the circuit board of the digital camera. Some of the other pads are used to provide control signals to a second integrated circuit that is mounted on the underside of the positioner. The second integrated circuit comprises the drivers of the controller.

The spacer and/or positioner, in one embodiment, collectively define one or more passages for transmission of light. Each of the passages is associated with a respective one of the camera channels and provides for transmission of light between the optics

portion and the sensor portion of such camera channel while limiting, minimizing and/or eliminating light “cross talk” from the other camera channels.

Figure 83C shows a plan view of the underside of the positioner (i.e., the major surface facing toward the spacer) and the second integrated circuit die mounted thereon. As stated above, the second integrated circuit comprises the drivers of the controller, which are used to drive the actuators portions of the positioner. A plurality of electrically conductive traces (some of which are shown) connect the outputs of the drivers to the respective actuator portions of the positioner. Although shown on the surface, it should be understood that one, some or all of such traces may be disposed within the positioner so as not to reside on the outer surface thereof.

A first plurality of electrical conductors pass through the spacer and and/or along the outside of the spacer to electrically connect some of the pads on the first integrated circuit to pads on the second integrated circuit die (driver bank integrated circuit).

A second plurality of electrical conductors connect the pads that supply the one or more outputs from the image processor to one or more pads on the circuit board for the digital camera.

The integrated circuit die, the spacer, and the positioner are bonded to the circuit board, the substrate, the integrated circuit die and the spacer, respectively, using any suitable method or methods, for example, but not limited to adhesive.

Although shown as two separate parts, it should be understood that the positioner and the spacer could be a single integral component, for example, fabricated as a single integral part or fabricated separately and thereafter joined together.

Figure 83B is a cross sectional view of another embodiment of the digital camera subsystem and a circuit board of the digital camera on which the digital camera subsystem may be mounted. In this embodiment, the stack up further includes a back end device disposed between the circuit board and the first integrated circuit die. The back end device may comprise one or more integrated circuits including for example, one or more portions of the post processor and/or additional memory for the digital camera subsystem.

Figures 84A-84C, 85A-85C, 87A-87B, 89, 92D, 93, 95A-95C, 107A-107B, 108A-108B and 109A-109B are representations of some other optics configurations that may be employed in one or more of the camera channels. It should be understood that any of the features and/or methods shown and/or employed in any of these configurations may also be used in any of the other configurations and/or in any other embodiments or aspects disclosed herein.

Figures 86A-86B, 87A-87B, 88, 101A-101F and 102A-102D are representations of some other configurations of the camera channels that may be employed in the digital camera subsystem. It should be understood that any of the features and/or methods shown and/or employed in any of these configurations may also be used in any of the other configurations and/or in any other embodiments or aspects disclosed herein.

Figures 86A-86B, 87A-87B, 88, 99, 100, 103A-103D and 104A-104D are representations of some other sensor configurations that may be employed in one or more of the camera channels. It should be understood that any of the features and/or methods shown and/or employed in any of these configurations may also be used in any of the other configurations and/or in any other embodiments or aspects disclosed herein. It should also be understood that the camera channels may be employed in any desired number, for example, one, two or more. Further examples include 4 array/lenses: red, blue, green, emerald (for color enhancement), 4 array/lenses: red, blue, green, infrared (for low light conditions) and 8 array/lenses: double the above configurations for additional pixel count and image quality.

Figures 85A-85E, 86A-86B, 87A-87B, 88, 91, 99, 100, 103A-103D and 104A-104D, 105 and 106 are representations of some other configurations that may be employed in association with the processor. It should be understood that any of the features and/or methods shown and/or employed in any of these configurations may also be used in any of the other configurations and/or in any other embodiments or aspects disclosed herein.

For example, Figure 84A is a cross sectional view of another embodiment of an optics portion mounted in another embodiment of the positioner 310. In this embodiment, the optics portion includes a lens stack having three lenslets. The positioner 310 has three seats. Each supports and/or helps position a respective one of the lenslets,

at least in part. A first seat defines a mounting position for a first one of the lenslets in the stack (i.e., an outer/lowermost lenslet). A second seat defines a mounting position for a second one of the lenslets (i.e., a center lenslet in the stack). A third seat supports a third lenslet (i.e., outer/uppermost lenslet) in the stack and defines a mounting position or such lenslet.

Figure 84B is a cross sectional view of another embodiment of an optics portion mounted in another embodiment of the positioner 310. In this embodiment, the optics portion includes a lens stack having three lenslets. The positioner has three seats. Each seat supports a respective one of the lenslets in the stack, at least in part.

Figure 84C is a cross sectional view of another embodiment of an optics portion mounted in another embodiment of the positioner 310. In this embodiment, the optics portion includes a lens stack having three lenslets. The positioner has one seat that supports and defines a mounting position for an outer/lowermost lenslet in the stack, which in turn supports and defines mounting positions for the other lenslets (i.e., the center lenslet and the outer/uppermost lenslet) in the stack.

Figure 85A is a digital camera subsystem employing the optics portion and positioner of Figure 84A. The digital camera subsystem is otherwise the same as the digital camera subsystem 210 of Figure 83A.

Figure 85B is a digital camera subsystem employing the optics portion and positioner of Figure 84B. The digital camera subsystem is otherwise the same as the digital camera subsystem 210 of Figure 83A.

Figure 85C is a digital camera subsystem employing the optics portion and positioner of Figure 84C. The digital camera subsystem is otherwise the same as the digital camera subsystem 210 of Figure 83A.

Figures 86A-86B are representations of a digital camera subsystem having three camera channels (i.e., red, green, blue). One or more portions of the processor are disposed on the sensor die. Although the three optics portions are shown mounted in a positioner that does not provide movement thereof, in some alternative embodiments the optics portions may be mounted in a positioner having one or more actuator portions to provide movement thereof.

Figures 87A-87B are representations of a digital camera subsystem having three camera channels (i.e., red, green, blue). Each of the sensor portions comprises a stack of three lenslets. Although the three optics portions are shown mounted in a positioner that does not provide movement thereof, in some alternative embodiments the optics portions may be mounted in a positioner having one or more actuator portions to provide movement thereof.

Figures 88 is a representations of a digital camera subsystem, in exploded view form, having three camera channels (i.e., red, green, blue). Each of the sensor portions comprises a stack of three lenslets, however, stacks with fewer than three lenslets may also be employed. A plurality of pads on an image sensor supply one or more outputs from the processor. A post processor is affixed to rear facing, major outer surface of the image sensor.

Figures 89 is a representation of further embodiments of the optics portions. One embodiment includes a lens (comprising one, two or three lenslets) having a color coating, an autofocus mask with an interference pattern and an IR coating. In some other embodiments, the color coating is replaced by a coating on top of the optics. In another embodiment, the color coating is replaced by dye in the lens. In other embodiments, a filter is employed below the lens or on the sensor portion.

Figure 90 depicts one method for assembling a digital camera subsystem.

Figure 91 depicts a digital camera subsystem with an optional memory affixed thereto.

Figures 92A- 92D are representations of a digital camera subsystem having four camera channels. In this embodiment, the positioner comprises a plate (e.g., a thin plate) defining a plurality of mounting holes. Each mounting hole is adapted to receive a respective one of the optics portions (or portion thereof). In this embodiment, the openings are formed by machining (e.g., boring). However, any suitable methods may be employed. In some other embodiments, for example, the positioner is fabricated as a casting with the mounting holes defined therein (e.g., using a mold with projections that define the openings through the positioner).

In this embodiment, each of the optics portions comprises a lens stack. Each lens stack includes one or more lenses (e.g., two lenses). The stack of lenses may be secured

in the mounting hole in any suitable manner, for example, but not limited to, mechanically (e.g., press fit, physical stops), chemically (e.g., adhesive), electronically (e.g., electronic bonding) and/or any combination thereof. In this embodiment, the mounting holes define a seat to control the depth at which the lens is positioned (e.g., seated) within the positioner. The depth may be different for each lens and is based, at least in part, on the focal length of the lens. For example, if a camera channel is dedicated to a specific color (or band of colors), the lens or lenses for that camera channel may have focal length specifically adapted to the color (or band of colors) to which the camera channel is dedicated. If each camera channels is dedicated to a different color (or band of colors) than the other camera channels, then each of the lenses may have a different focal length, for example, to tailor the lens to the respective sensor portion, and each of the seats have a different depth.

In this embodiment, the positioner is a solid device that may offer a wide range of options for manufacturing and material. Of course, other suitable frames can be readily designed, all of which fall within the inventive scope.

In some embodiments, the lens and positioner may be manufactured as a single molded component and/or the lens may be manufactured with tabs that may be used to form the positioner.

In this embodiment, the positioner does not provide movement of the optic portions however, in some alternative embodiments the optics portions may be mounted in a positioner having one or more actuator portions to provide movement thereof.

Figures 93 is a representations of a digital camera subsystem having optics portions with two lenslets. The lenslets may be color and IR coated and may be press fit into the positioner to form a hermetic seal while helping to eliminate the possibility of outgassing (which might occur if adhesive was used). Alignment may be carried out using IR alignment marks. The optics portions may have different focal lengths from one another. The positioner does not provide movement of the optic portions however, in some alternative embodiments the optics portions may be mounted in a positioner having one or more actuator portions to provide movement thereof.

Figures 95A-95C are representations of further embodiments of optics portions that may be employed in the positioner of Figure 92A-92D. The positioner does not

provide movement of the optic portions however, in some alternative embodiments the optics portions may be mounted in a positioner having one or more actuator portions to provide movement thereof.

Figure 97 is a representation of a digital camera subsystem in the form of a microdisplay with a silicon microphone mounted thereto.

Figure 98 is a representation of a camera system having two digital camera subsystems mounted back to back. One embodiment employs plastic lenses. Another embodiment employs glass lenses.

Figure 99 is a representation of a digital camera subsystem that includes a molded plastic packaging.

Figure 100 is a representation of digital camera subsystem that includes a ceramic packaging.

Figures 101A-101F and 102A-102D are representations of some other configurations of camera channels that may be employed in the digital camera subsystem

Figures 103A-103D are representations of some other sensor and or processor configurations that may be employed in one or more of the camera channels.

Figures 104A-104D are representations of another sensor configurations that may be employed in one or more of the camera channels. In this configurations, there are three sensor portions each of which has a different size than the others.

Figure 105 is a block diagram representation of an image sensor having three sensor portions and a processor coupled thereto

Figure 106 is a block diagram representation of another embodiment of the processor.

Figures 107A-107B are views of an optics portion that is adapted for use in a red camera channel and comprises a stack of three lenslets. Also represented is the light transmitted by the stack.

Figures 108A-108B are views of an optics portion that is adapted for use in a green camera channel and comprises a stack of three lenslets. Also represented is the light transmitted by the stack.

Figures 109A-109B are views of an optics portion that is adapted for use in a blue camera channel and comprises a stack of three lenslets. Also represented is the light transmitted by the stack.

It should also be understood that although the digital camera subsystem 210 is shown employed in a digital camera 200, the present invention is not limited to such. Indeed, the digital camera subsystem 400 and/or any of the methods and/or apparatus that may be employed therein may be used by itself or in any type of device, including for example, but not limited to, still and video cameras, cell phones, other personal communications devices, surveillance equipment, automotive applications, computers, manufacturing and inspection devices, toys, and/or a wide range of other and continuously expanding applications. Moreover, other devices that may employ a digital camera subsystem and/or any of the methods and/or apparatus employed may or may not include the housing, circuit board 310, peripheral user interface 320, power supply 330, electronic image storage media 340 and aperture 380 depicted in Figure 2 (for example, the circuit board may not be unique to the camera function but rather the DCS be an add-on to an existing circuit board, such as in a cell phone) and may or may not employ methods and/or apparatus not shown in Figure 3.

A digital camera may be a stand-alone product or may be imbedded in other appliances, such as cell phones, computers or the myriad of other imaging platforms now available or may be created in the future, such as those that become feasible as a result of this invention.

One or more embodiments of one or more aspects of the present invention may have one or more of the advantages below. A device according to the present invention can have multiple separate arrays on a single image sensor, each with its own lens. The simple geometry of a smaller, multiple arrays allows for a smaller lens (diameter, thickness and focal length), which allows for reduced stack height in the digital camera.

Each array can advantageously be focused on one band of visible spectrum. Among other things, each lens may be tuned for passage of that one specific band of wavelength. Since each lens would therefore not need to pass the entire light spectrum, the number of elements will be reduced, likely to one or two.

Further, due to the focused bandwidth for each lens, each of the lenses may be dyed during the manufacturing process for its respective bandwidth (e.g., red for the array targeting the red band of visible spectrum). Alternatively, a single color filter may be applied across each lens. This process eliminates the traditional color filters (the sheet of individual pixel filters) thereby reducing cost, improving signal strength and eliminating the pixel reduction barrier.

In some embodiments, once the integrated circuit die with the sensor portions (and possibly one or more portions of the processor) have been assembled, the assembly is in the form of a hermetically sealed device. Consequently, such device does not need a "package" and as such, if desired, can be mounted directly to a circuit board which in some embodiments saves part cost and/or manufacturing costs.

As stated above, the method and apparatus of the present invention is not limited to use in digital camera systems but rather may be used in any type of system including but not limited to any type of information system.

In addition, it should be understood that the features disclosed herein can be used in any combination.

Note that, except where otherwise stated, terms such as, for example, "comprises", "has", "includes", and all forms thereof, are considered open-ended, so as not to preclude additional elements and/or features.

Also note that, except where otherwise stated, terms such as, for example, "in response to" and "based on" mean "in response at least to" and "based at least on", respectively, so as not to preclude being responsive to and/or based on, more than one thing.

As used herein identifying, determining, and generating includes identifying, determining, and generating, respectively, in any way, including, but not limited to, computing, accessing stored data and/or mapping (e.g., in a look up table) and/or combinations thereof.

While there have been shown and described various embodiments, it will be understood by those skilled in the art that the present invention is not limited to such embodiments, which have been presented by way of example only, and various changes and modifications may be made without departing from the scope of the invention.

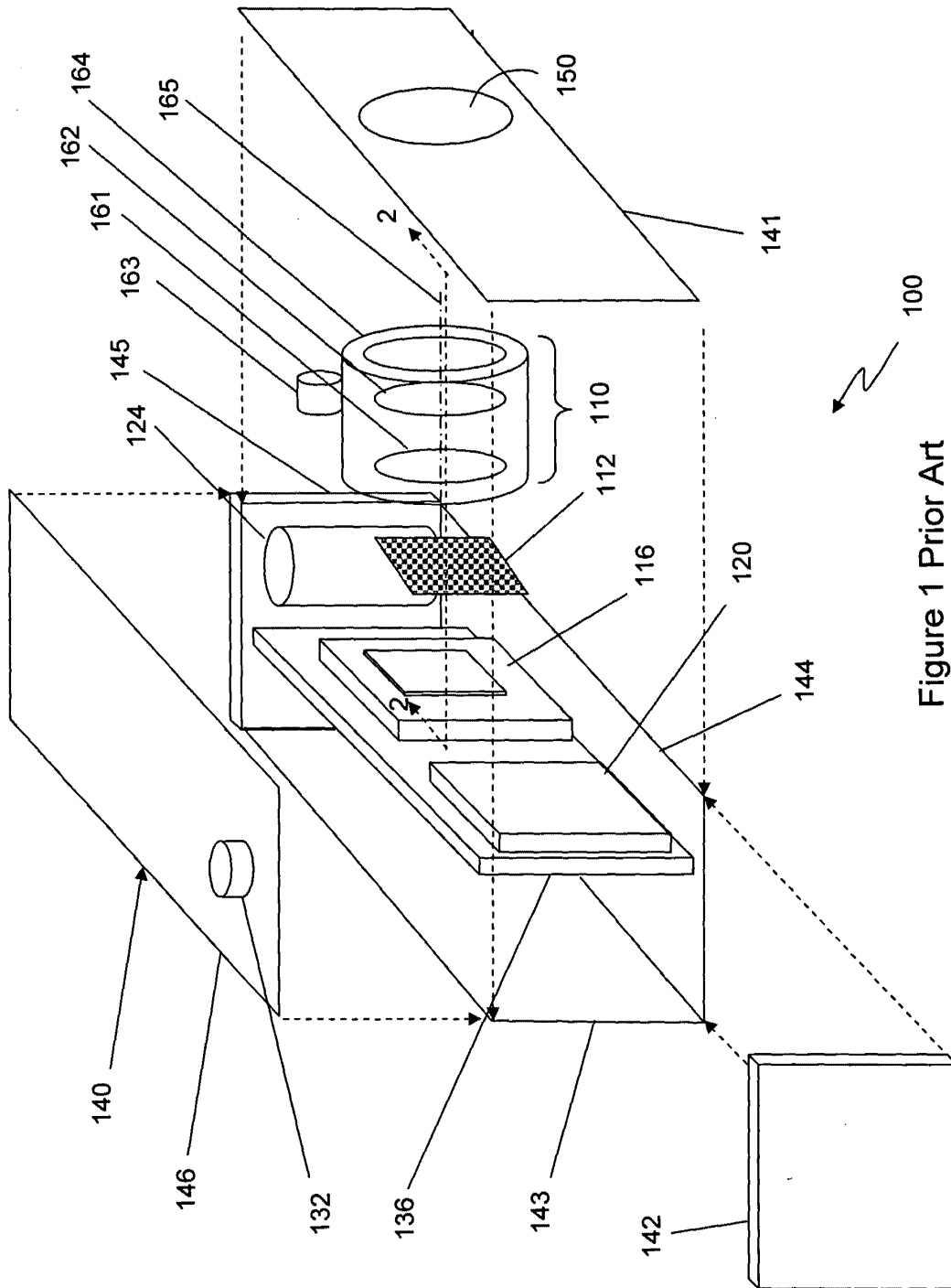


Figure 1 Prior Art

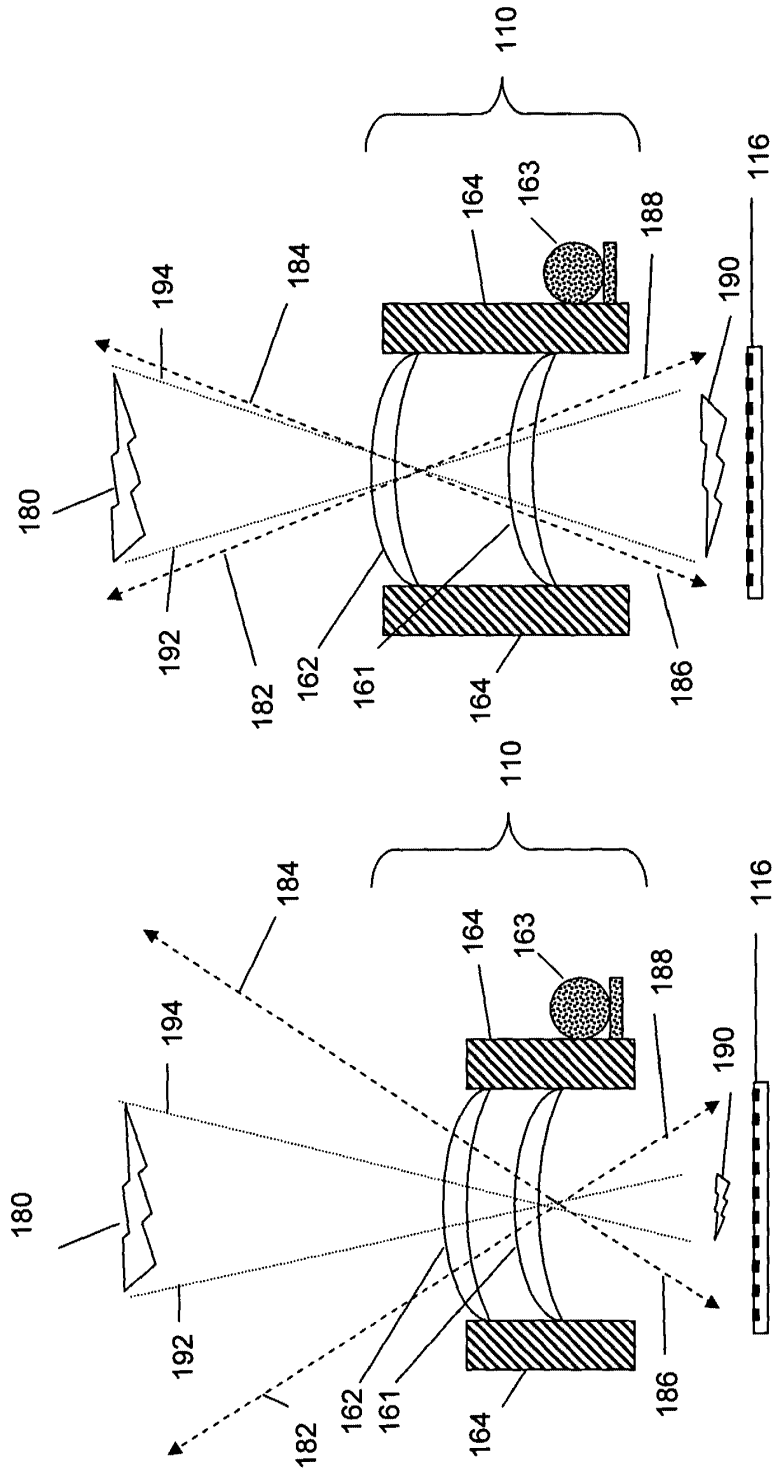


Figure 2B Prior Art

Figure 2A Prior Art

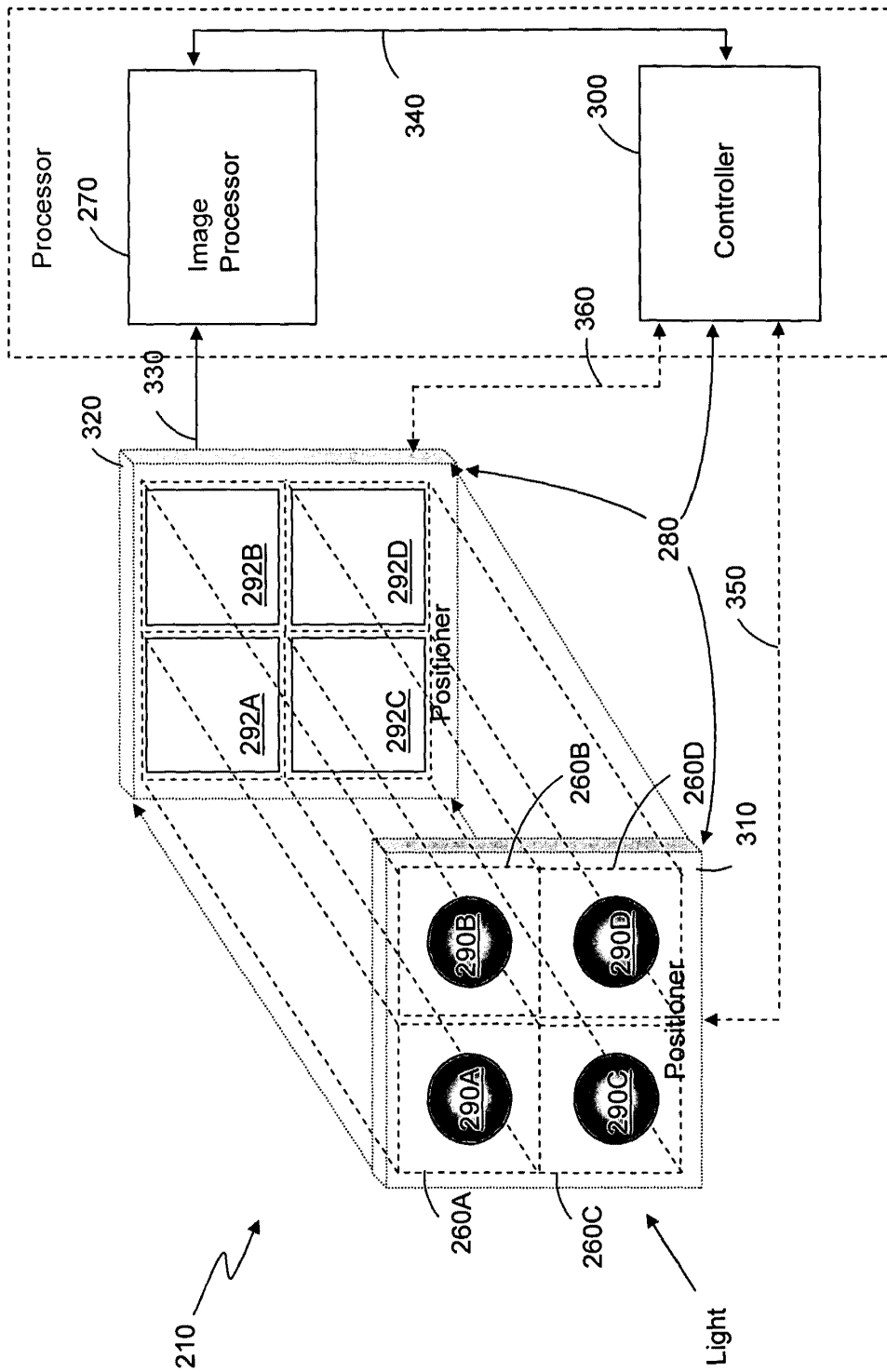


Figure 4A

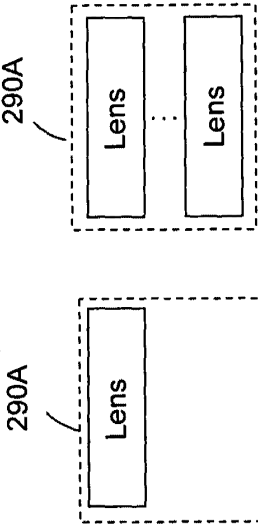


Figure 5A

Figure 5B

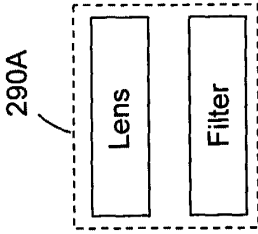


Figure 5C

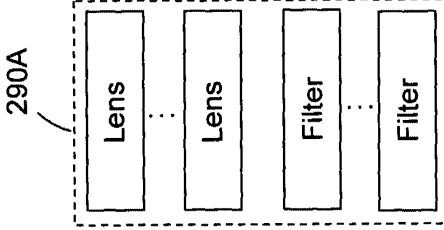


Figure 5D

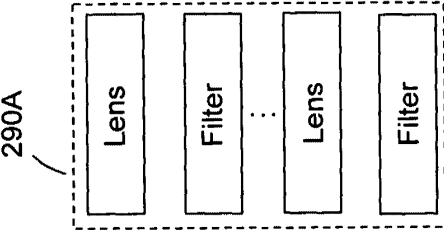


Figure 5E

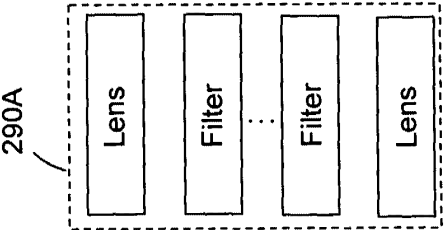


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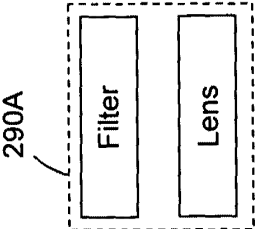


Figure 5G

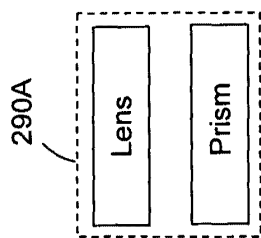


Figure 5H

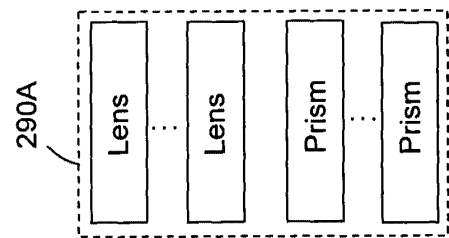


Figure 5I

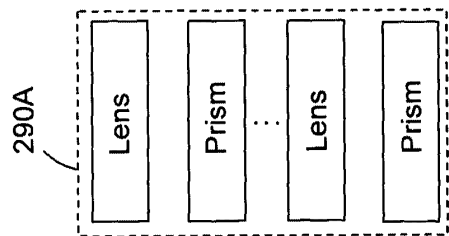


Figure 5J

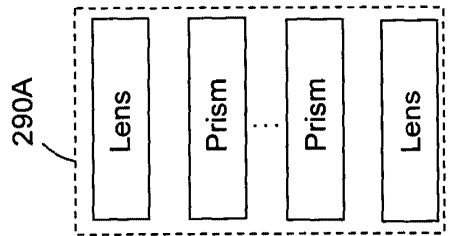


Figure 5K

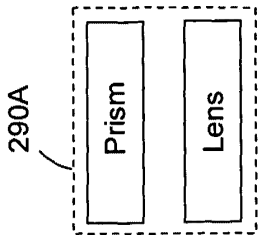


Figure 5L

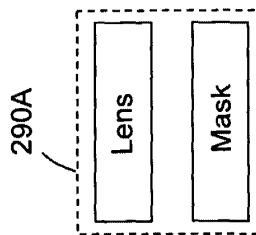


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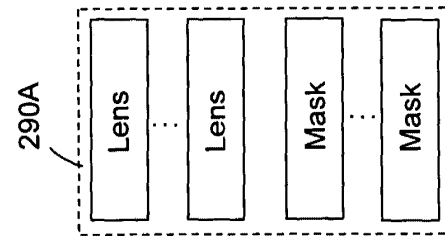


Figure 5N

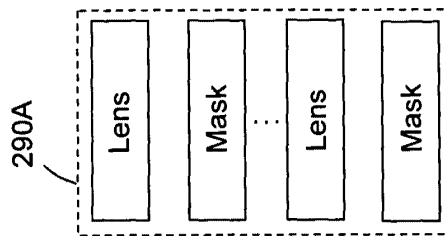


Figure 5O

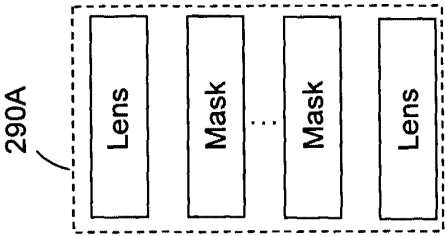


Figure 5P

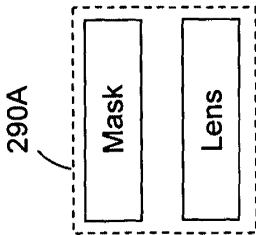


Figure 5Q

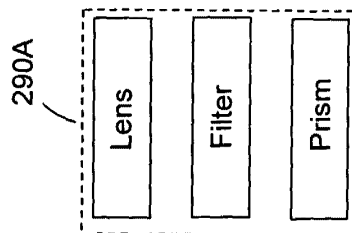


Figure 5R

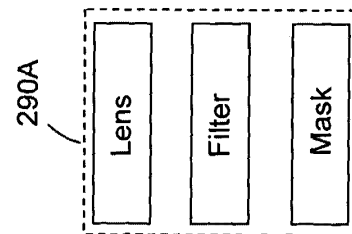


Figure 5S

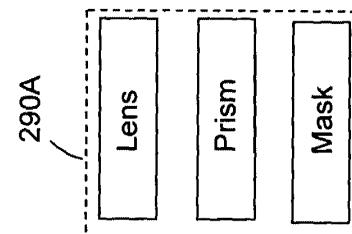


Figure 5T

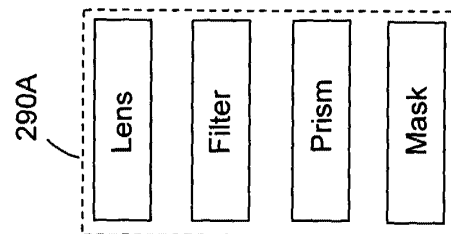


Figure 5U

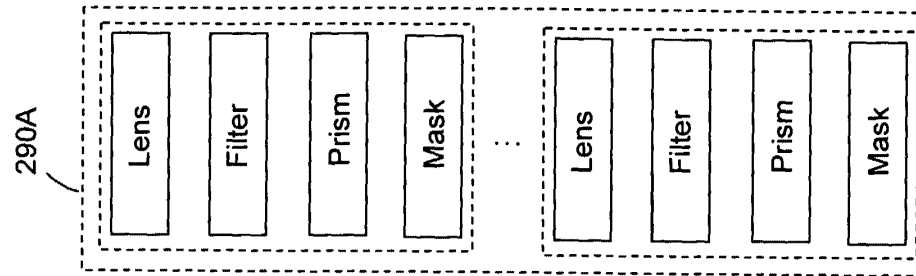
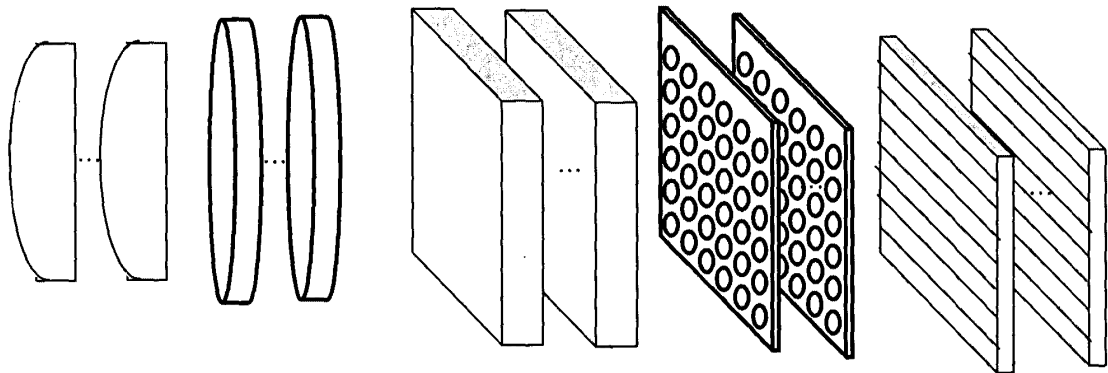


Figure 5V



290A

Figure 5W

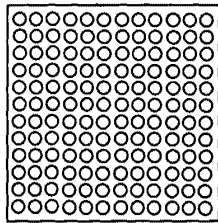


Figure 6A

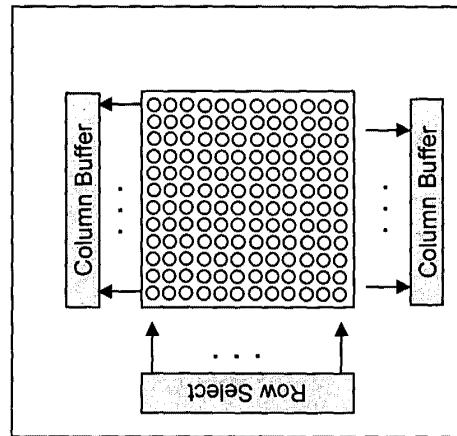


Figure 6B

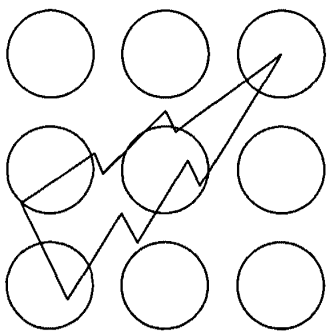


Figure 7A

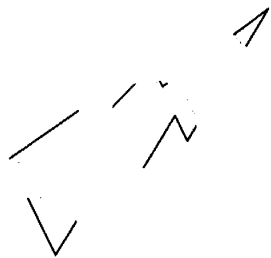


Figure 7B

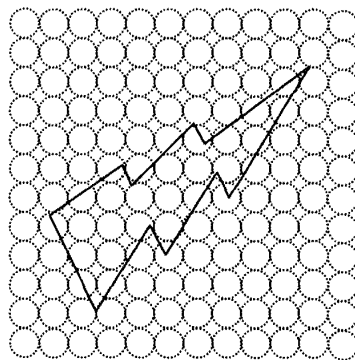


Figure 8A

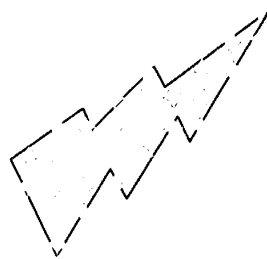


Figure 8B

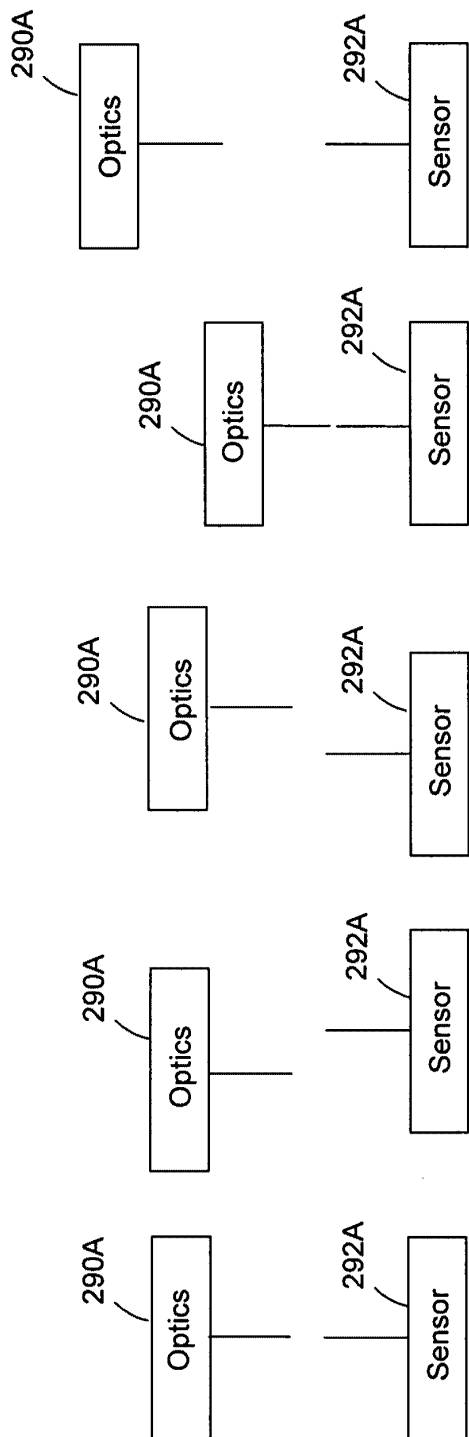


Figure 9A

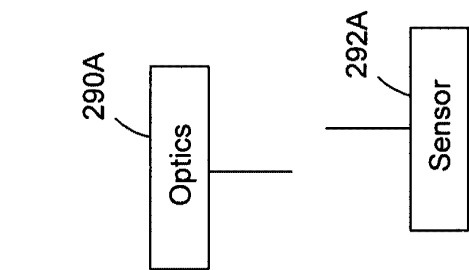


Figure 9B

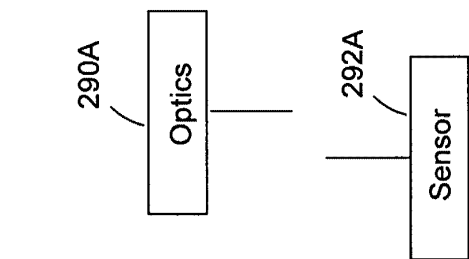


Figure 9C

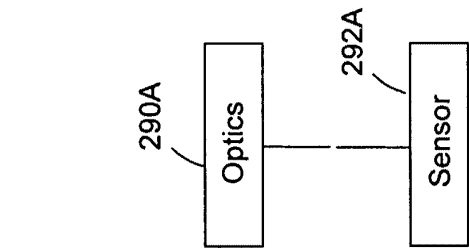


Figure 9D

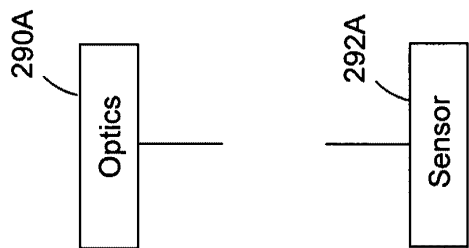


Figure 9E

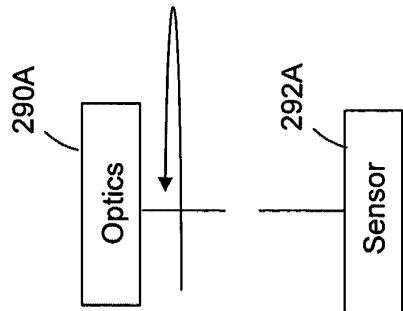


Figure 9F

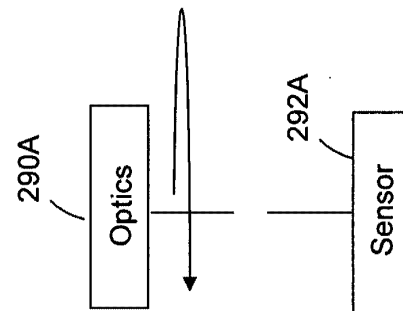


Figure 9G

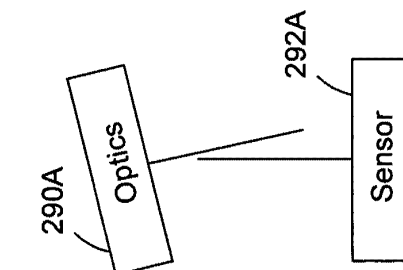


Figure 9H

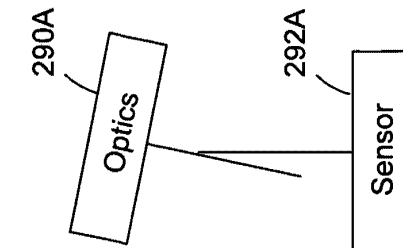
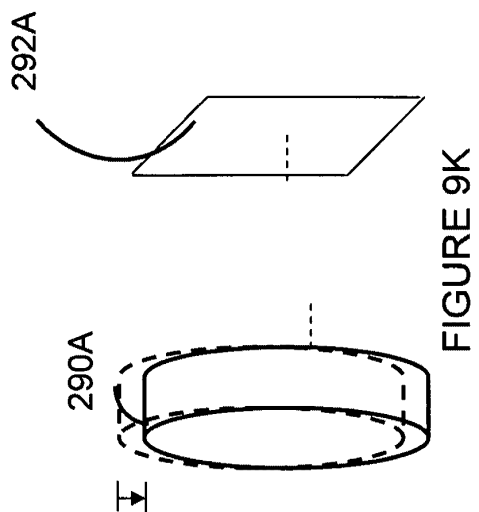
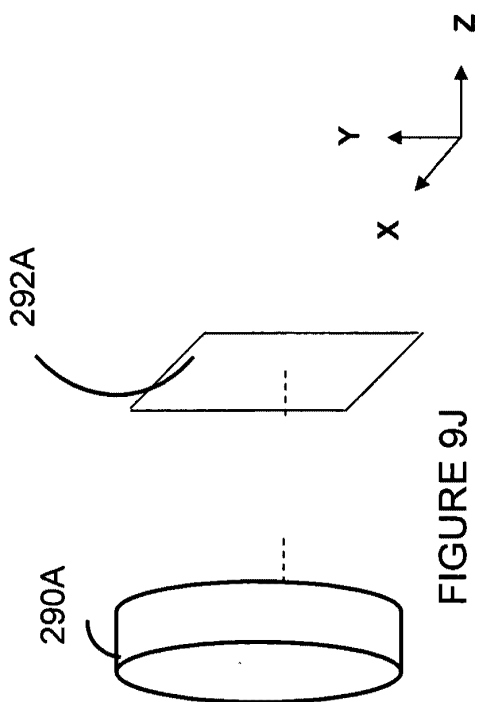
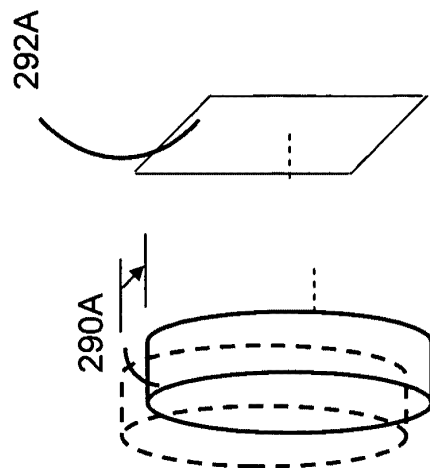
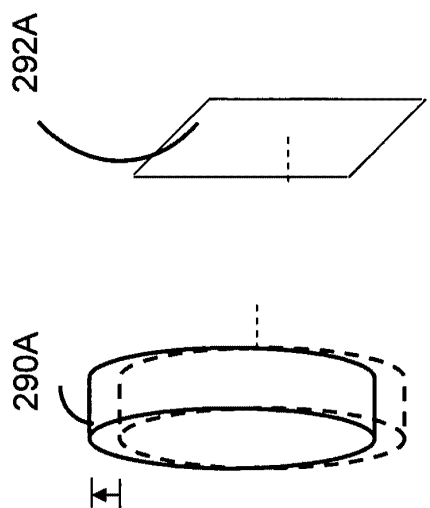


Figure 9I



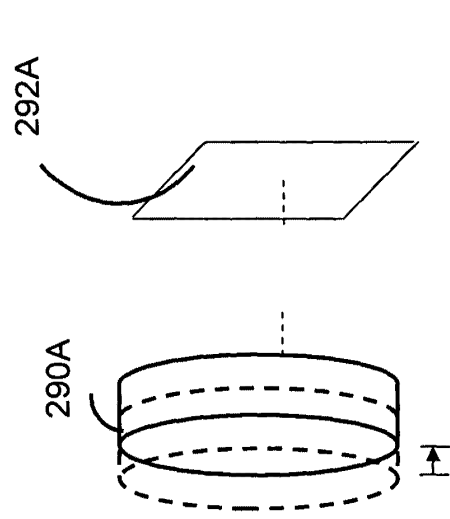


FIGURE 90

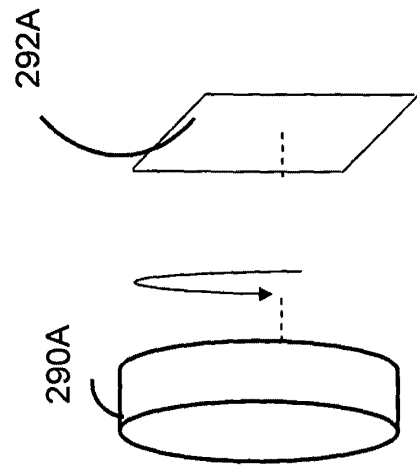


FIGURE 9Q

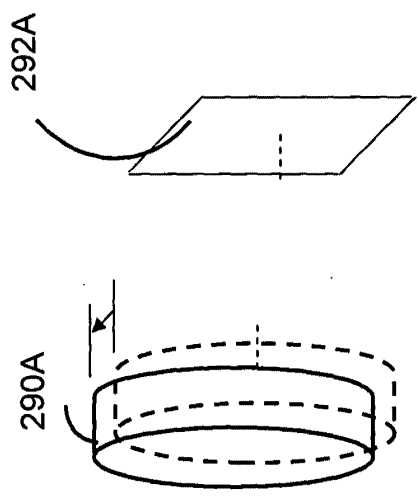


FIGURE 9N

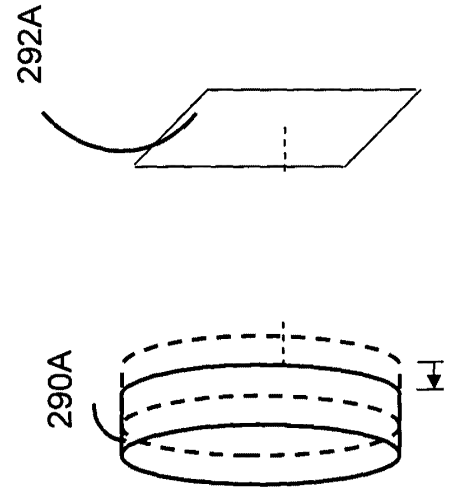


FIGURE 9P

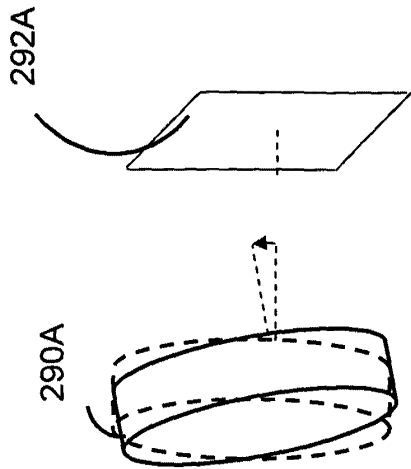


FIGURE 9S

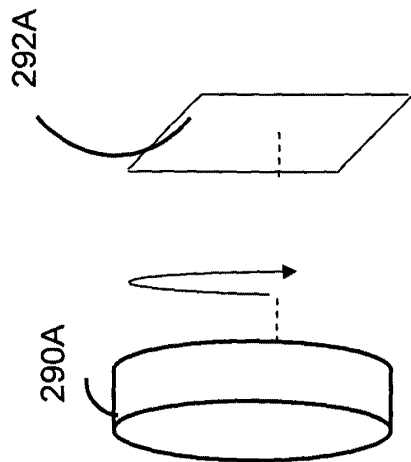


FIGURE 9R

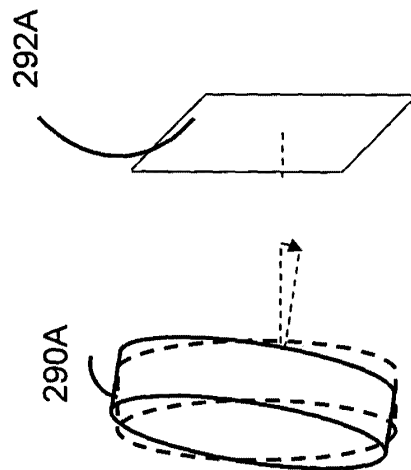
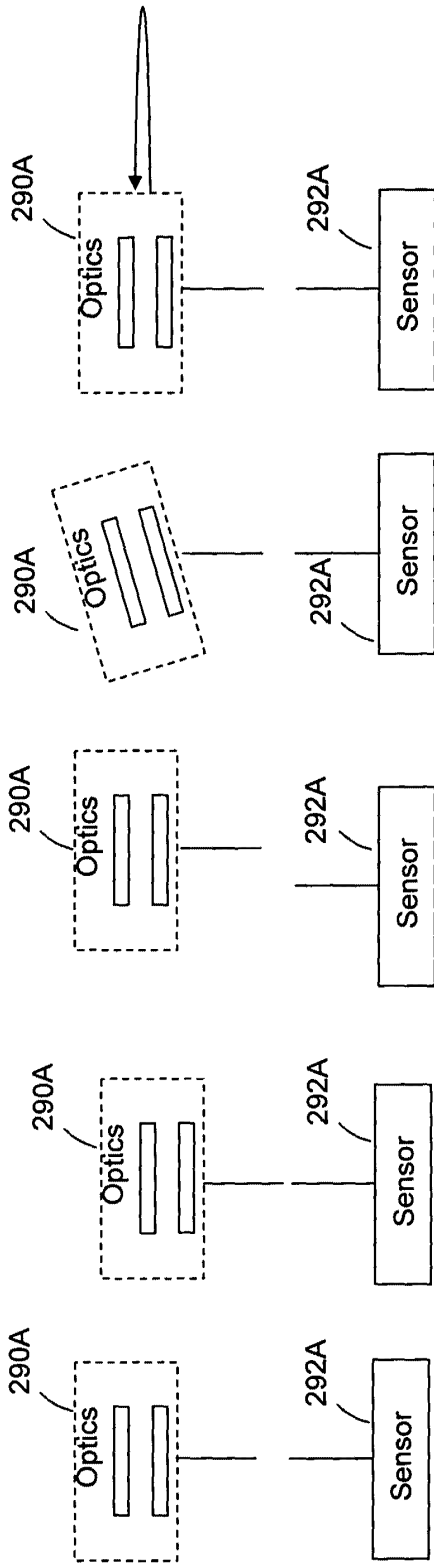
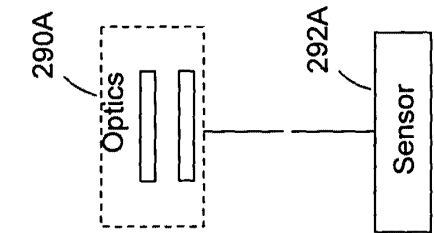
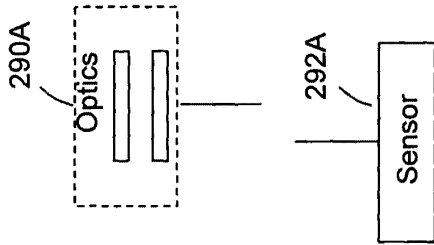
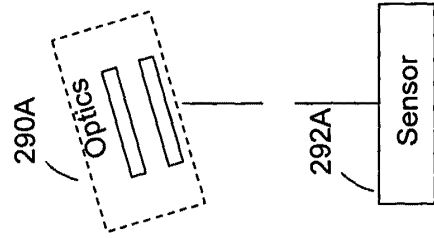
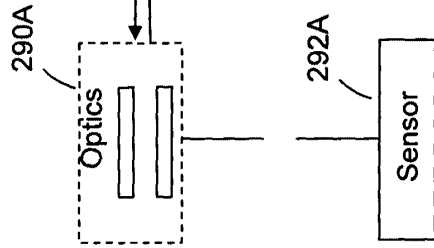
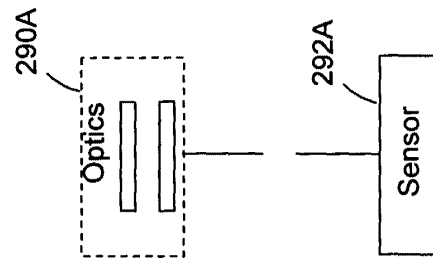
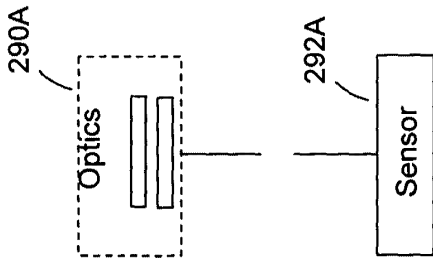
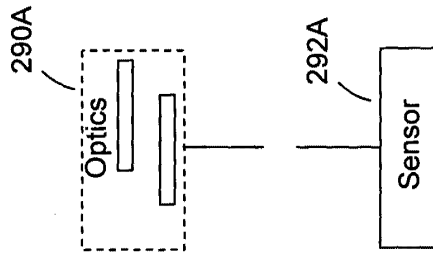
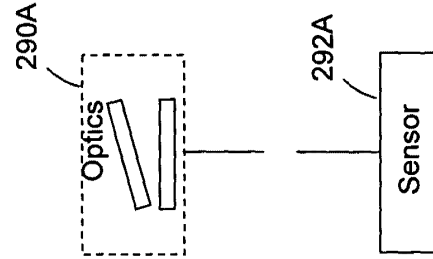
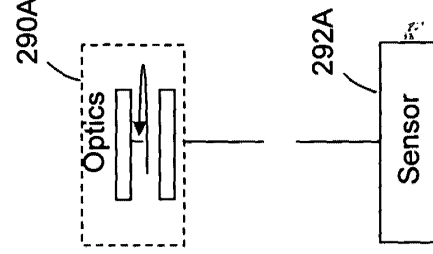


FIGURE 9T



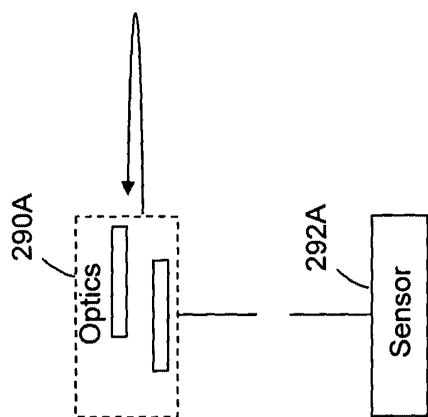


Figure 10K

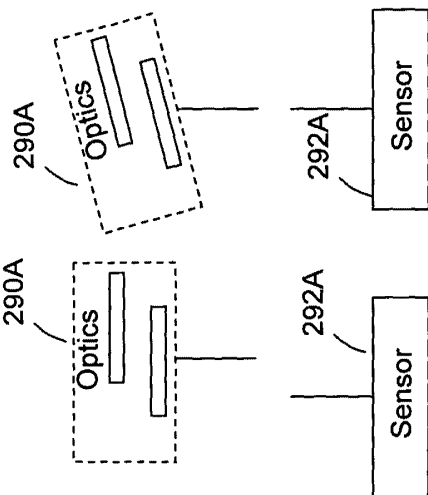


Figure 10L

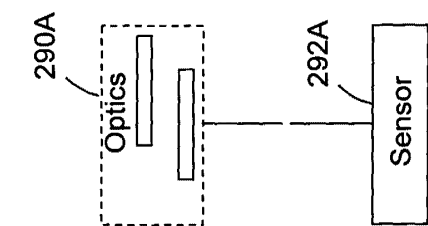


Figure 10M

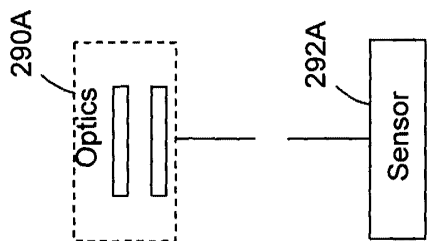


Figure 10N

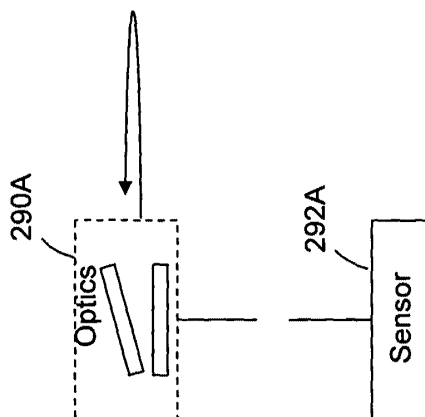


Figure 10O

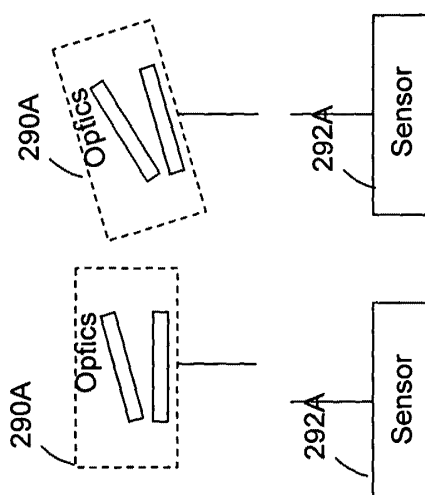


Figure 10P

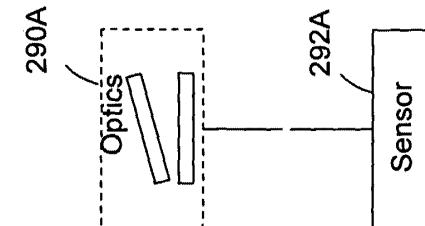


Figure 10Q

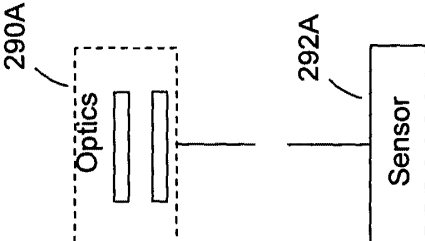


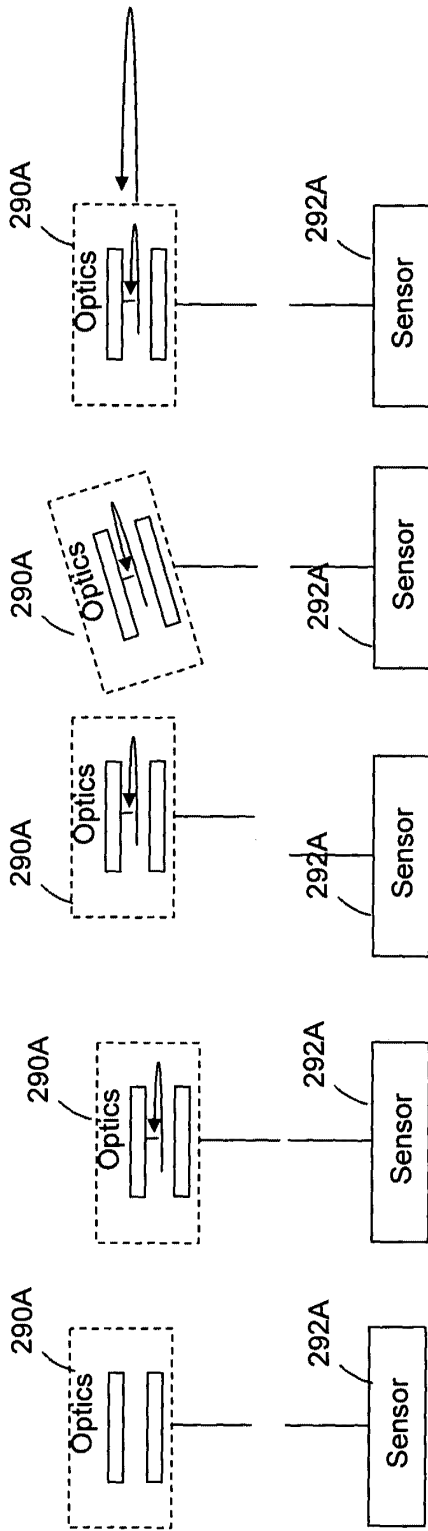
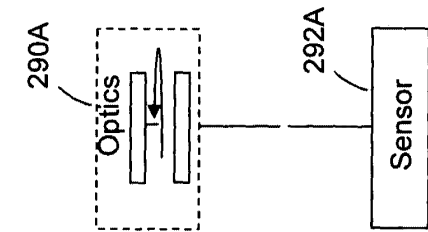
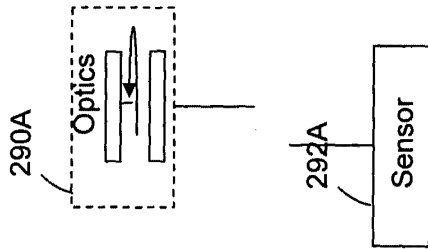
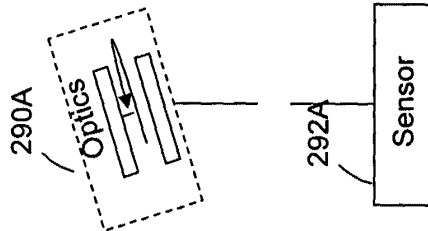
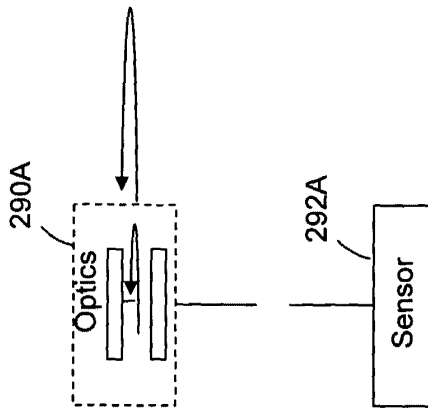
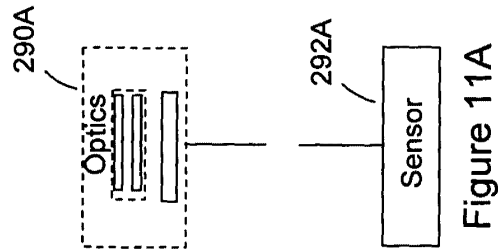
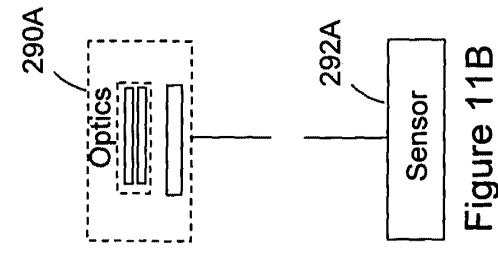
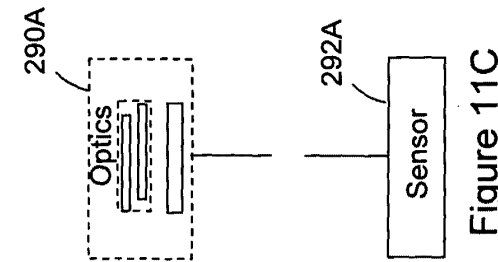
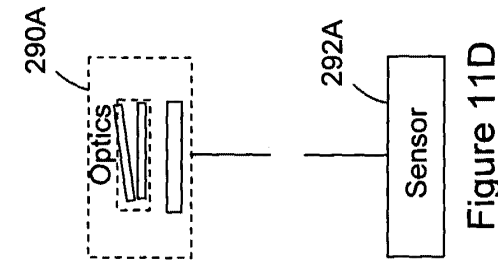
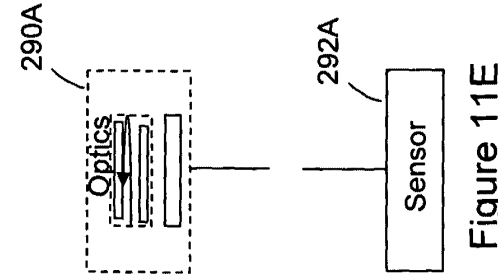
Figure 10R

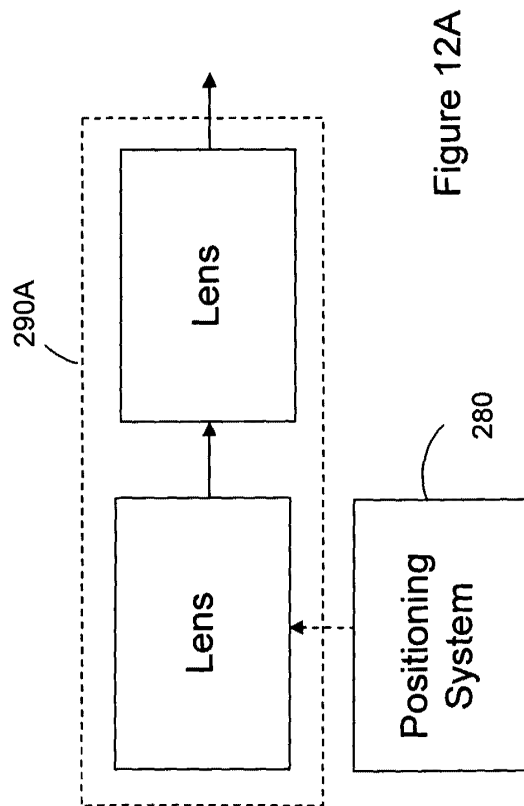
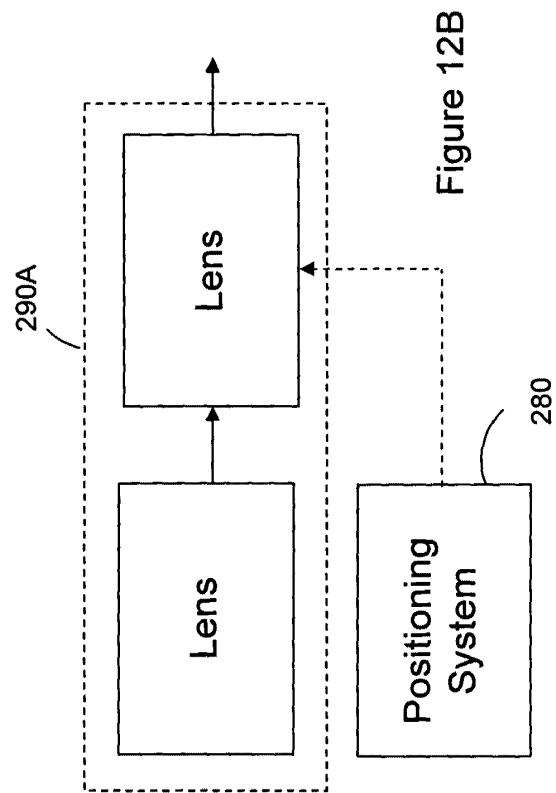


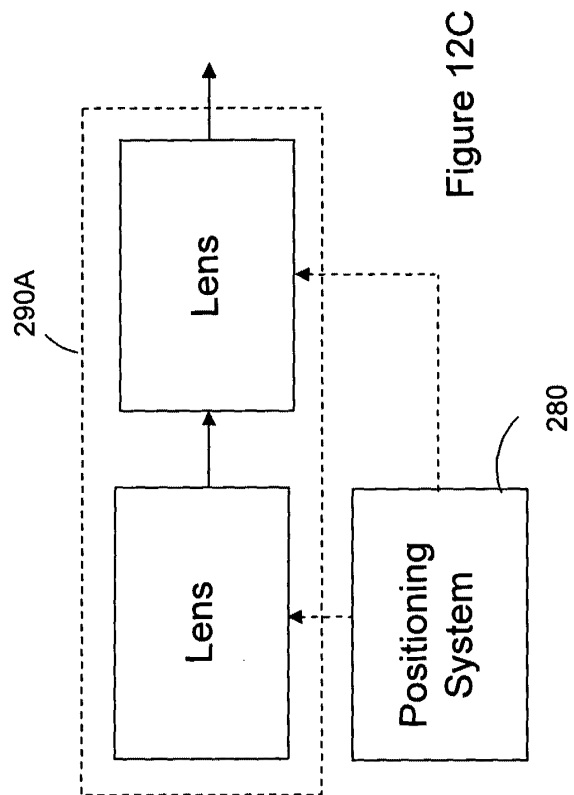
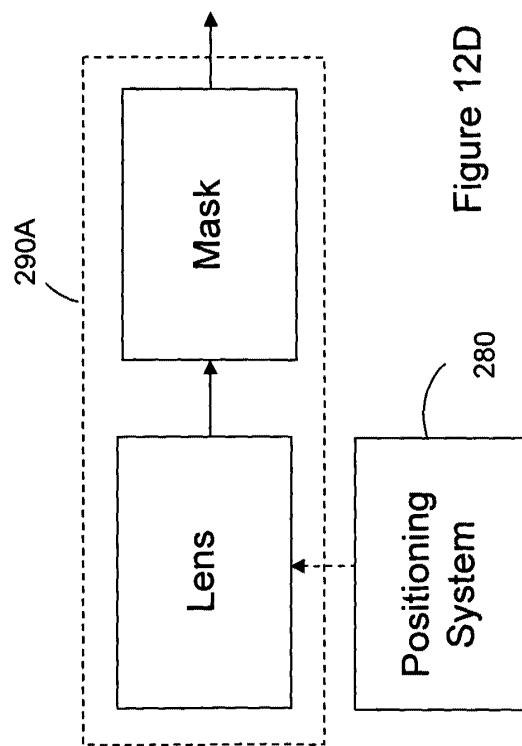
Figure 10S

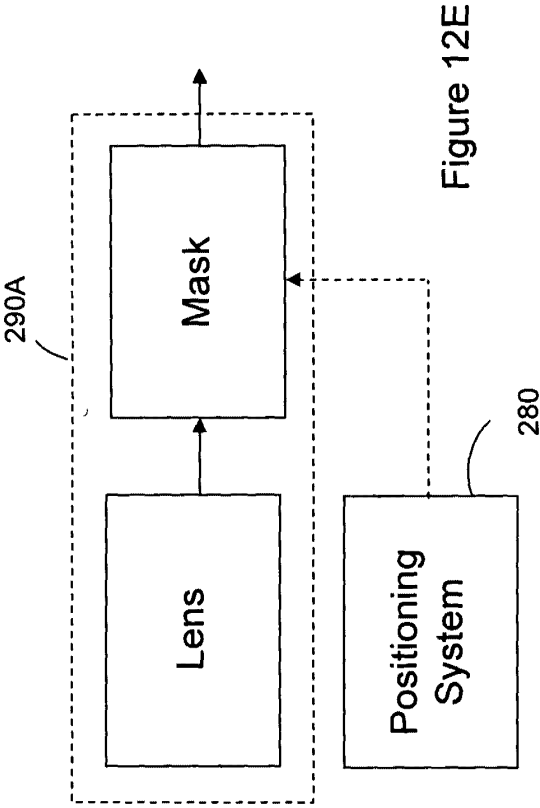
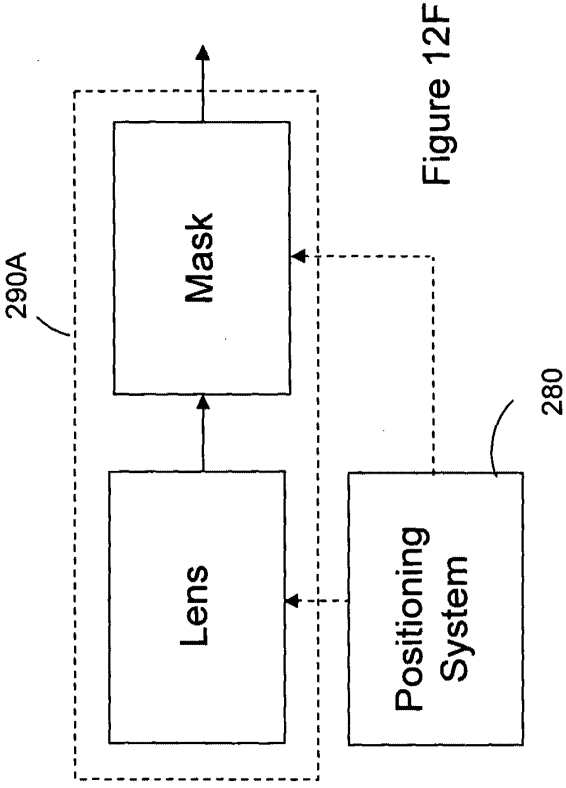


Figure 10T









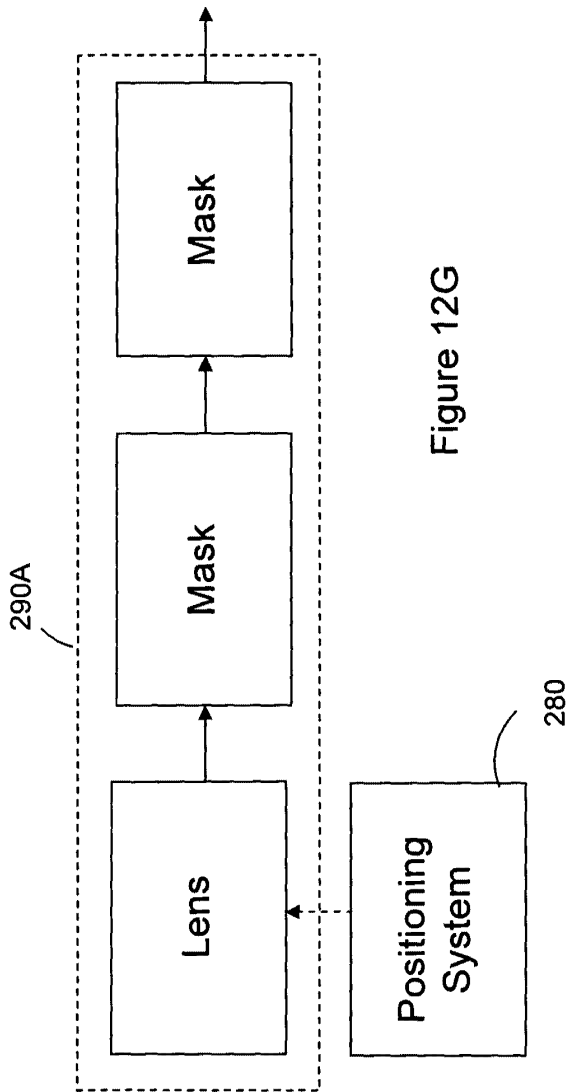


Figure 12G

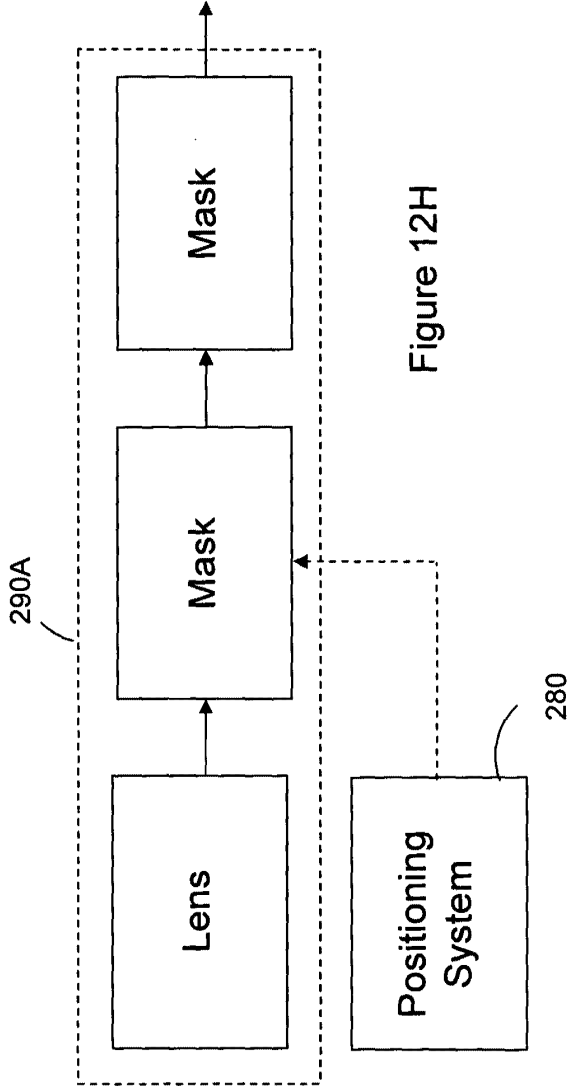


Figure 12H

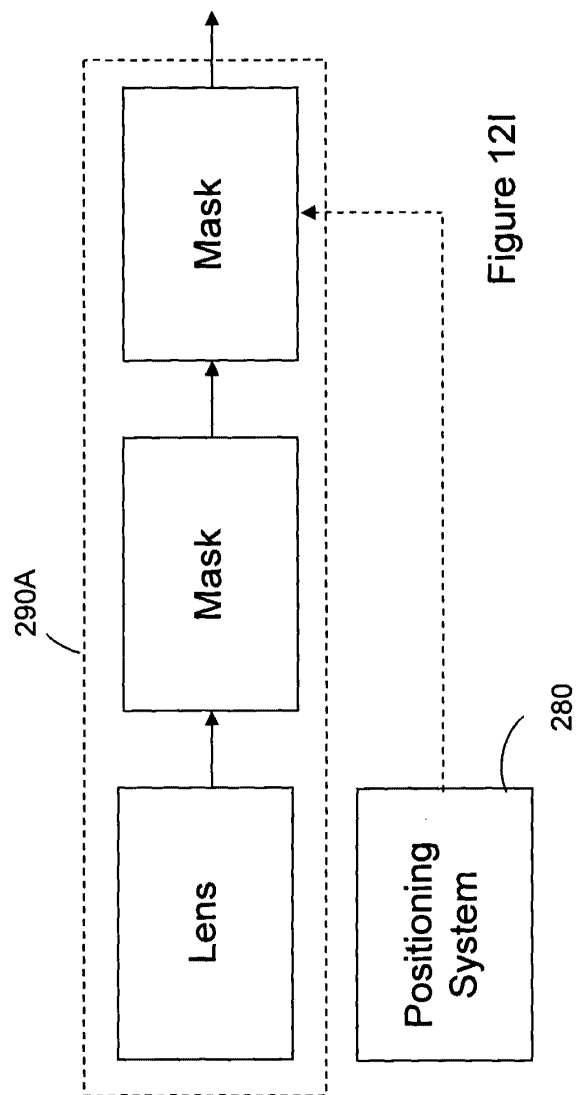


Figure 12I

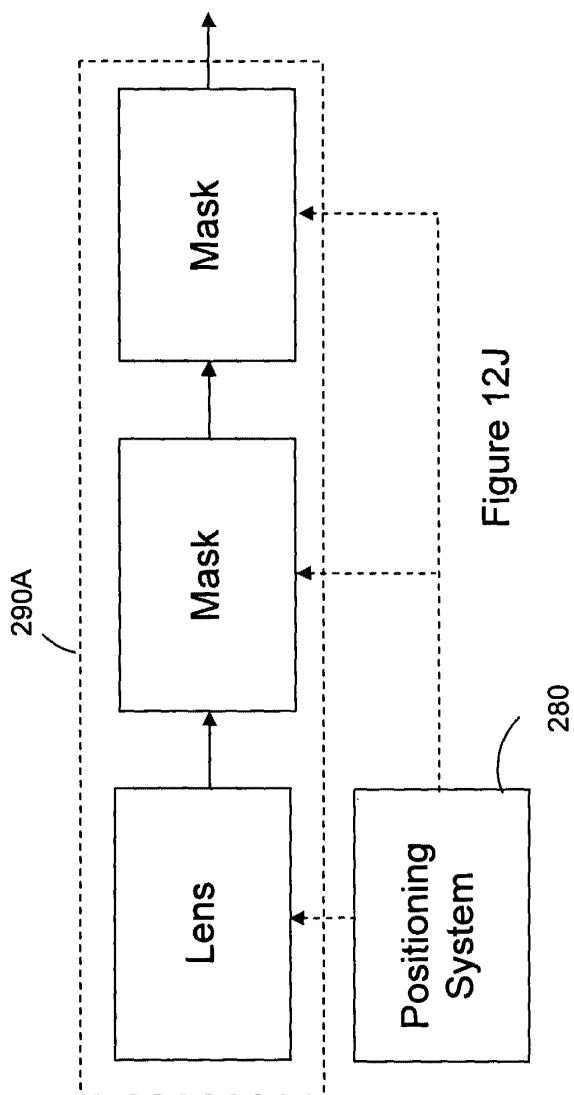
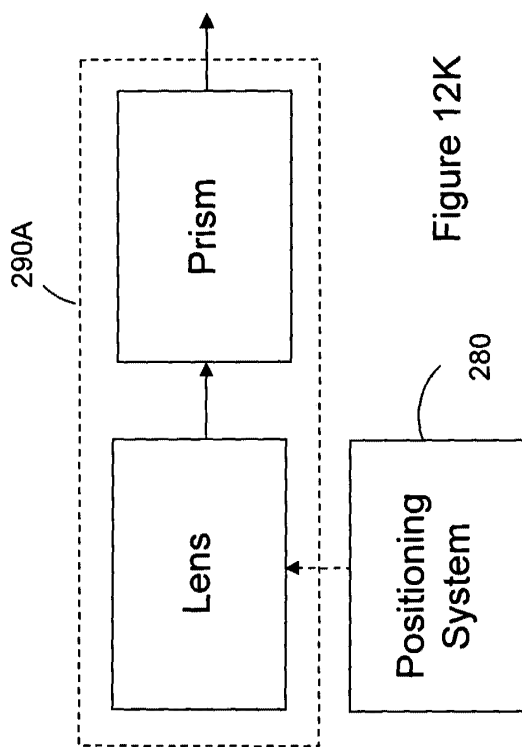
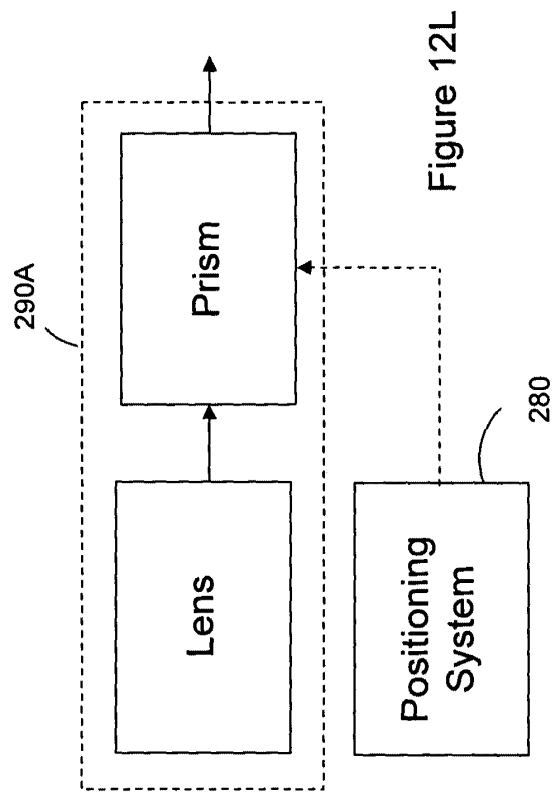


Figure 12J



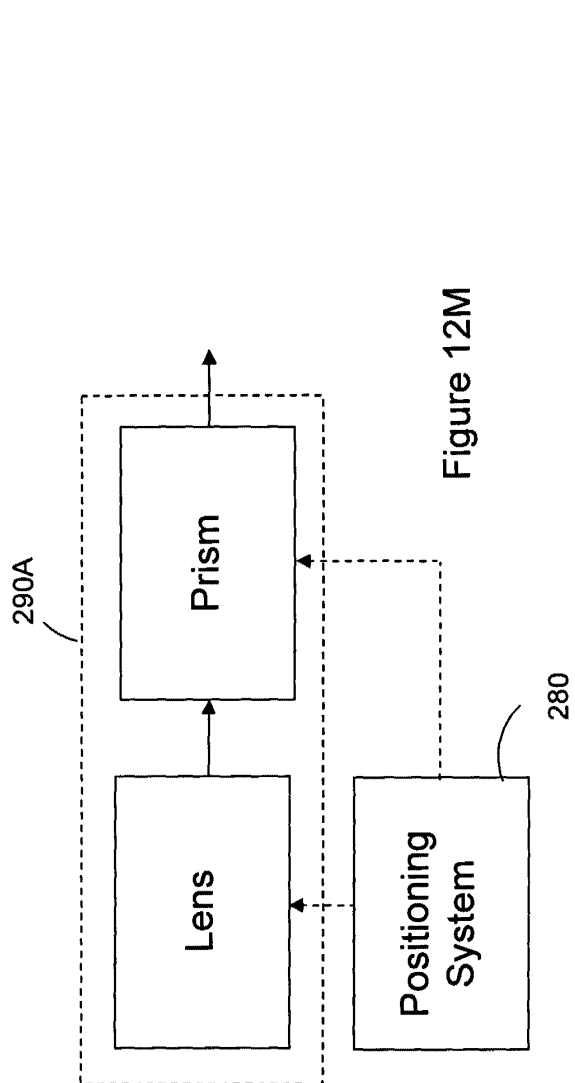


Figure 12M

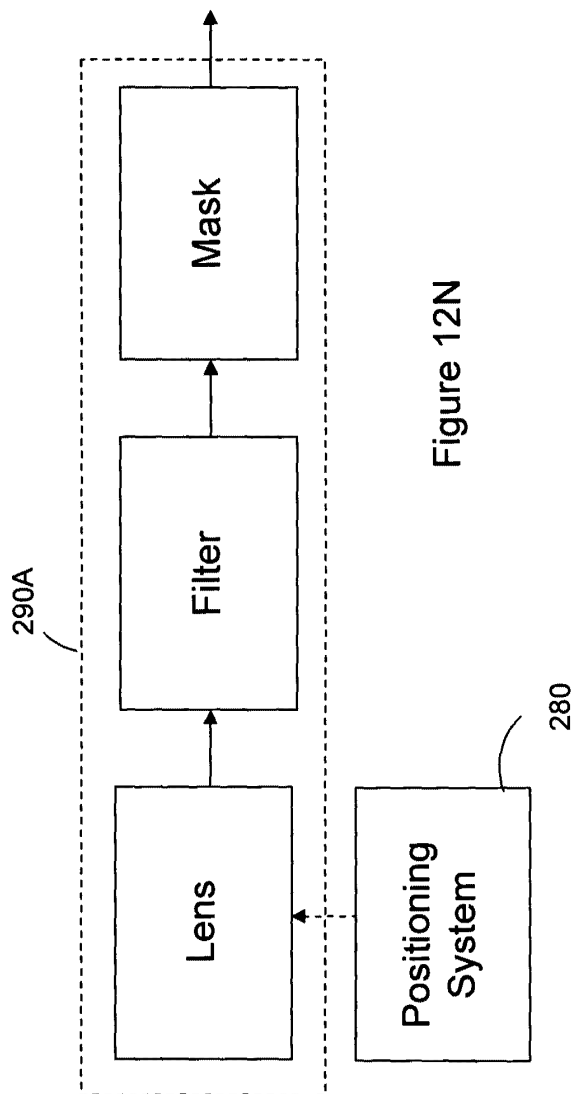


Figure 12N

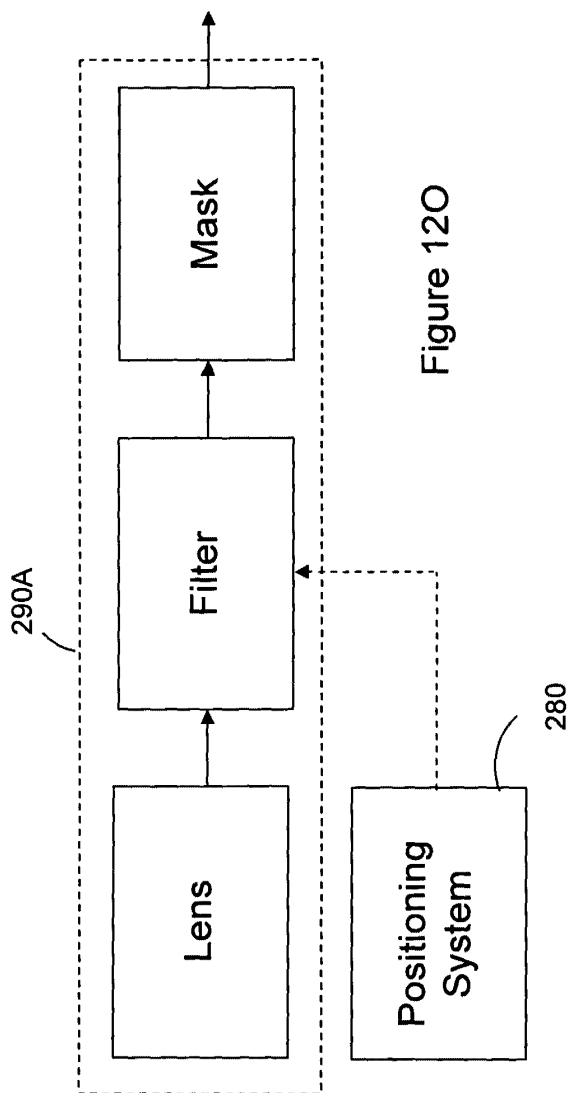


Figure 12O

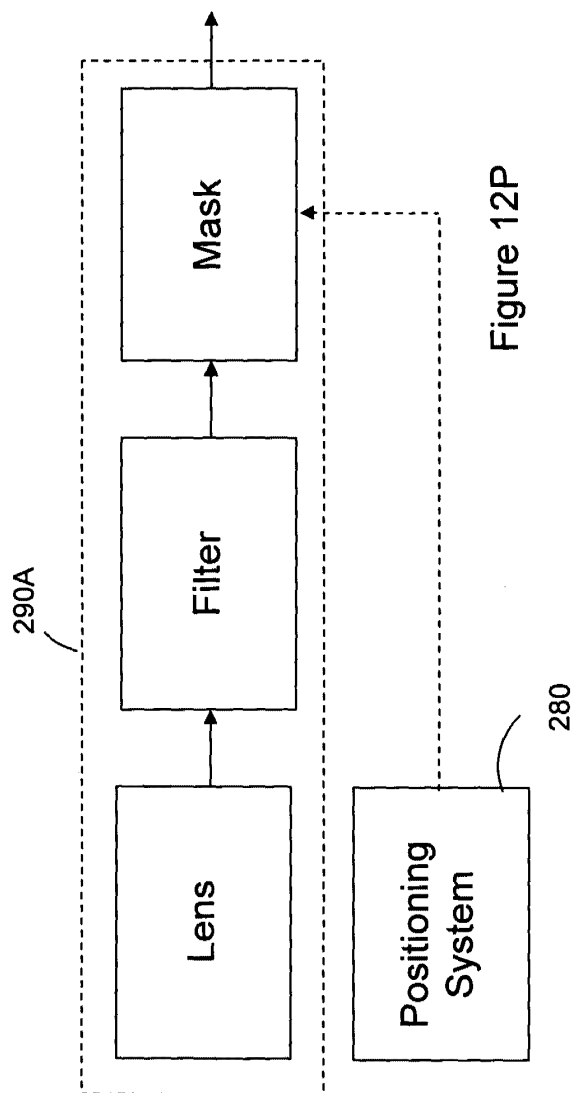


Figure 12P

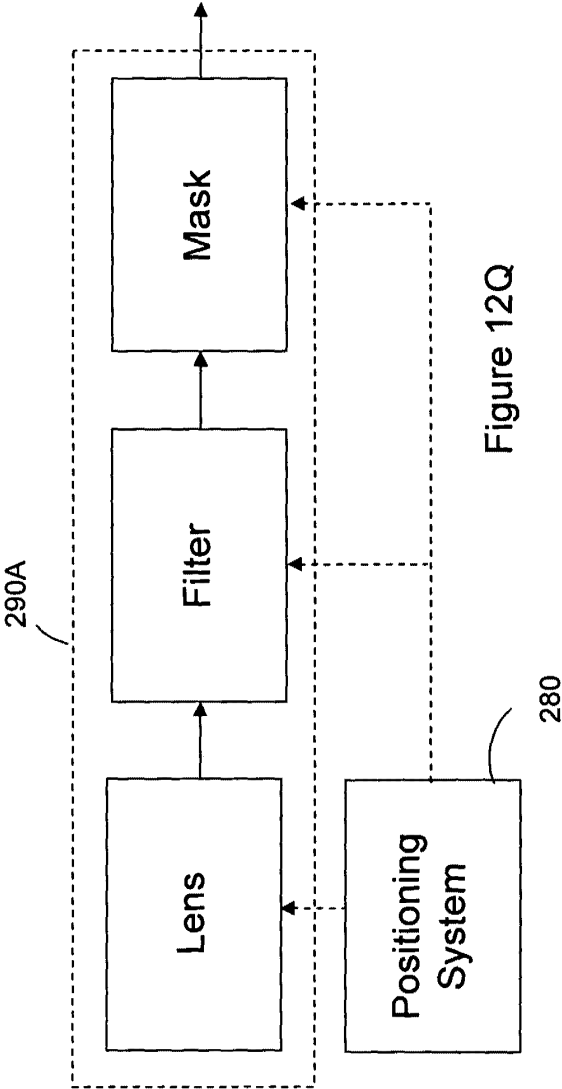


Figure 12Q

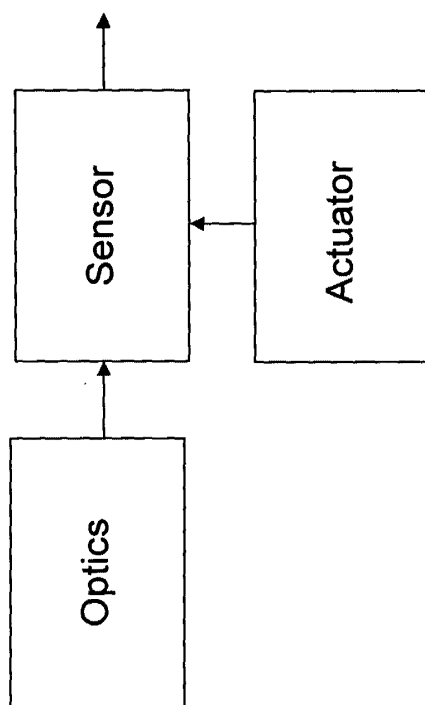


Figure 12R

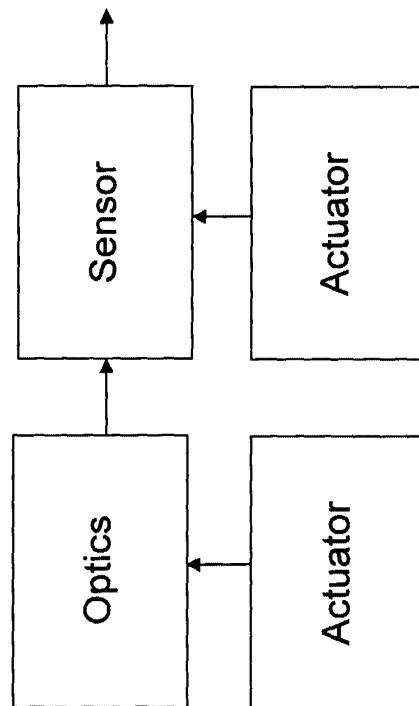


Figure 12S

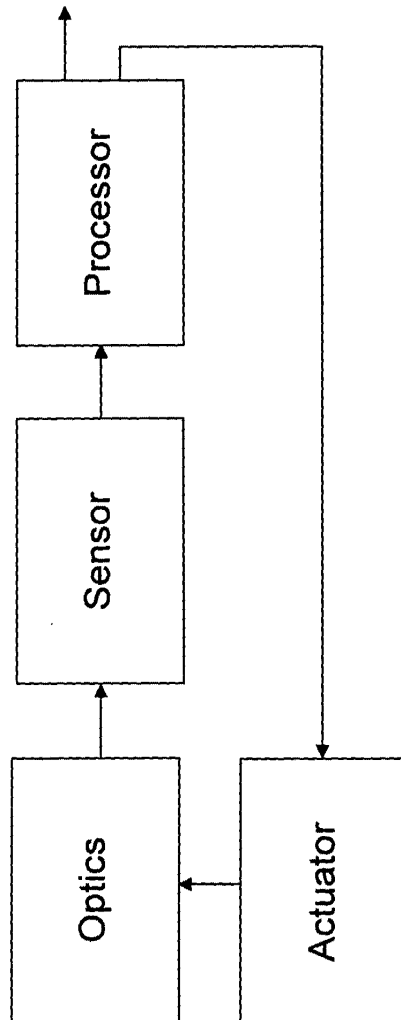


Figure 12T

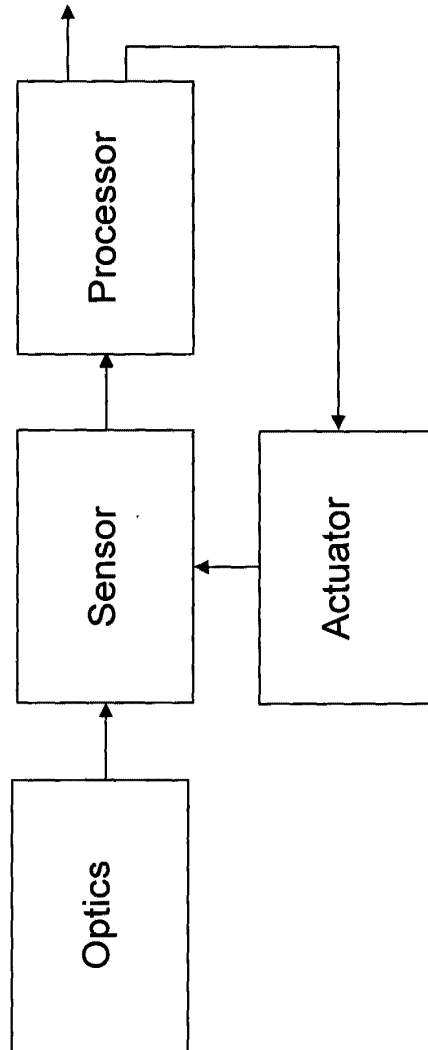


Figure 12U

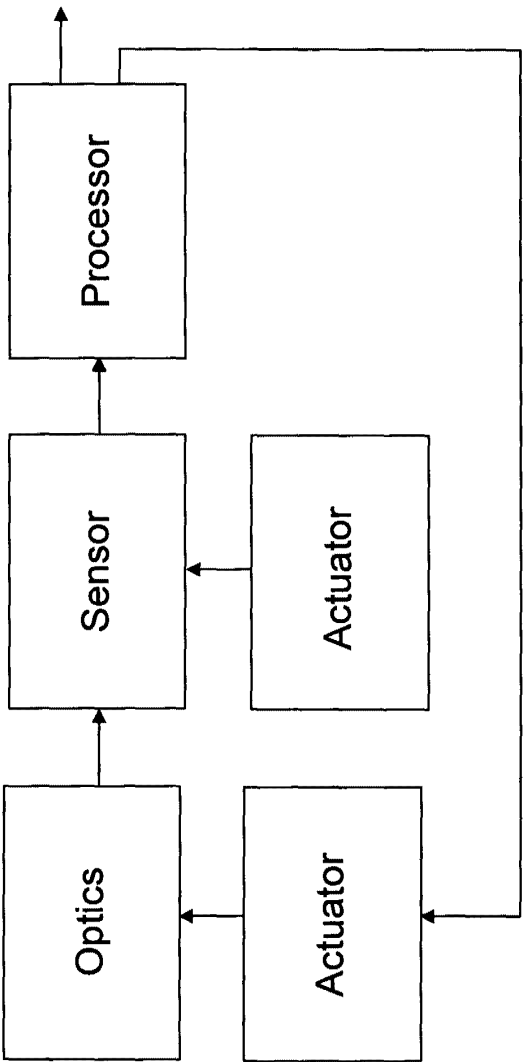


Figure 12V

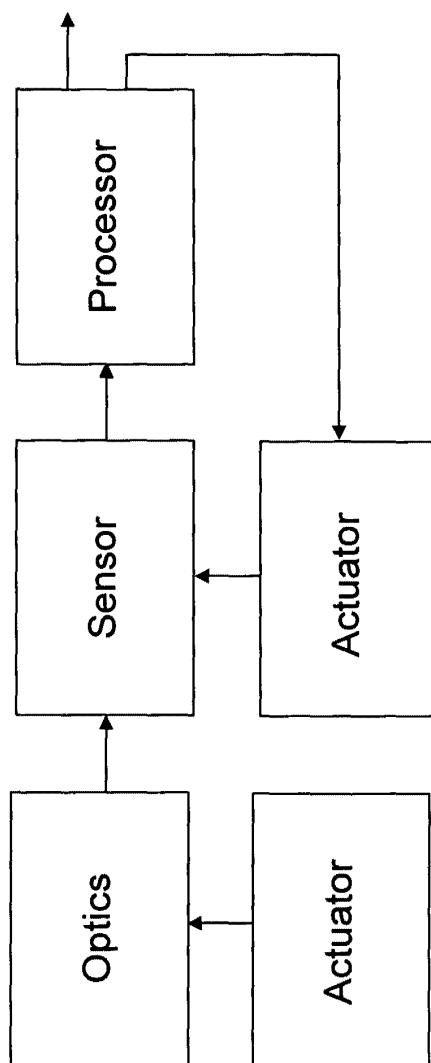


Figure 12W

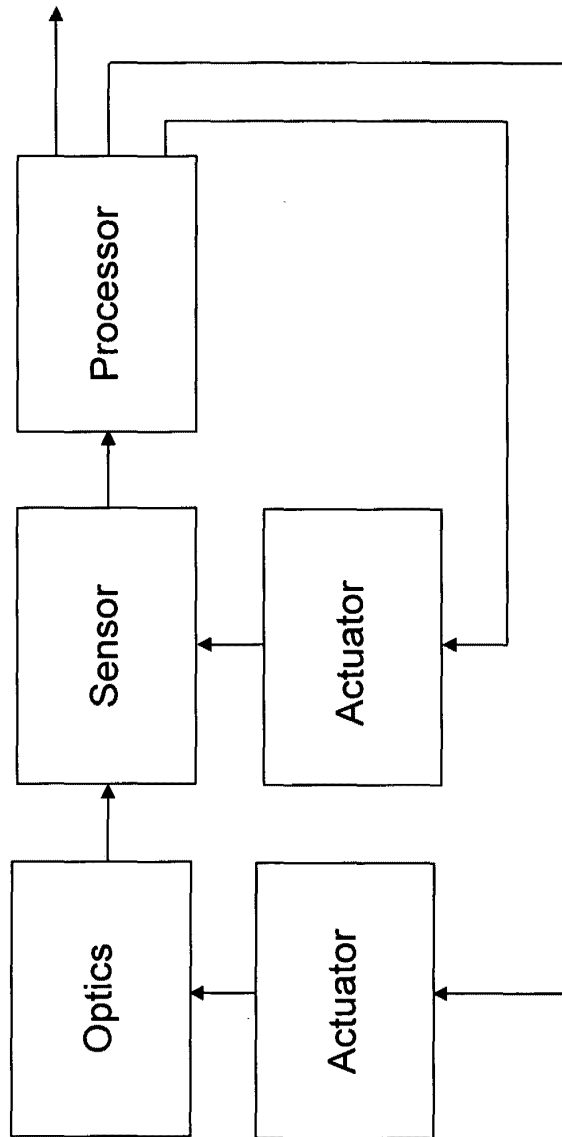


Figure 12X

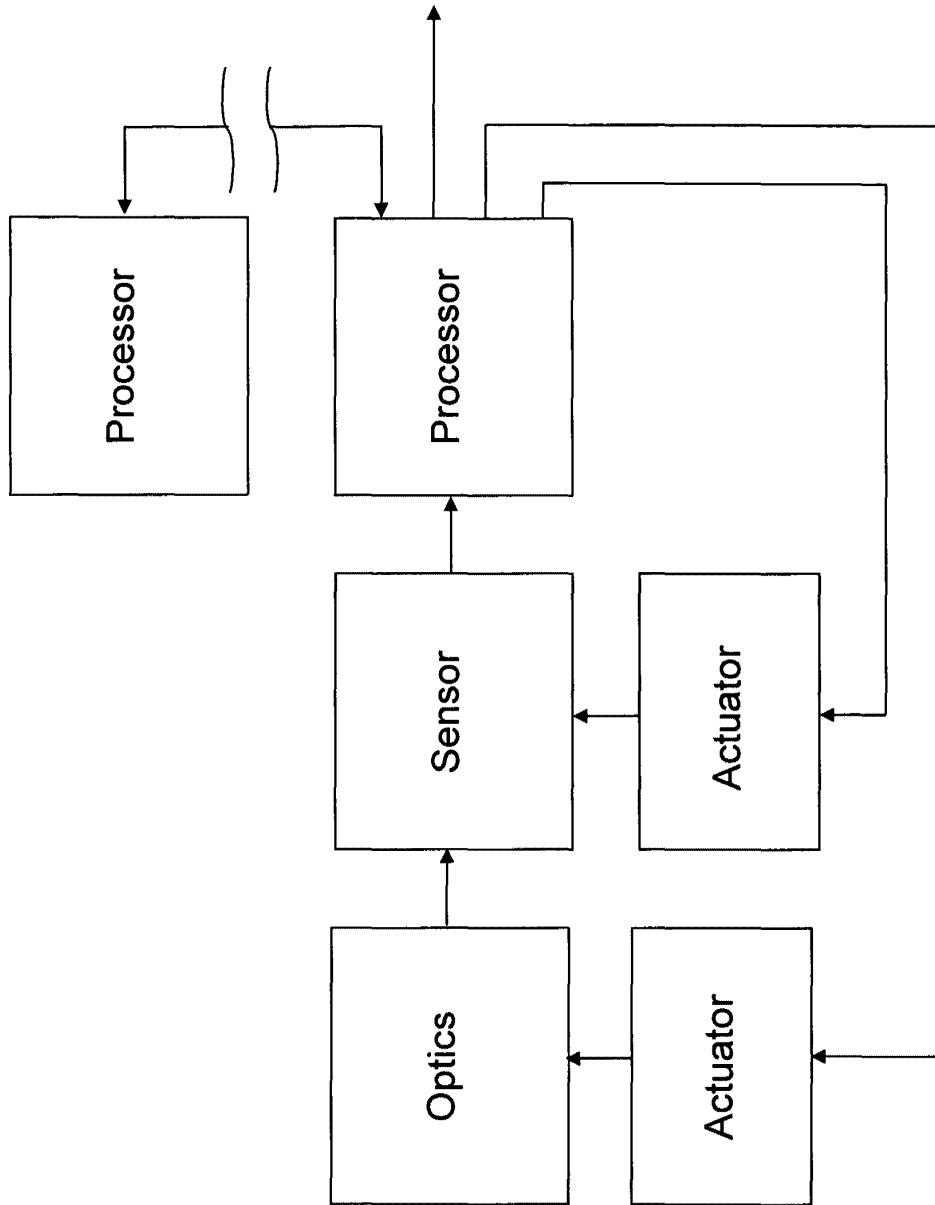


Figure 12Y

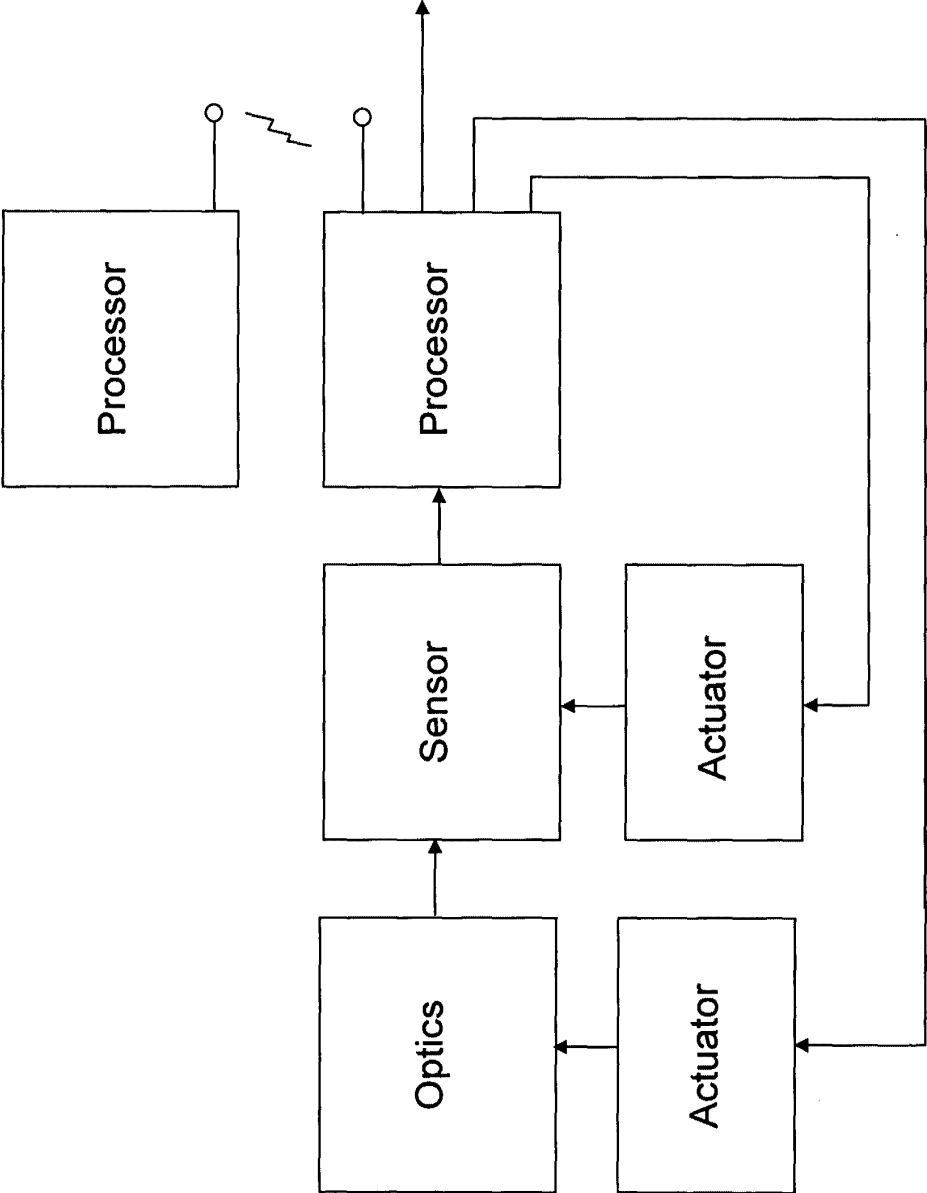


Figure 12Z

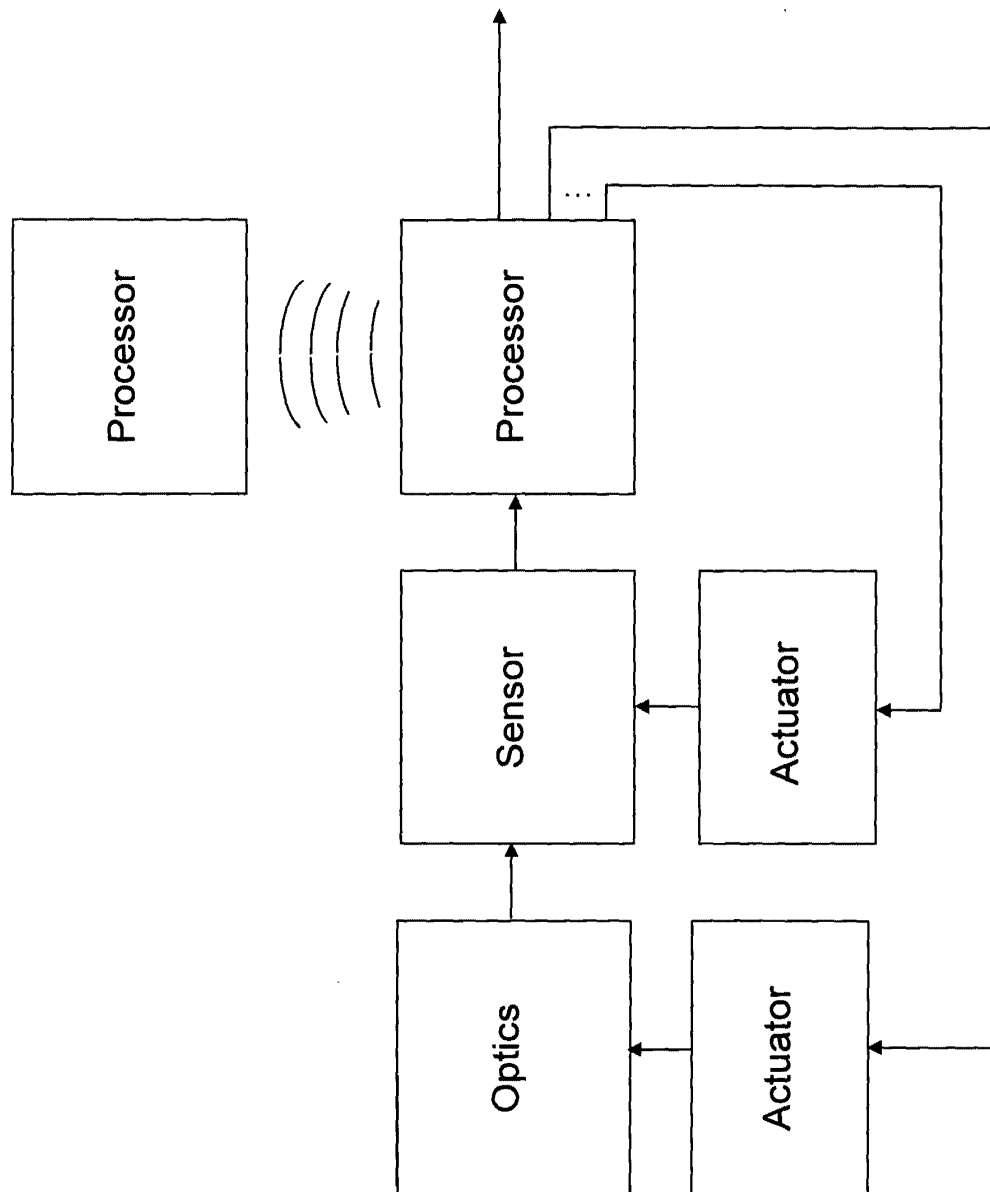


Figure 12AA

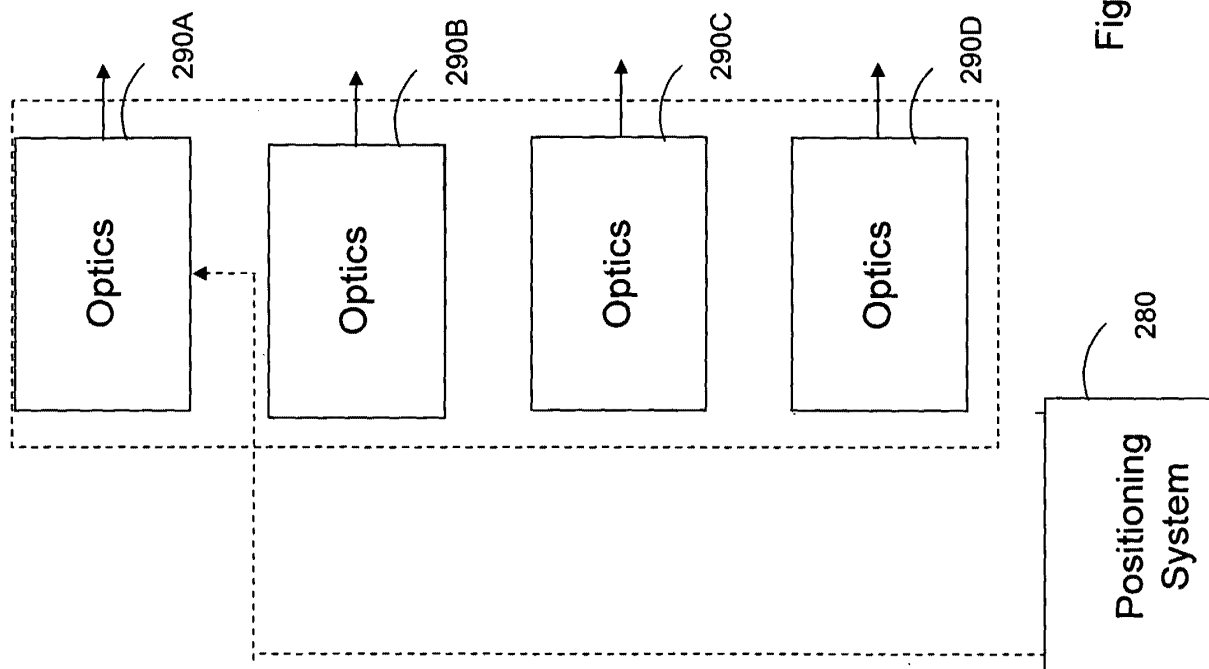


Figure 13A

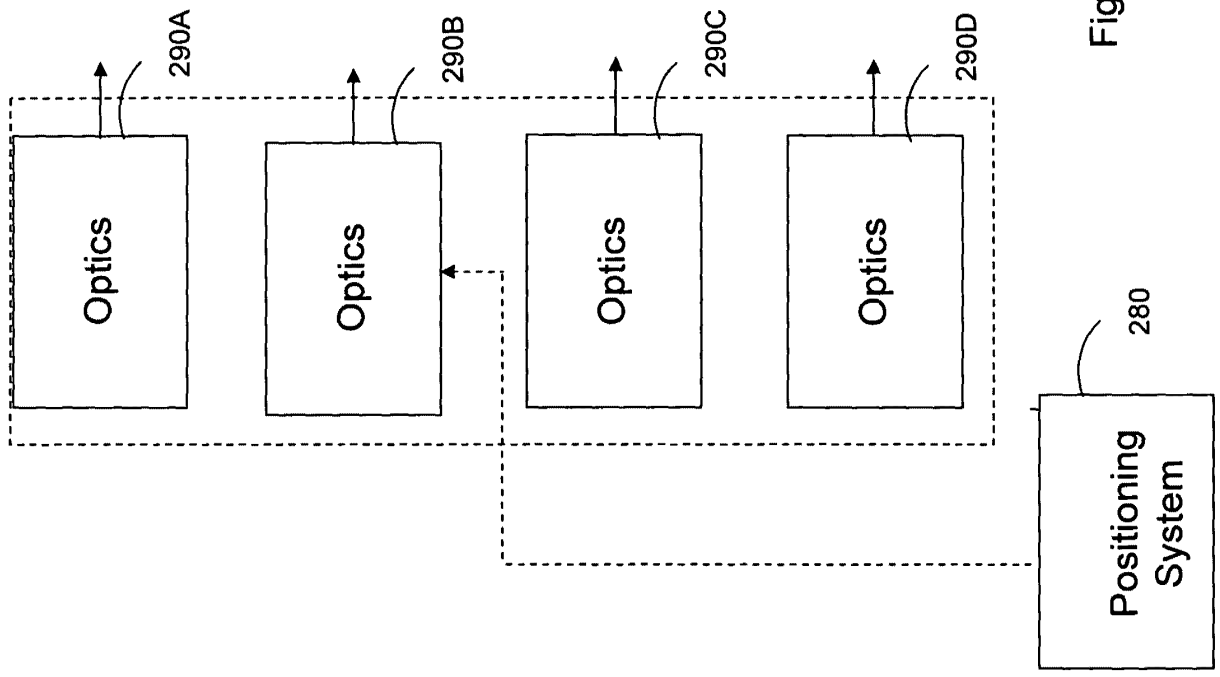


Figure 13B

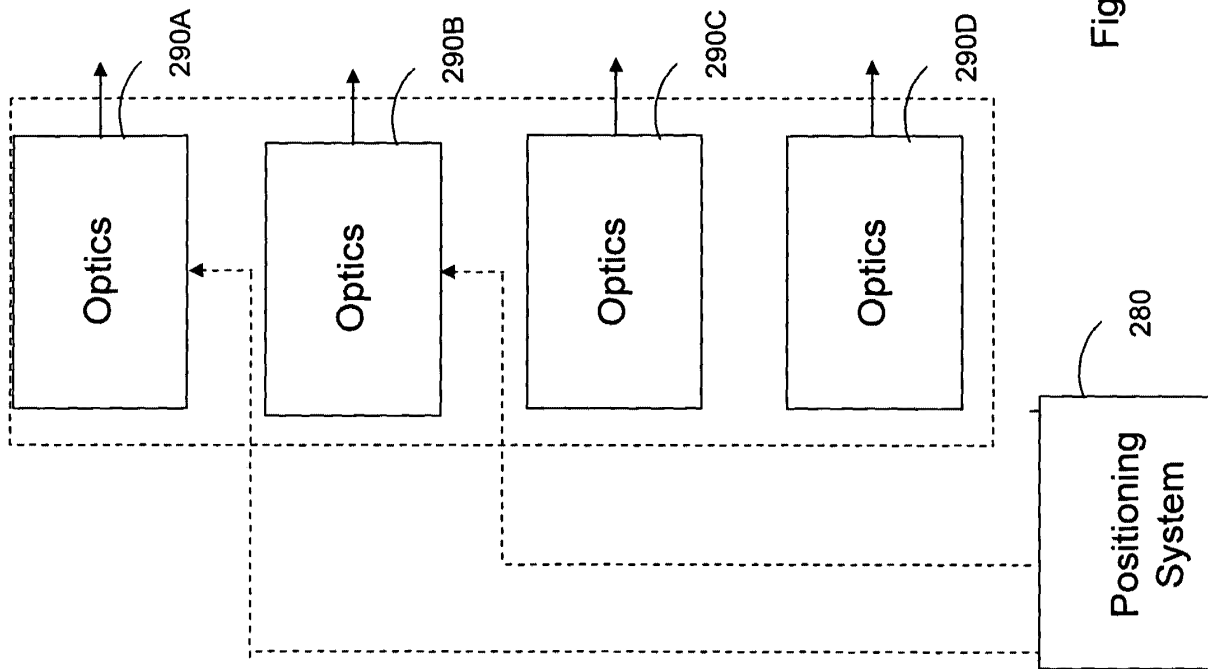


Figure 13C

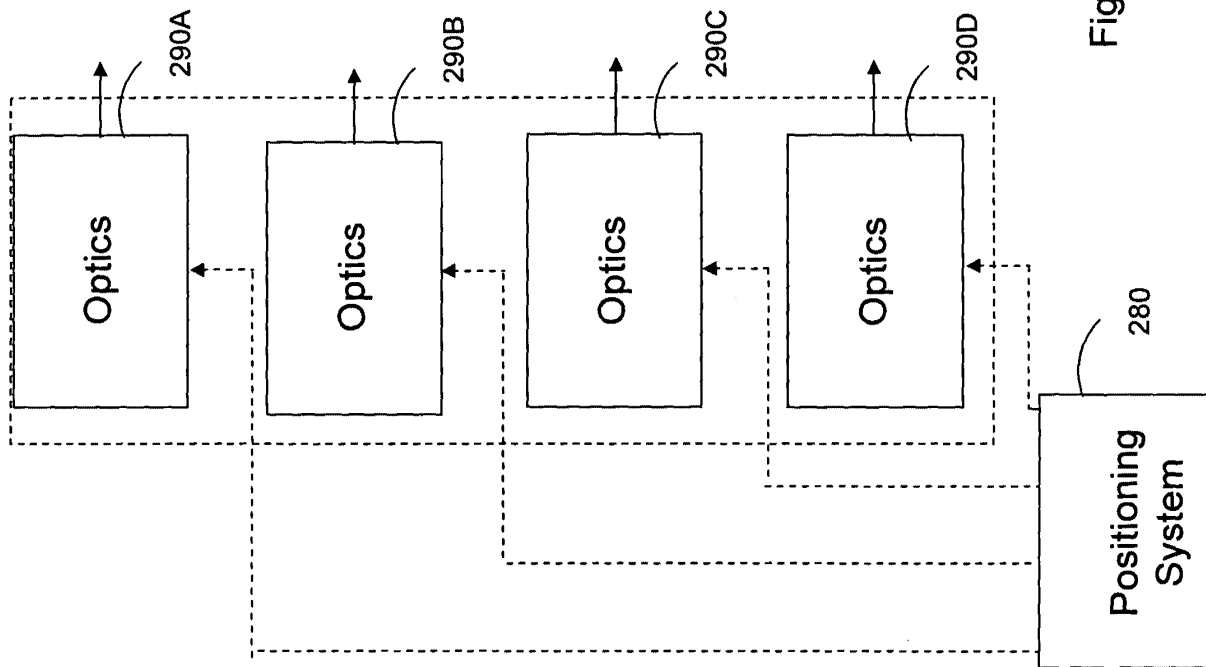


Figure 13D

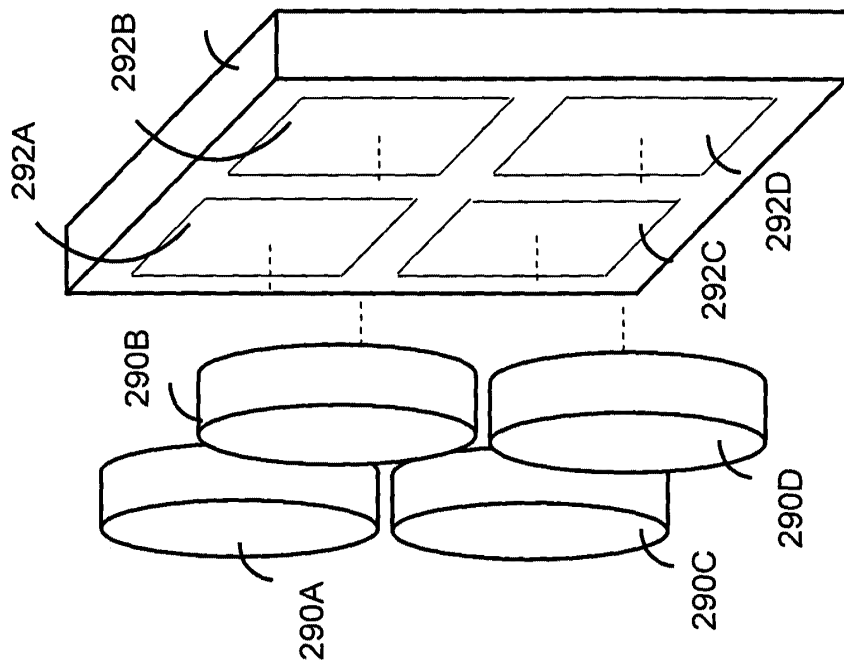


Figure 13F

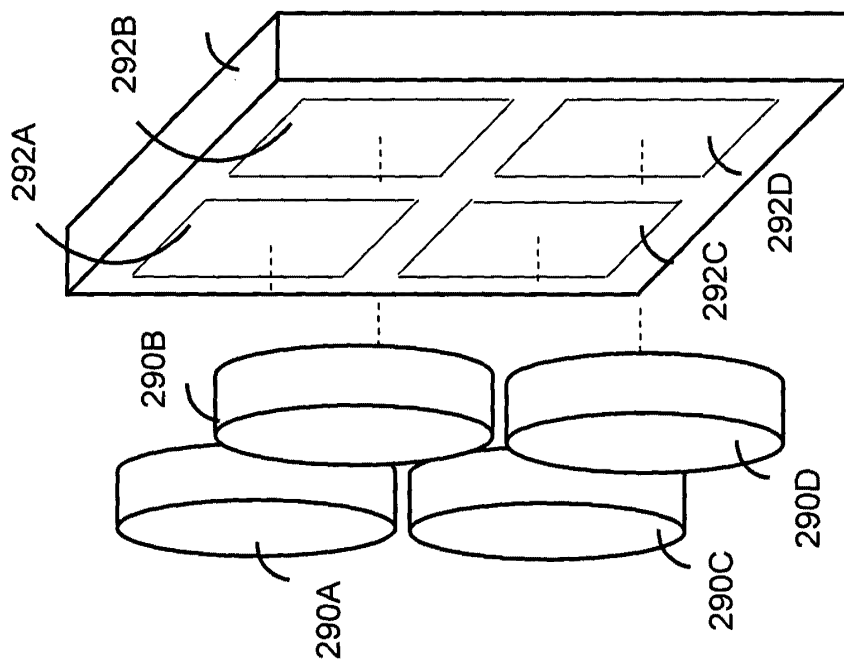


Figure 13E

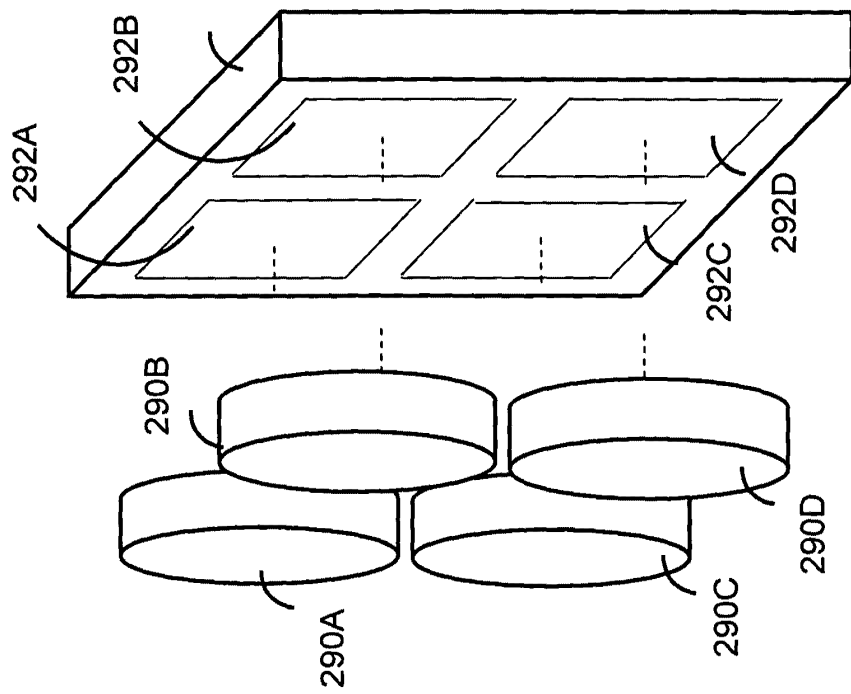


Figure 13H

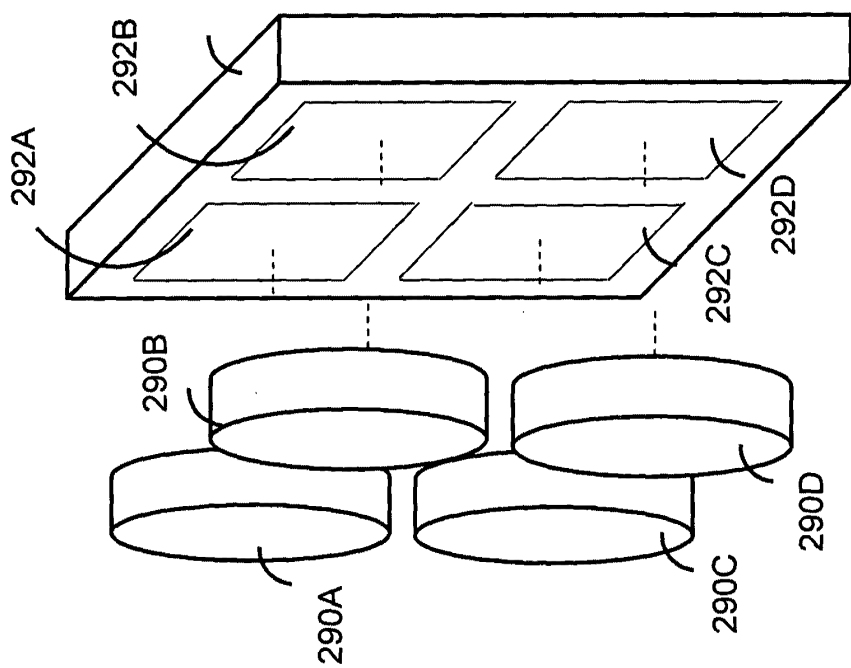


Figure 13G

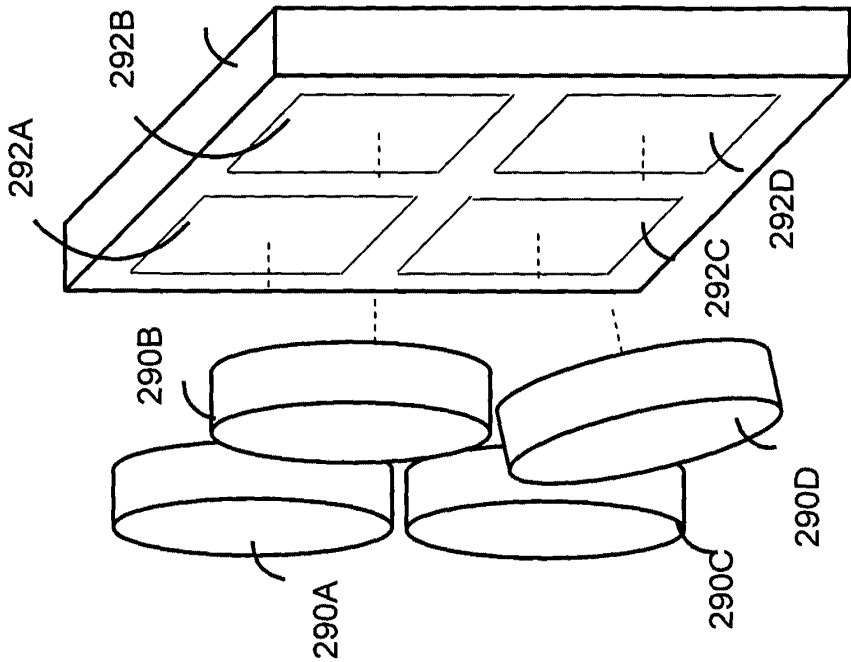


Figure 13J

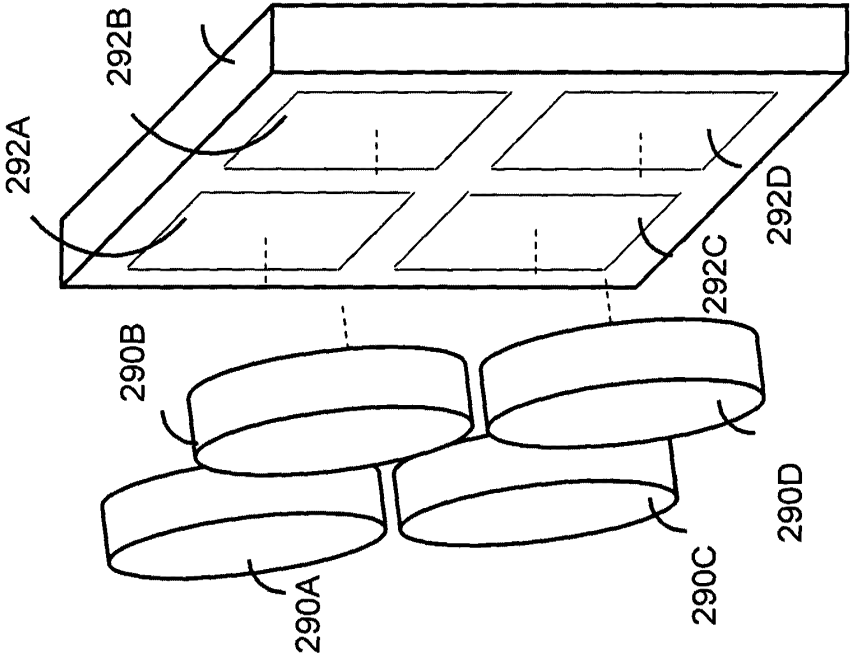


Figure 13I

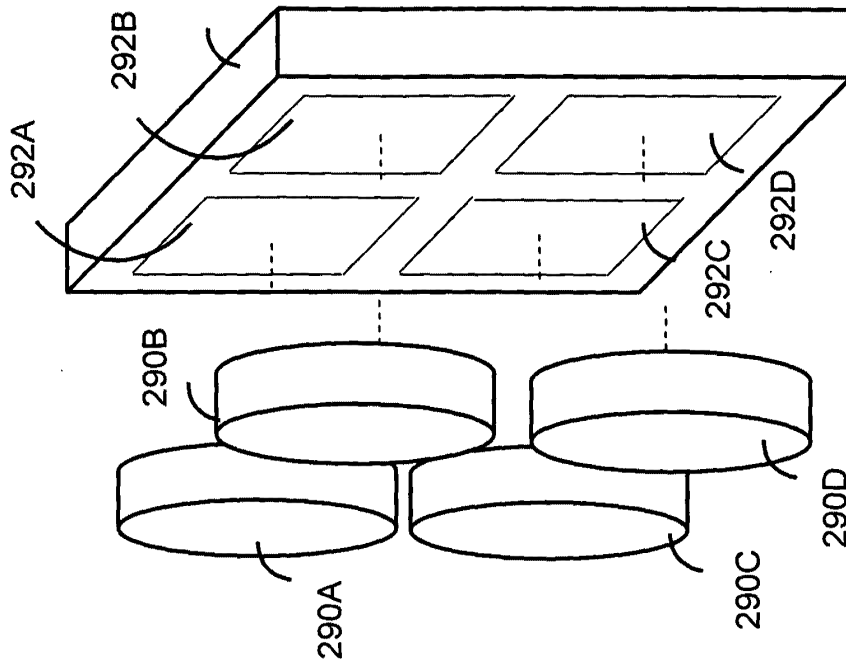


Figure 13L

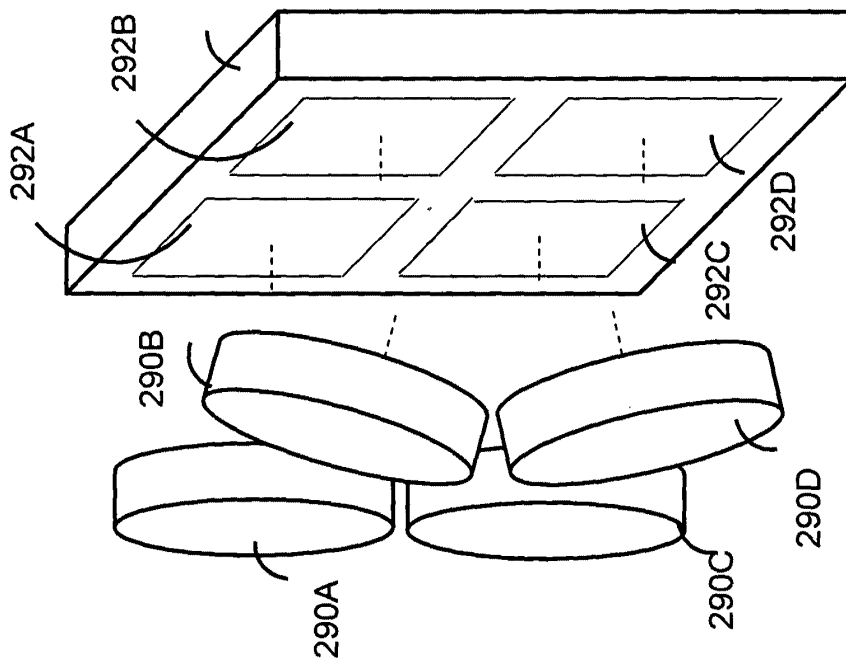


Figure 13K

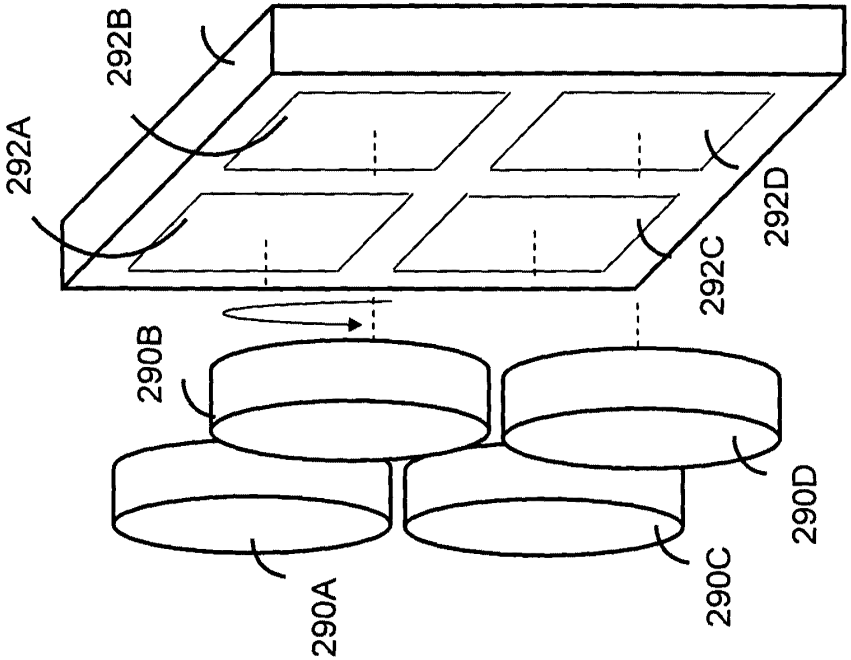


Figure 13N

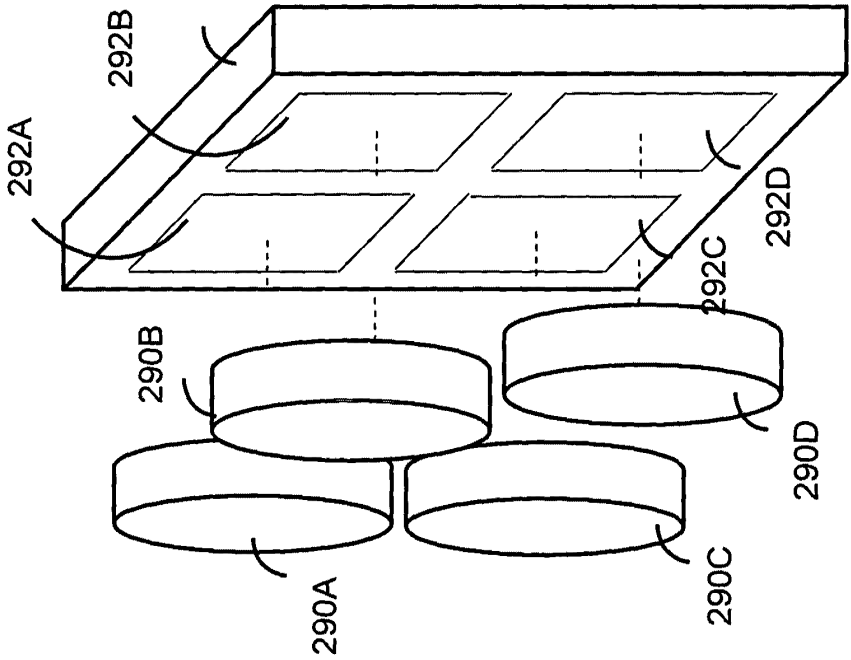


Figure 13M

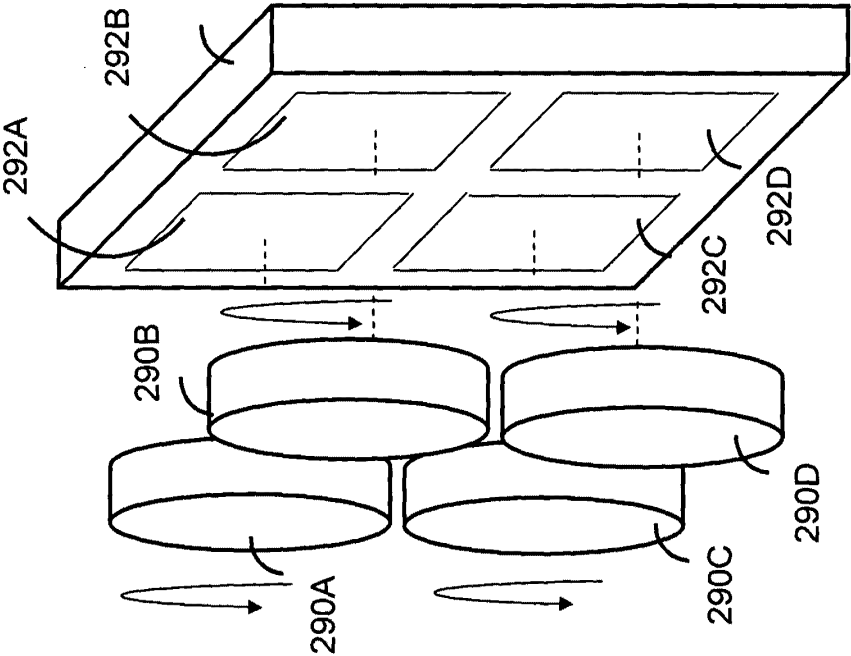


Figure 130

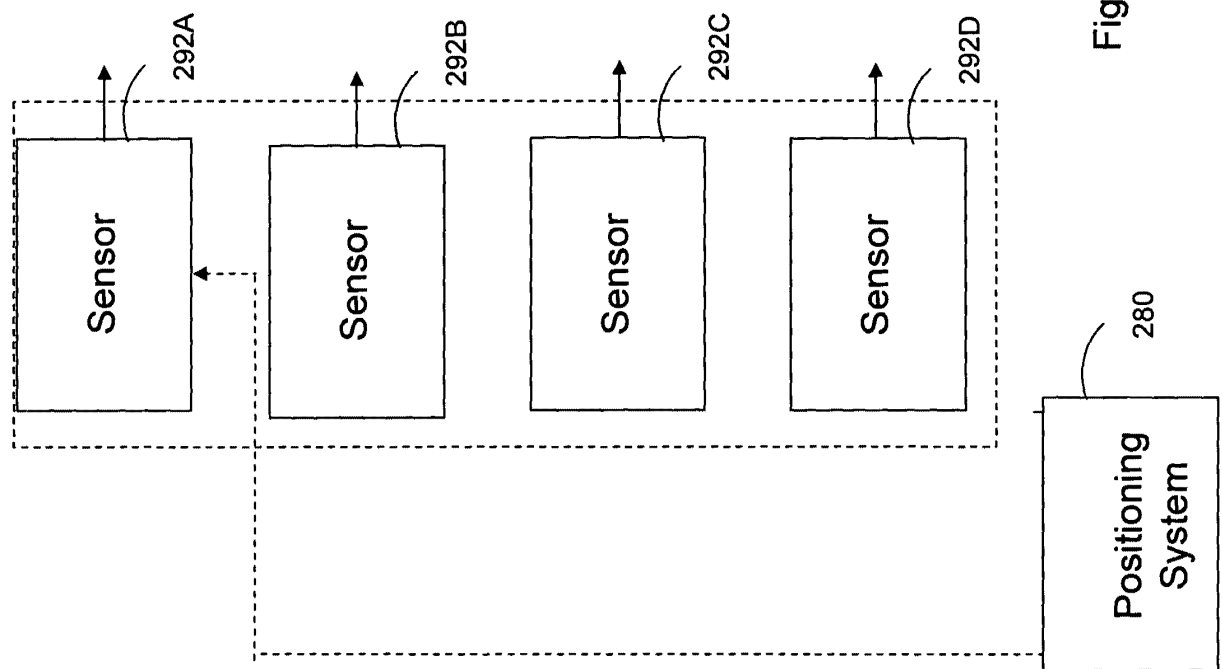


Figure 14A

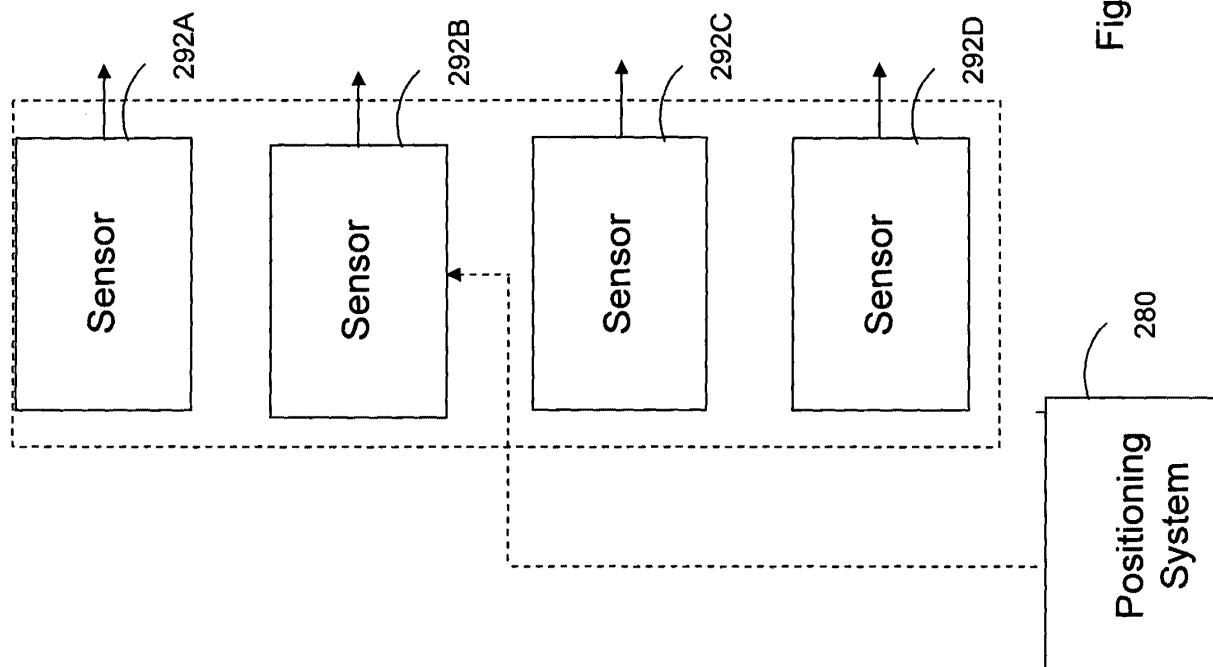


Figure 14B

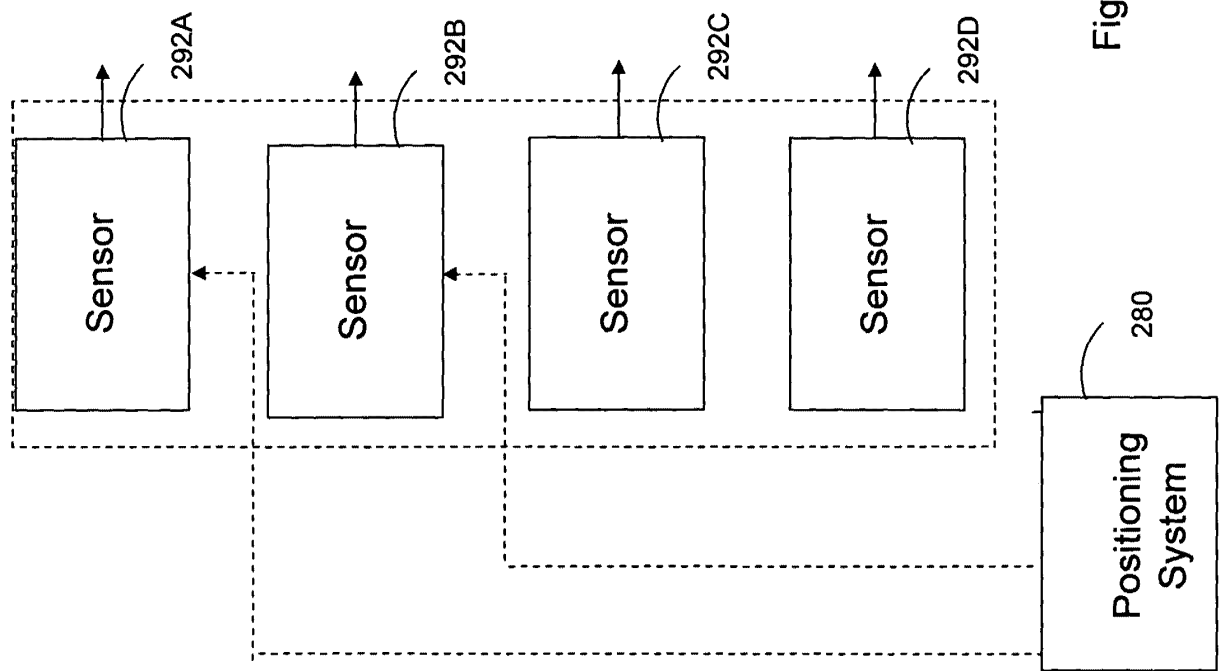


Figure 14C

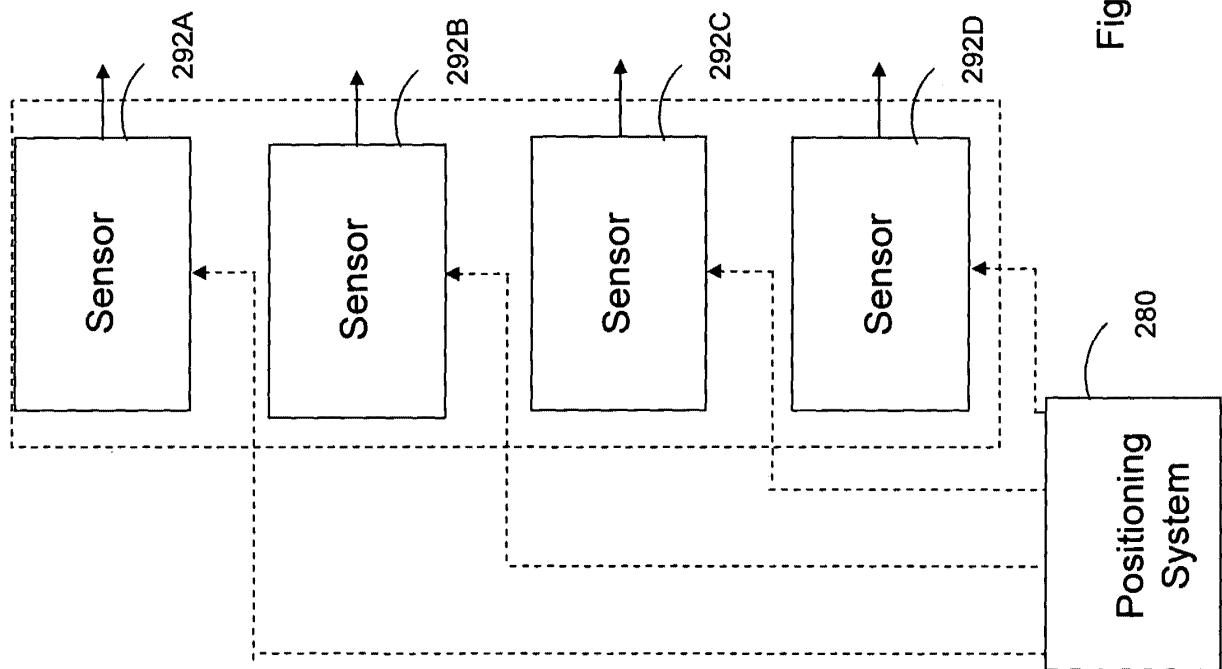


Figure 14D

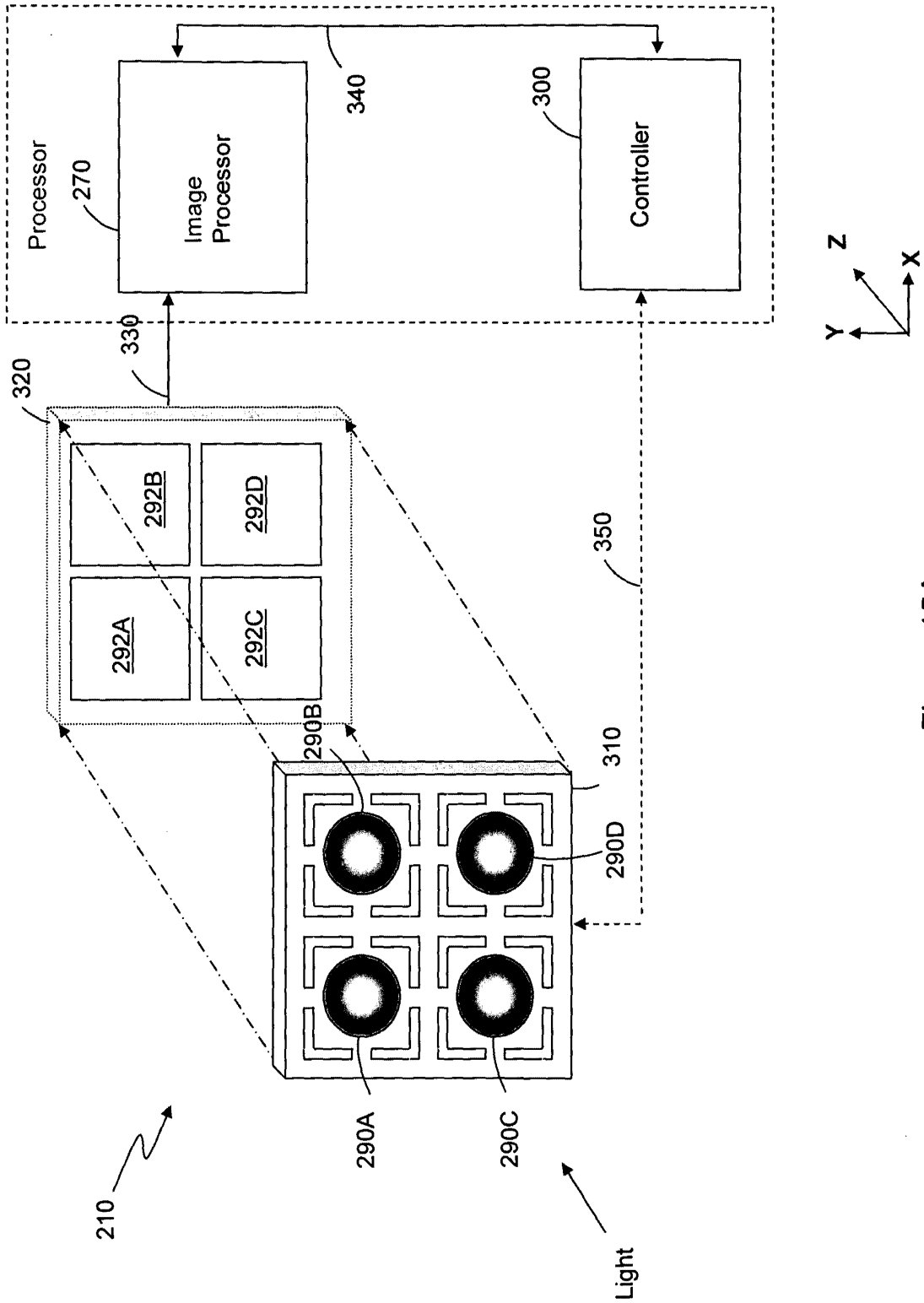
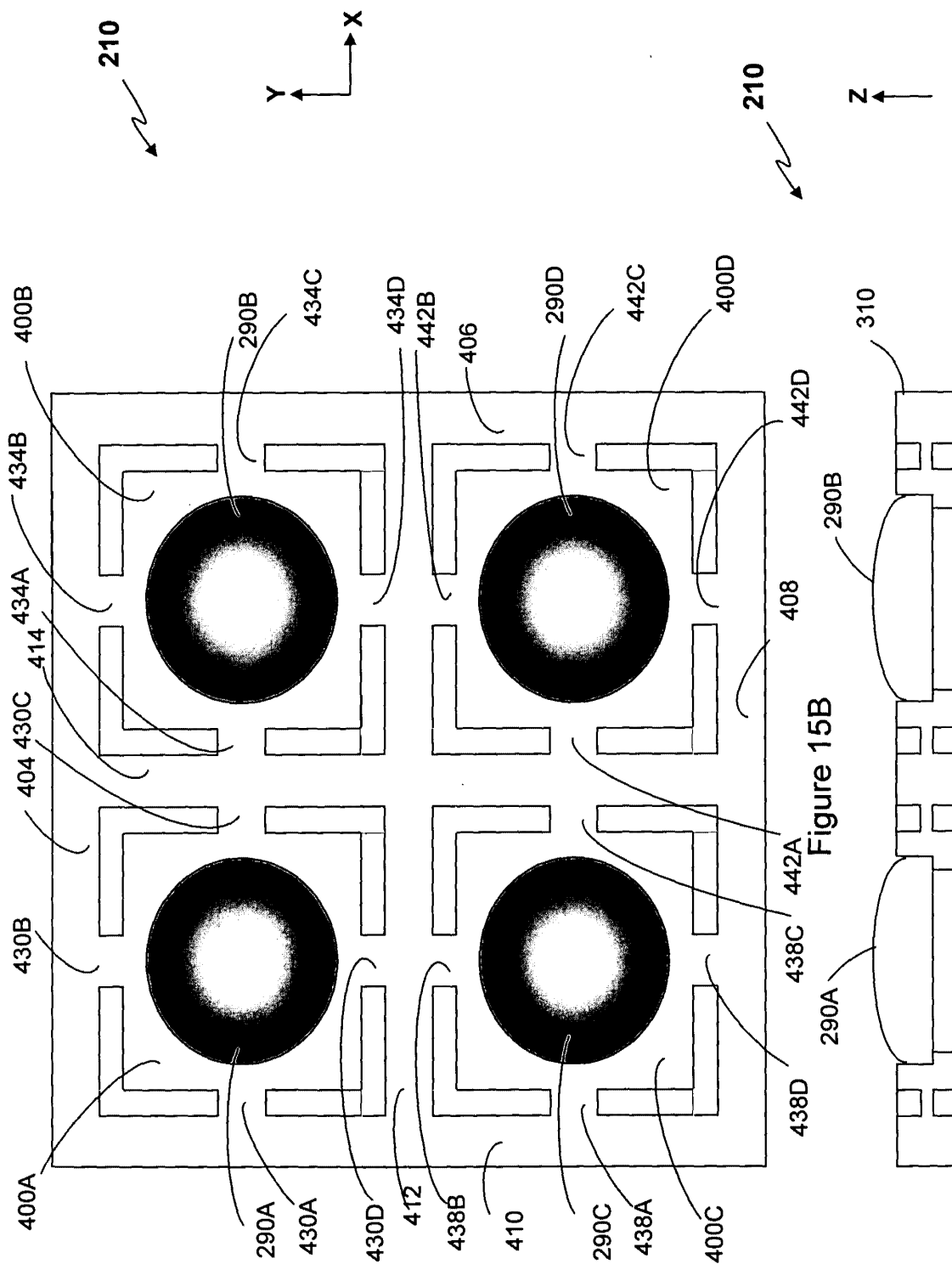


Figure 15A



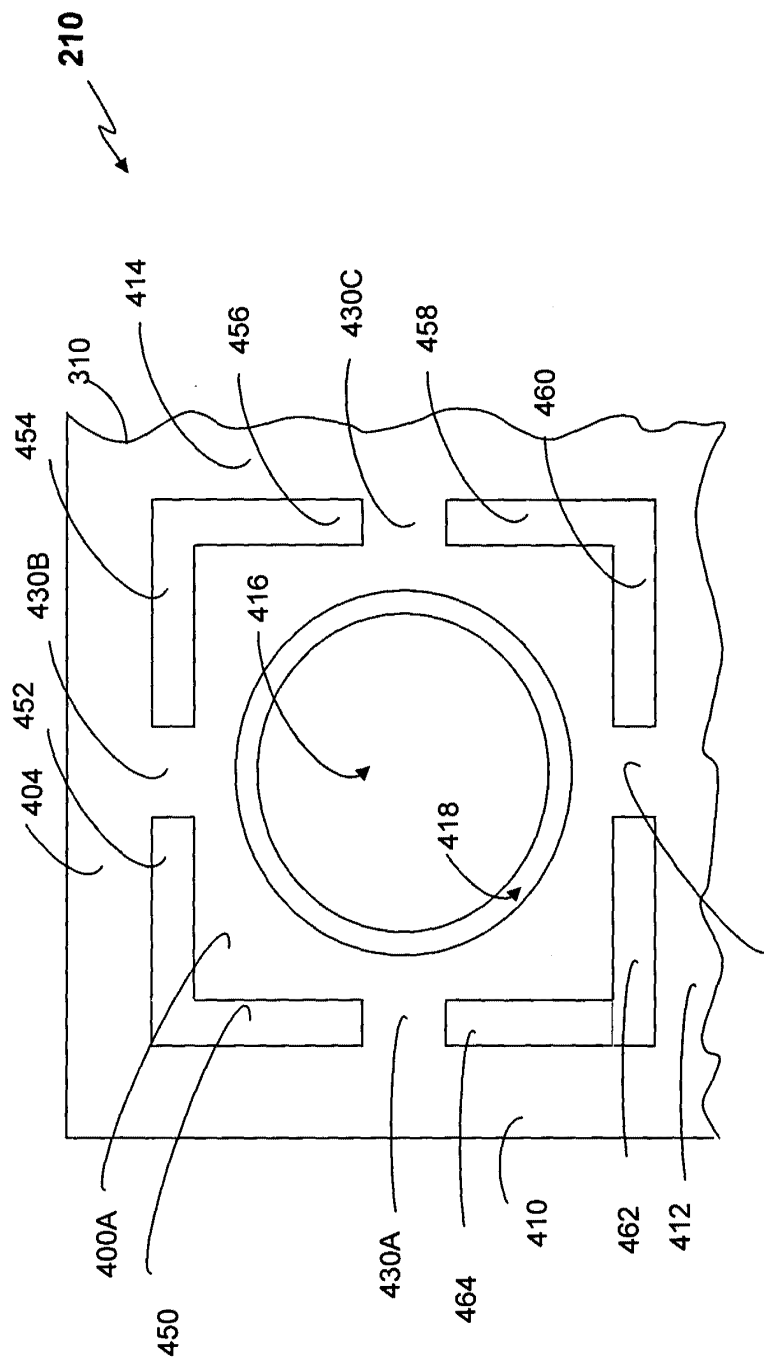


Figure 15D

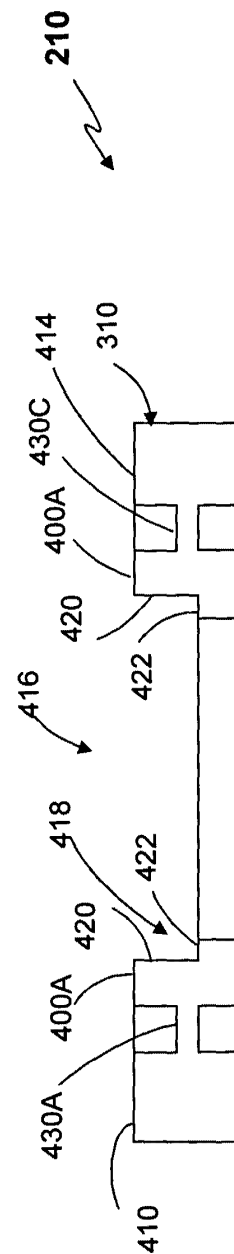
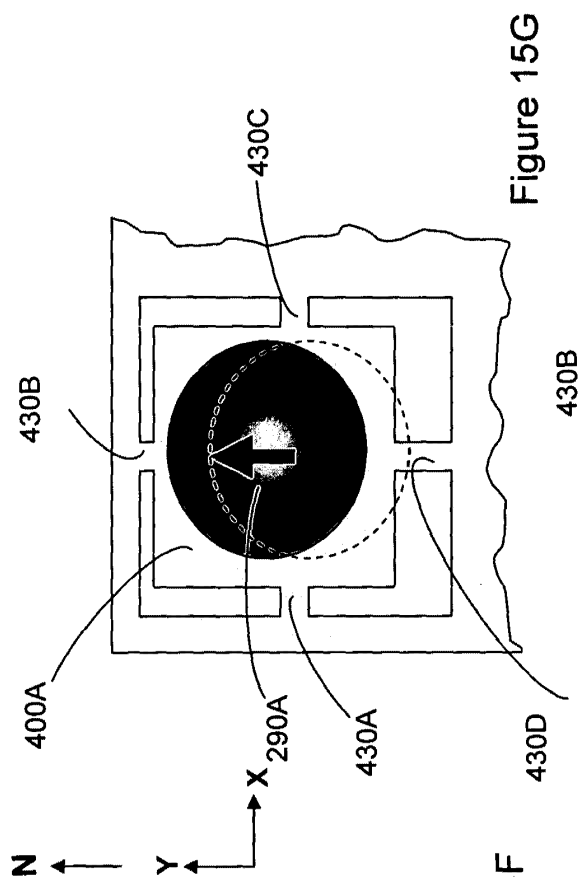
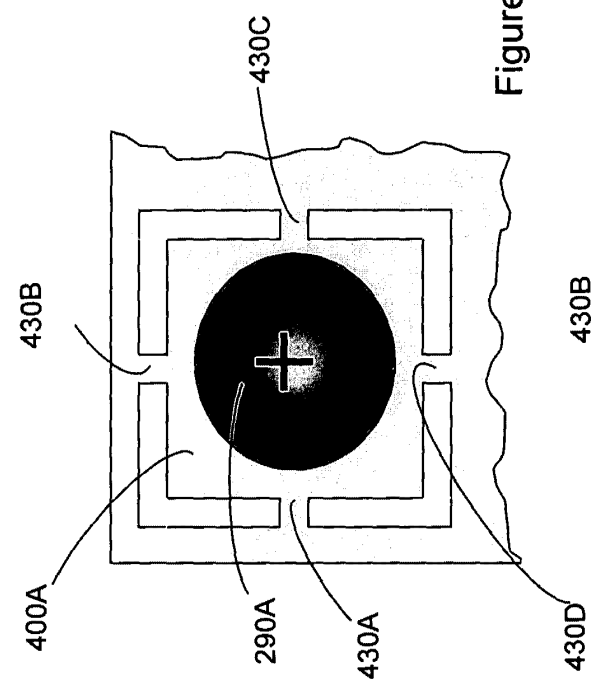
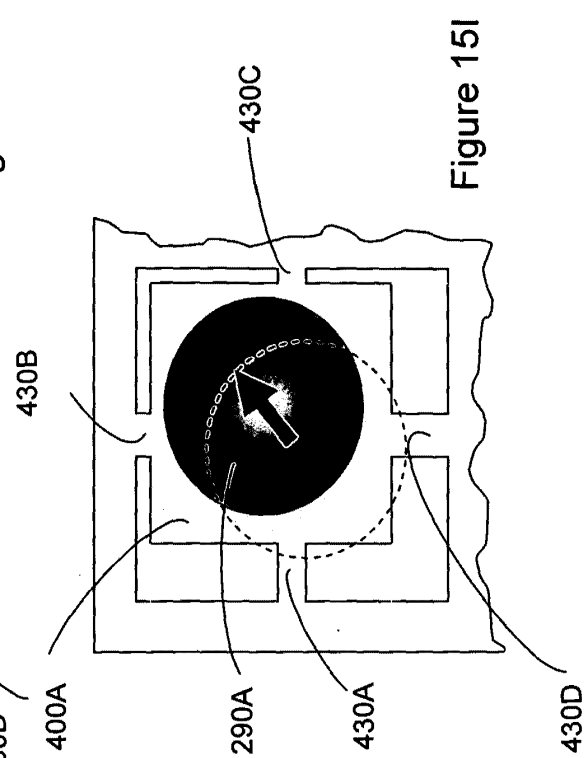
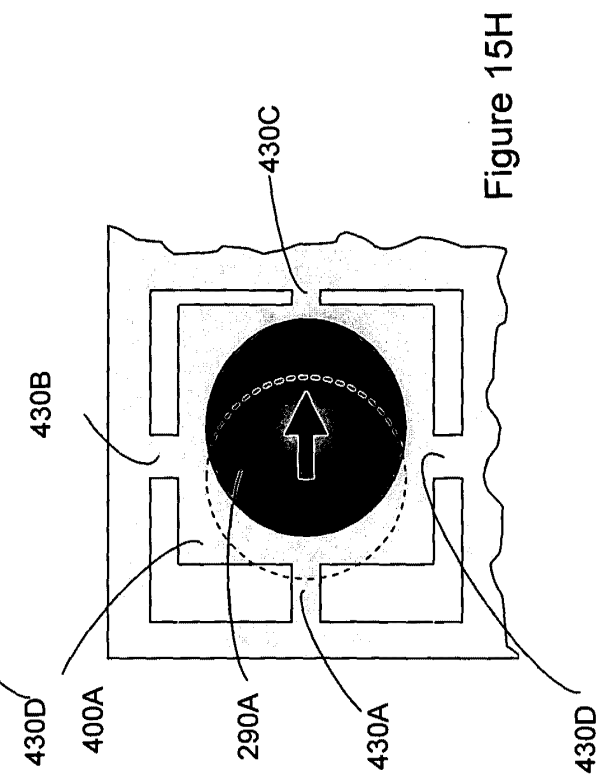


Figure 15E



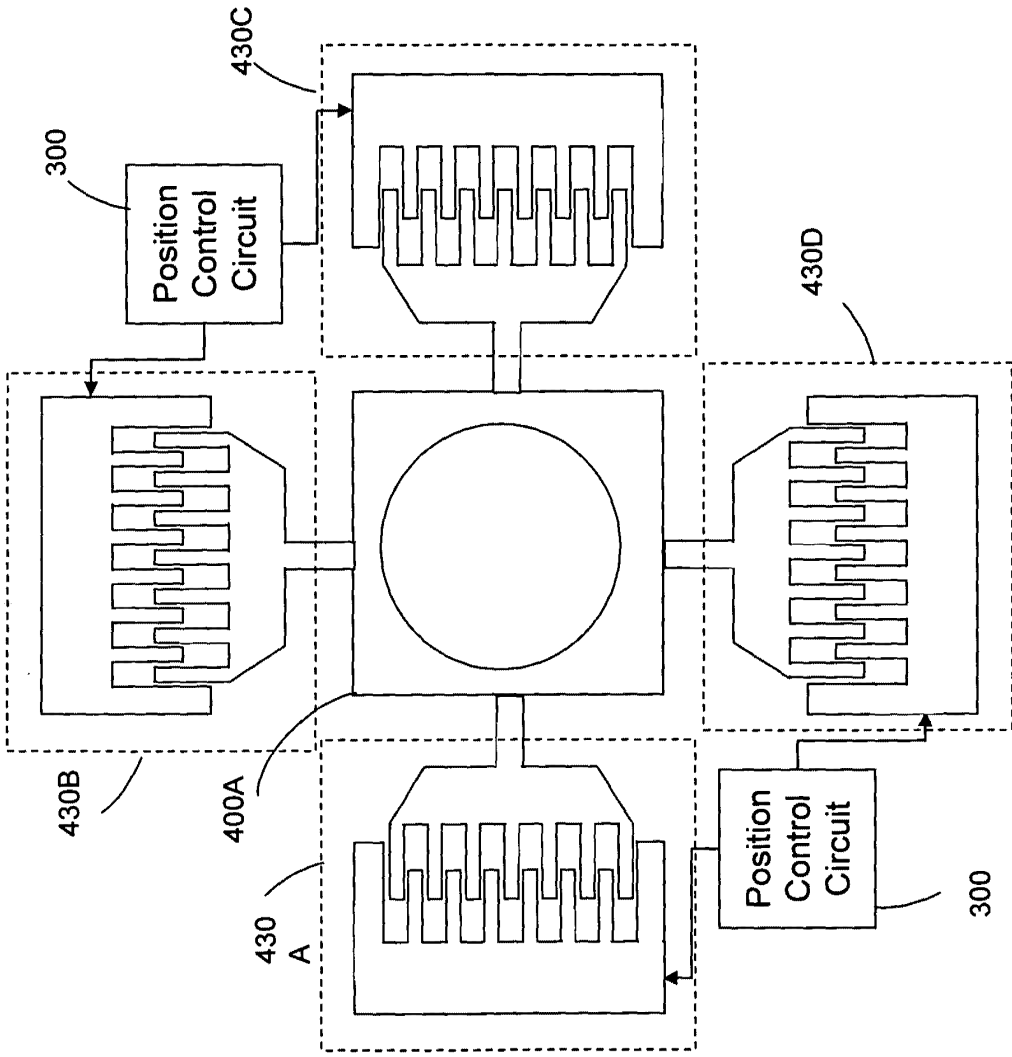


Figure 15J

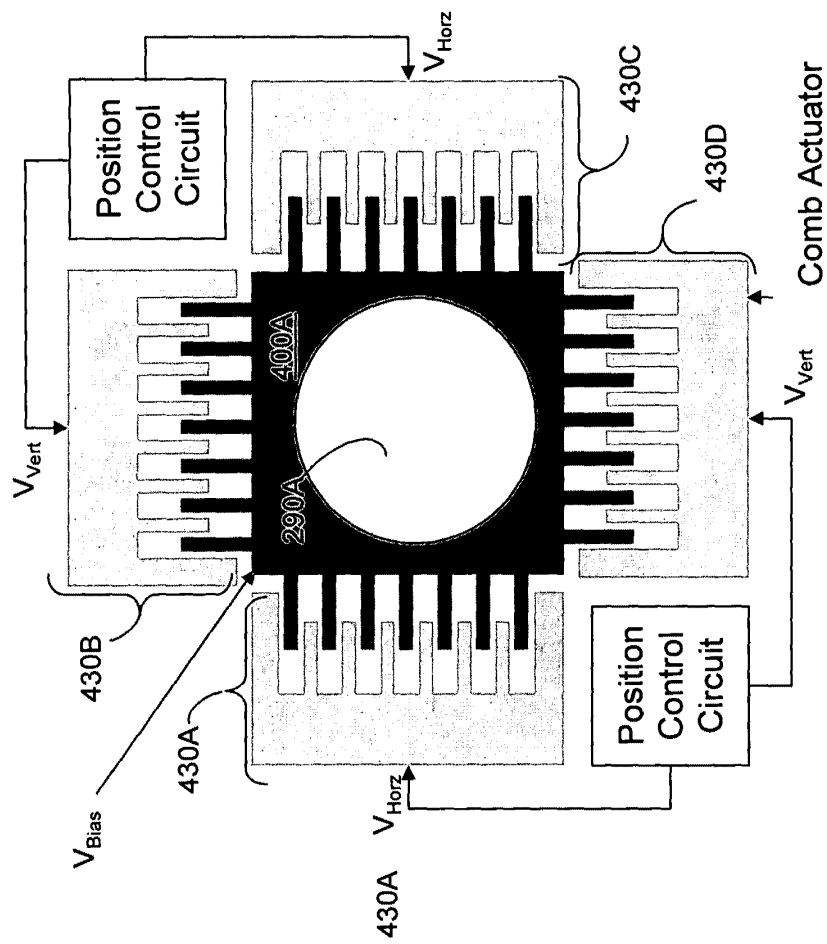


Figure 15K

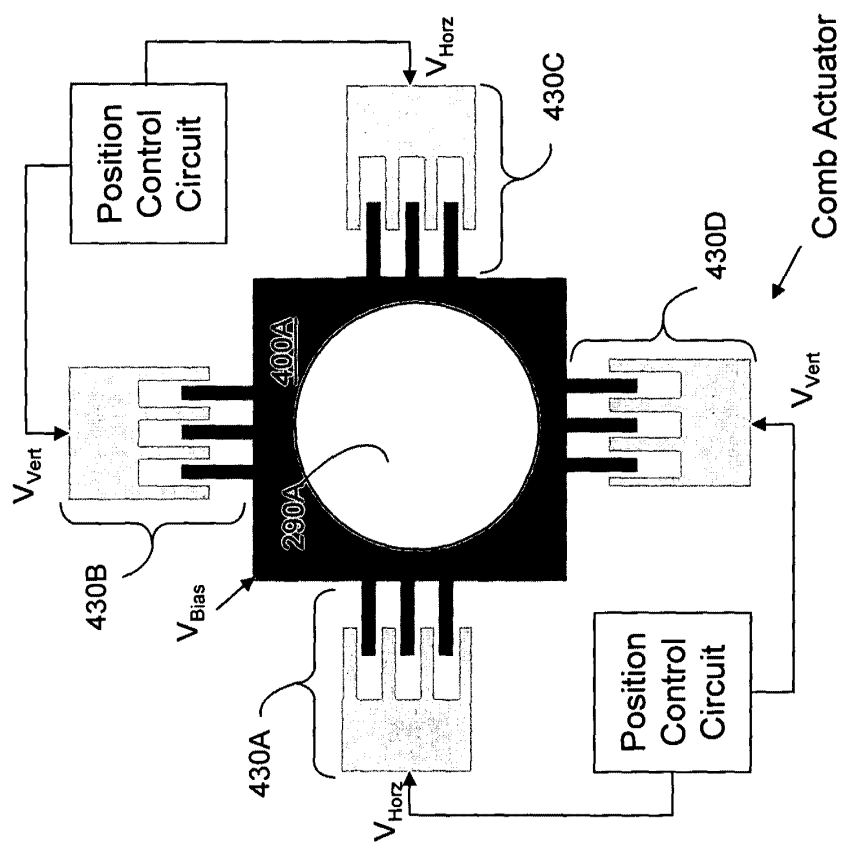


Figure 15L

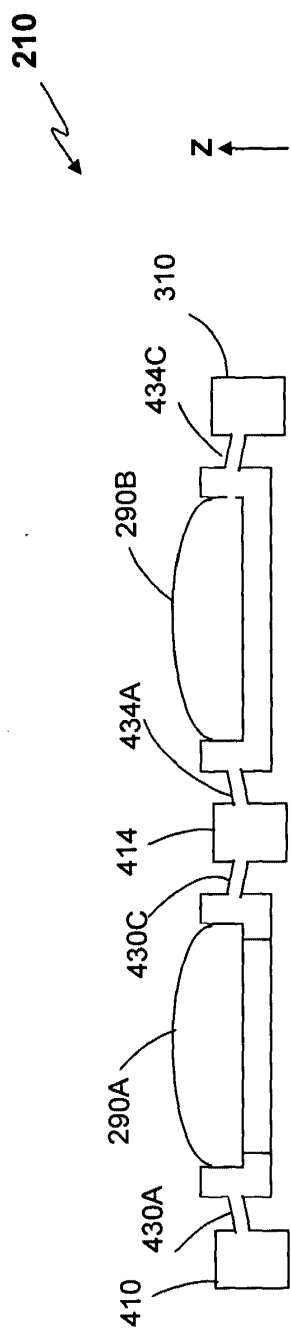


Figure 16A

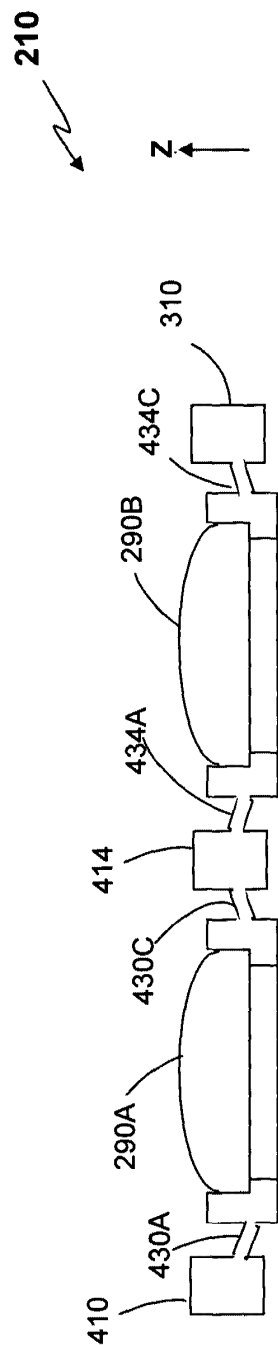
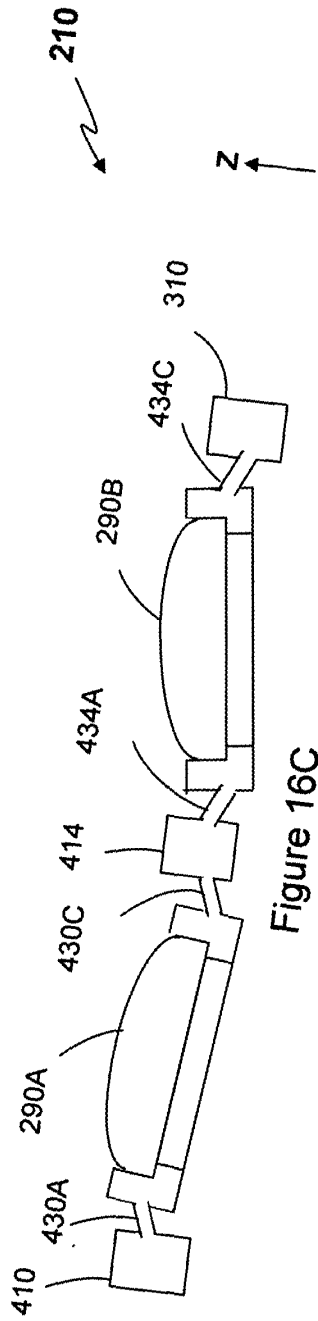
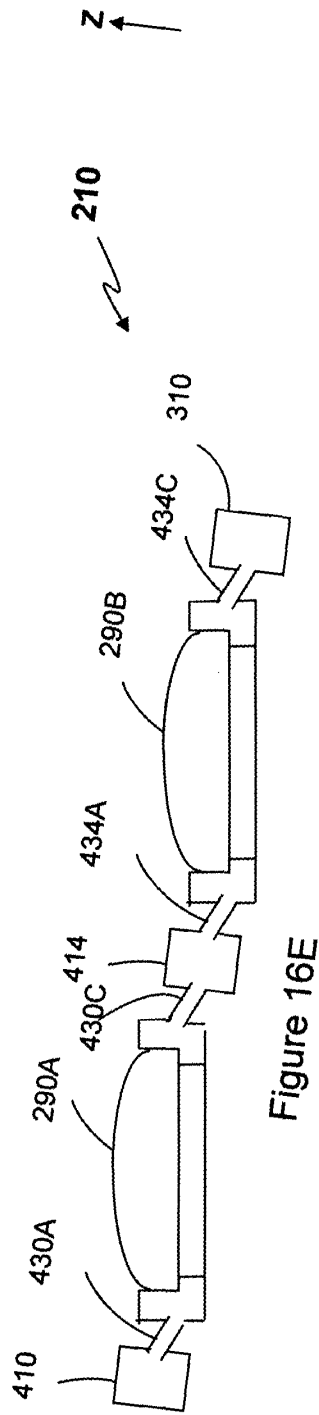
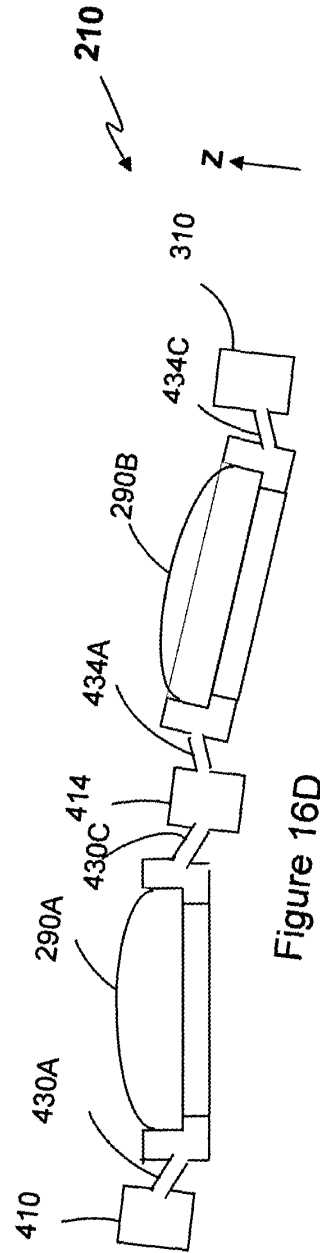


Figure 16B



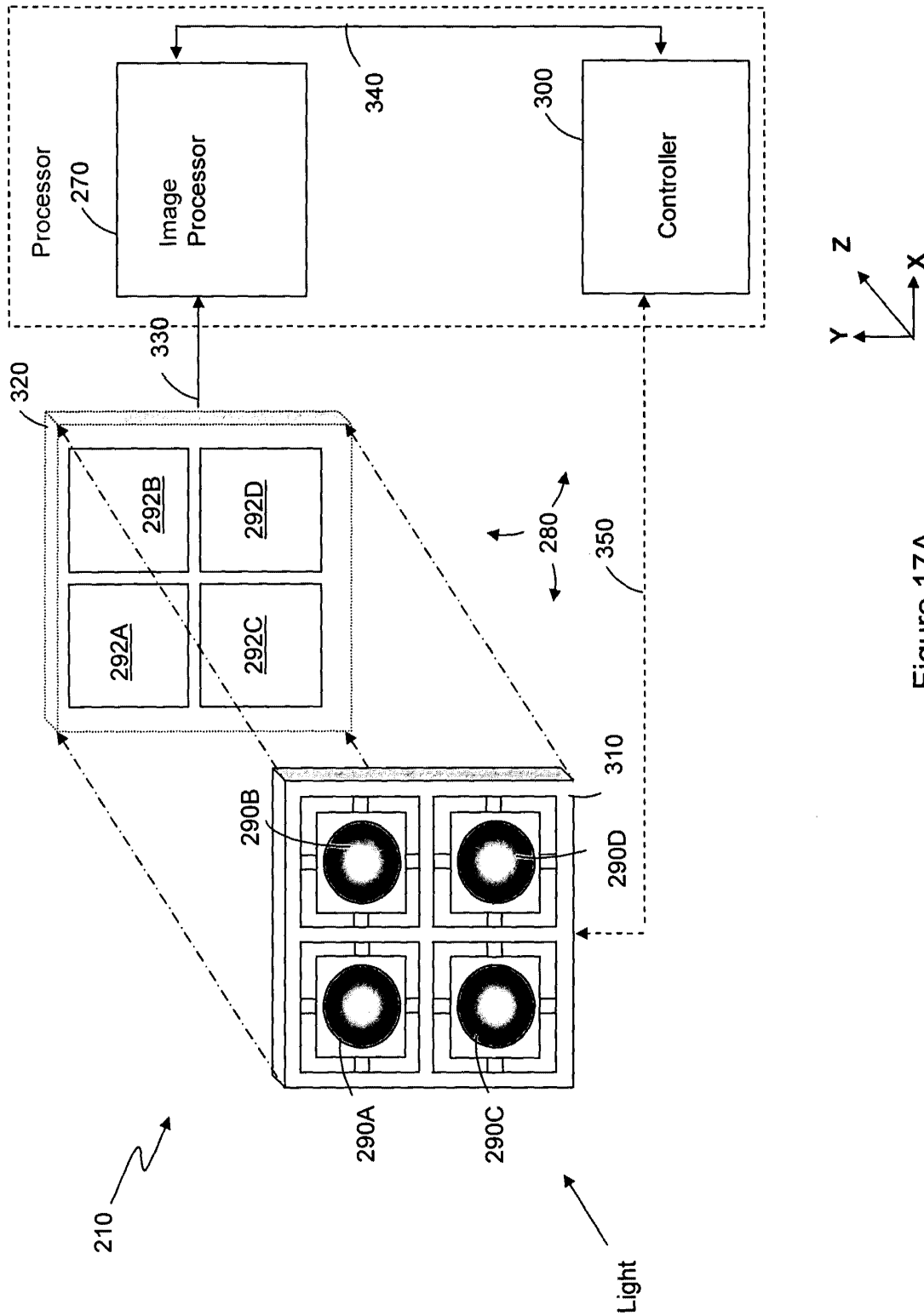


Figure 17A

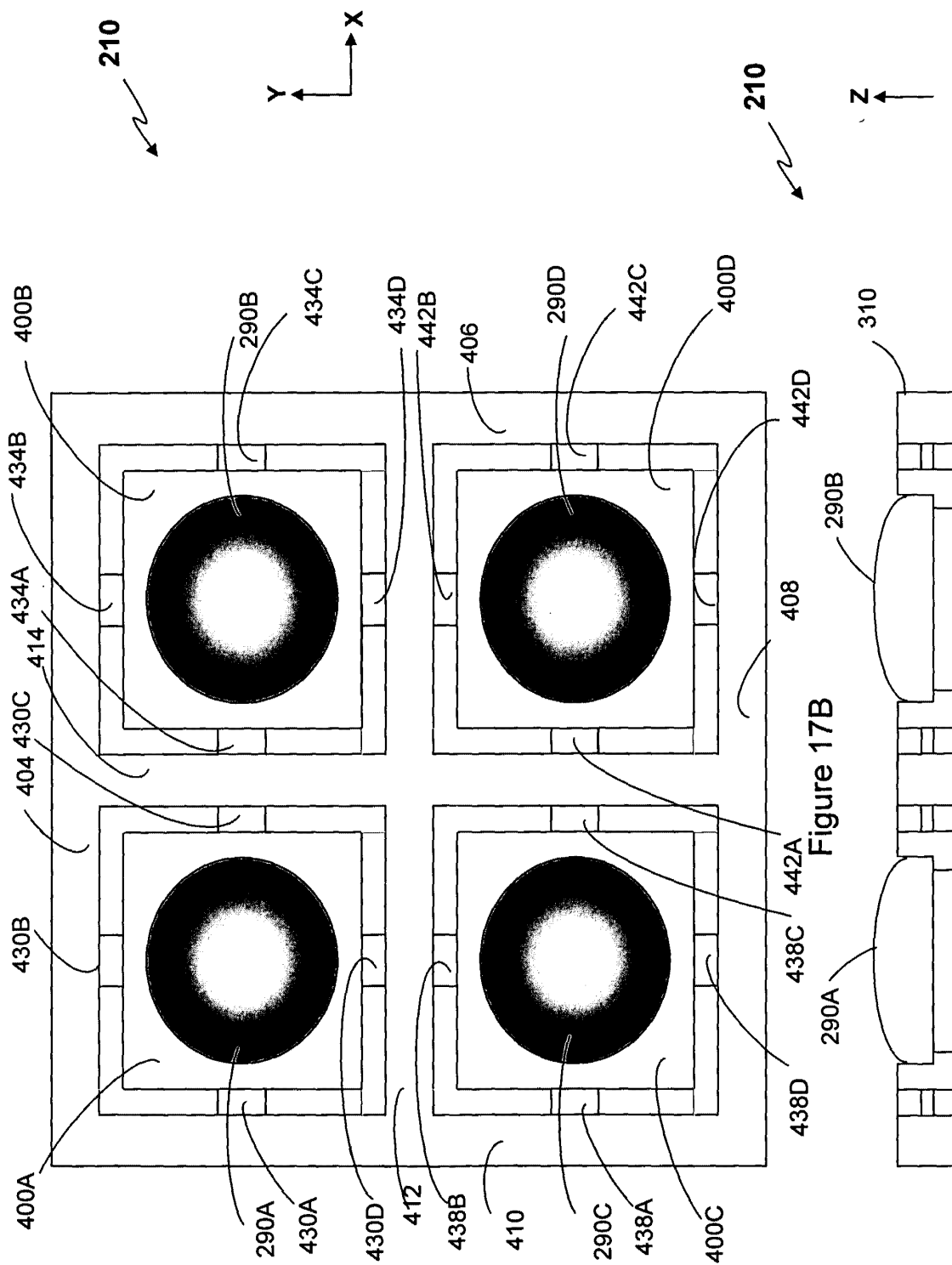


Figure 17C

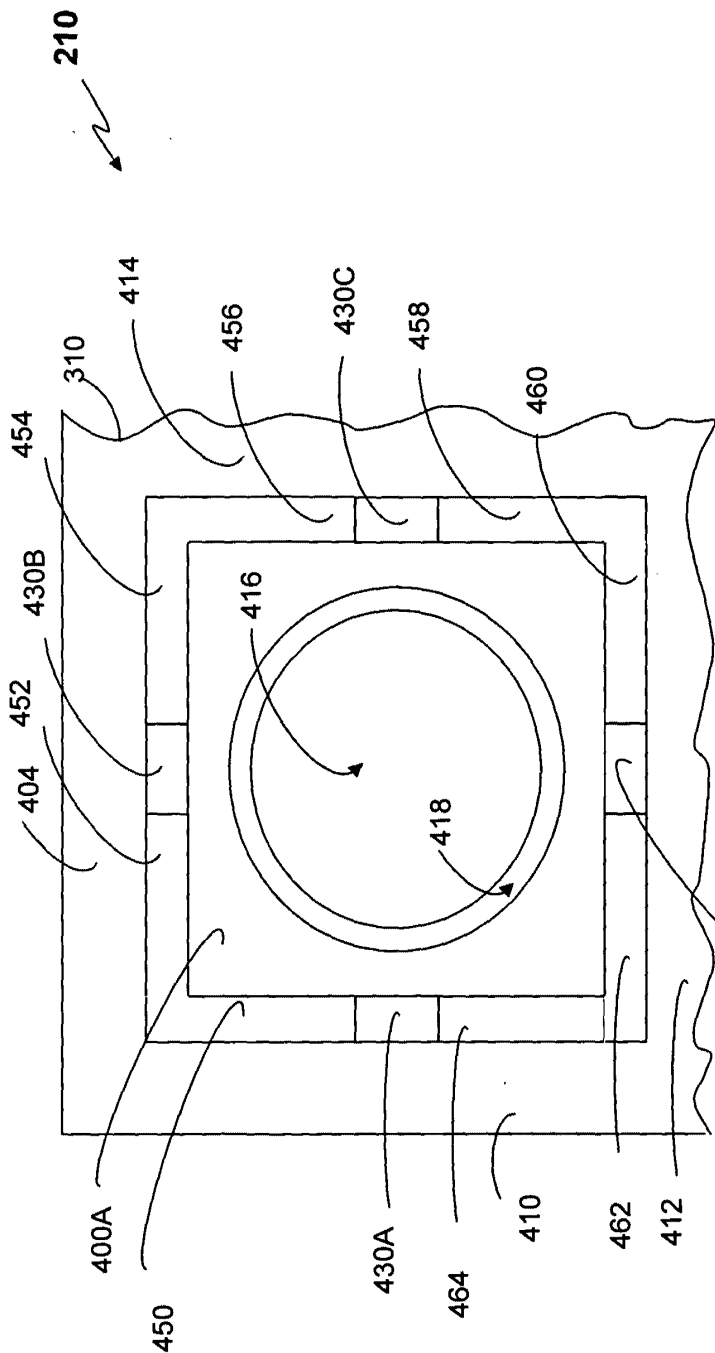


Figure 17D

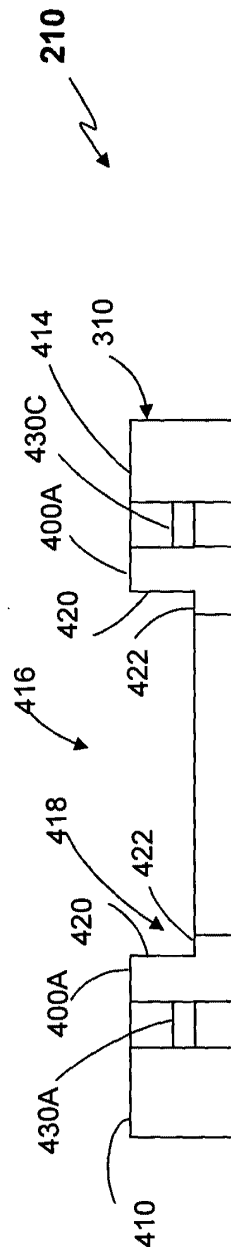


Figure 17E

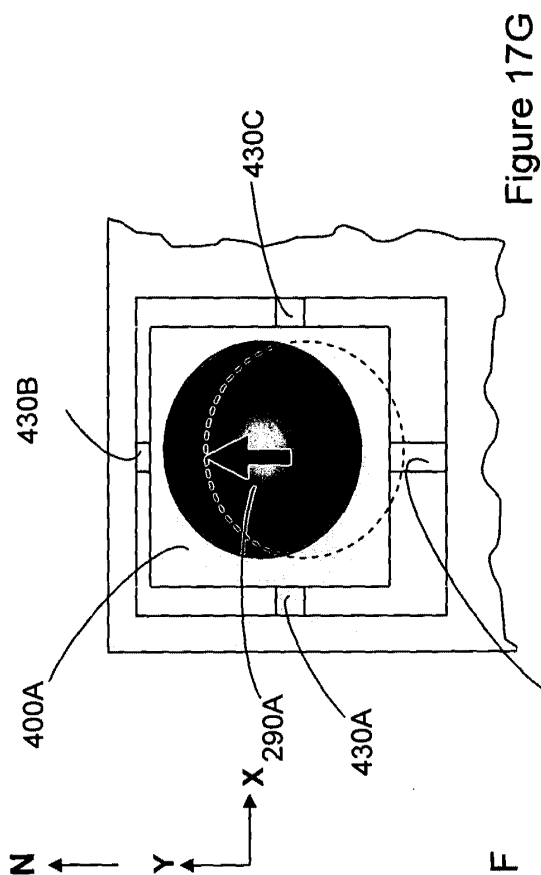


Figure 17F

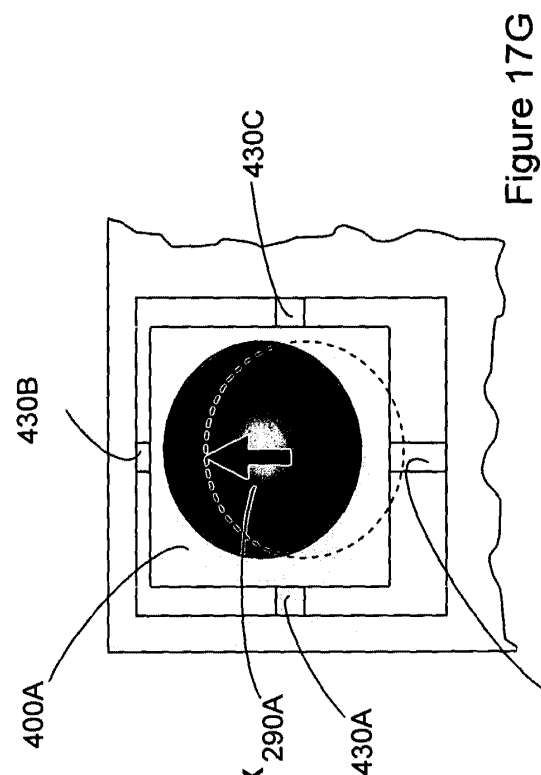


Figure 17G

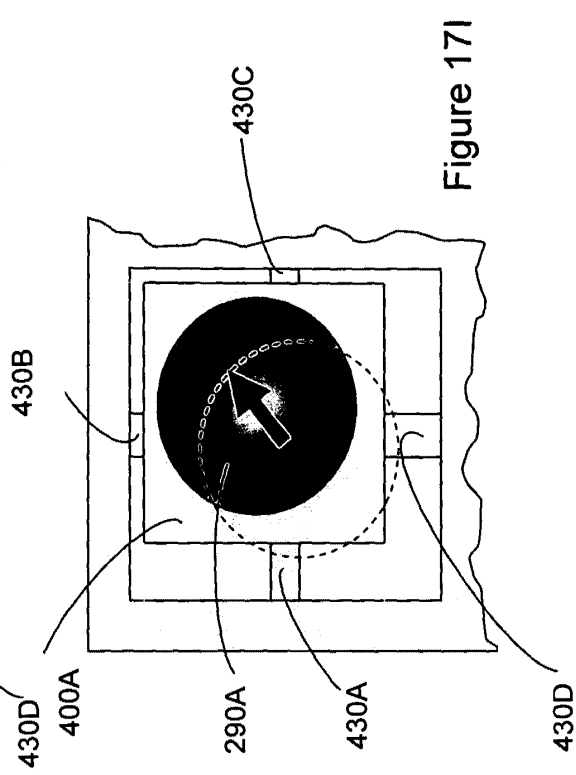


Figure 17H

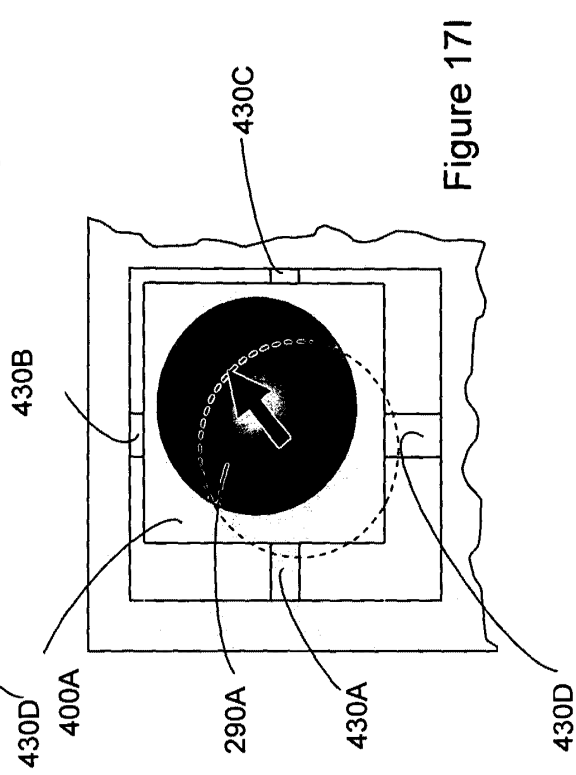


Figure 17I

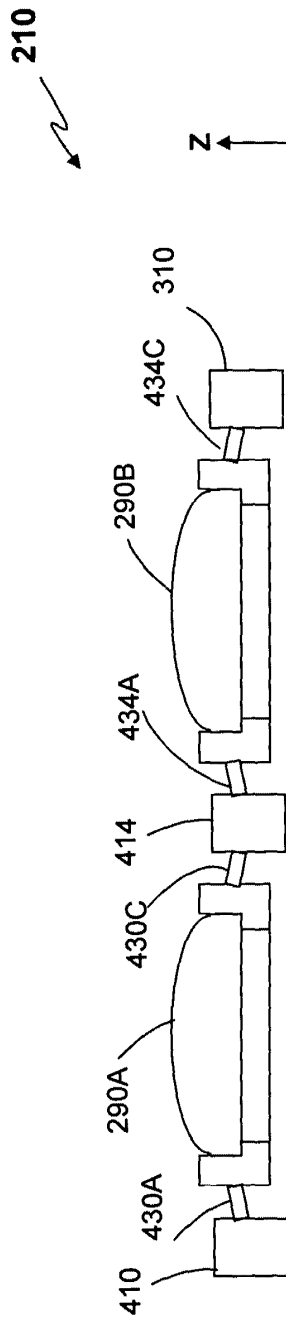


Figure 18A

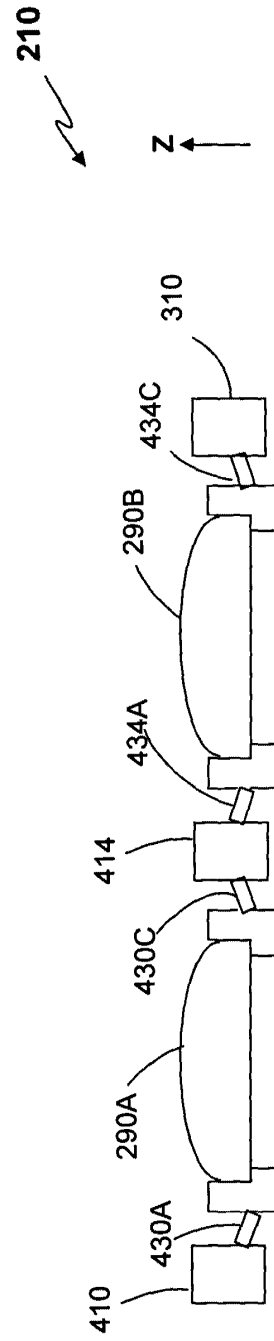
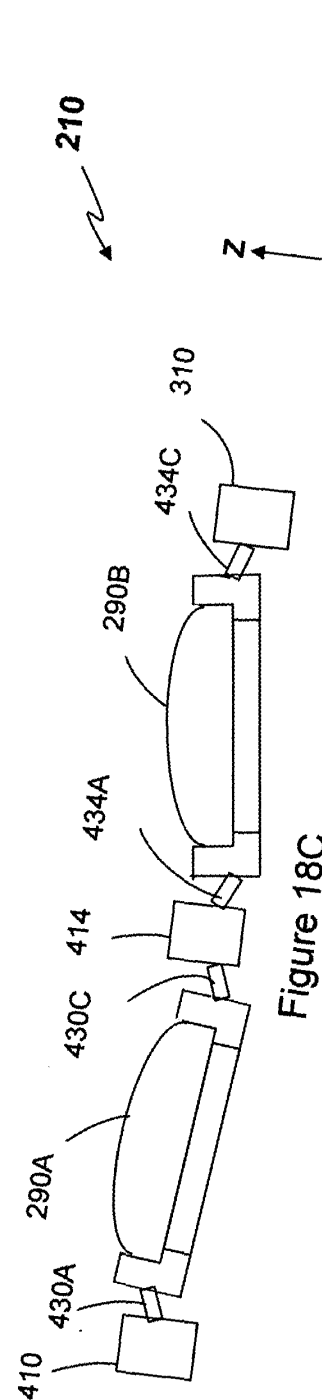
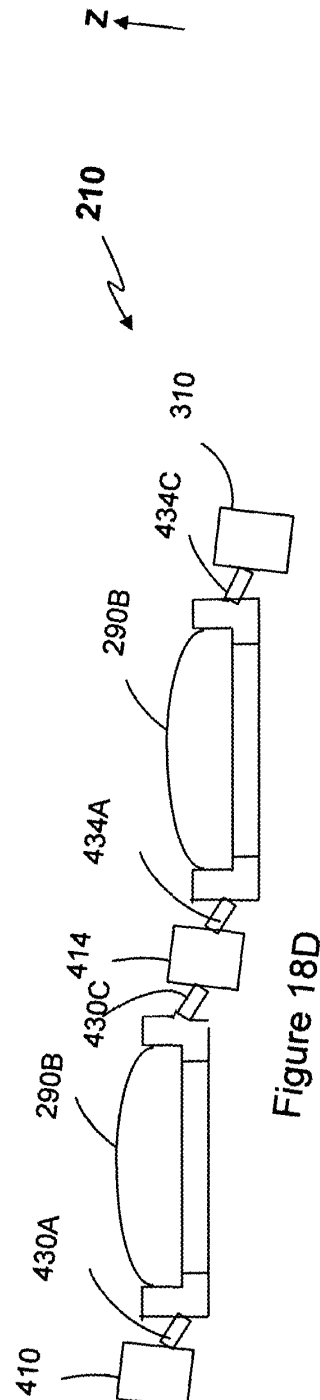
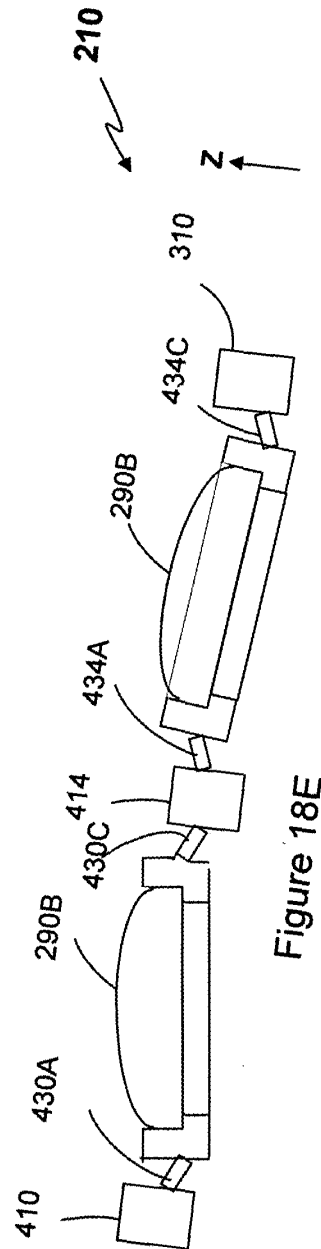


Figure 18B



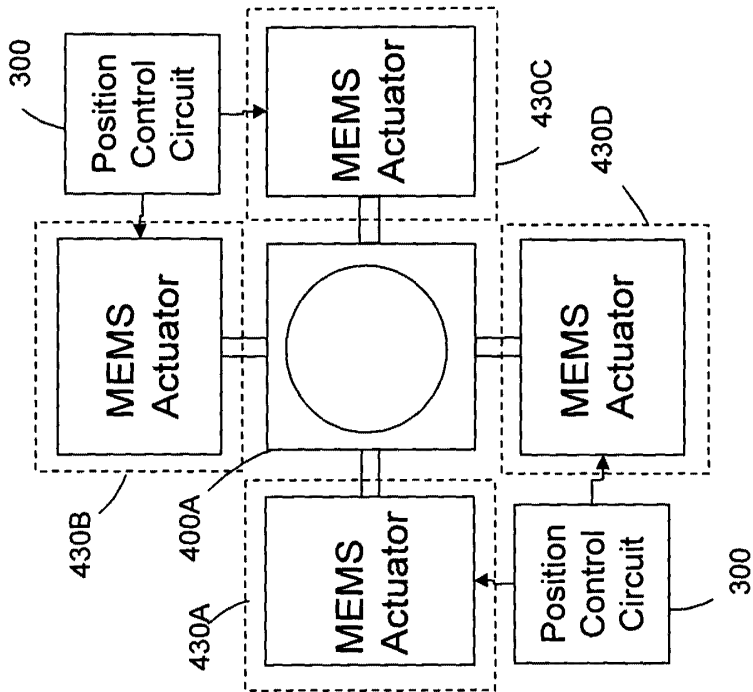


Figure 19B

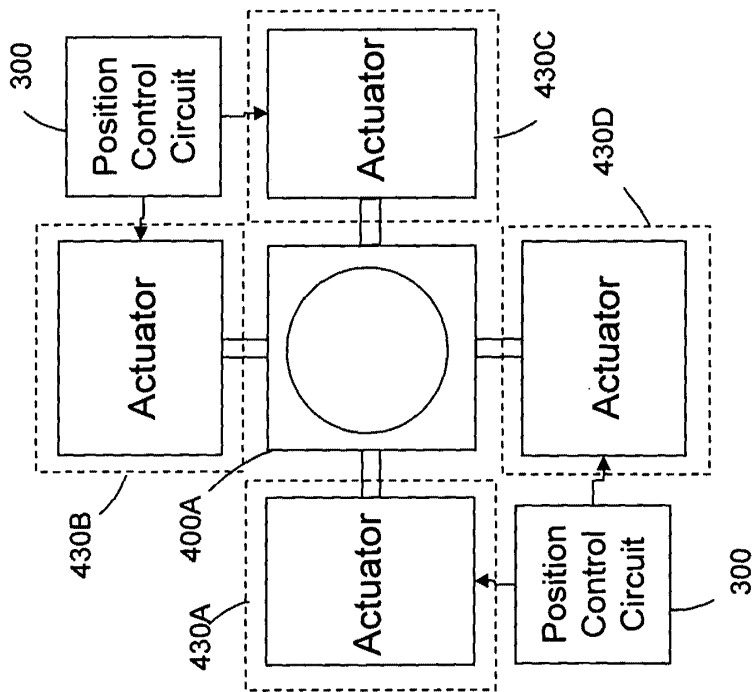


Figure 19A

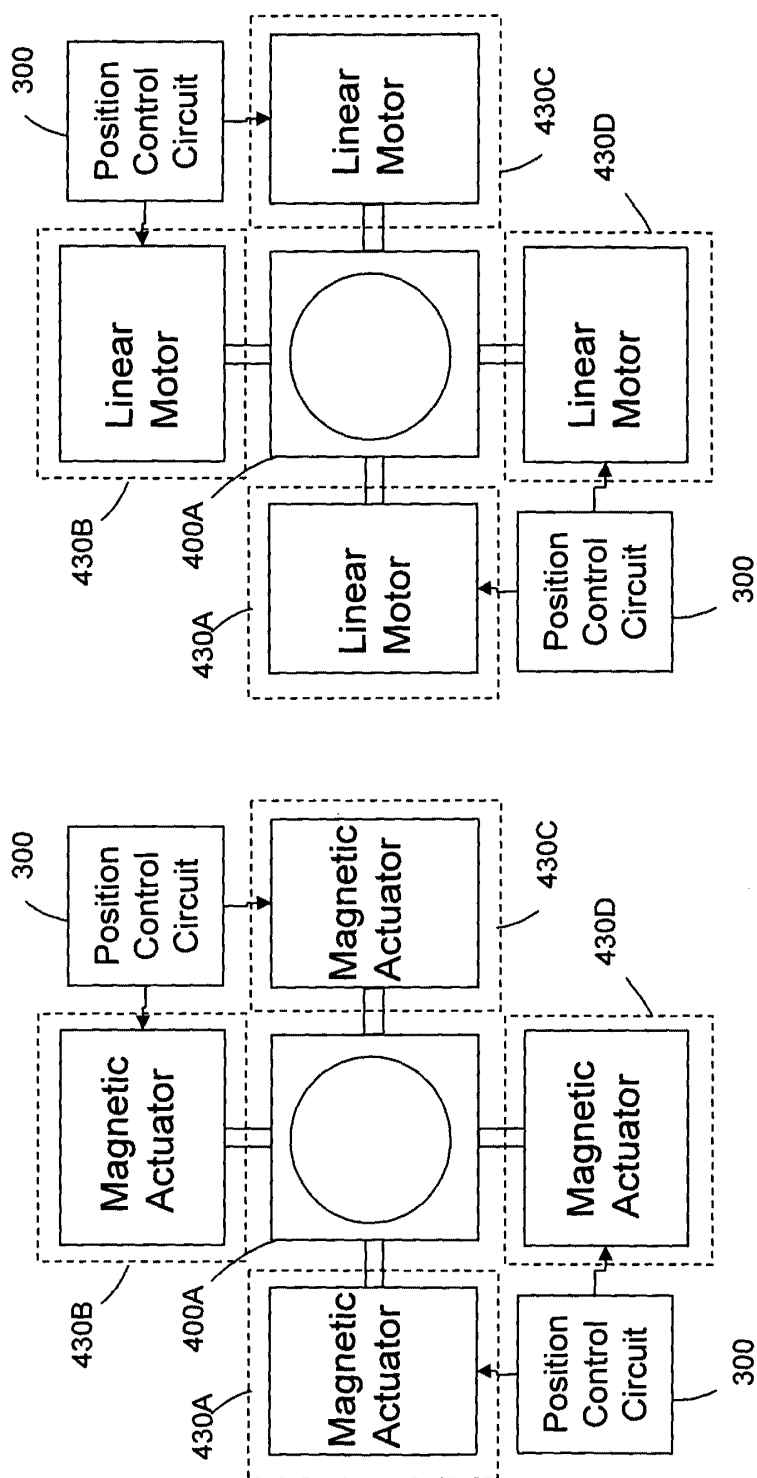


Figure 19D

Figure 19C

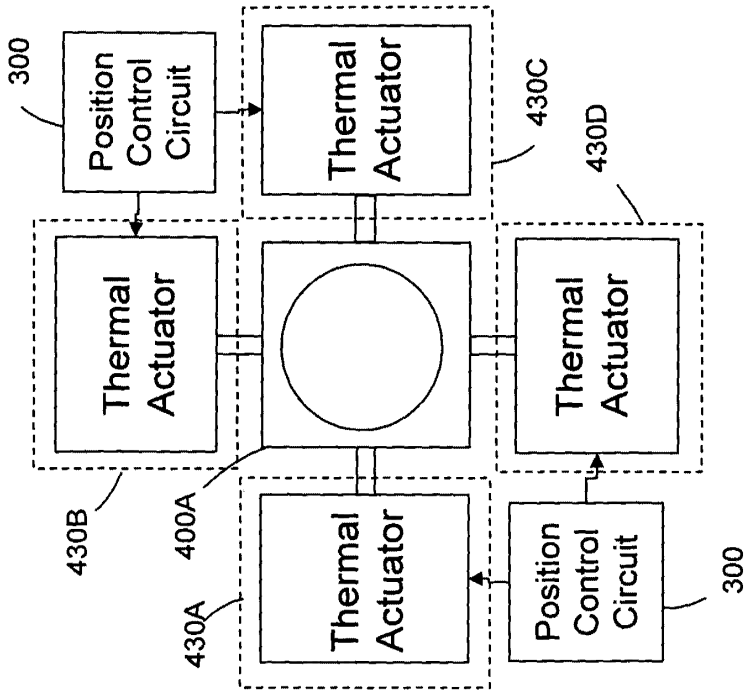


Figure 19F

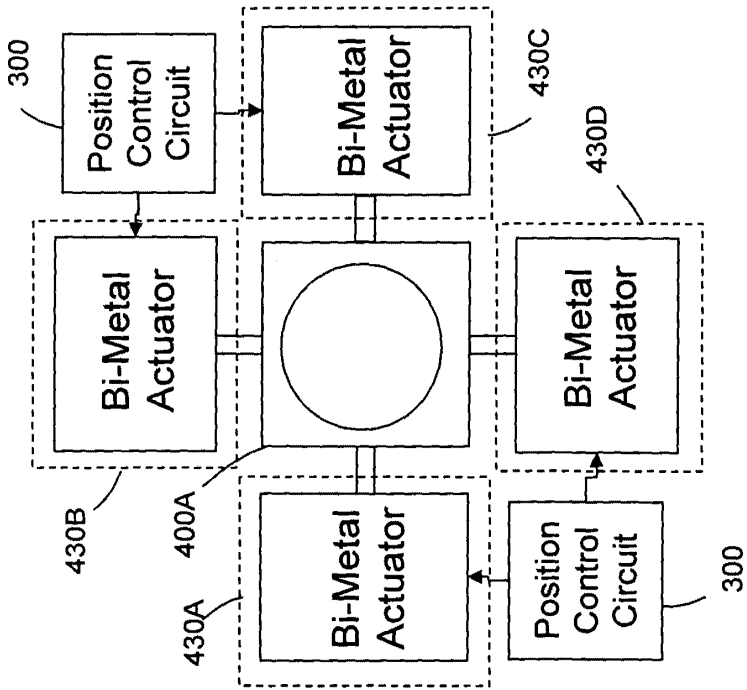


Figure 19E

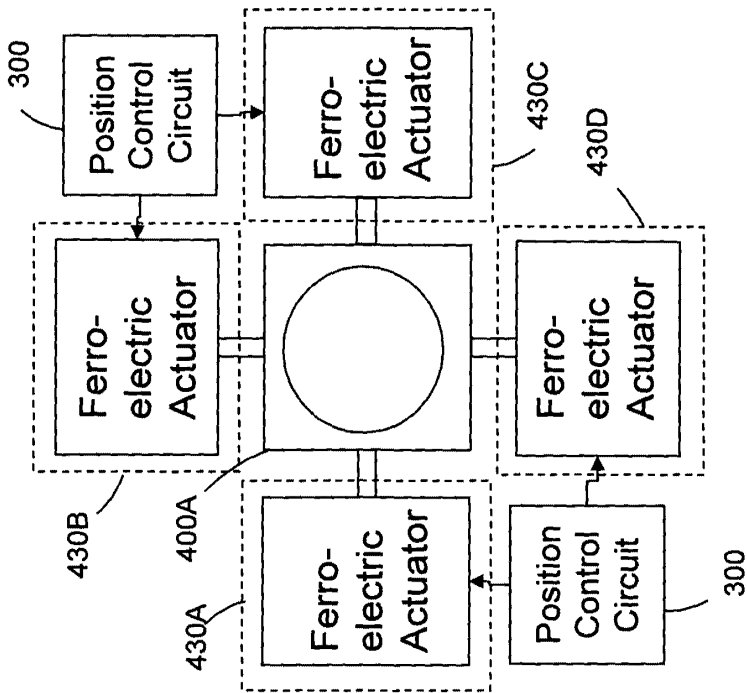


Figure 19G

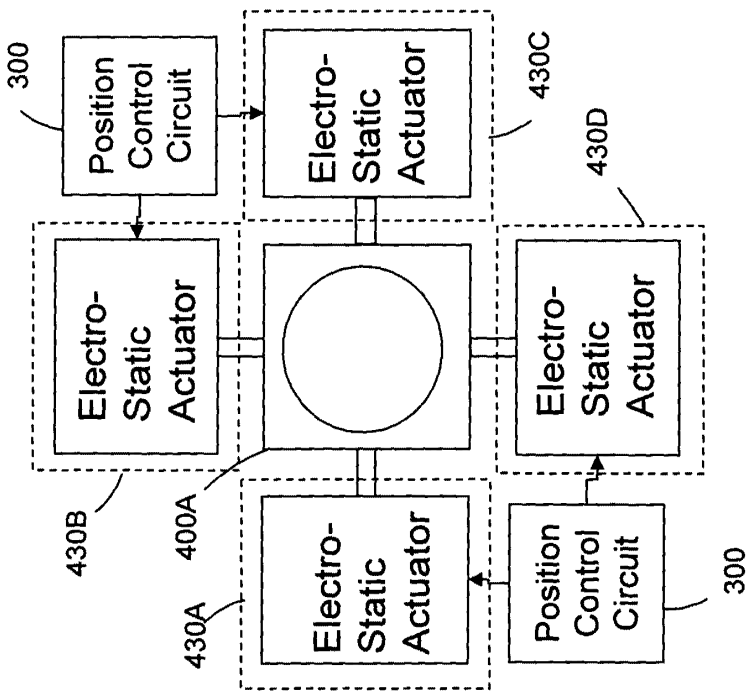


Figure 19H

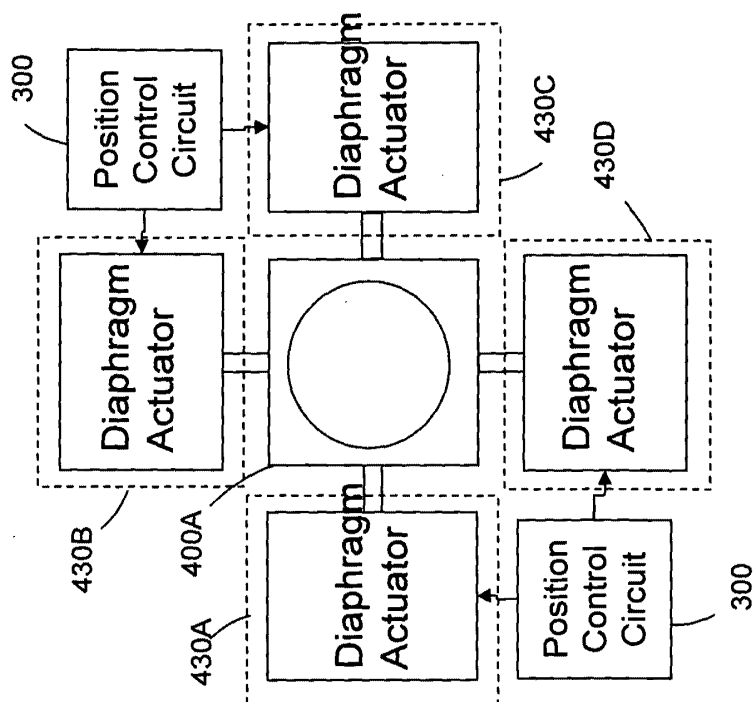


Figure 19J

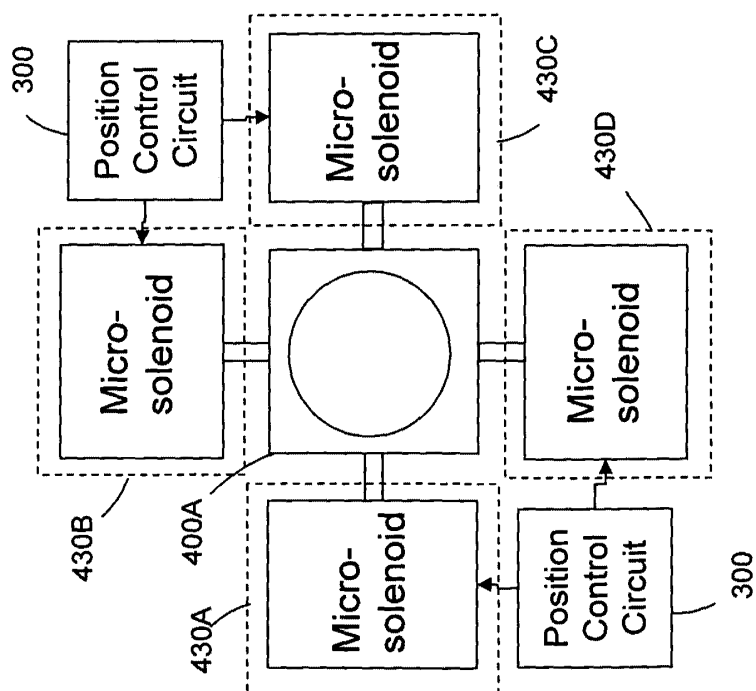


Figure 19I

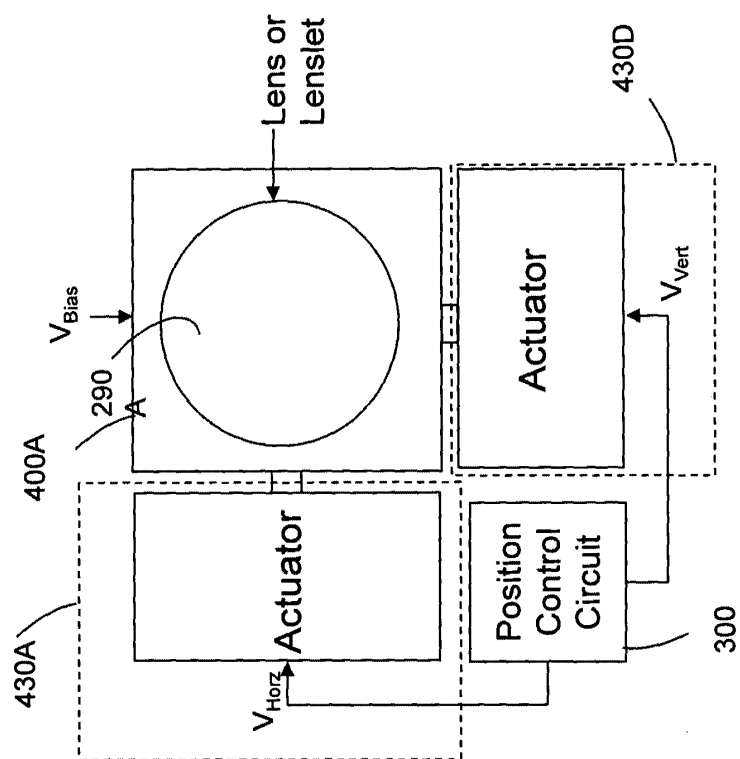


Figure 20A

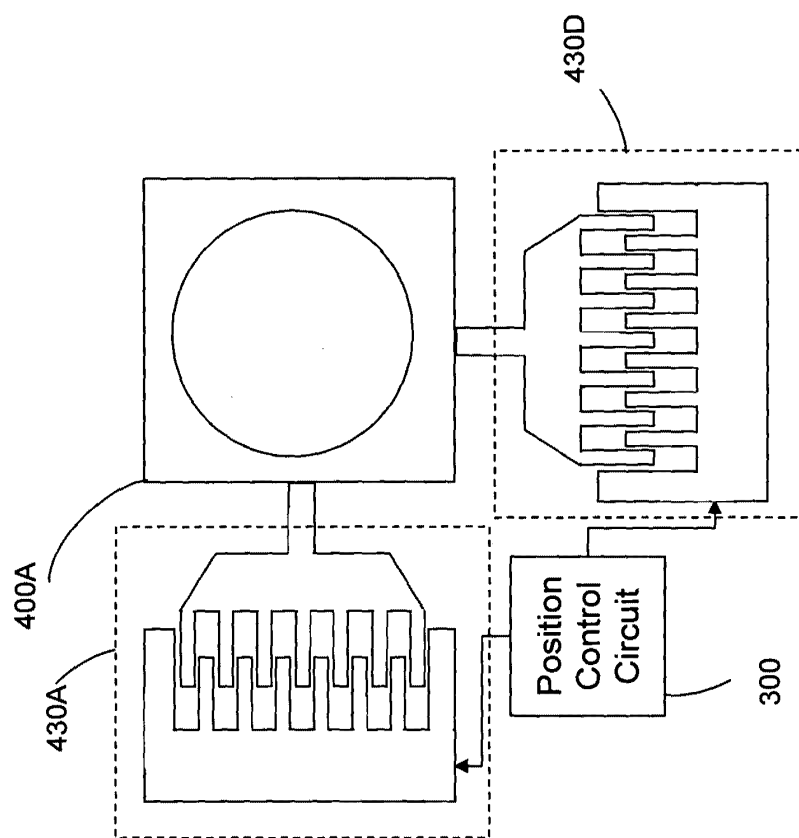


Figure 20B

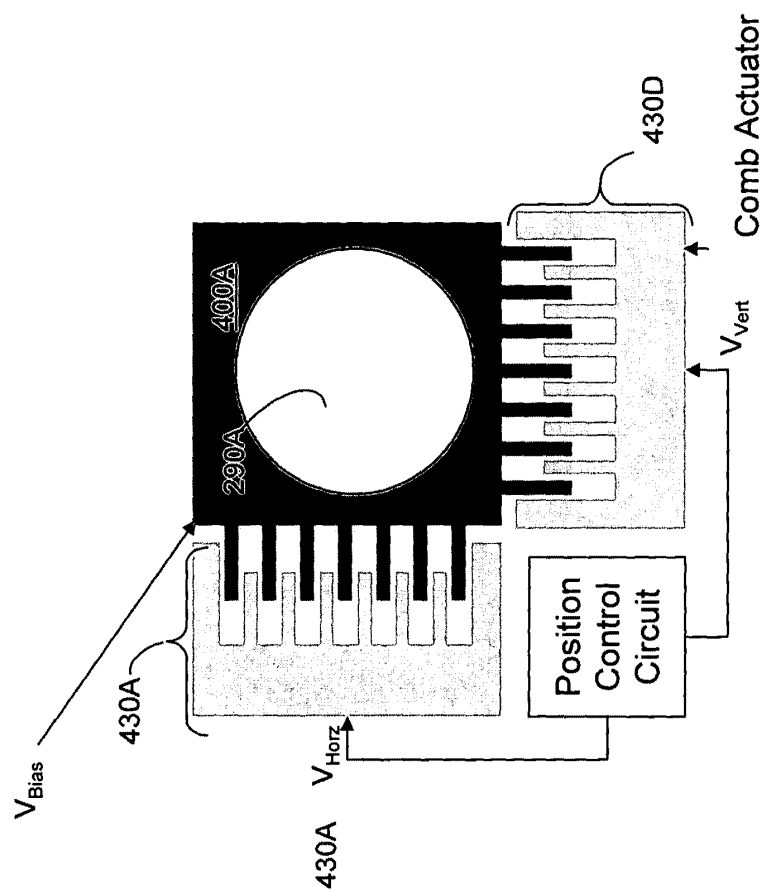


Figure 20C

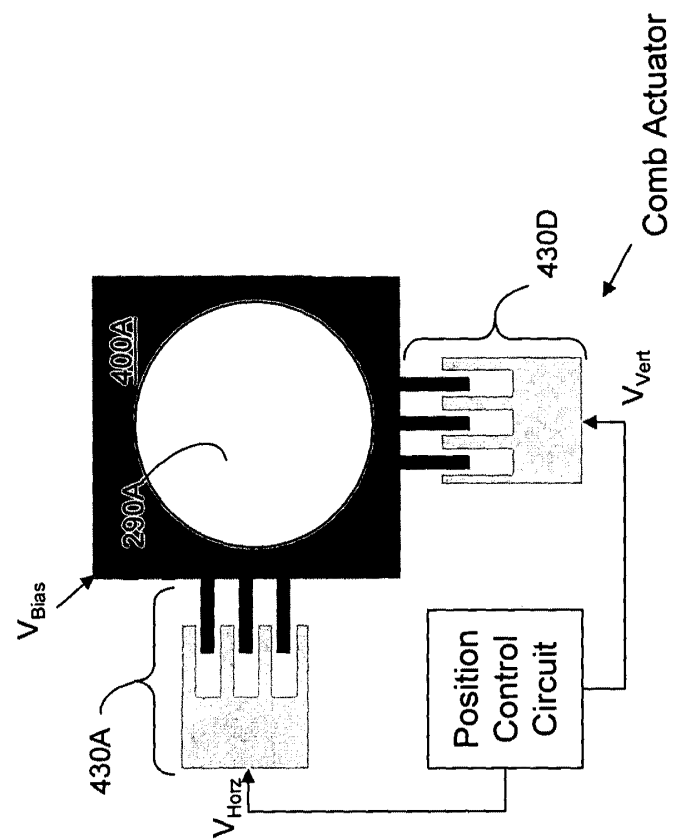


Figure 20D

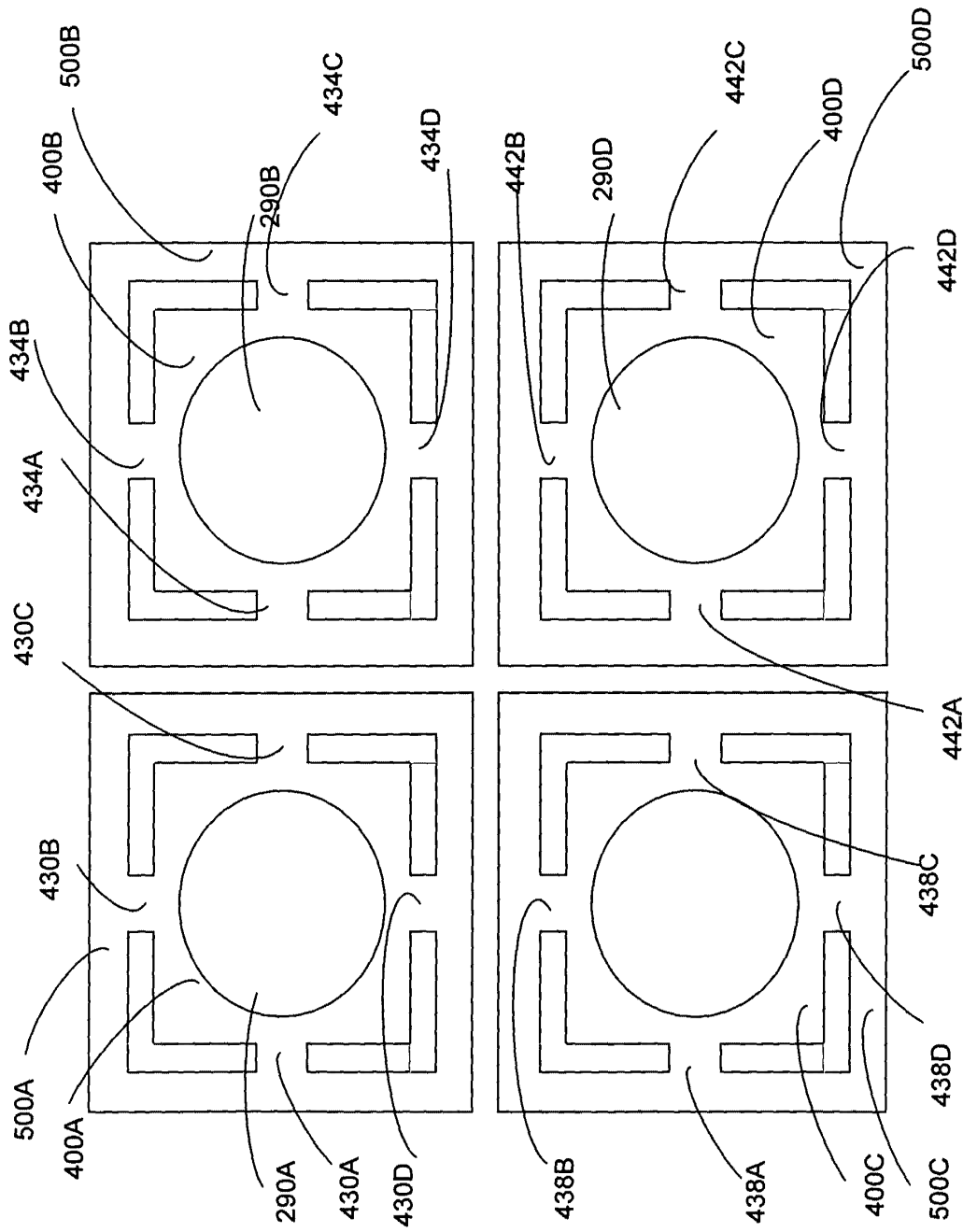


Figure 21A

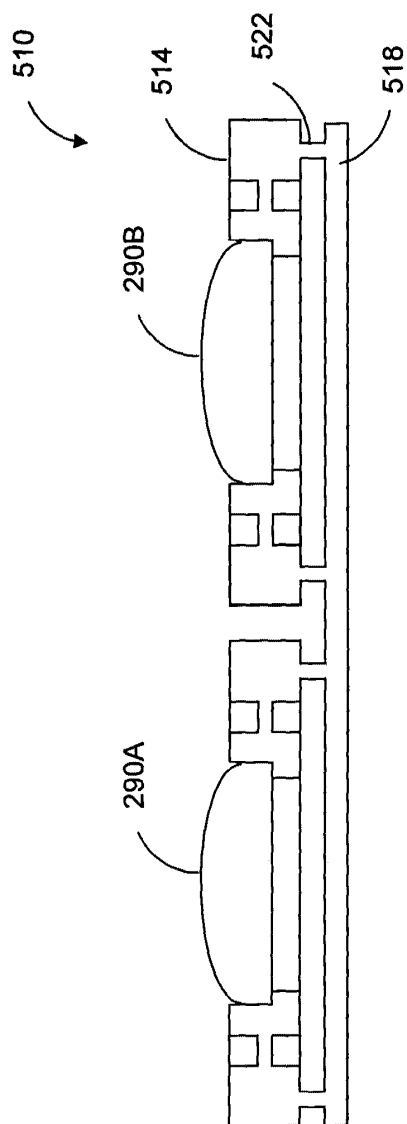


Figure 21B

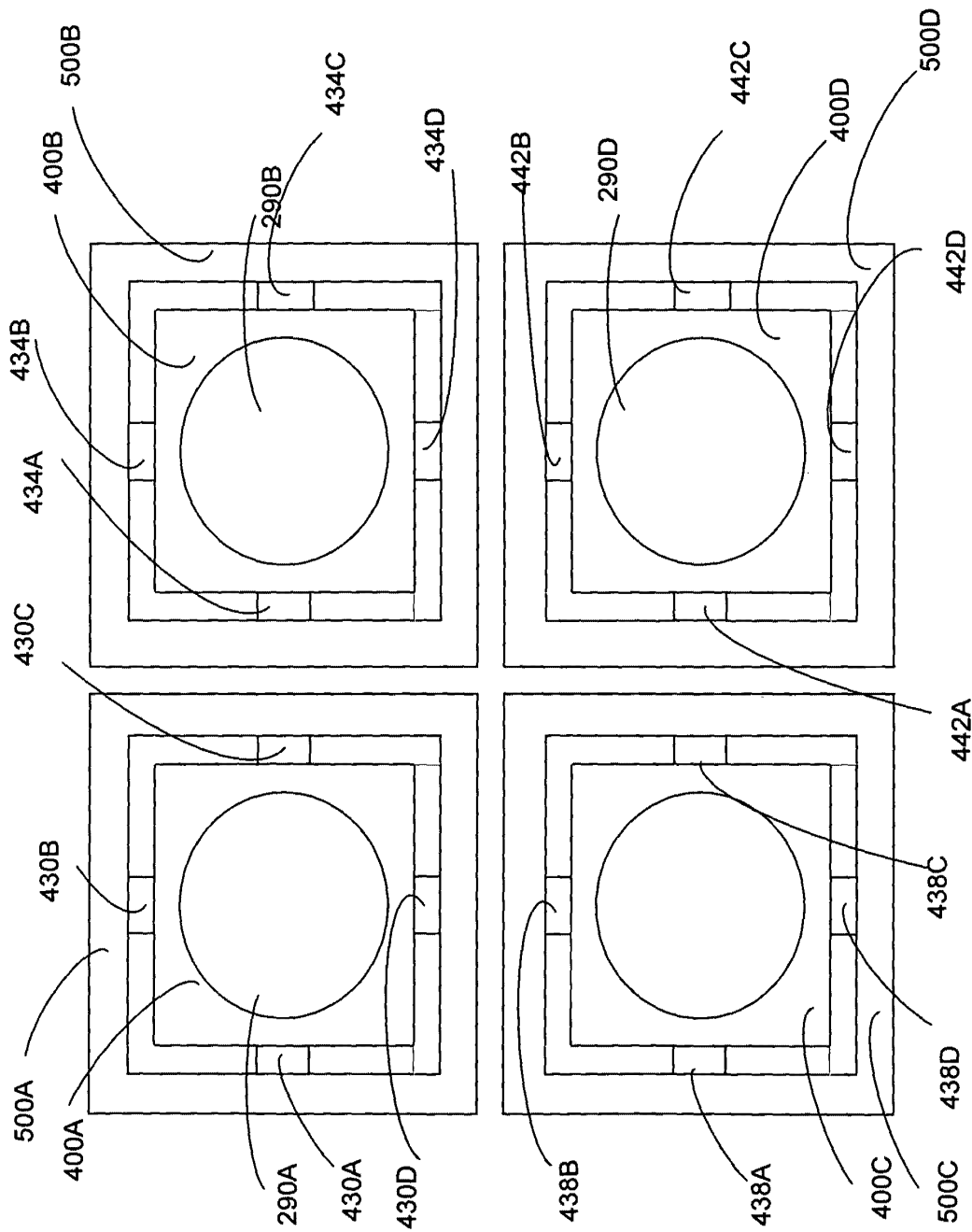


Figure 21C

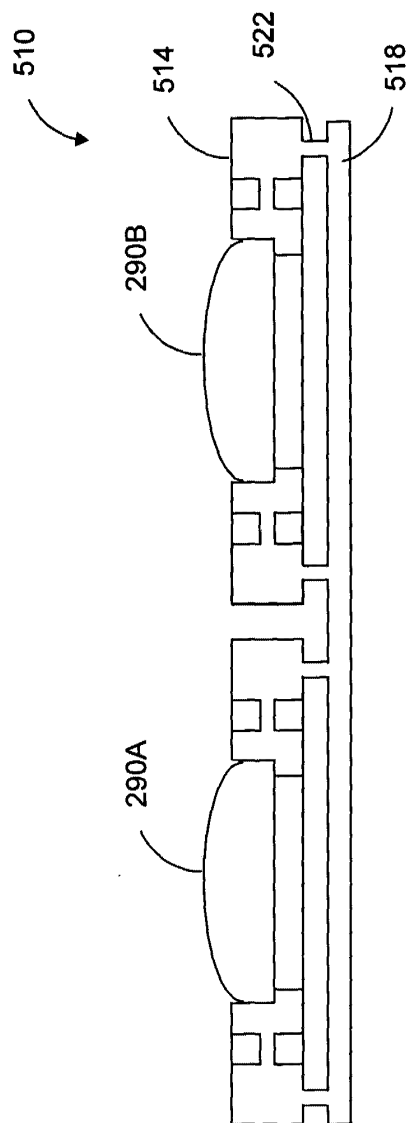


Figure 21D

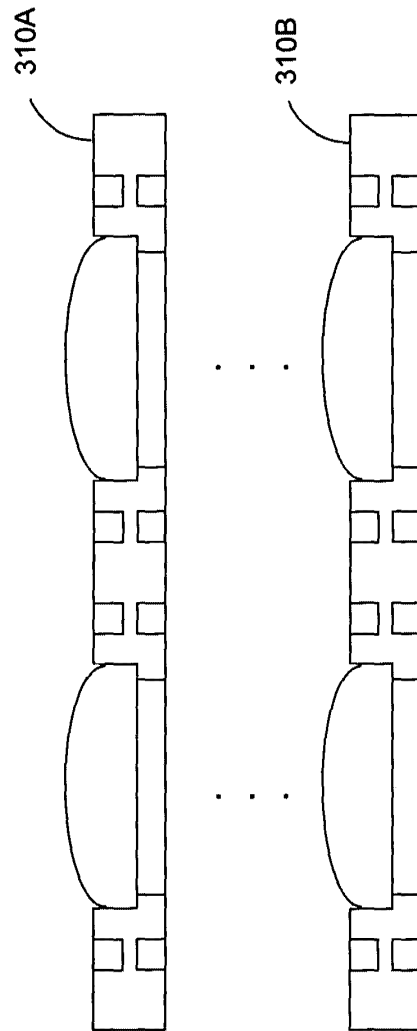


Figure 22

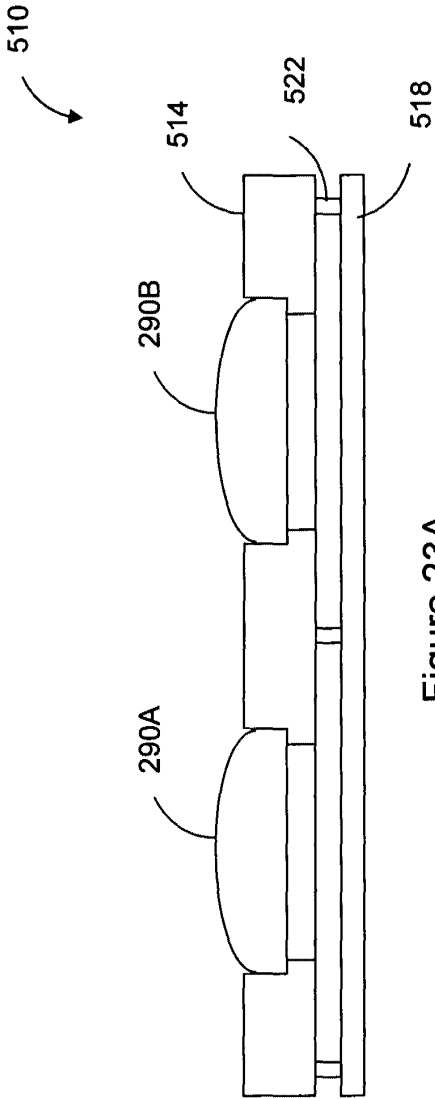


Figure 23A

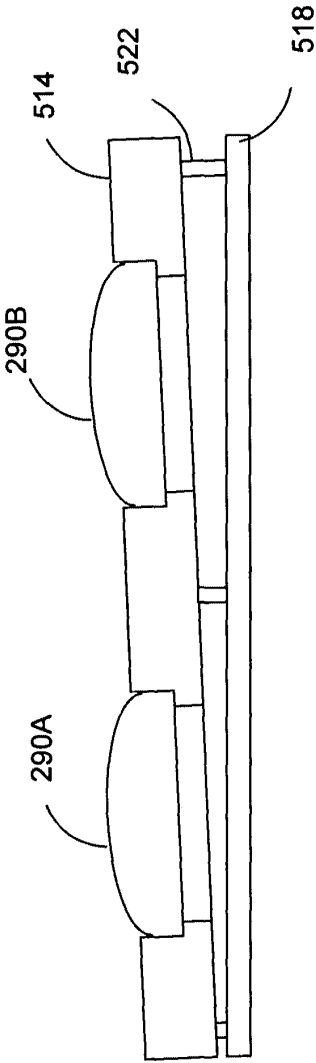


Figure 23B

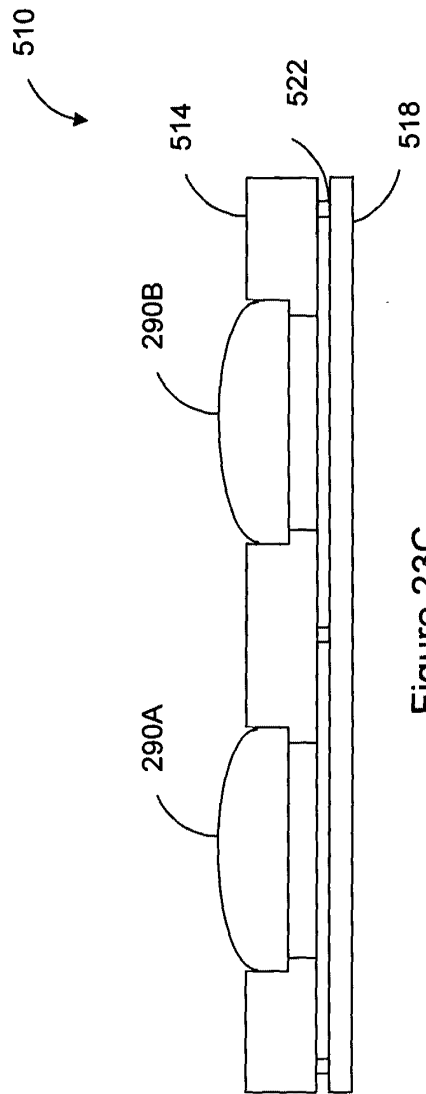


Figure 23C

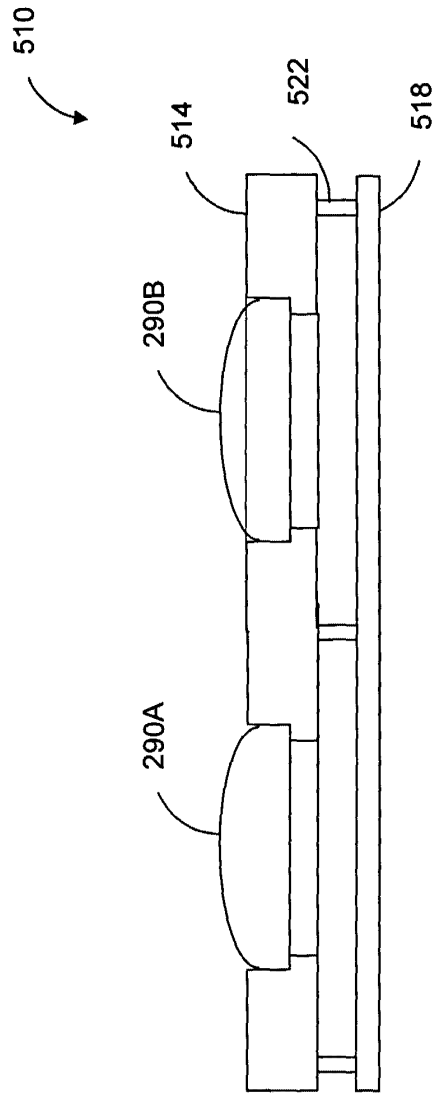
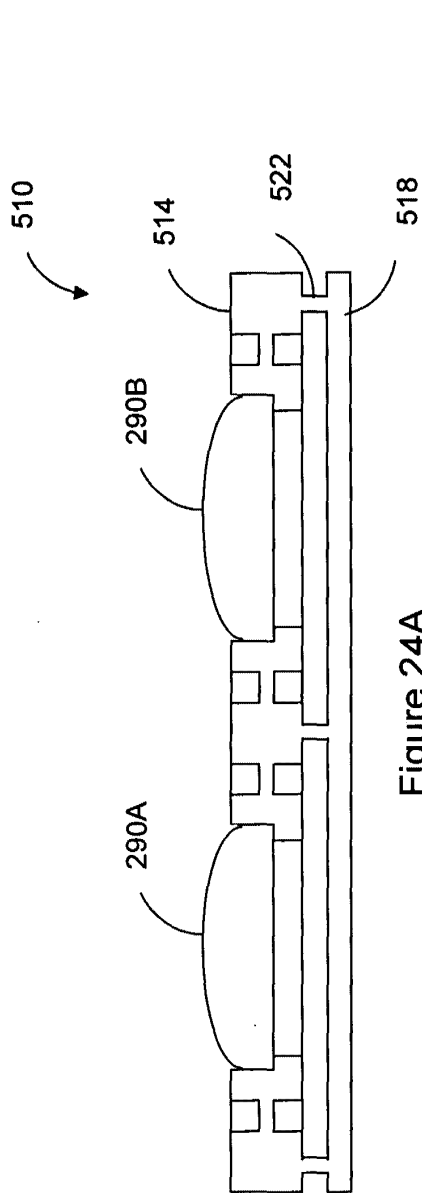
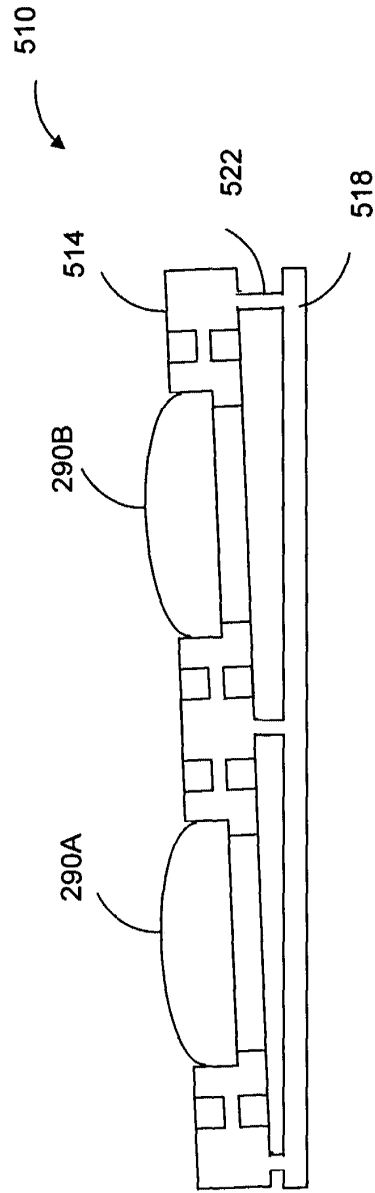


Figure 23D



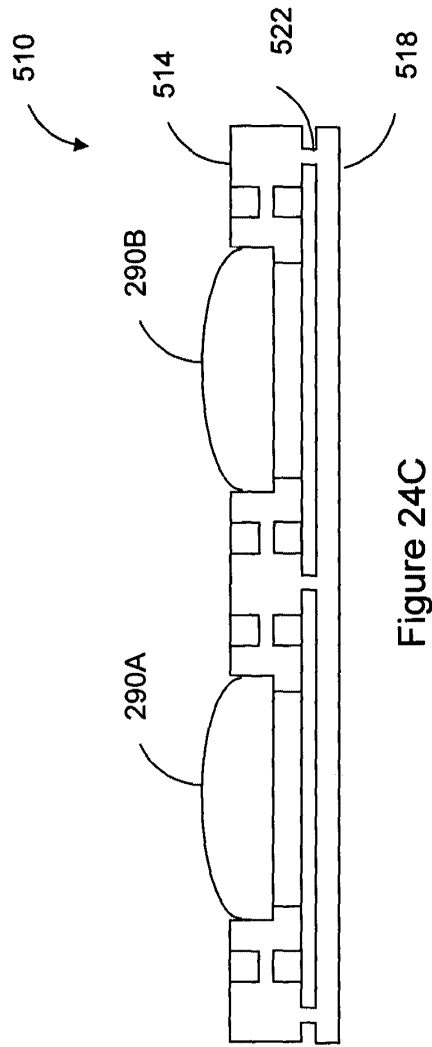


Figure 24C

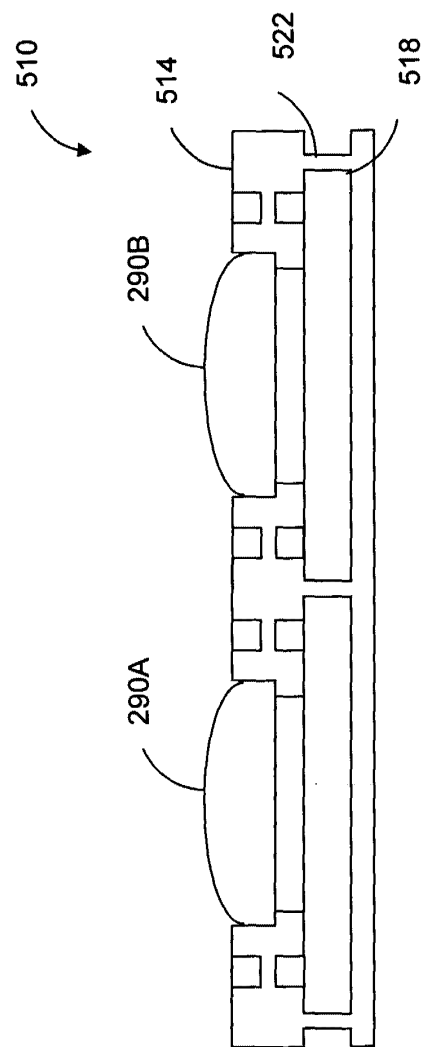


Figure 24D

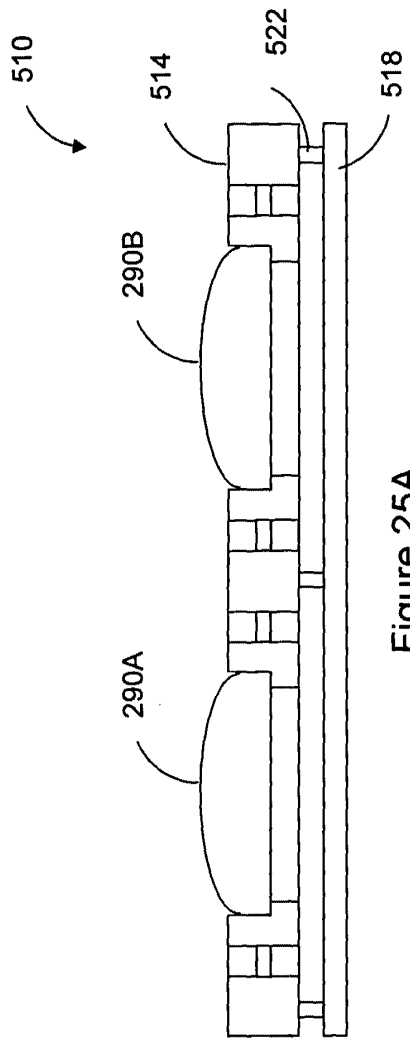


Figure 25A

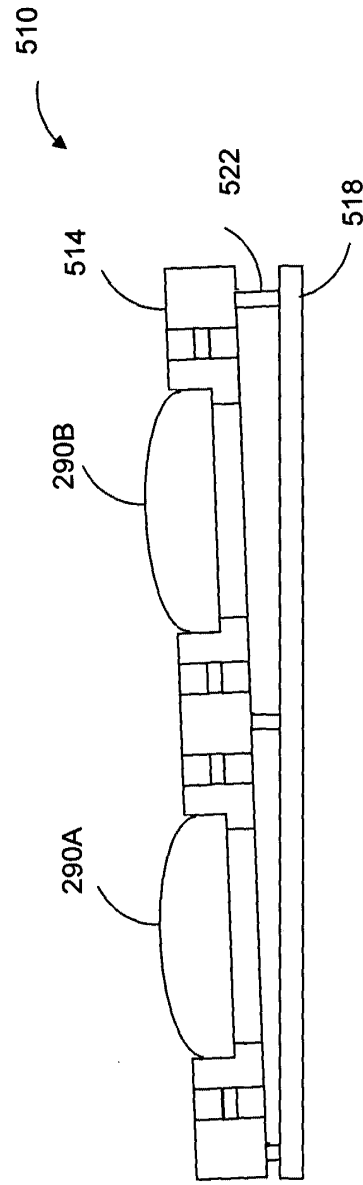


Figure 25B

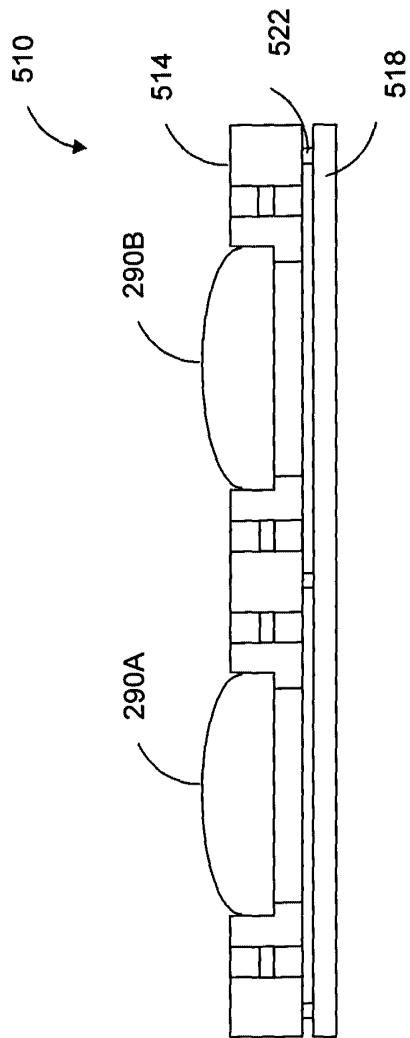


Figure 25C

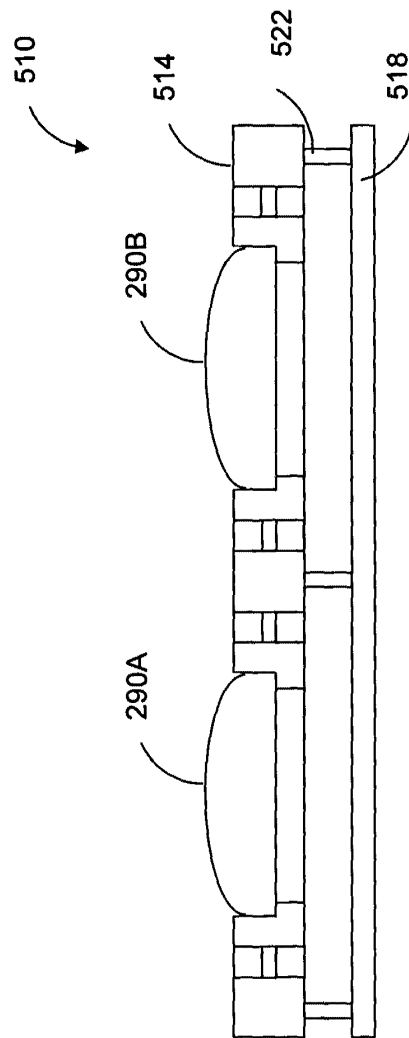


Figure 25D

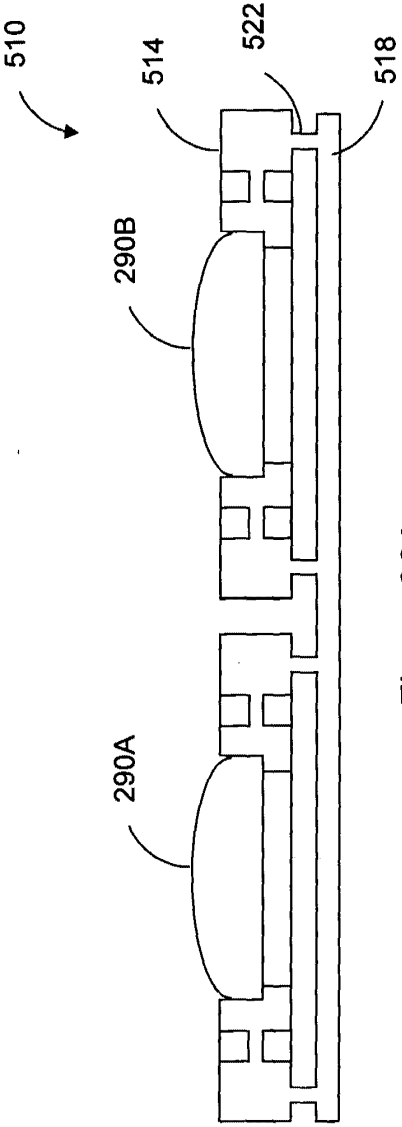


Figure 26A

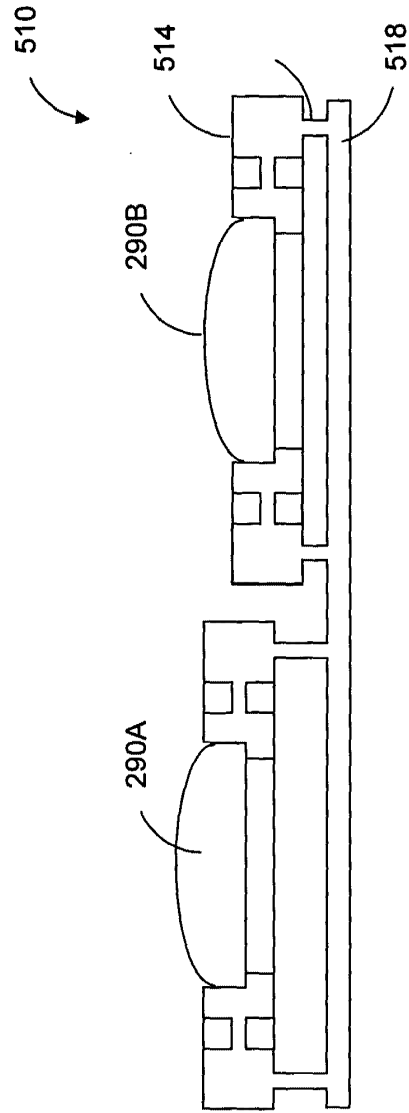


Figure 26B

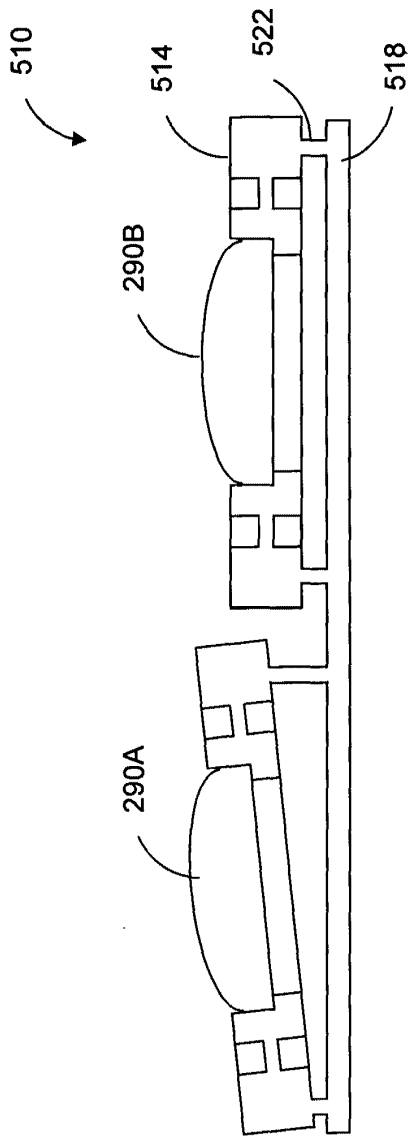


Figure 26C

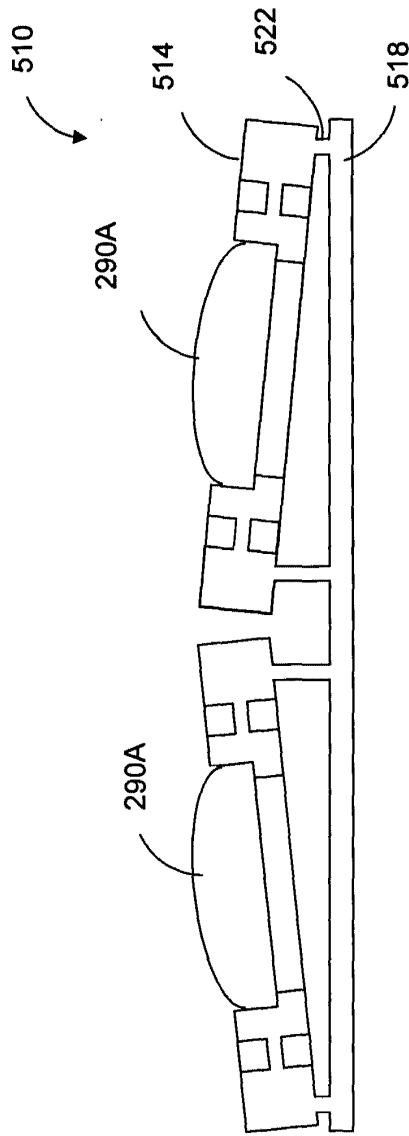


Figure 26D

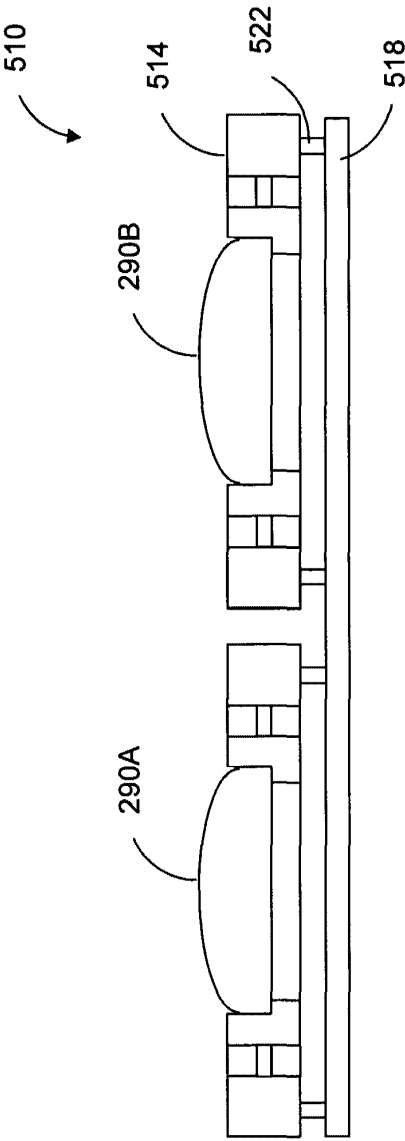


Figure 27A

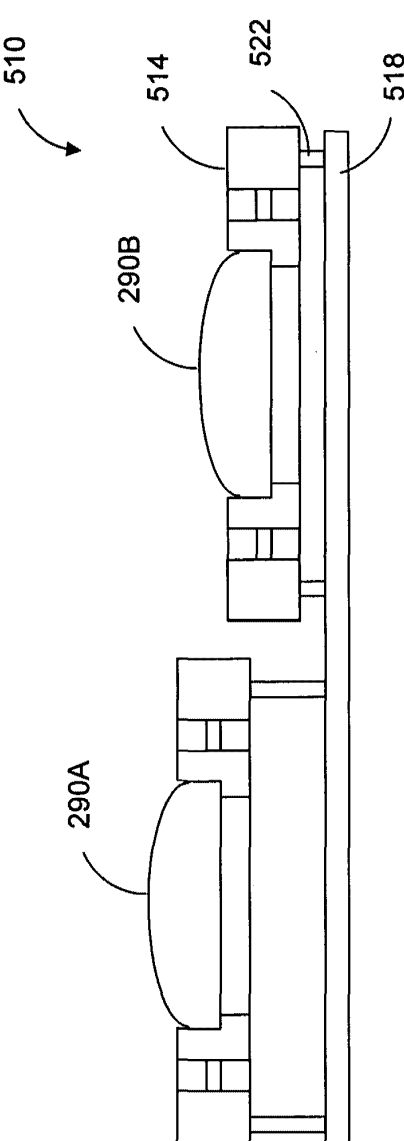


Figure 27B

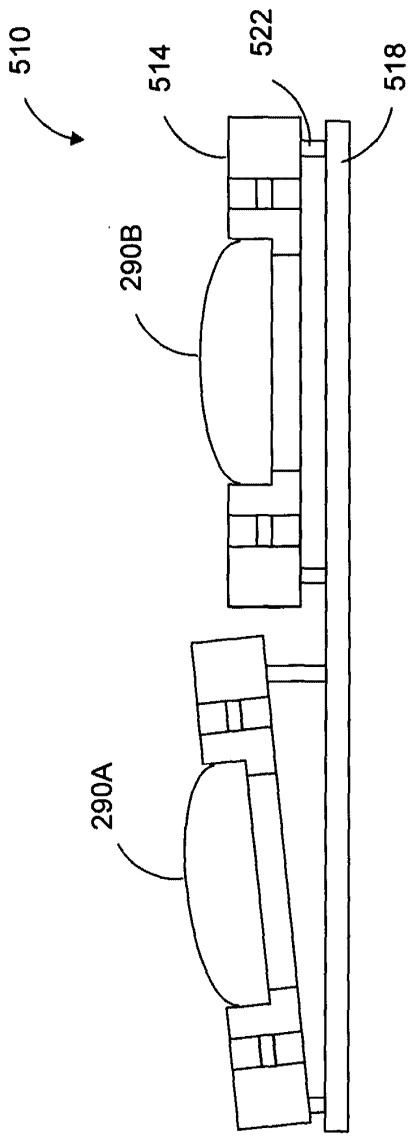


Figure 27C

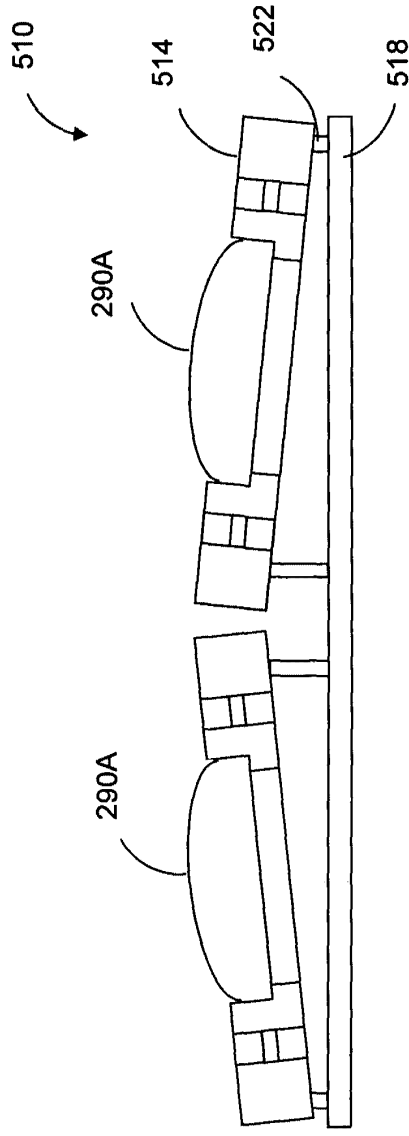


Figure 27D

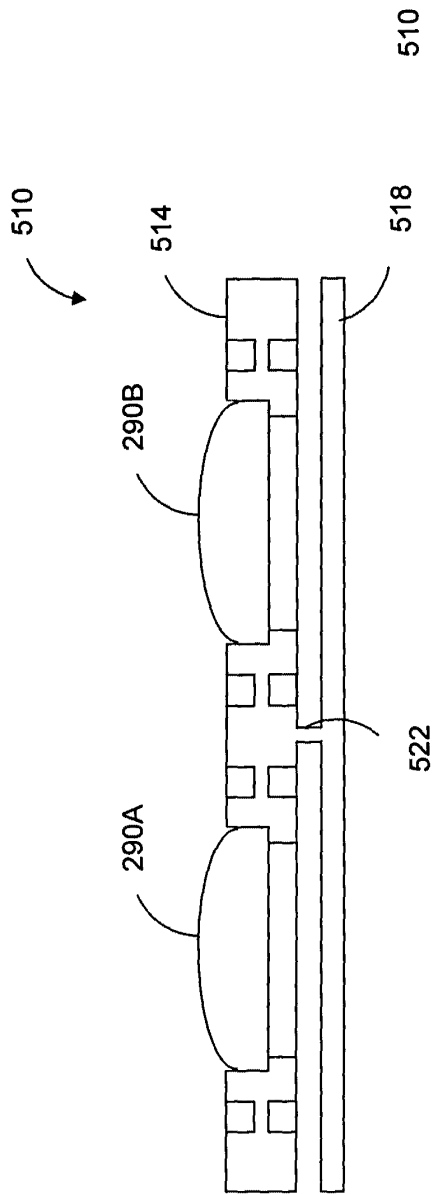


Figure 28A

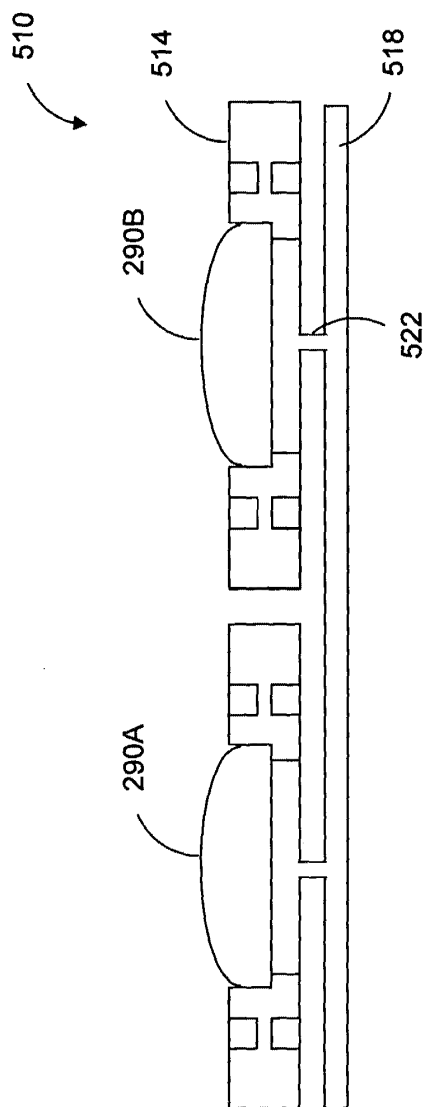


Figure 28B

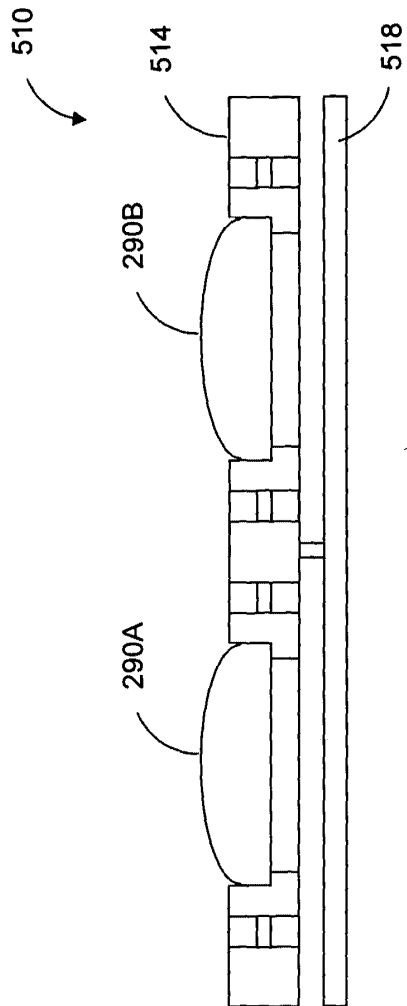


Figure 28C

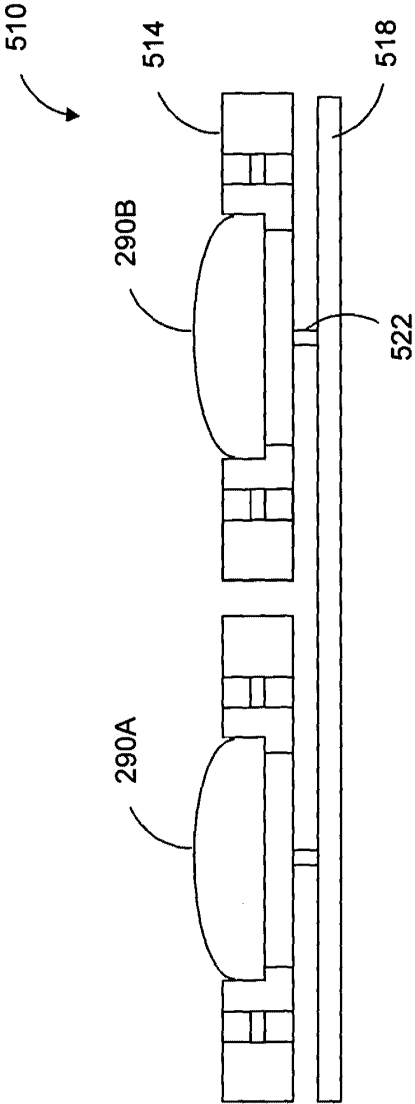


Figure 28D

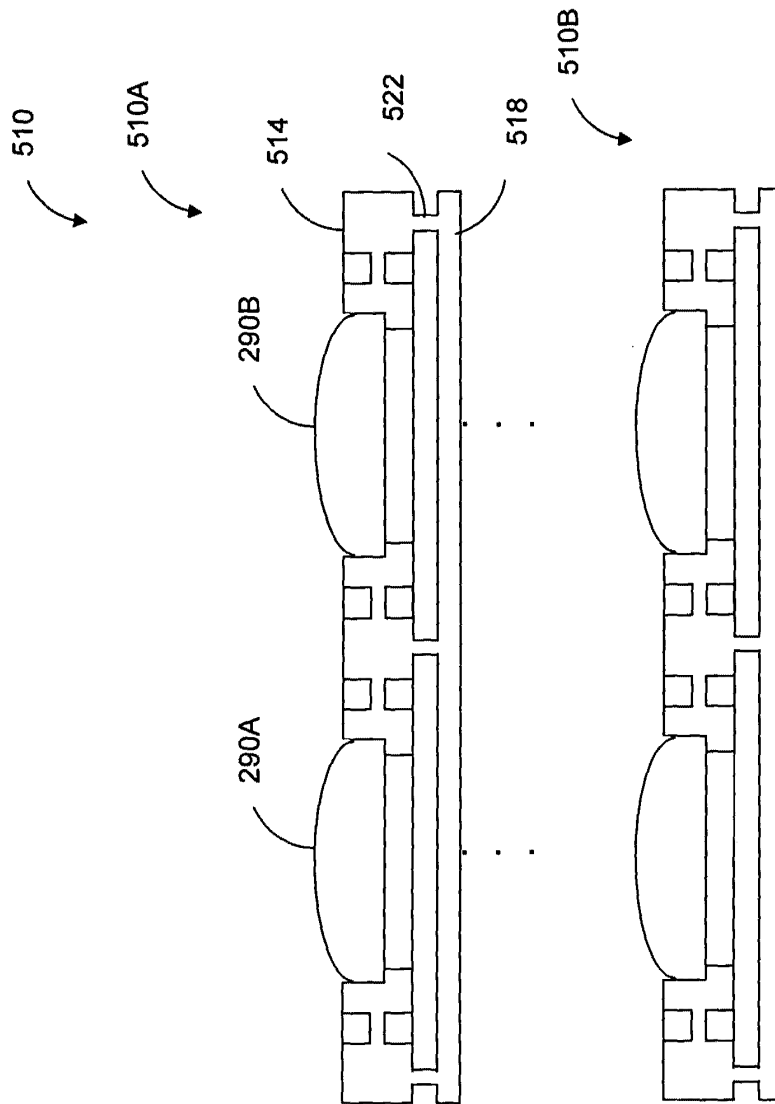


Figure 29

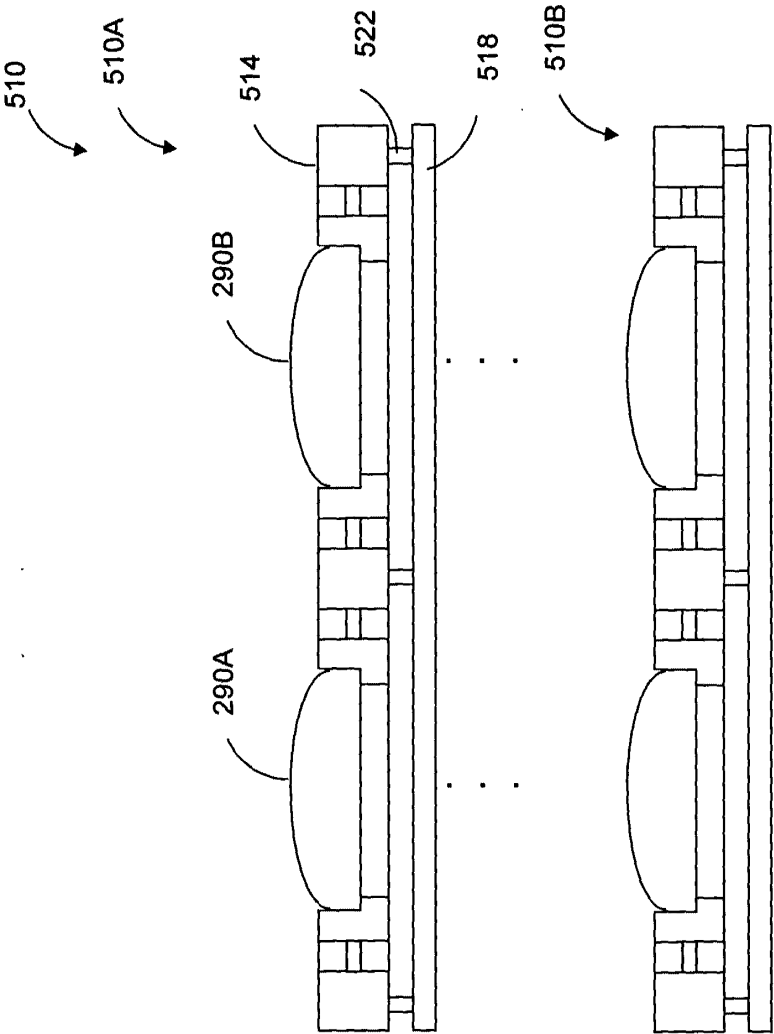
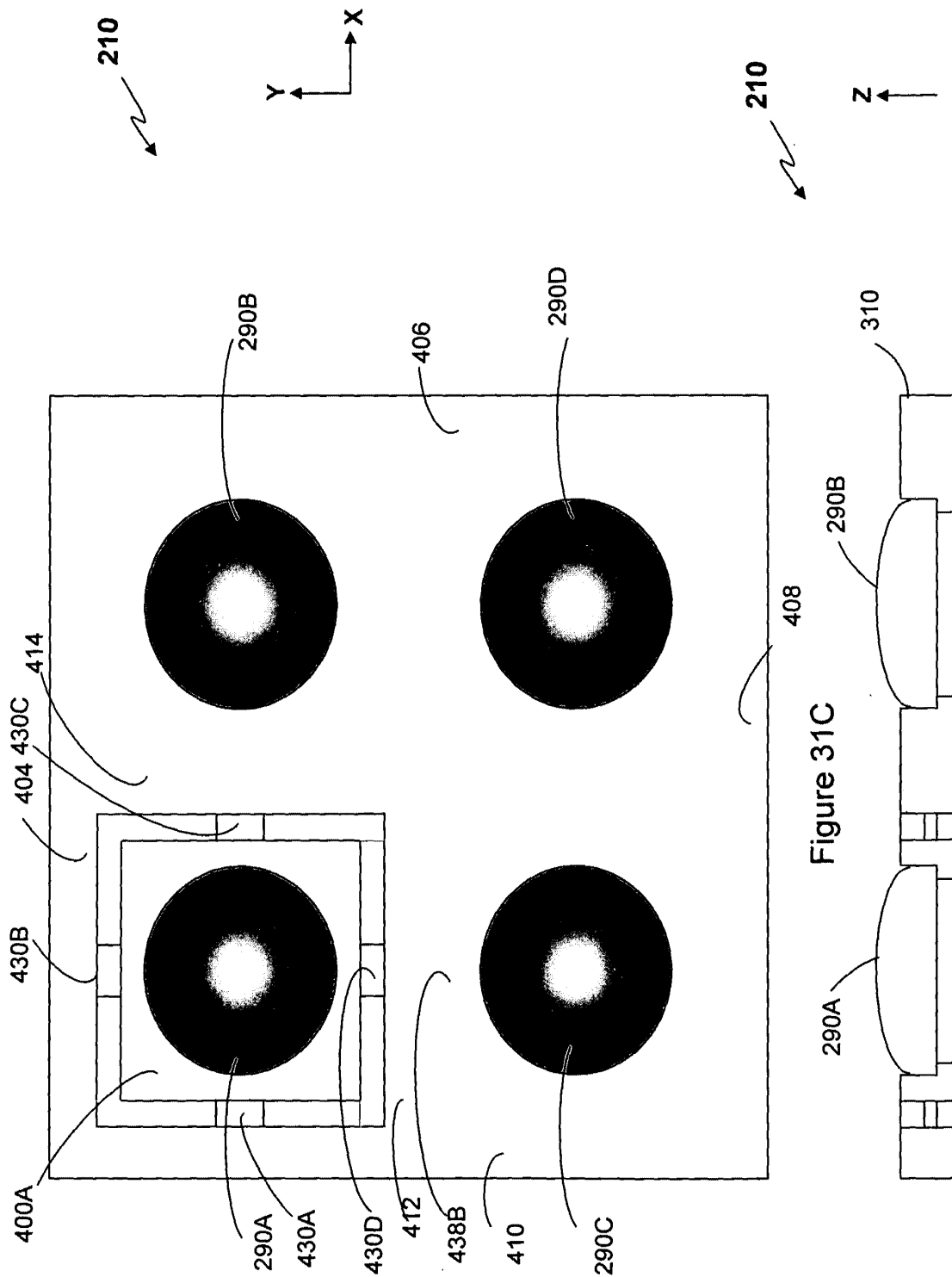
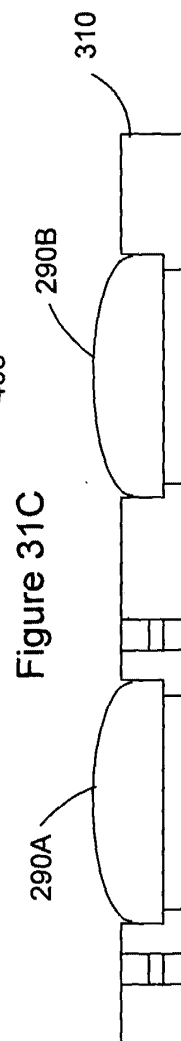


Figure 30



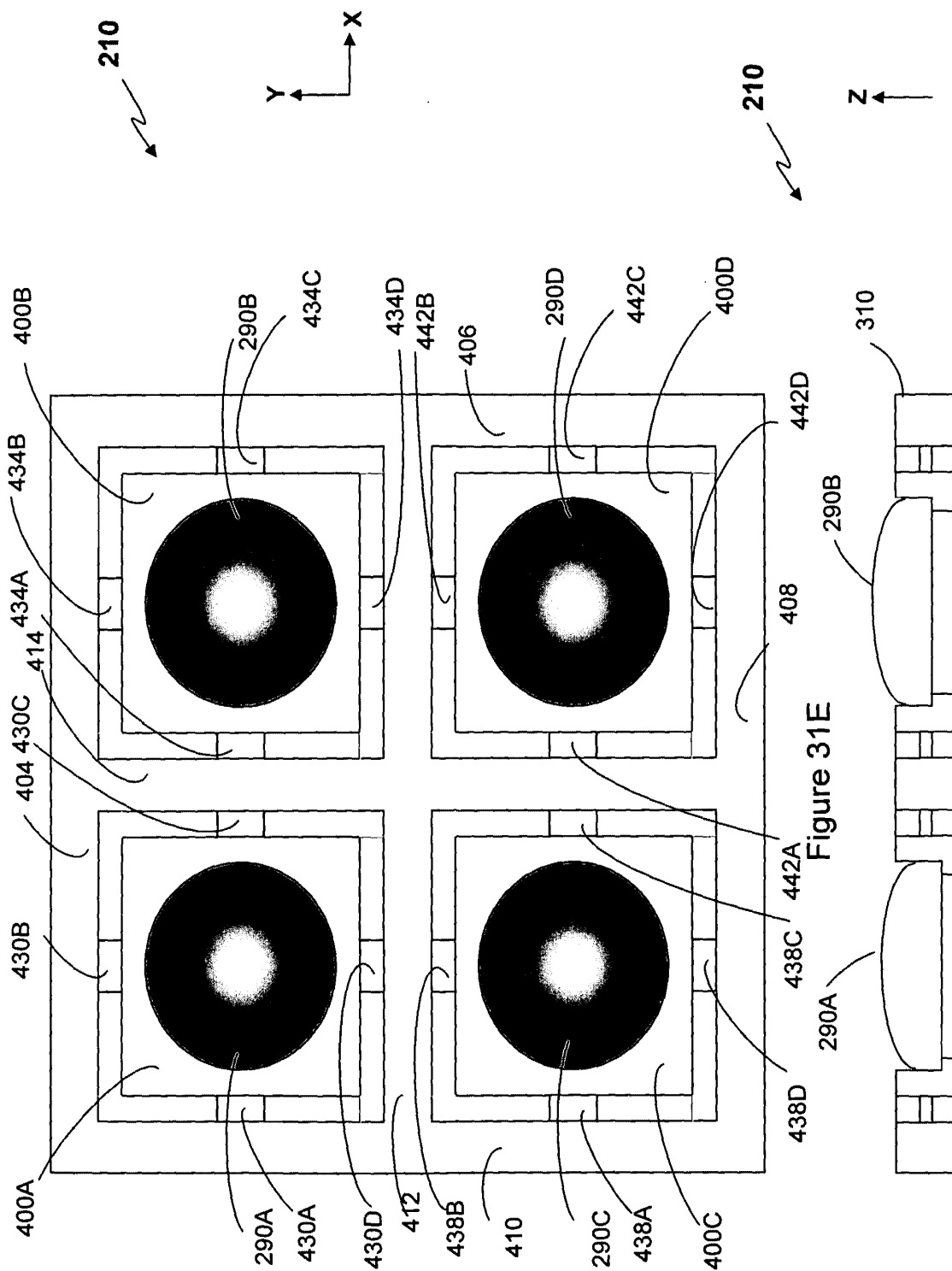


Figure 31E

Figure 31F

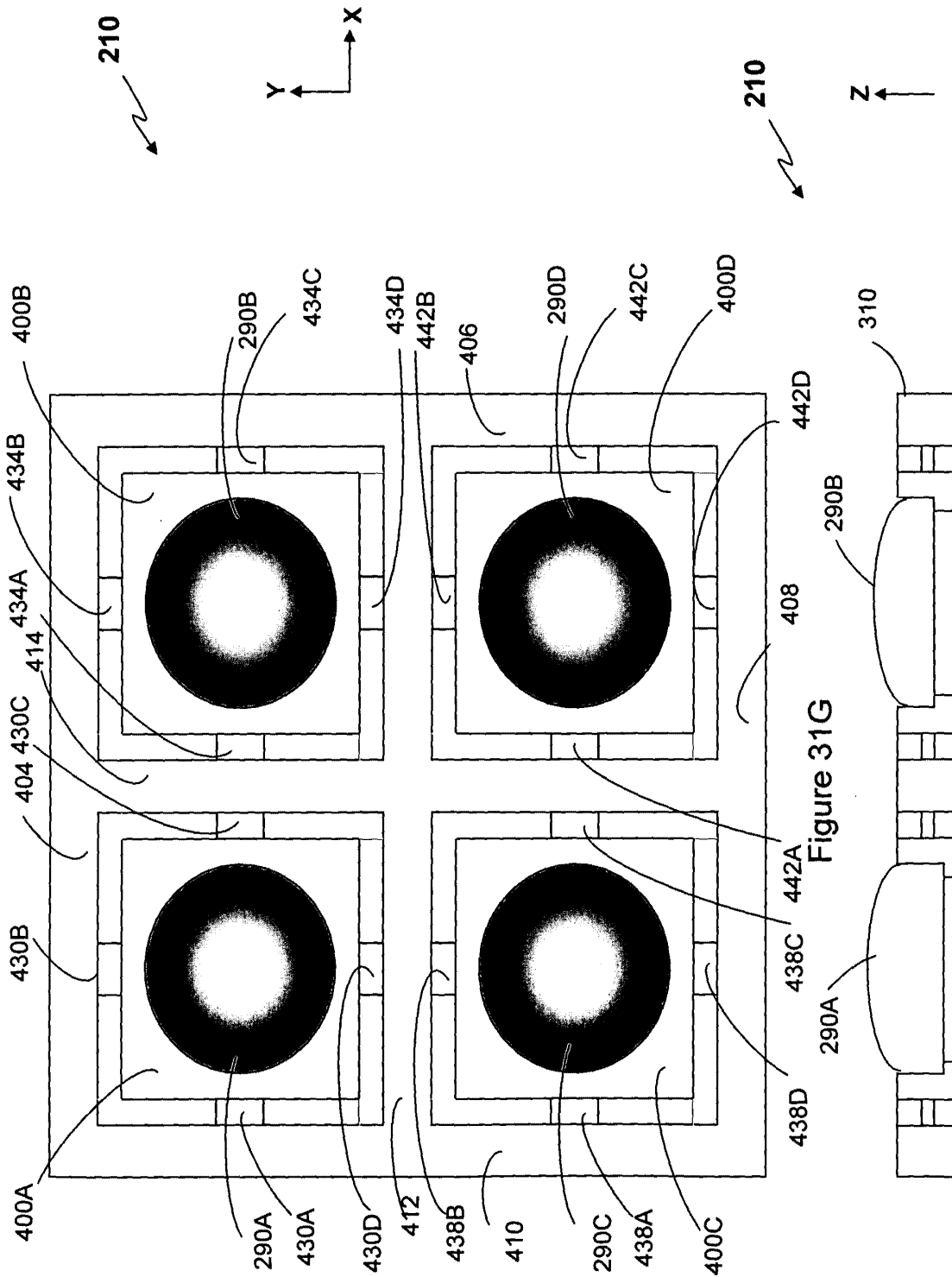
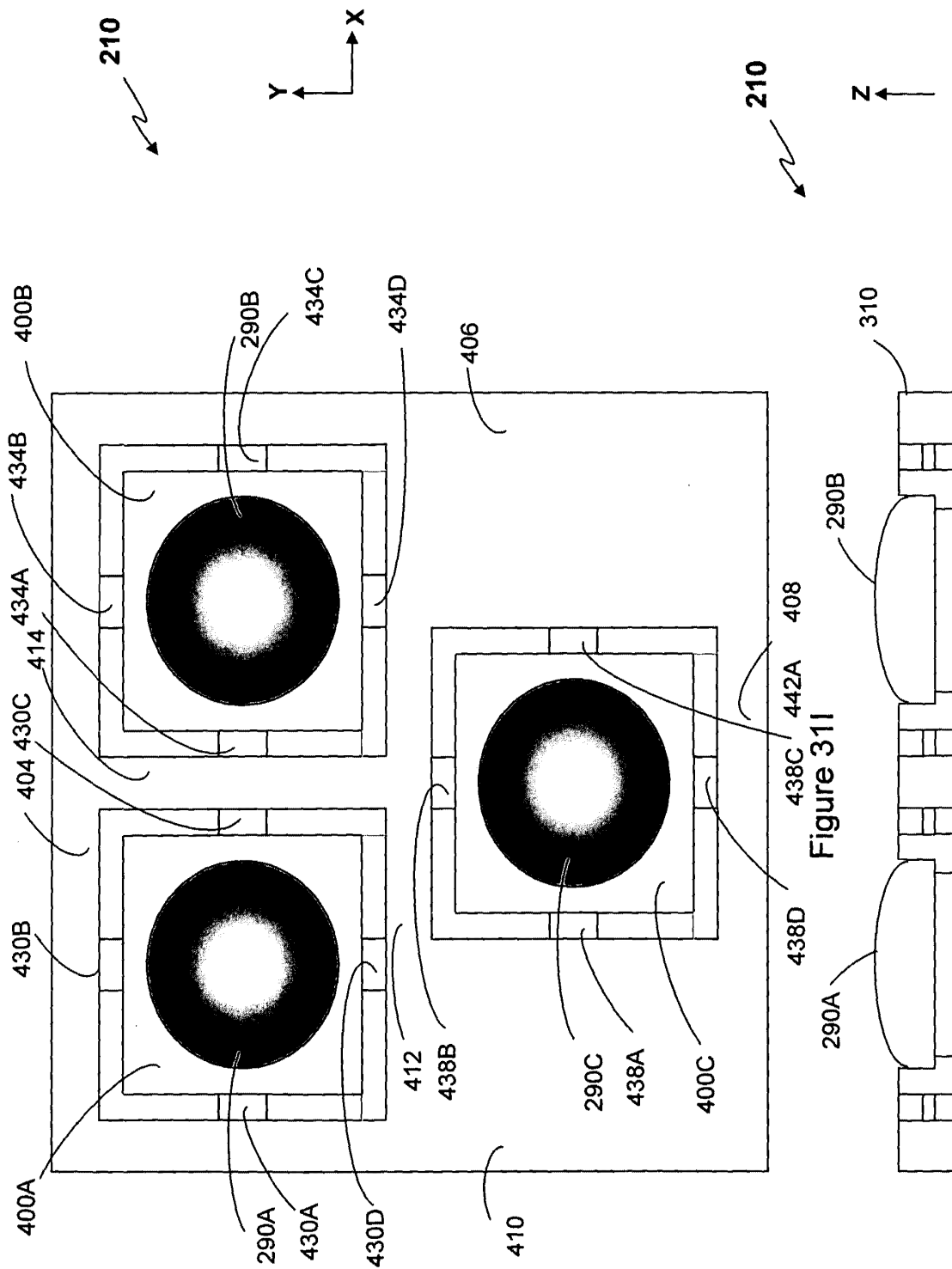
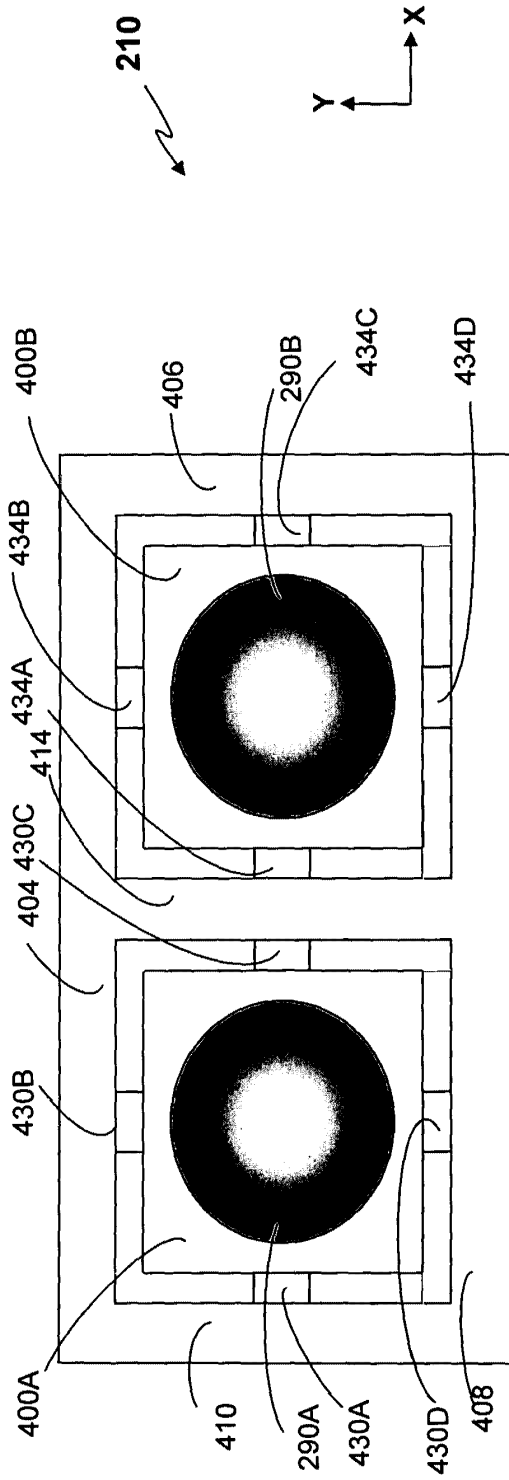
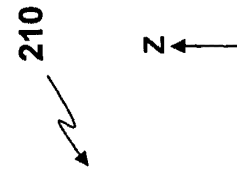
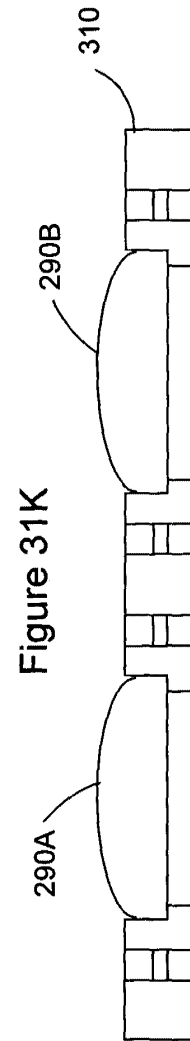


Figure 31H





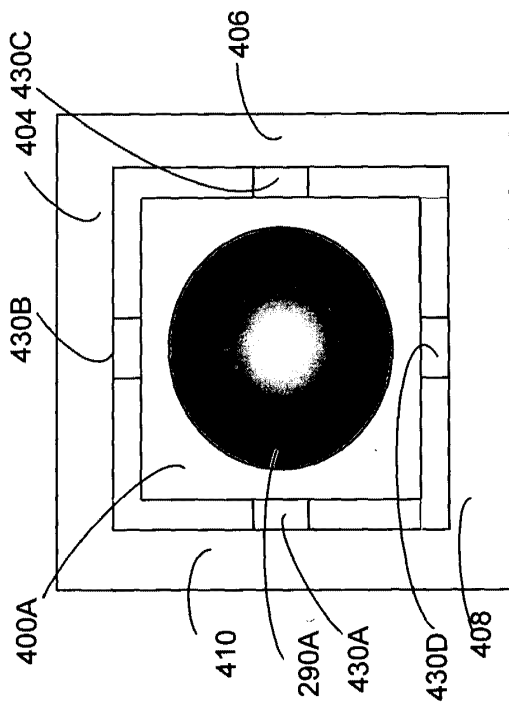
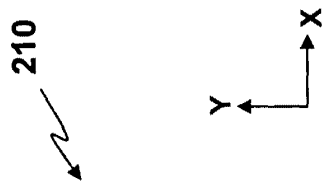


Figure 31M

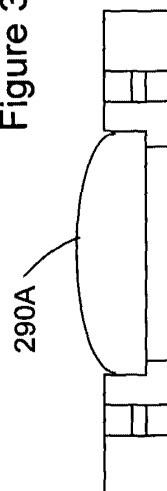


Figure 31N

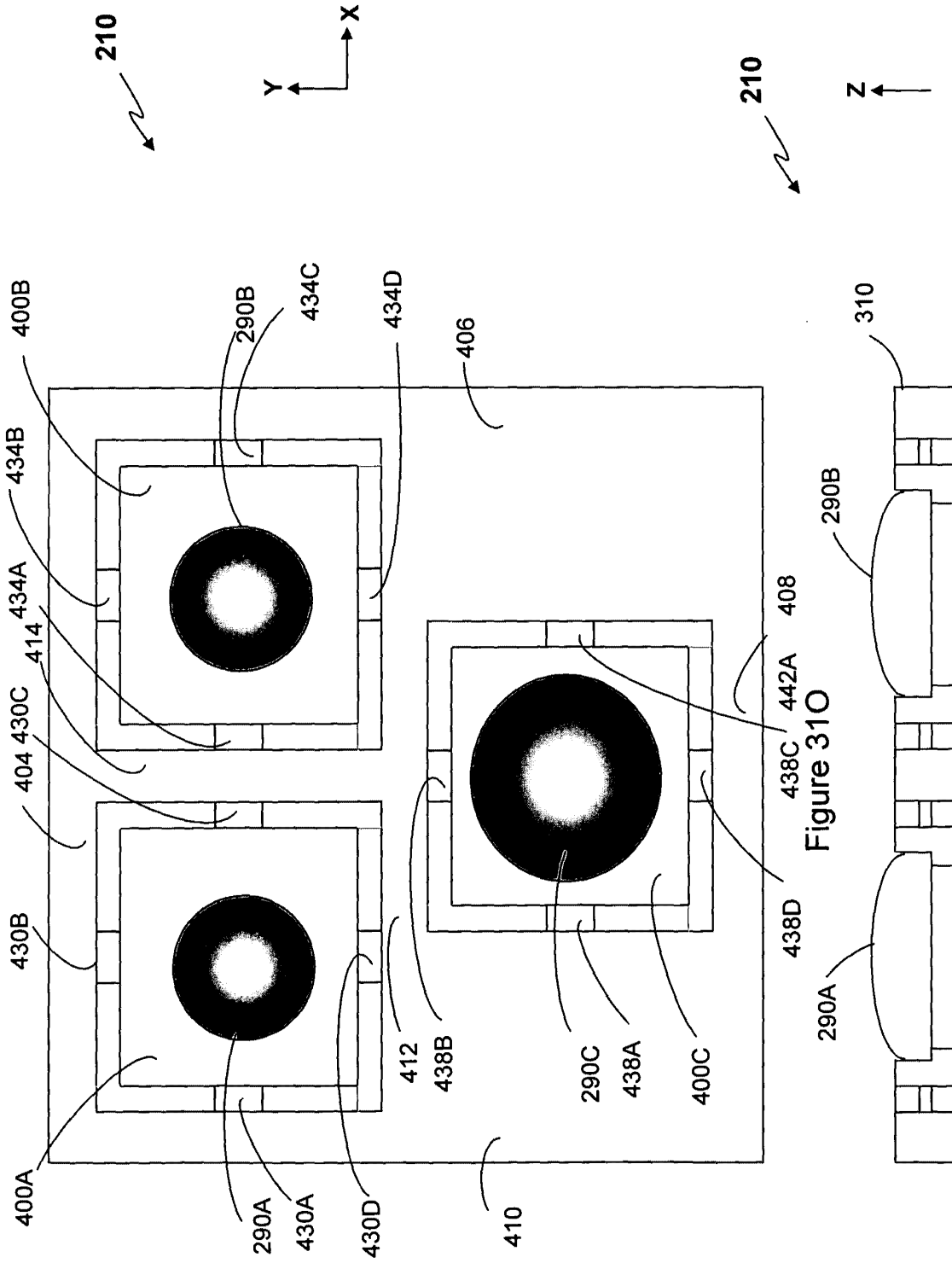


Figure 31P

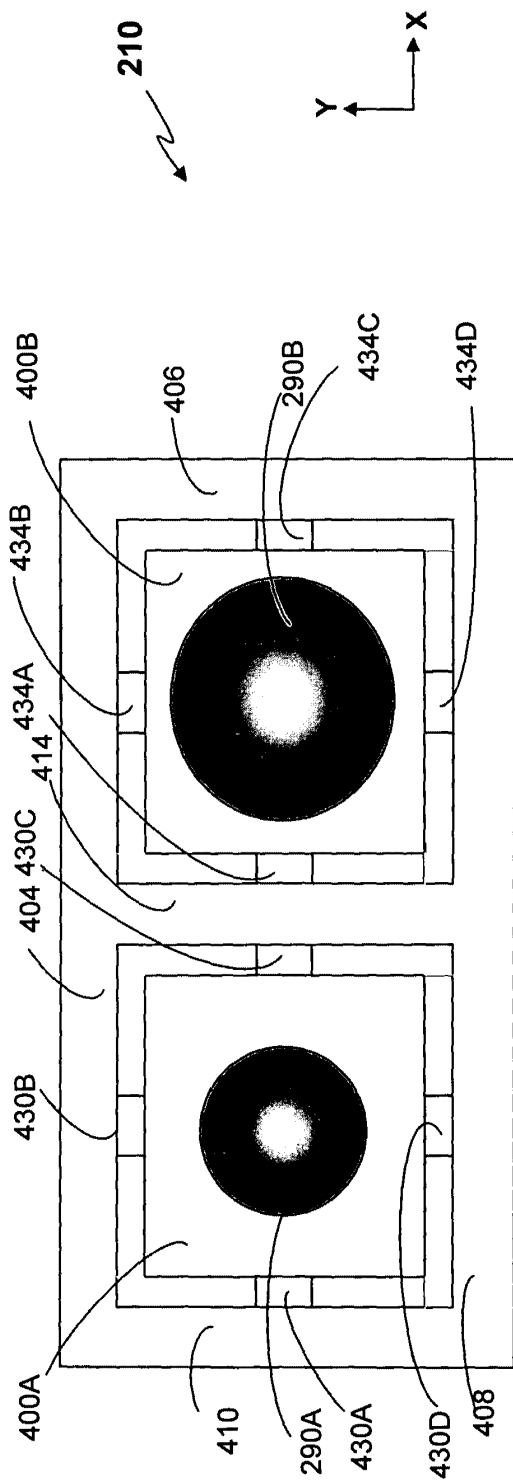
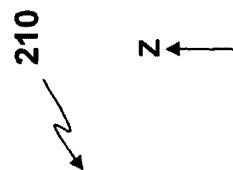
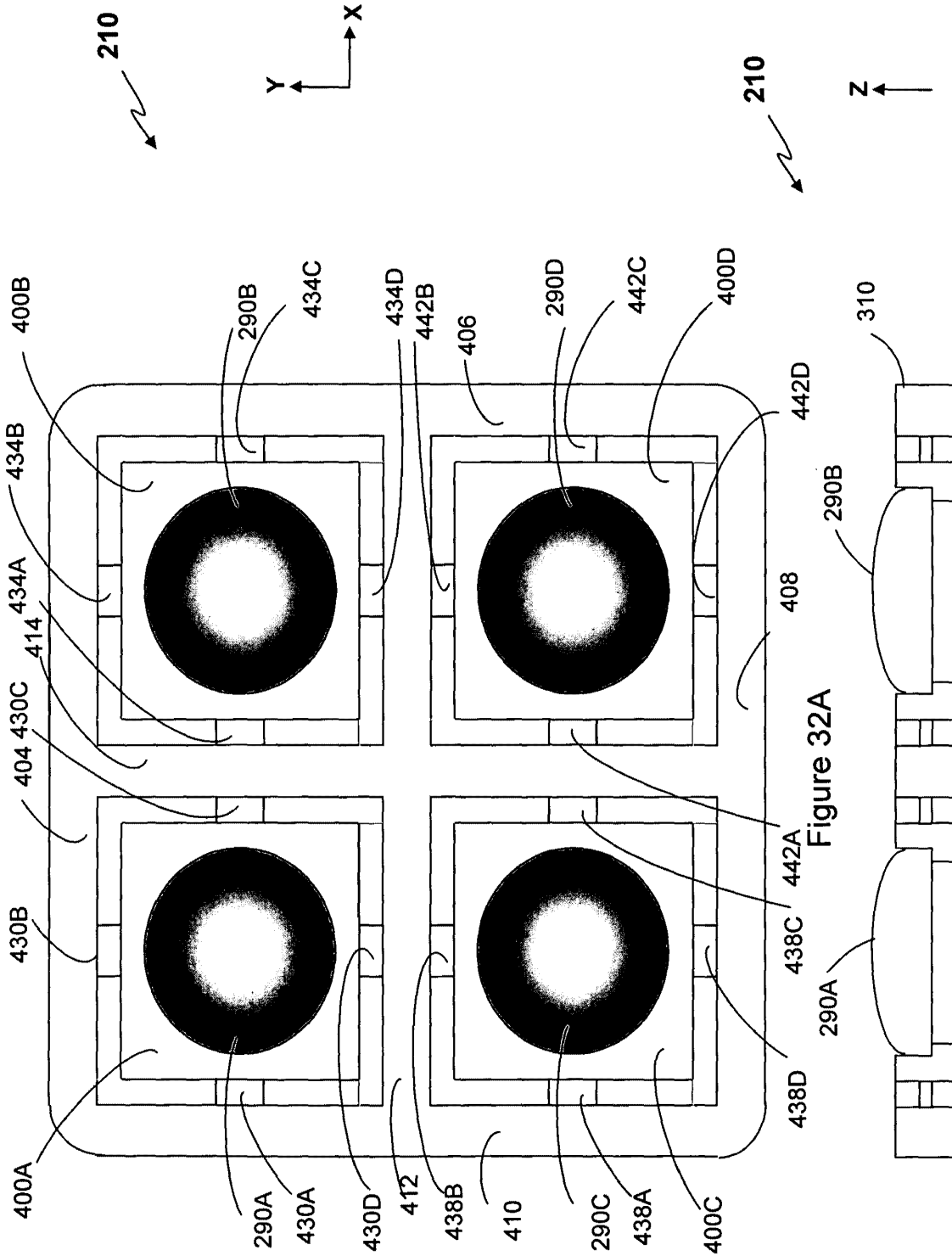


Figure 31Q

Figure 31R



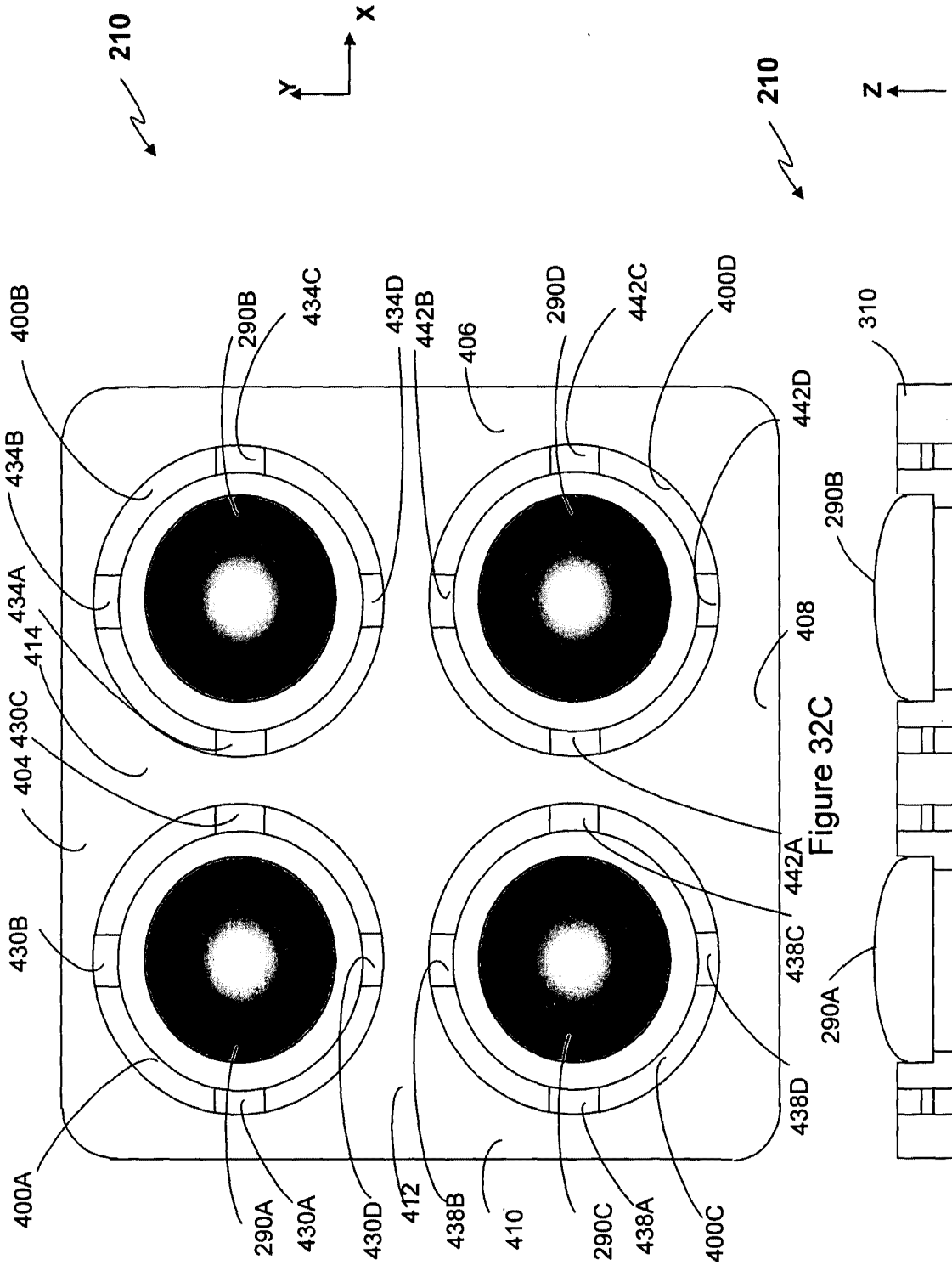
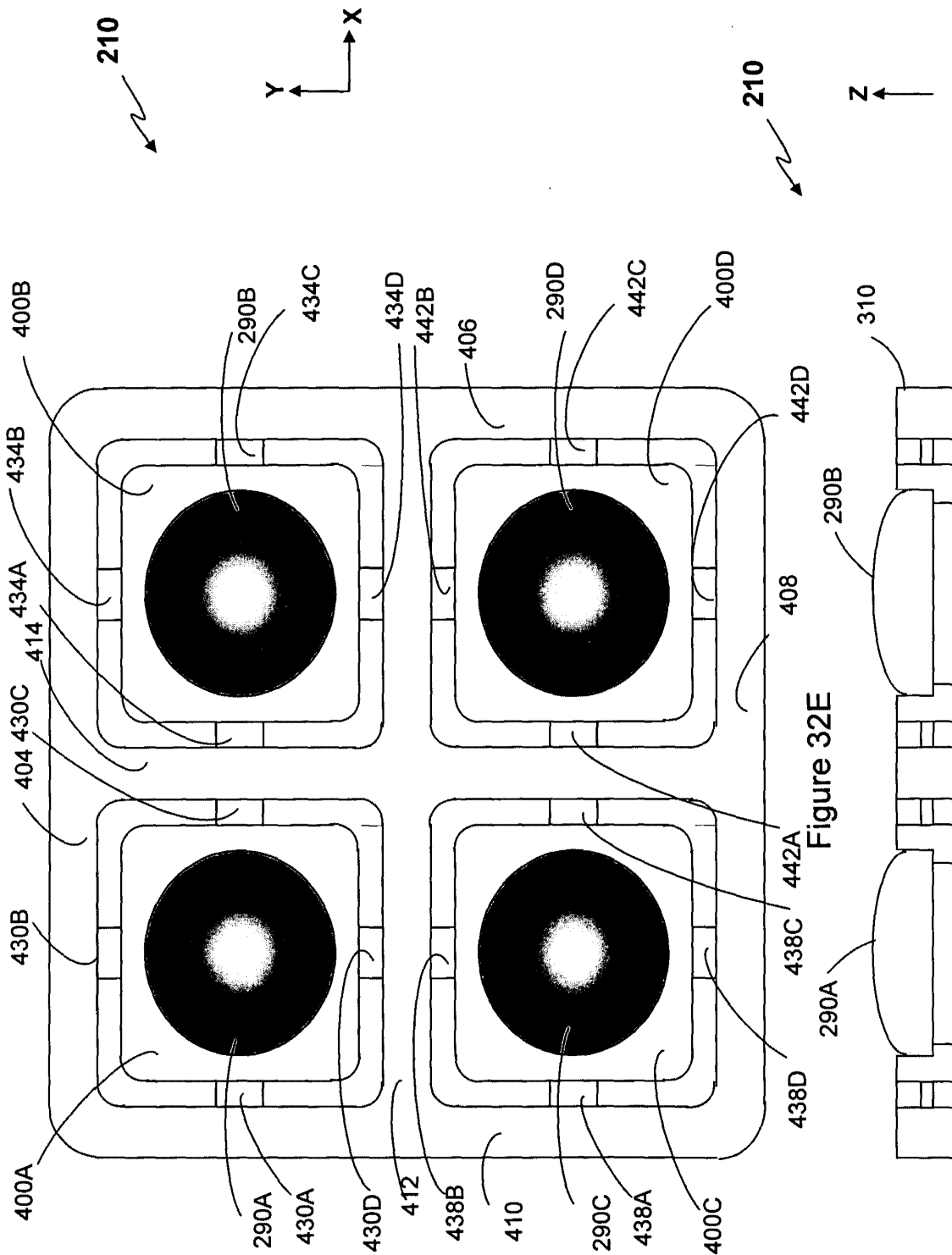


Figure 32C

Figure 32D



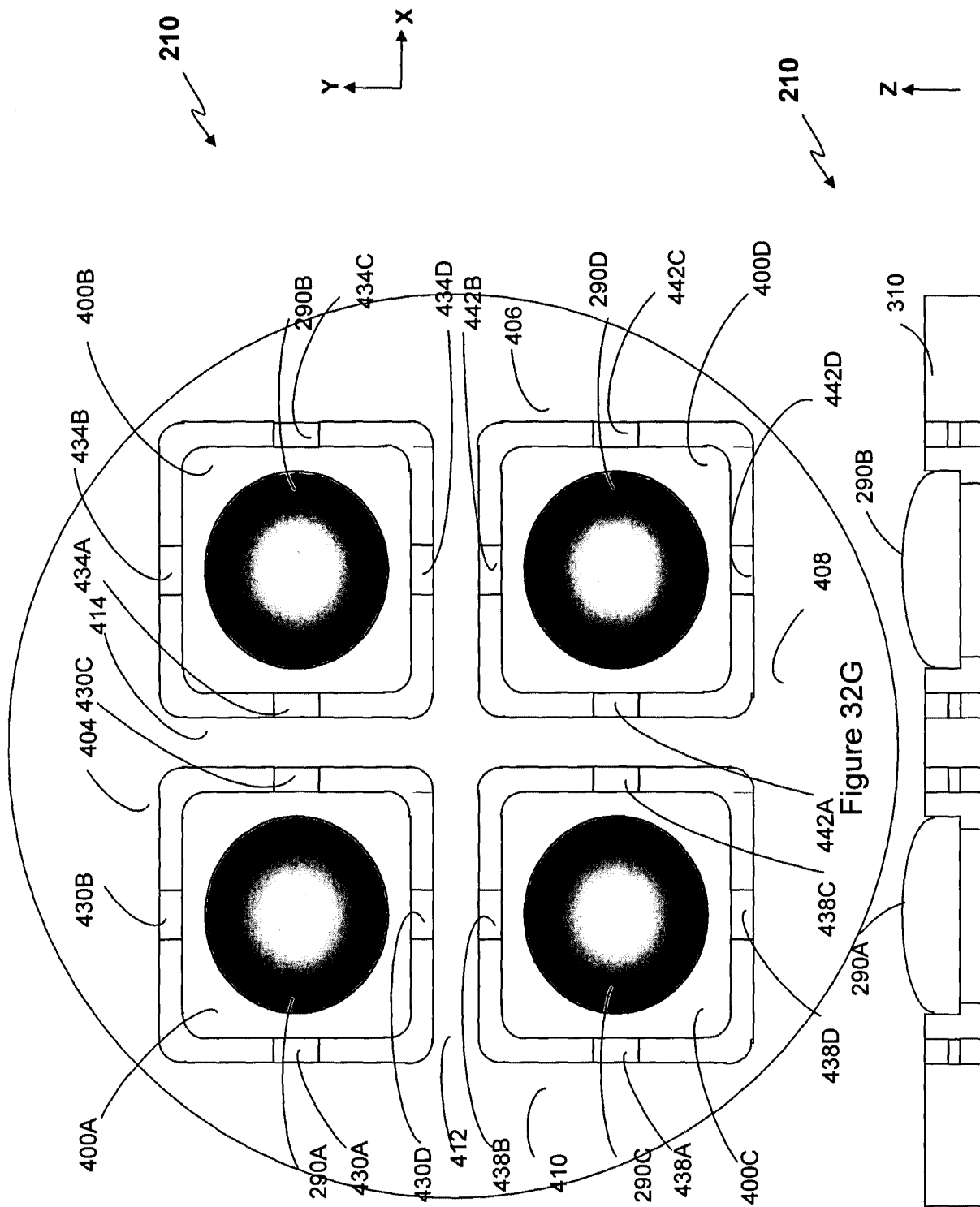


Figure 32H

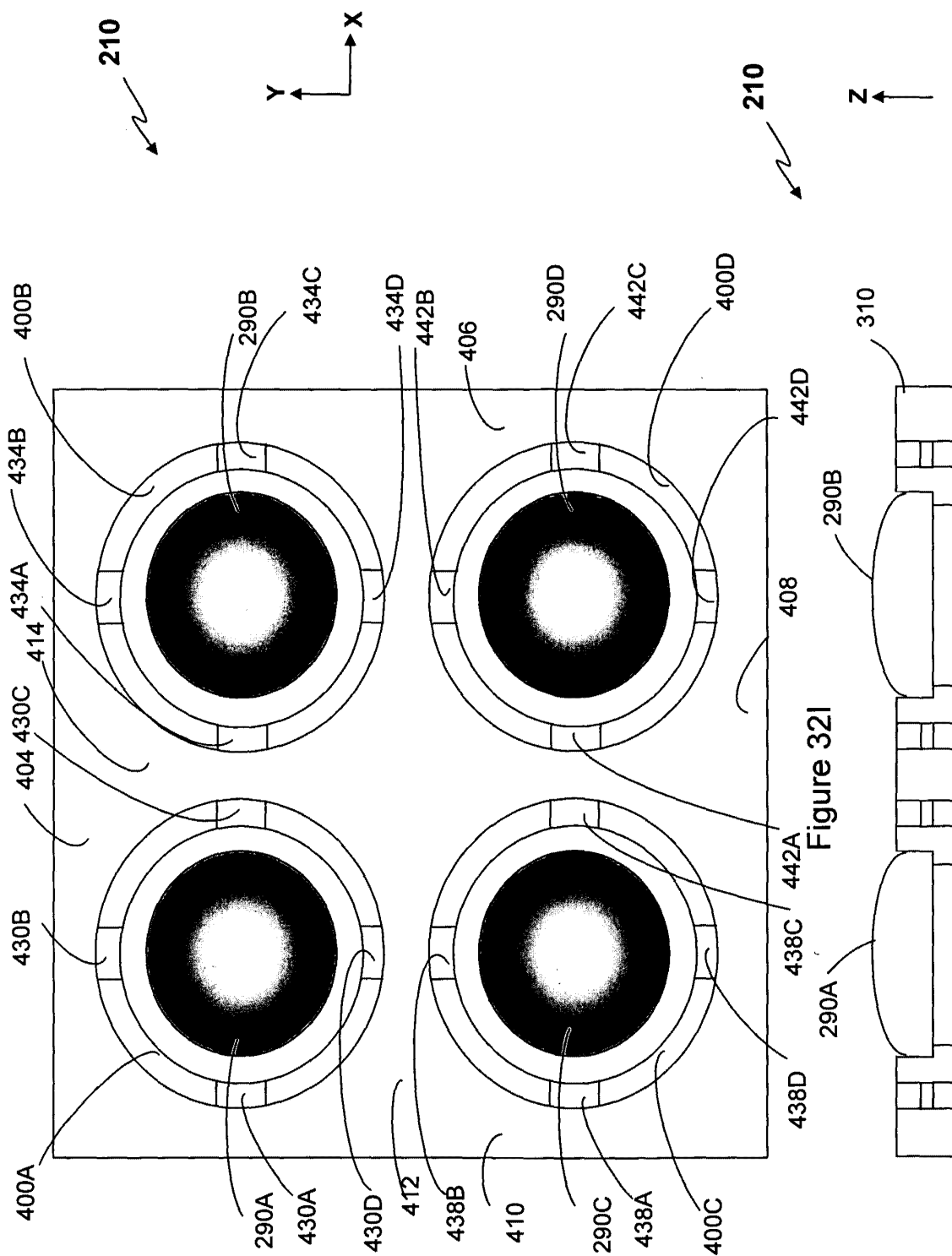


Figure 32I

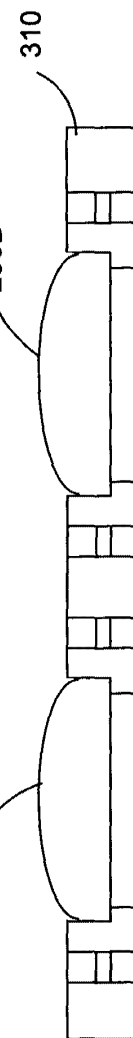


Figure 32J

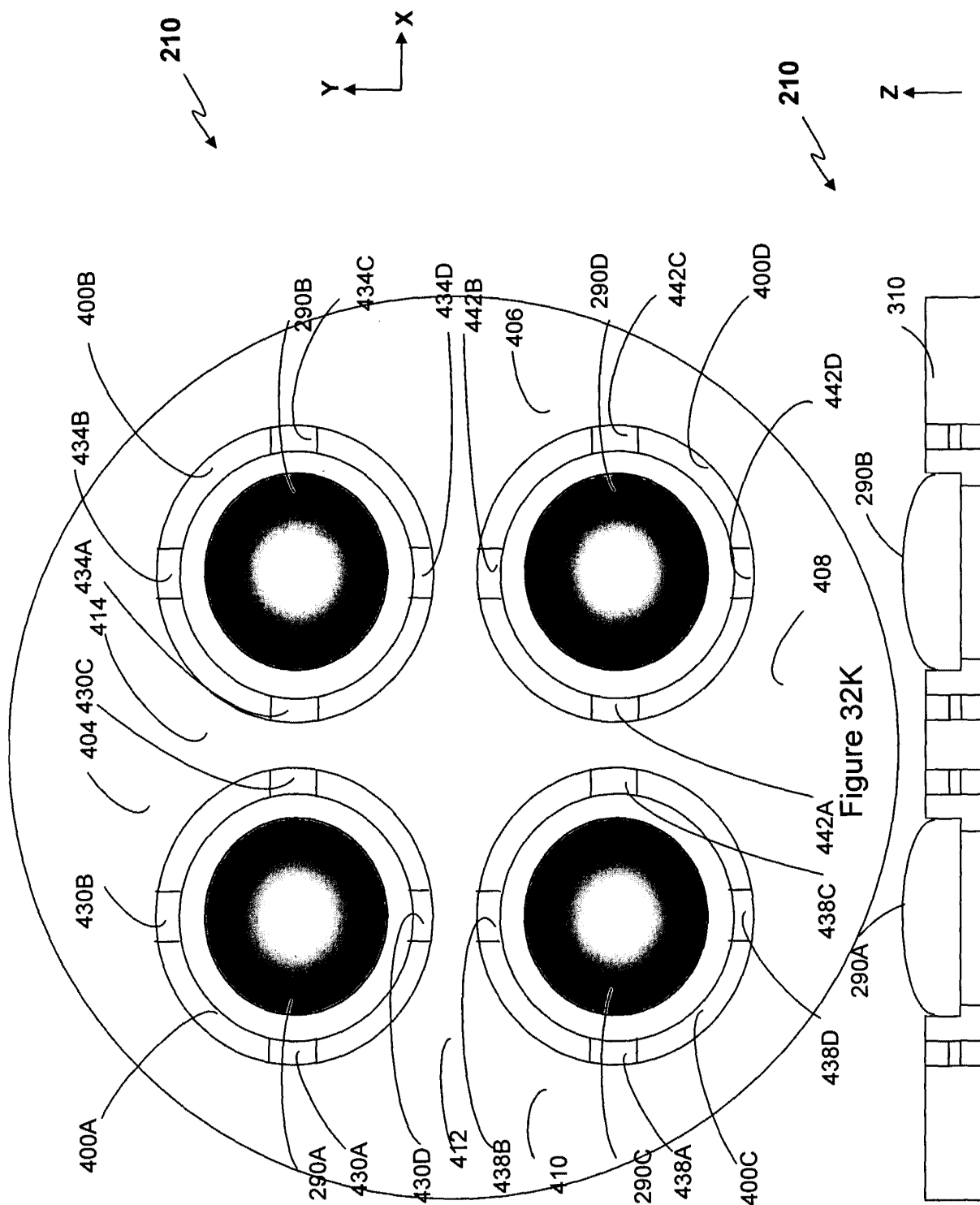
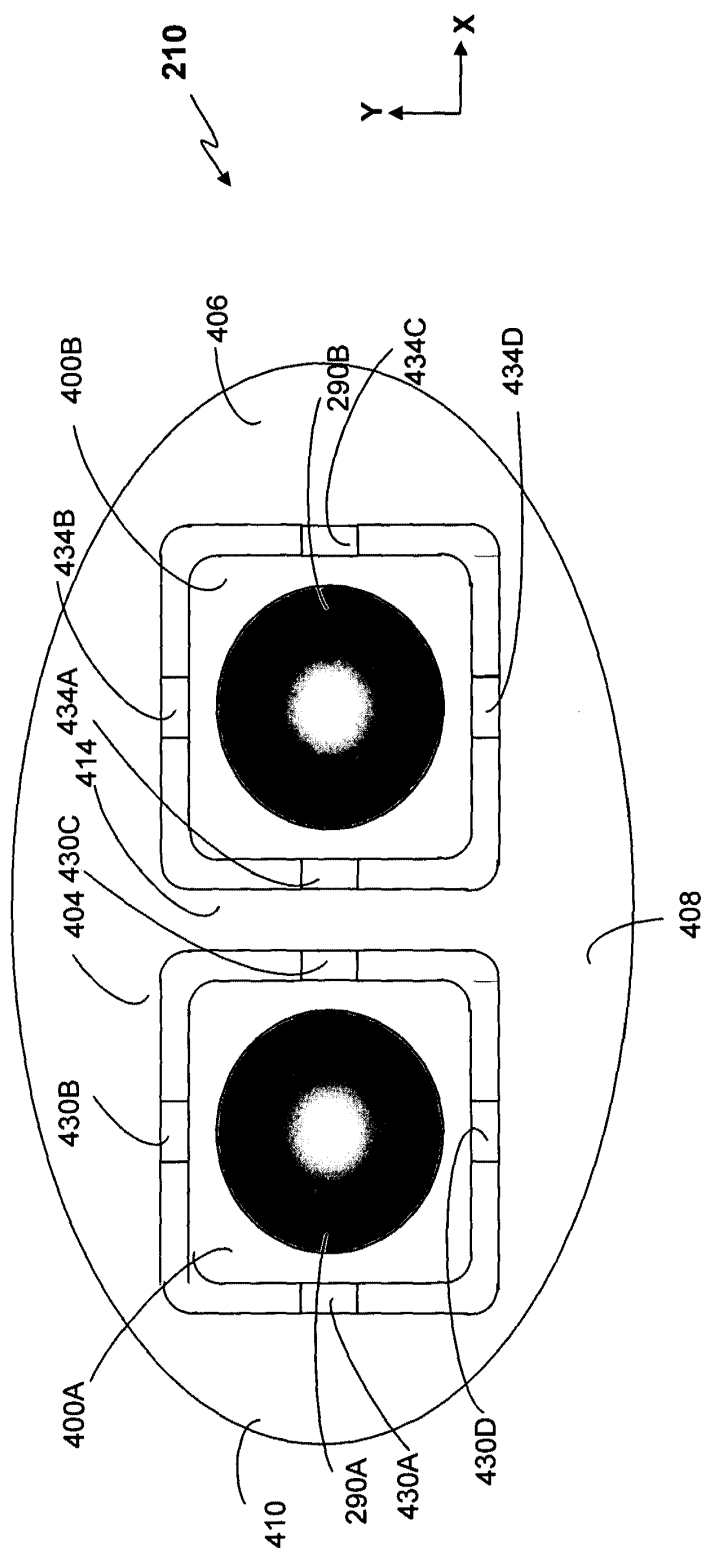
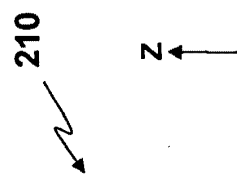
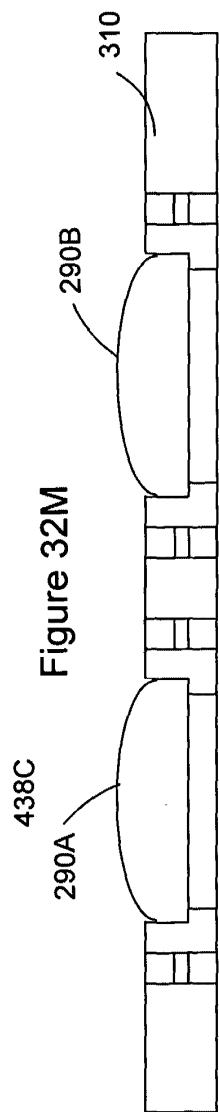


Figure 32L



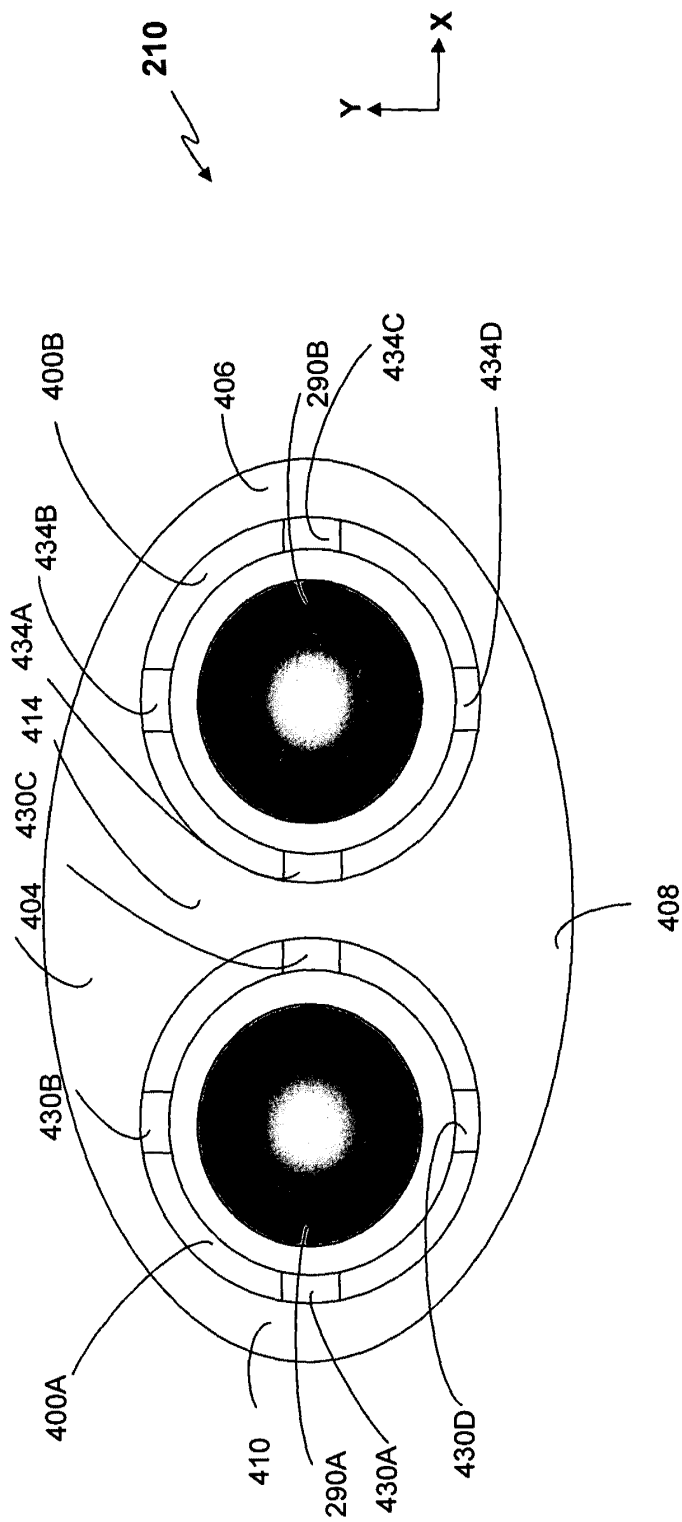
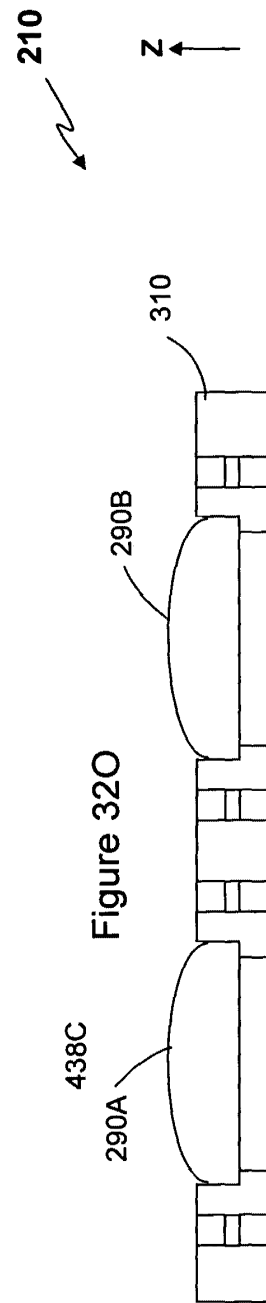


Figure 32O

Figure 32P

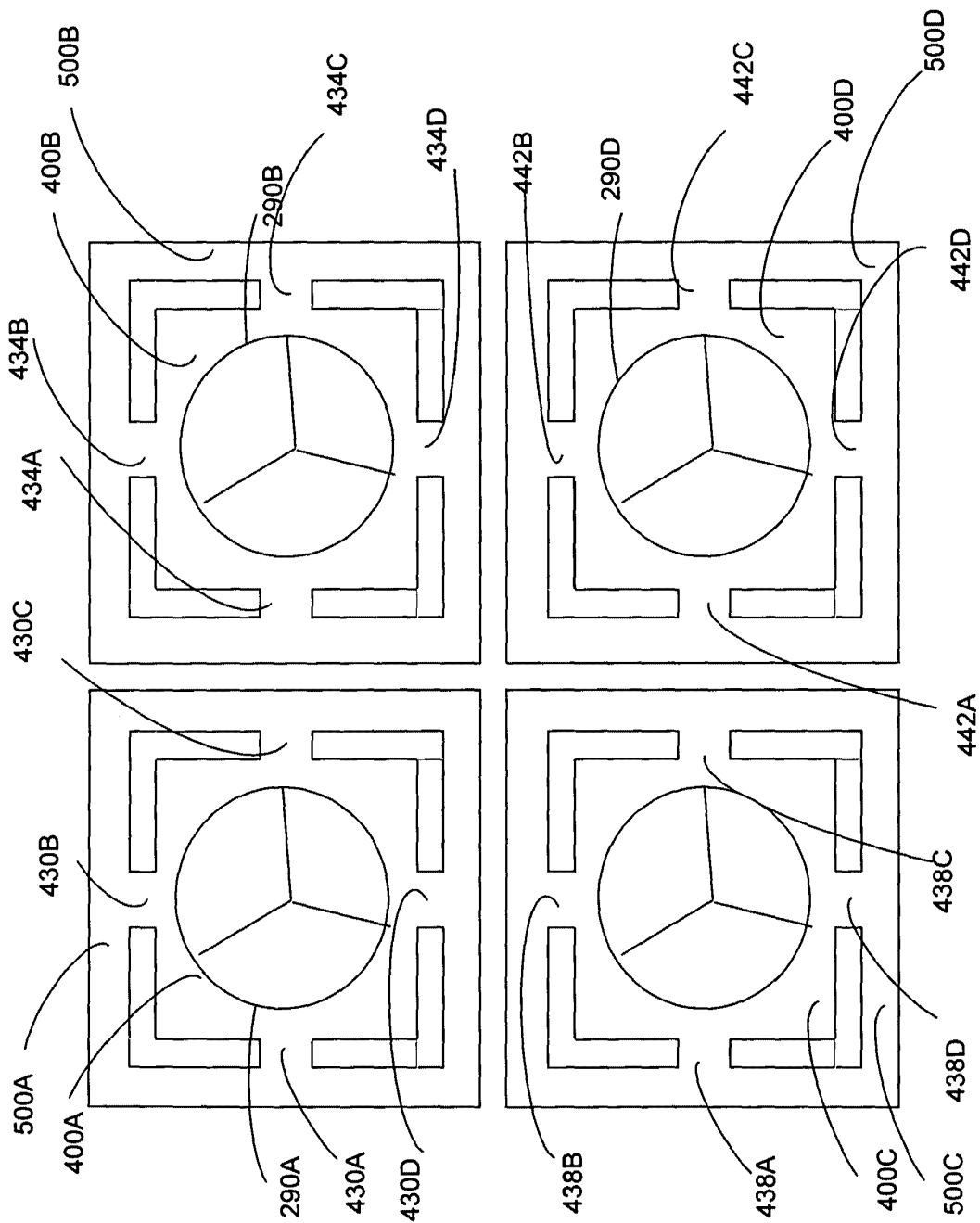


Figure 33A

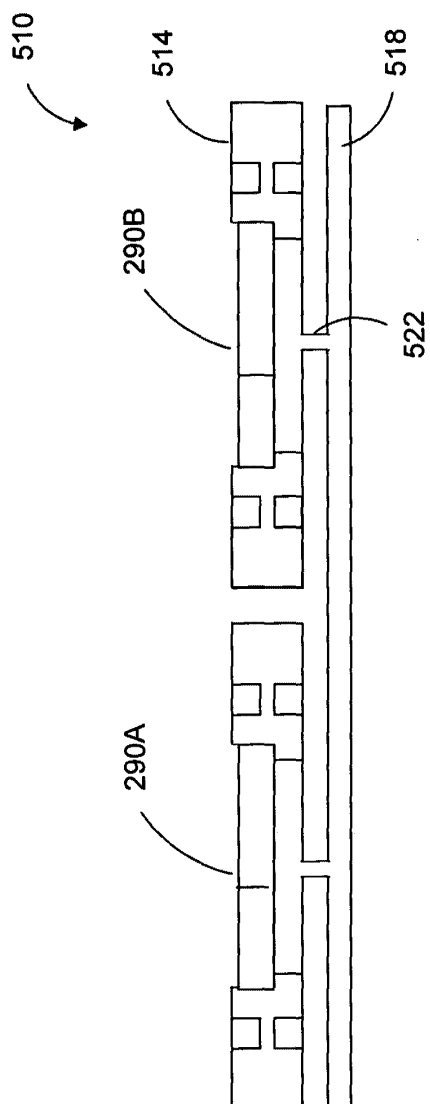


Figure 33B

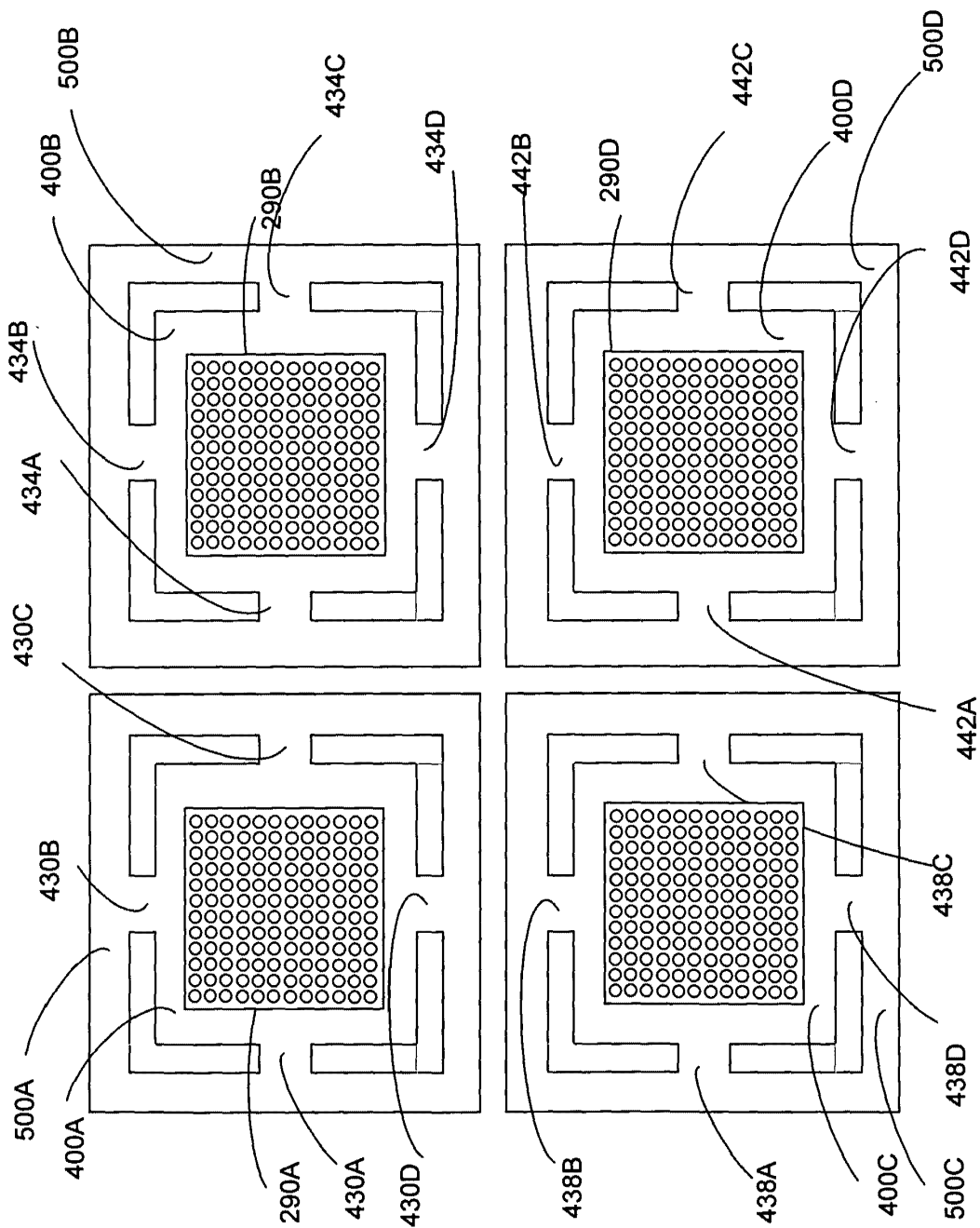


Figure 33C

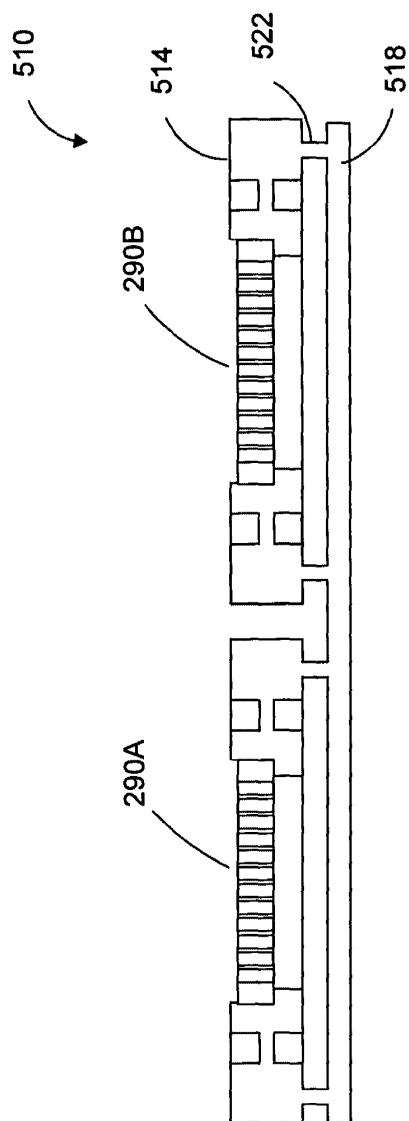


Figure 33D

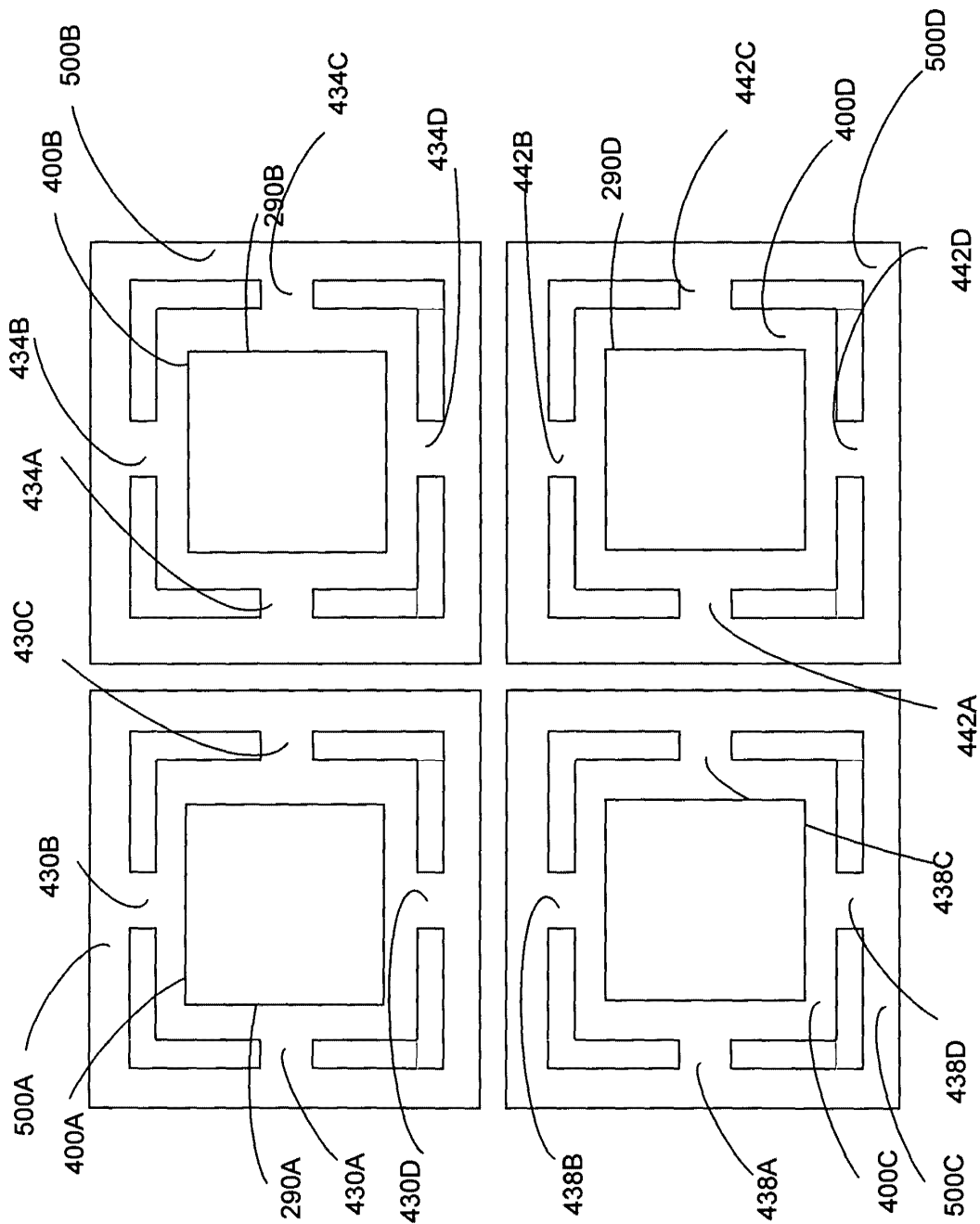


Figure 33E

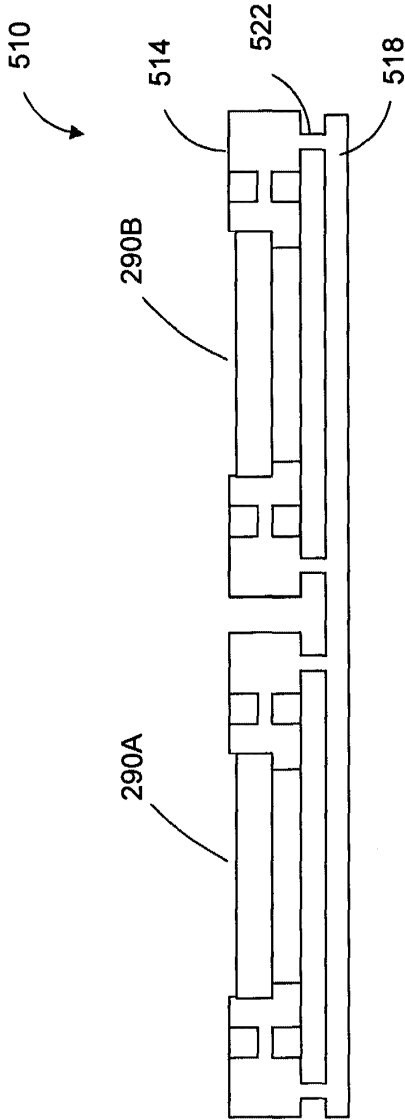


Figure 33F

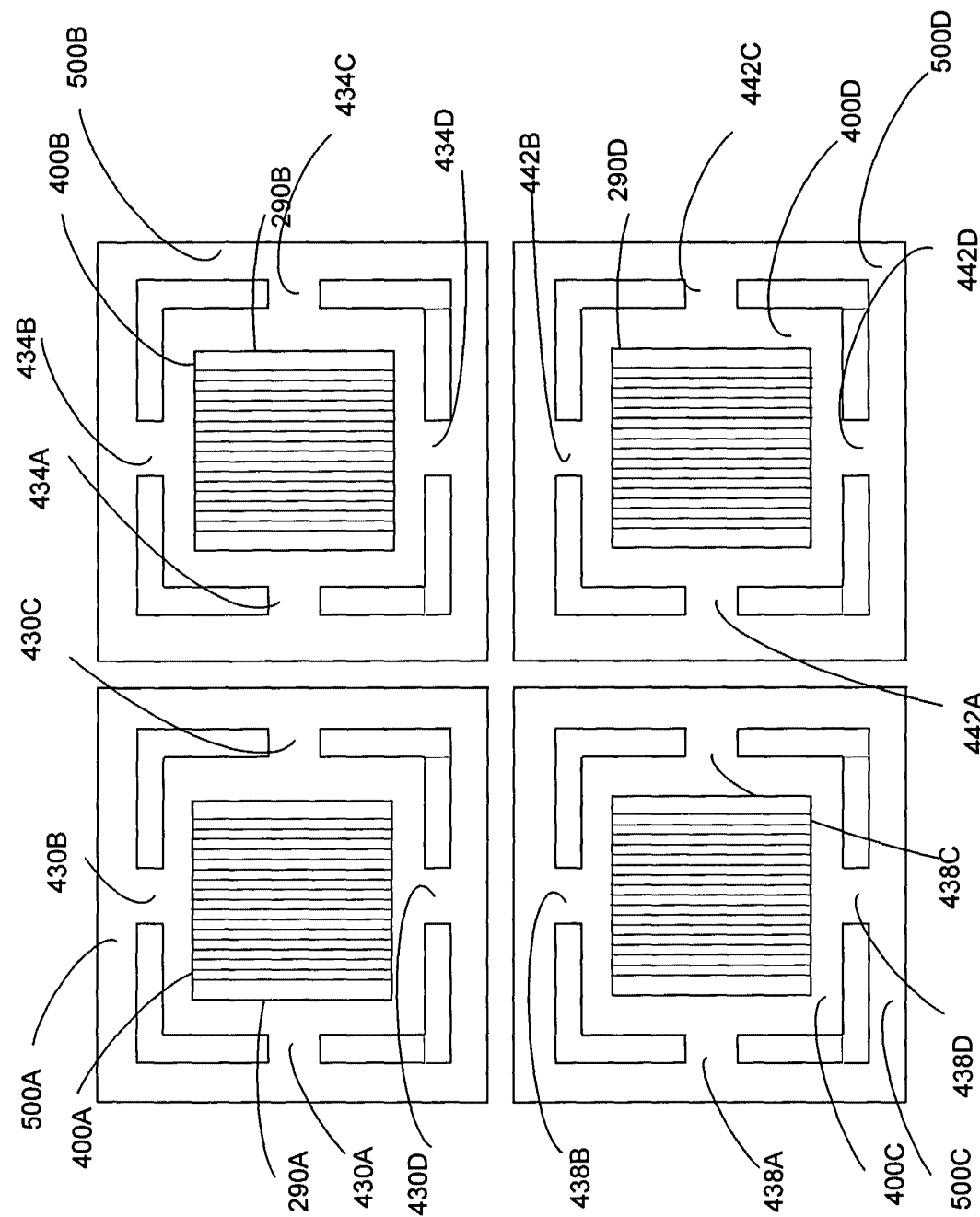


Figure 33G

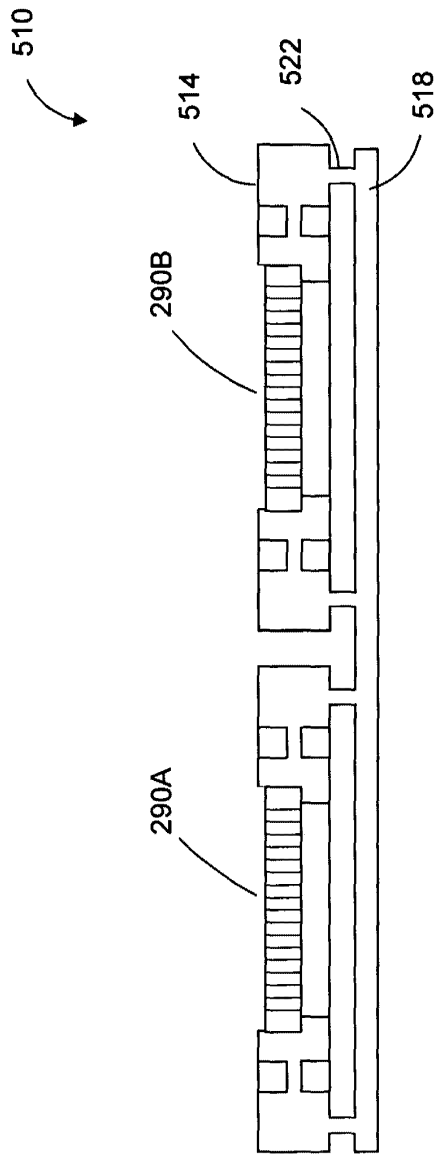


Figure 33H

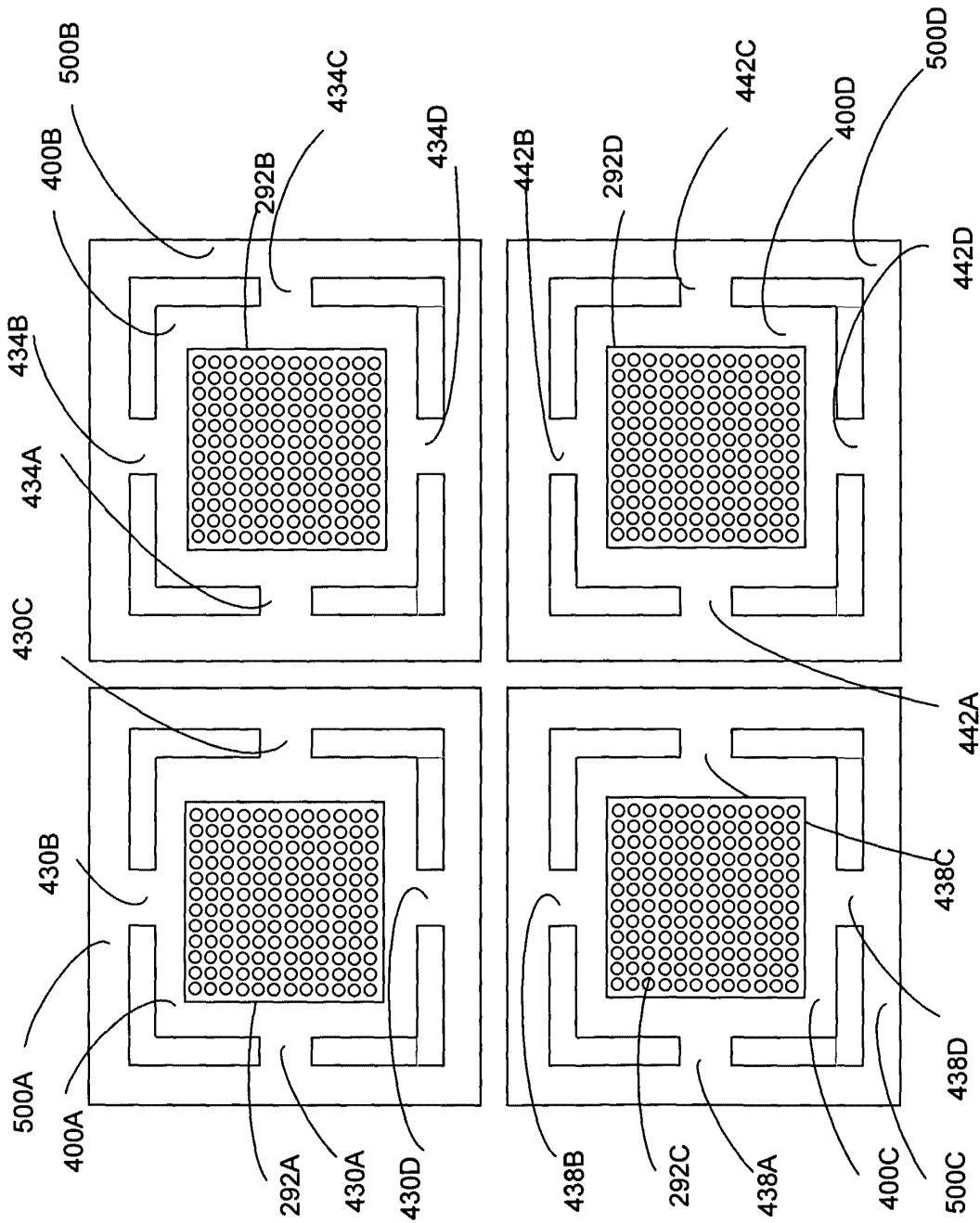


Figure 33I

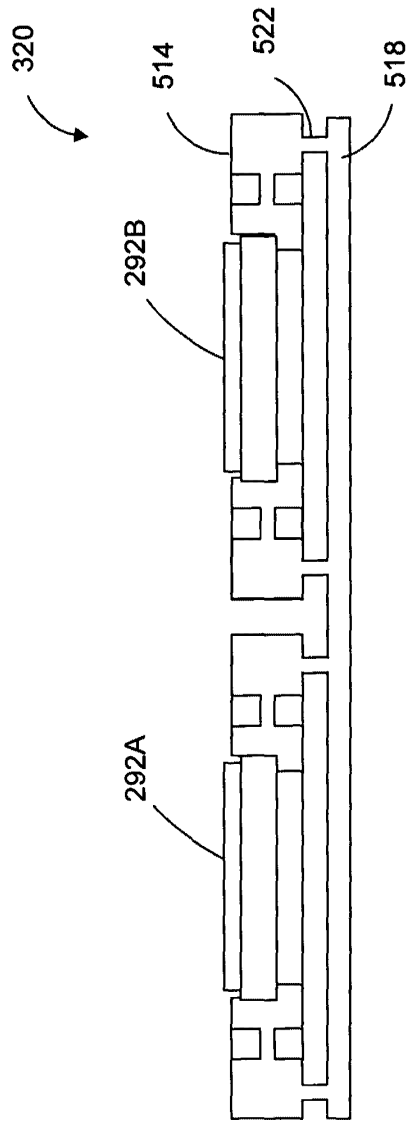


Figure 33J

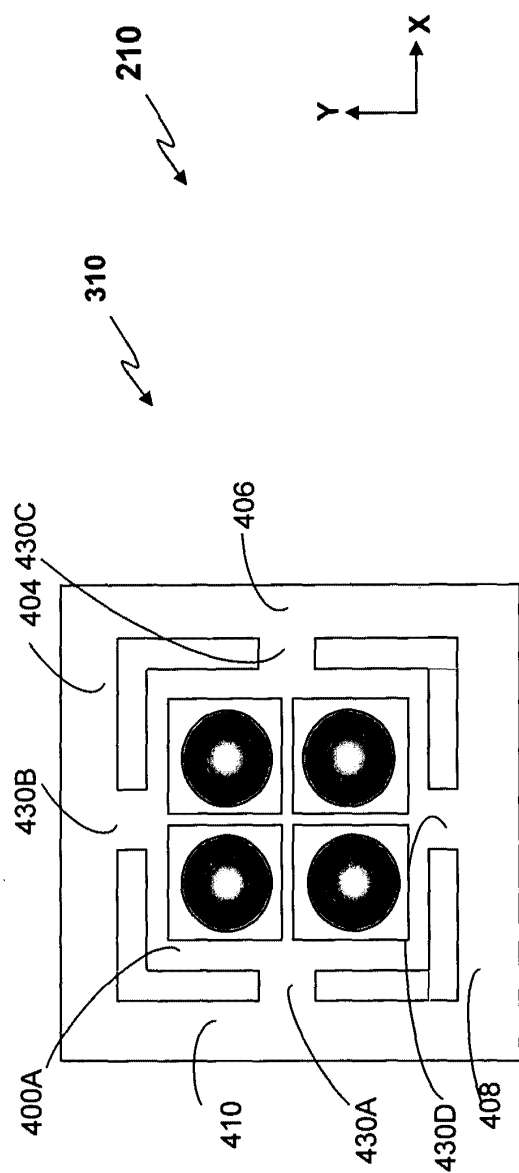


Figure 33K

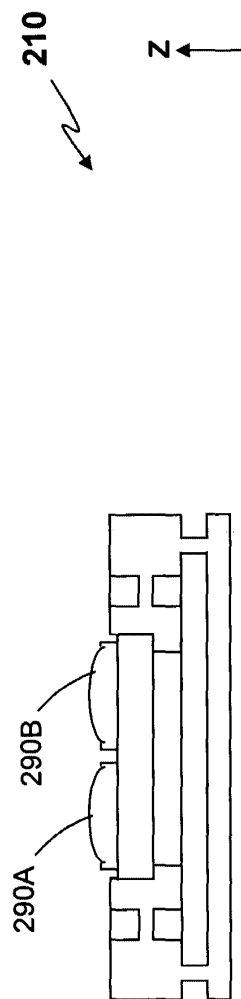


Figure 33L

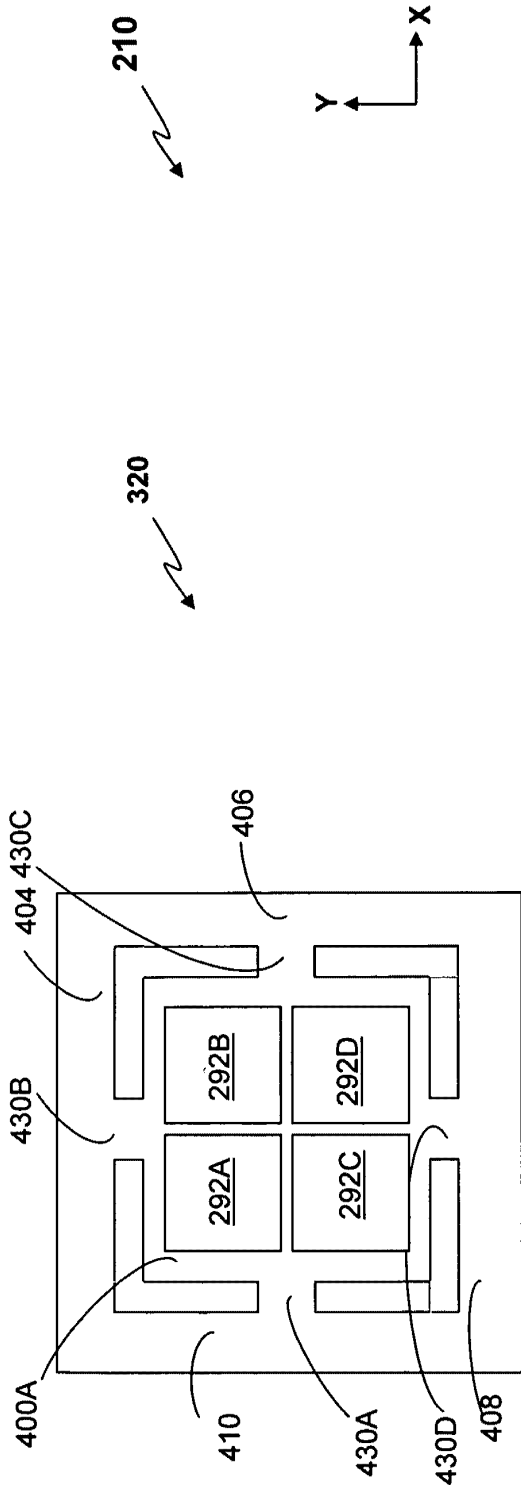


Figure 33M



Figure 33N

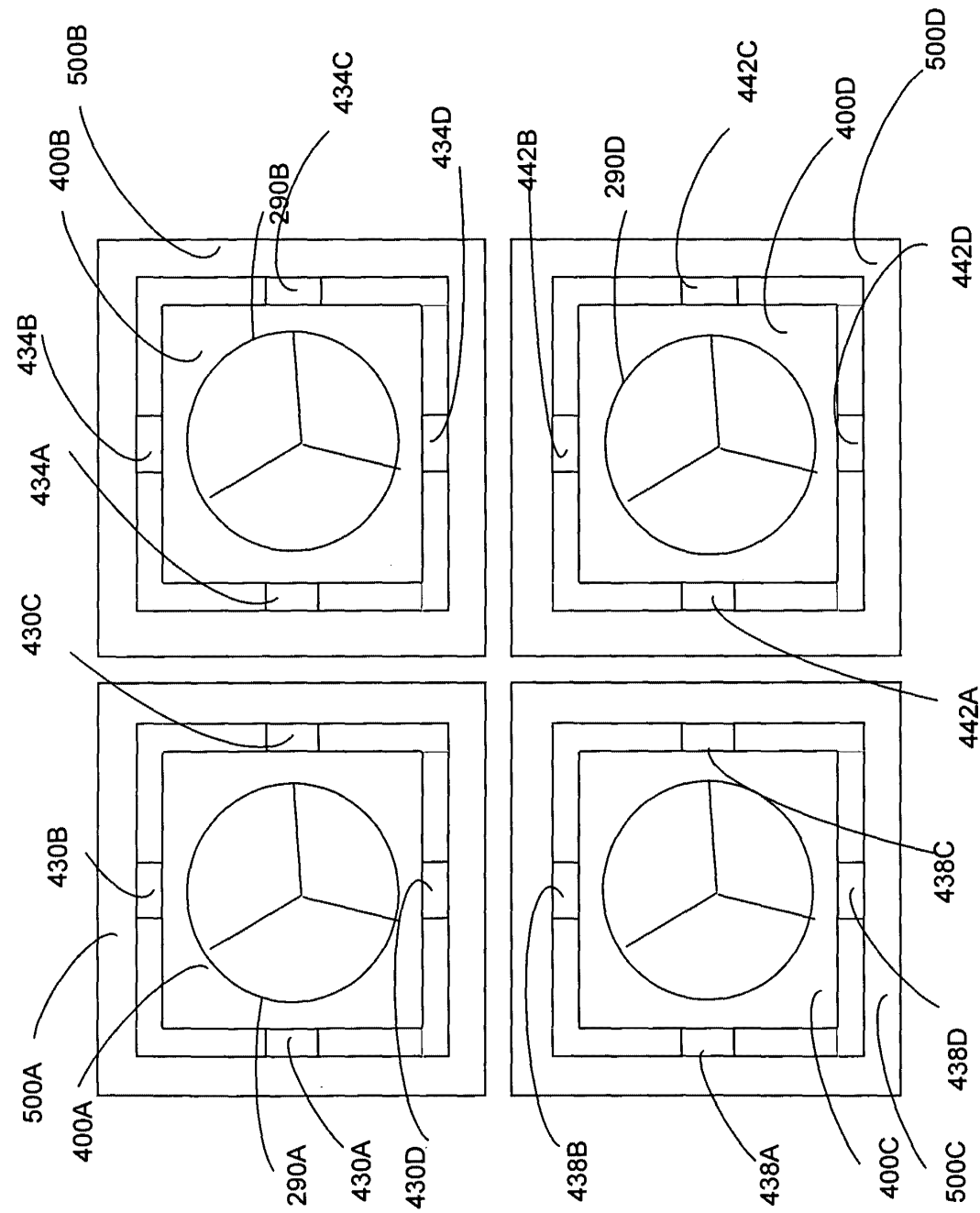


Figure 34A

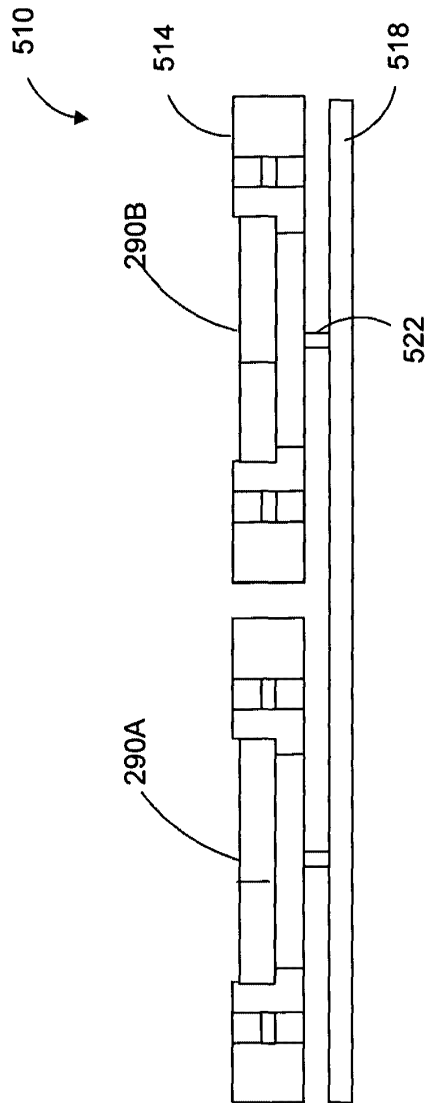


Figure 34B

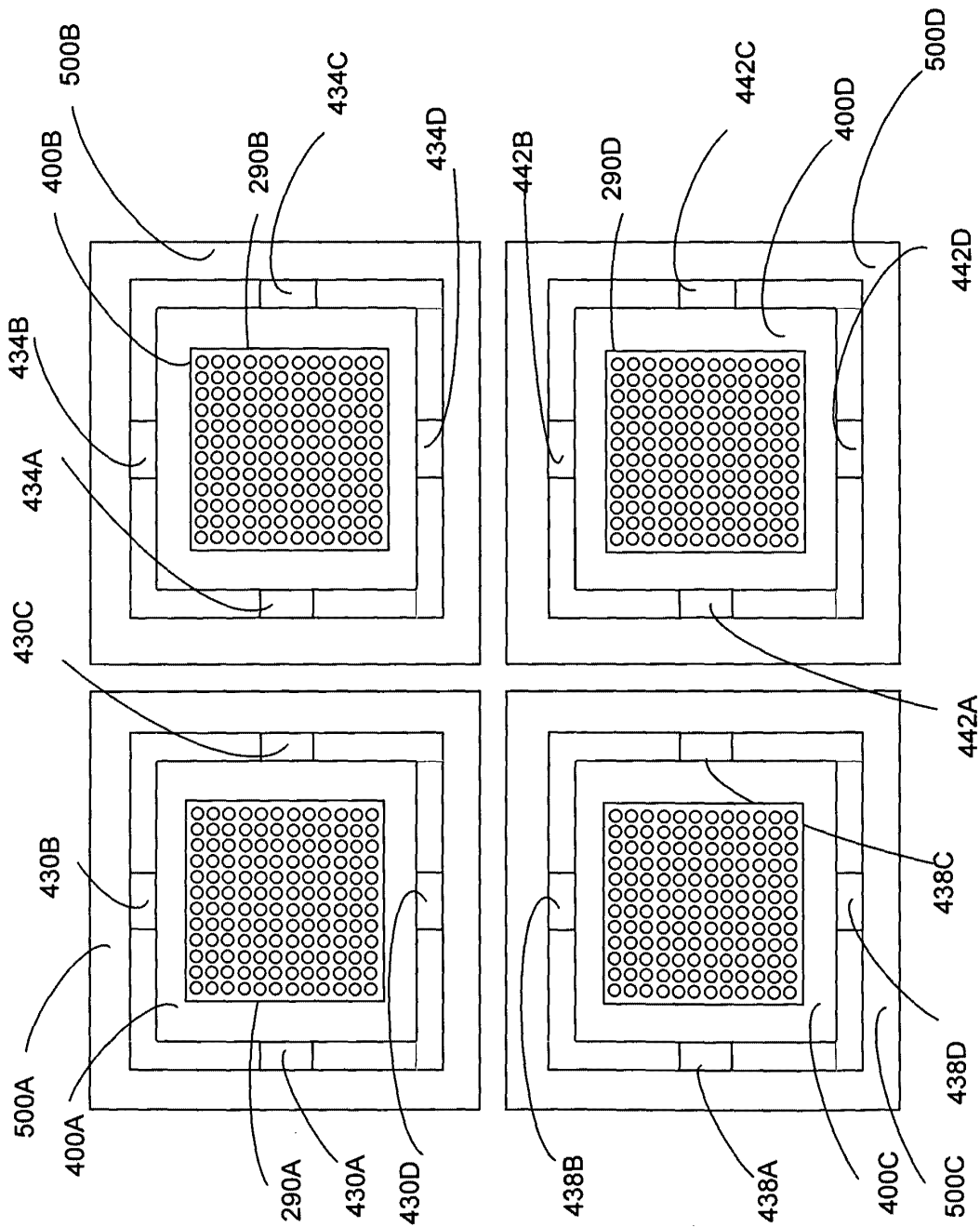


Figure 34C

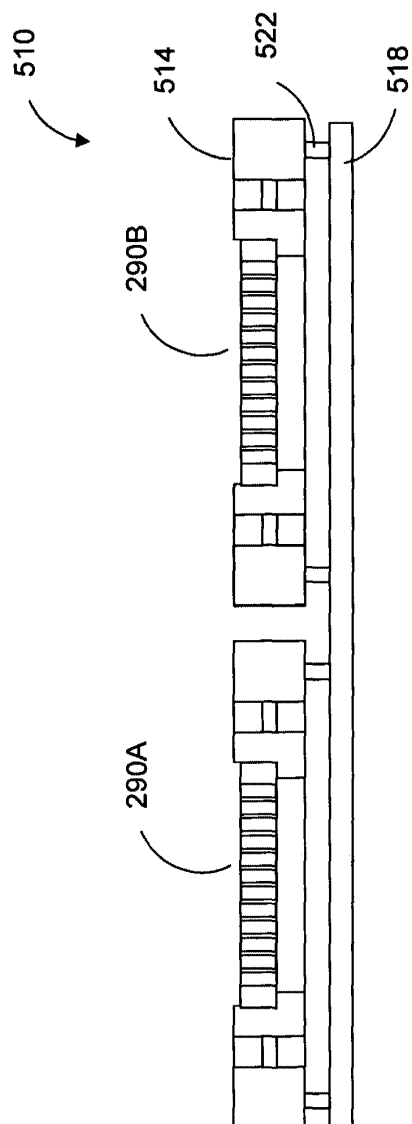


Figure 34D

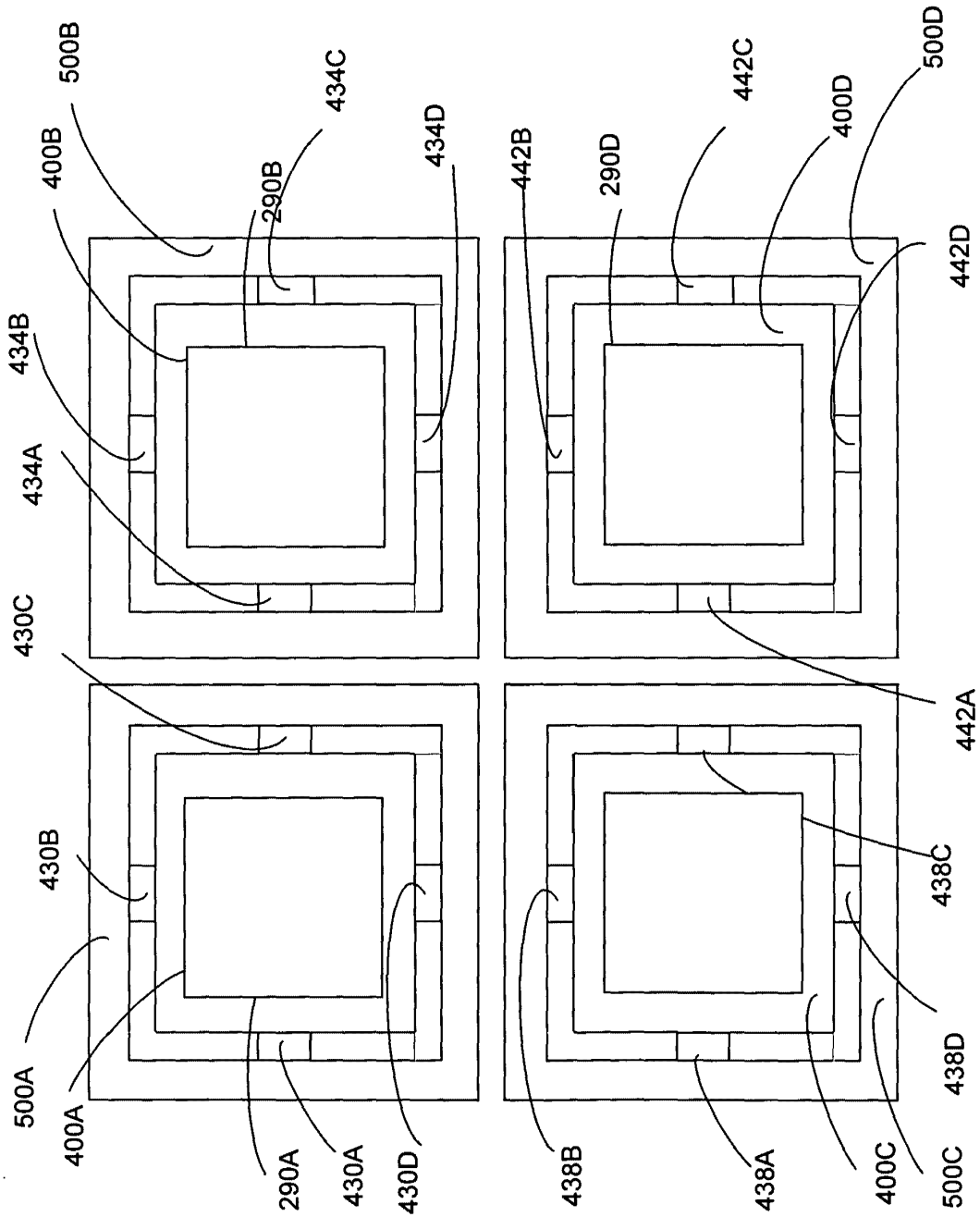


Figure 34E

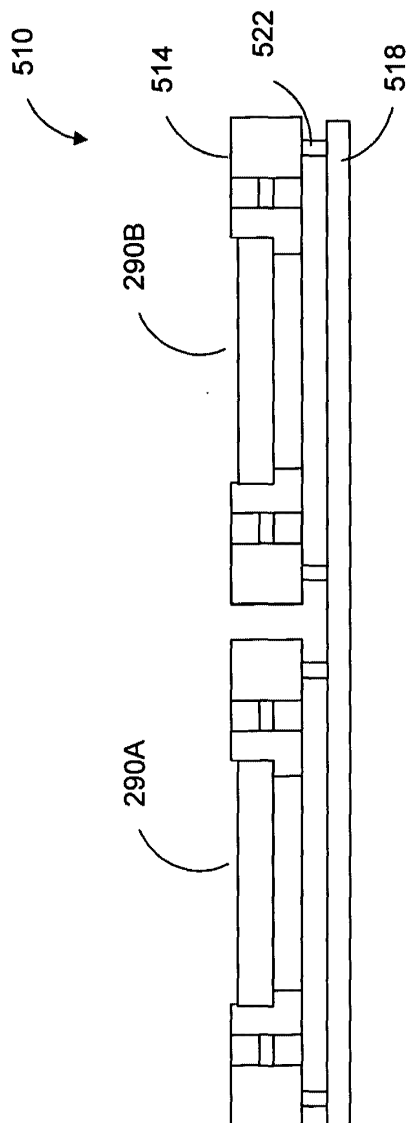


Figure 34F

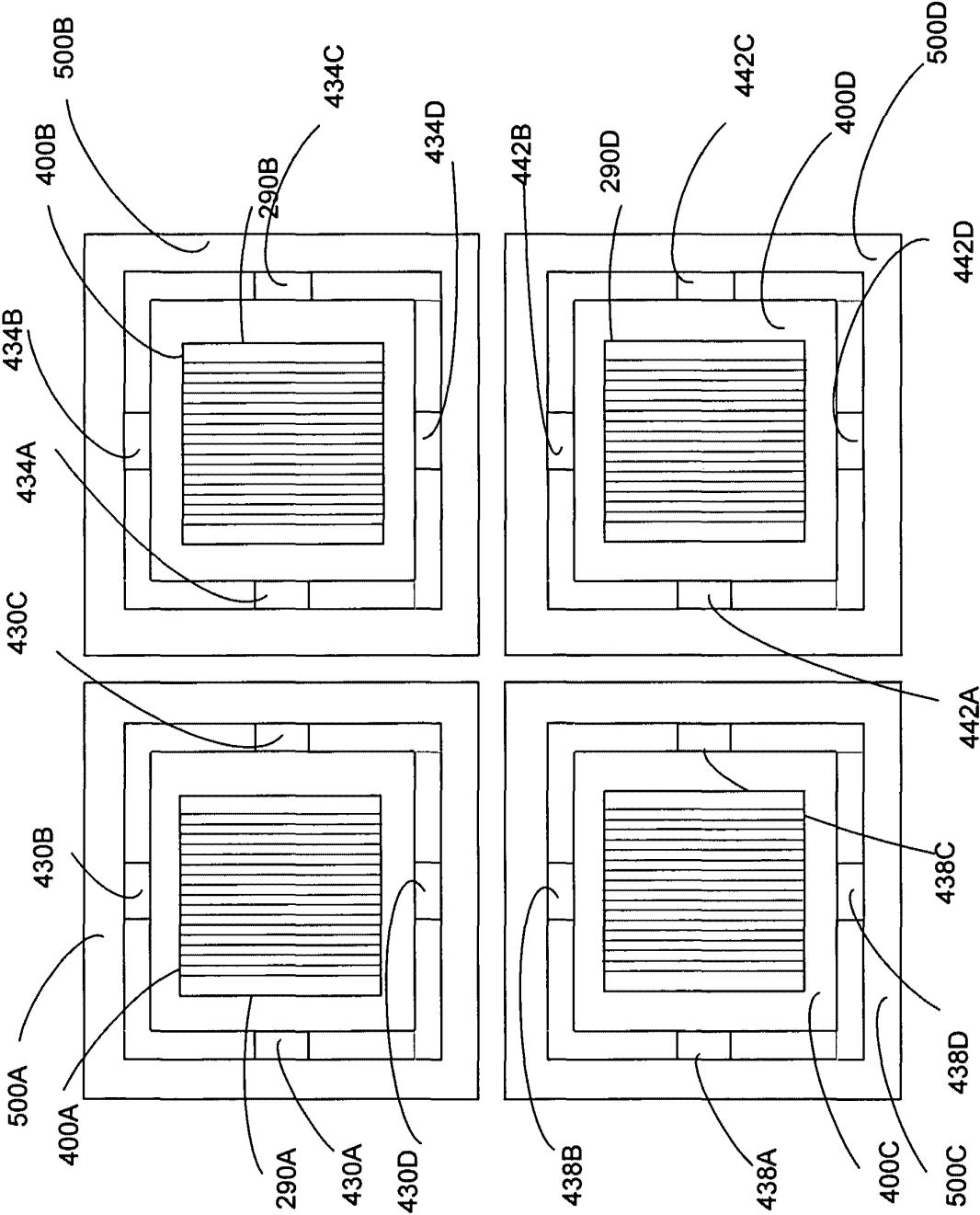


Figure 34G

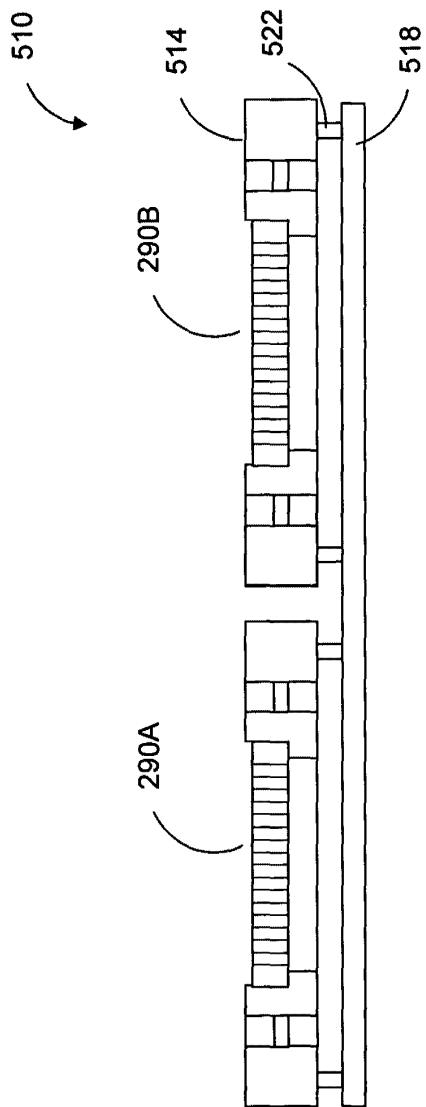


Figure 34H

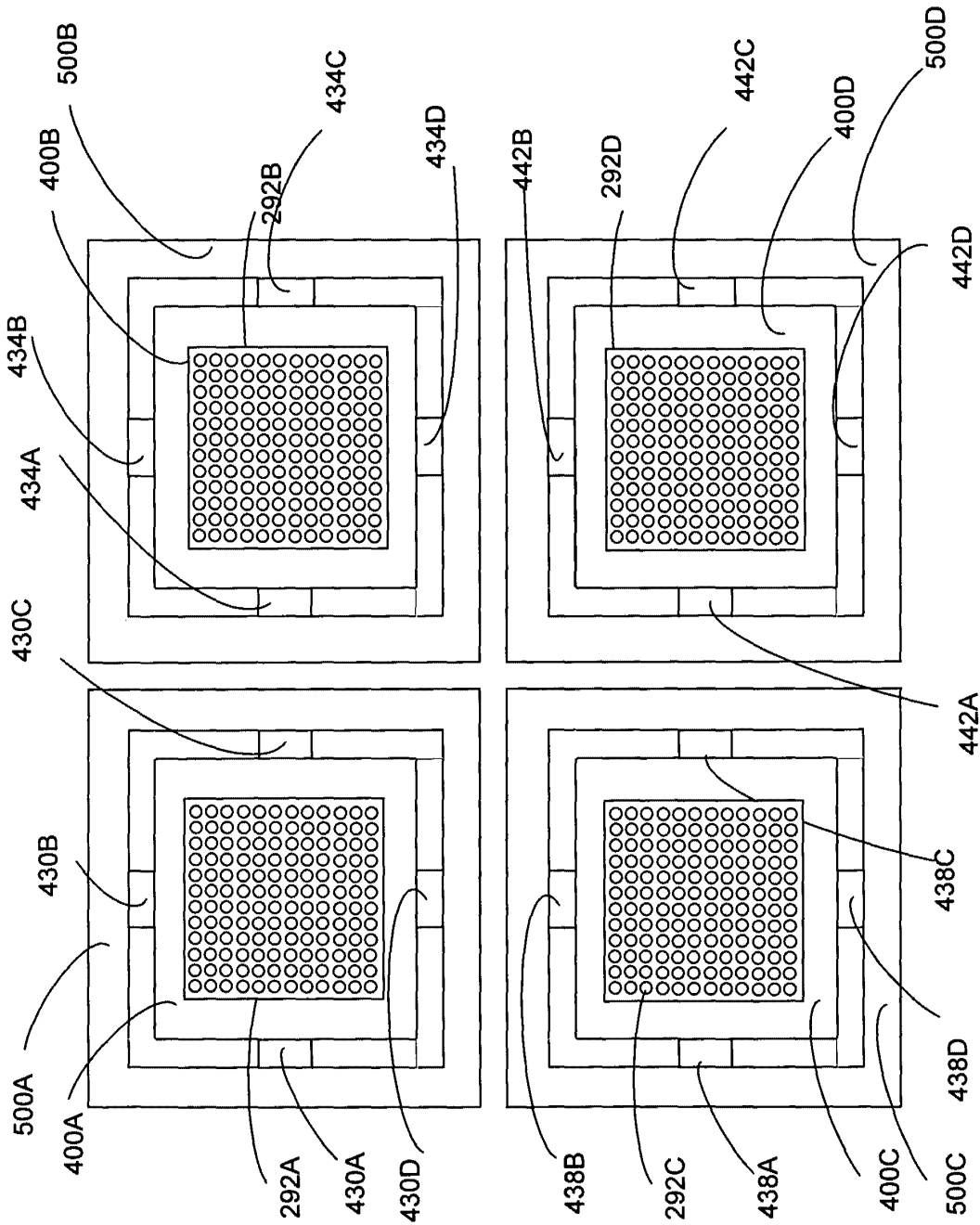


Figure 34I

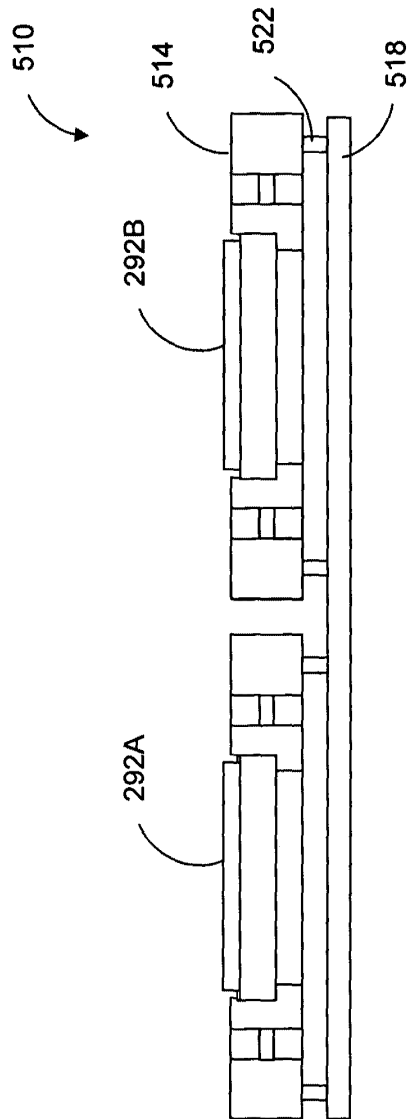


Figure 34J

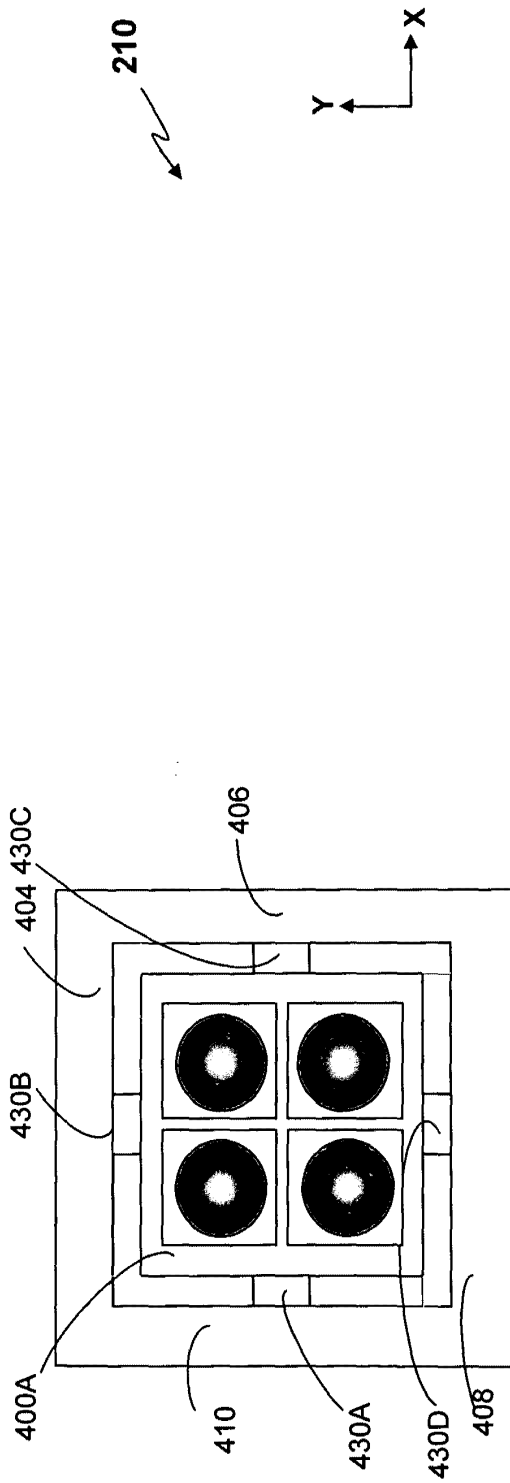


Figure 34K



Figure 34L

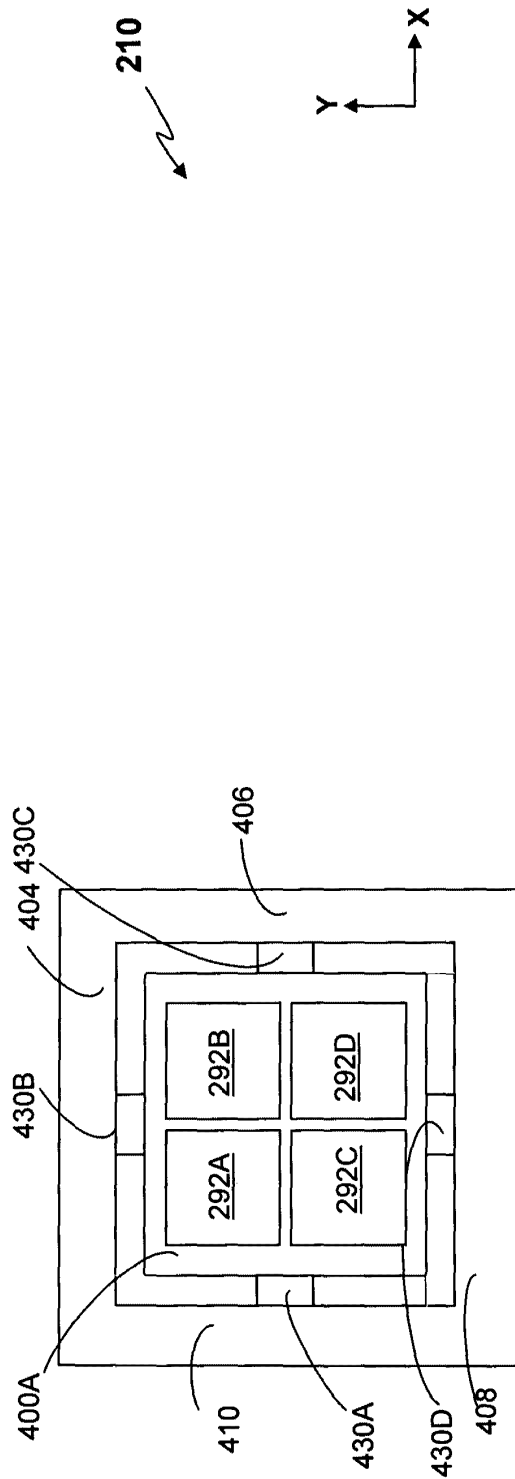


Figure 34M



Figure 34N

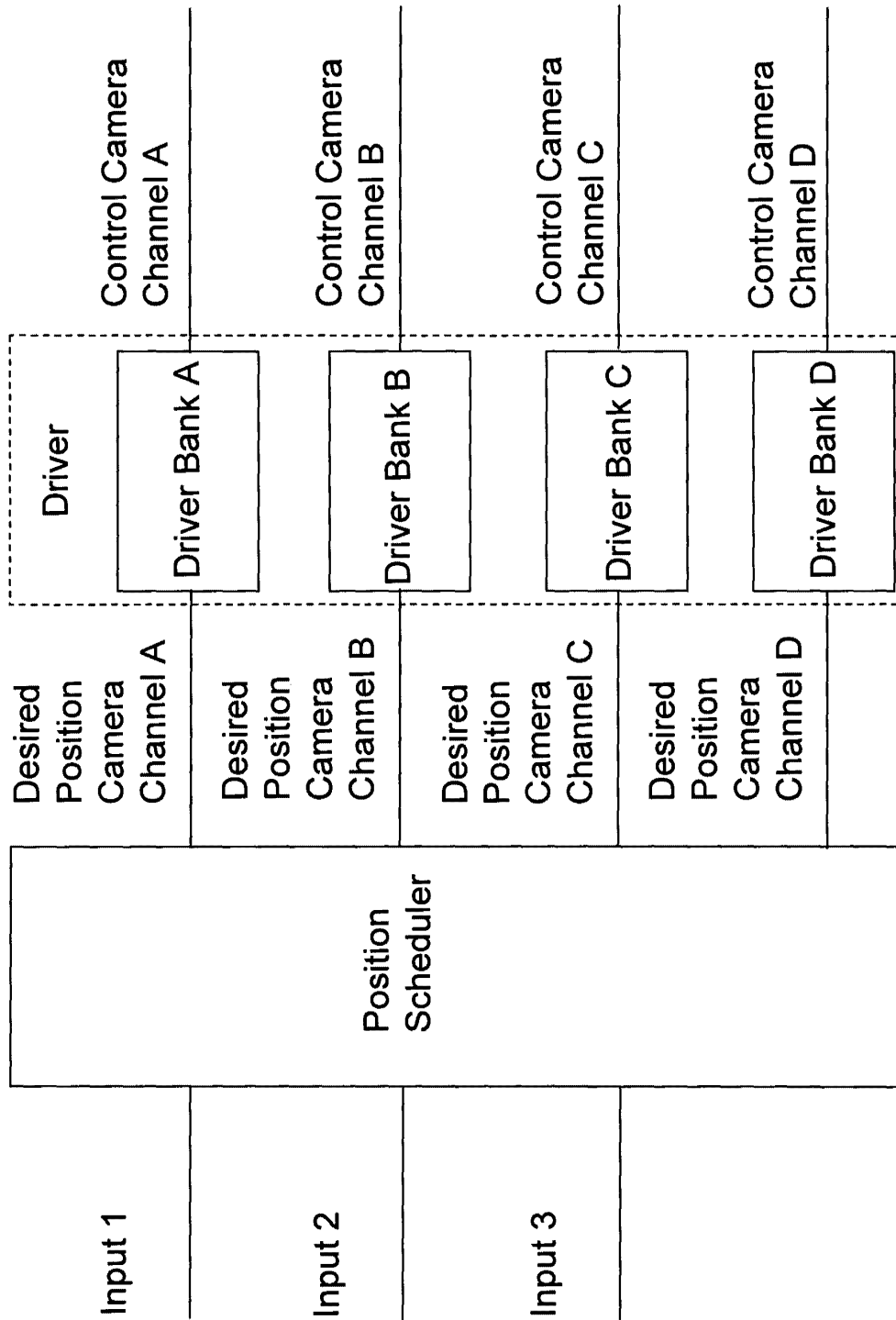


Figure 35A

Position Schedule Mapping												
Input Mode	Outputs											
	Position Channel A				Position Channel B				Position Channel C			
	A	B	C	D	A	B	C	D	A	B	C	D
normal mode	0	0	0	0	0	0	0	0	0	0	0	0
2x resolution	1	0	0	0	1	0	0	0	1	0	0	0
3x resolution	0	1	0	0	0	1	0	0	0	1	0	0
4x resolution	1	1	0	0	1	1	0	0	1	1	0	0
2x zoom	1	0	0	0	1	0	0	0	1	0	0	0
3x zoom	0	1	0	0	0	1	0	0	0	1	0	0
4x zoom	1	1	0	0	1	1	0	0	1	1	0	0
range finder	1	0	0	0	0	0	0	0	1	0	0	0

Figure 35B

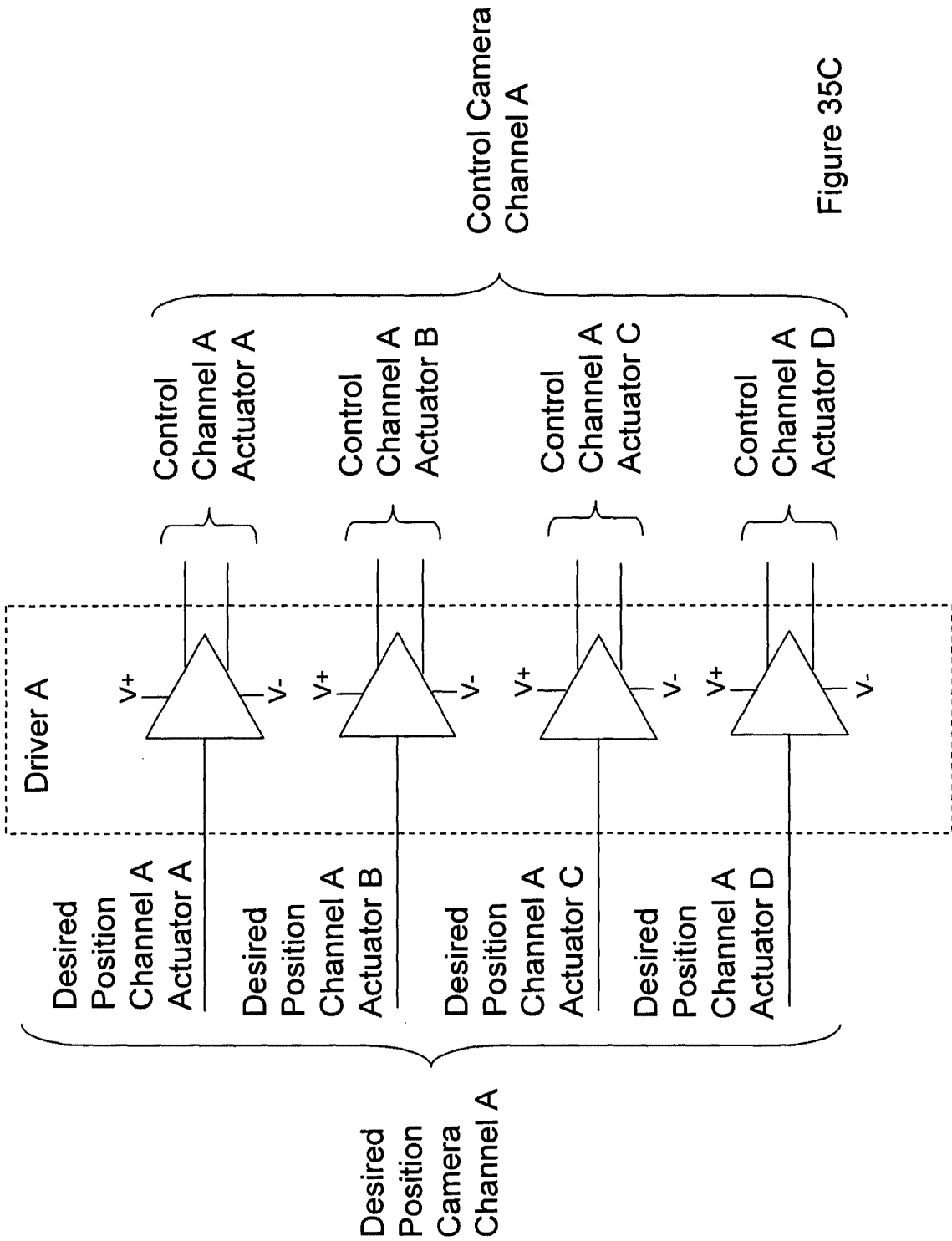


Figure 35C

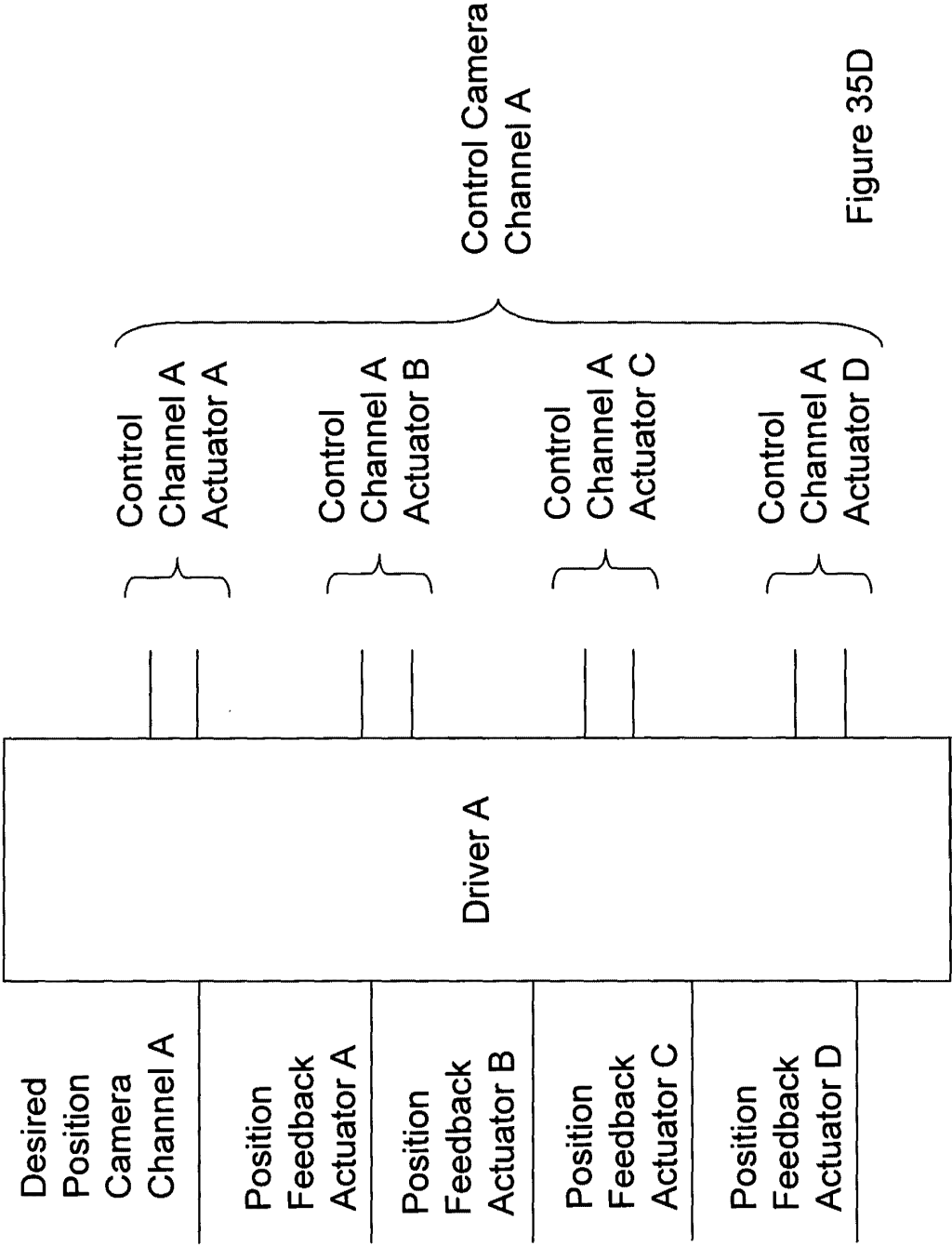


Figure 35D

Calibration of Positioner

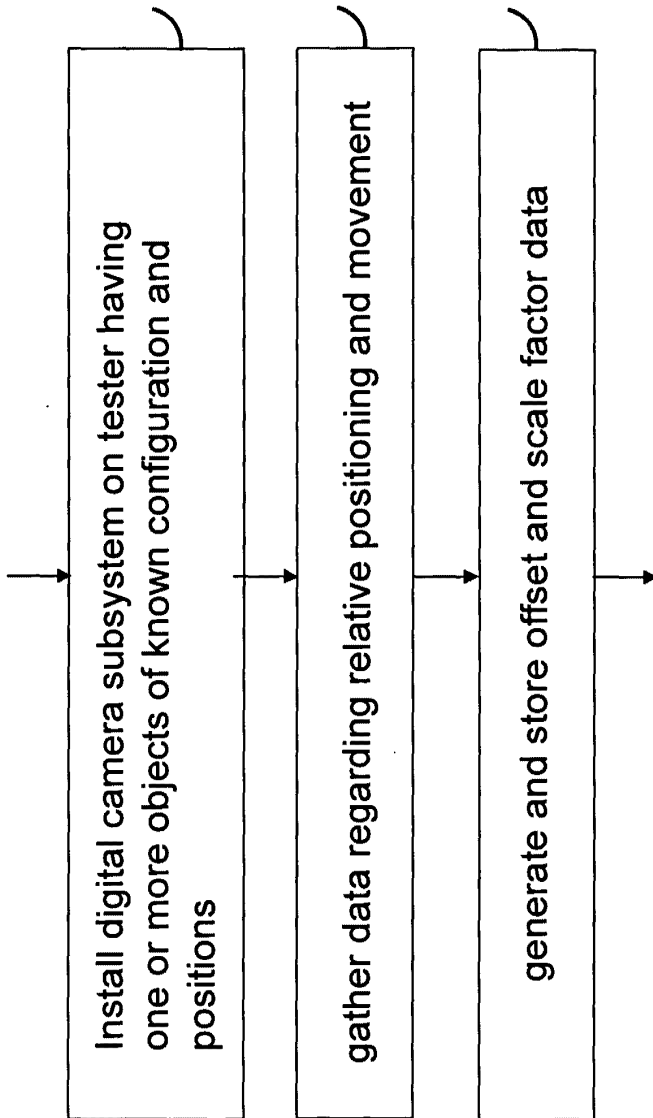


Figure 35E

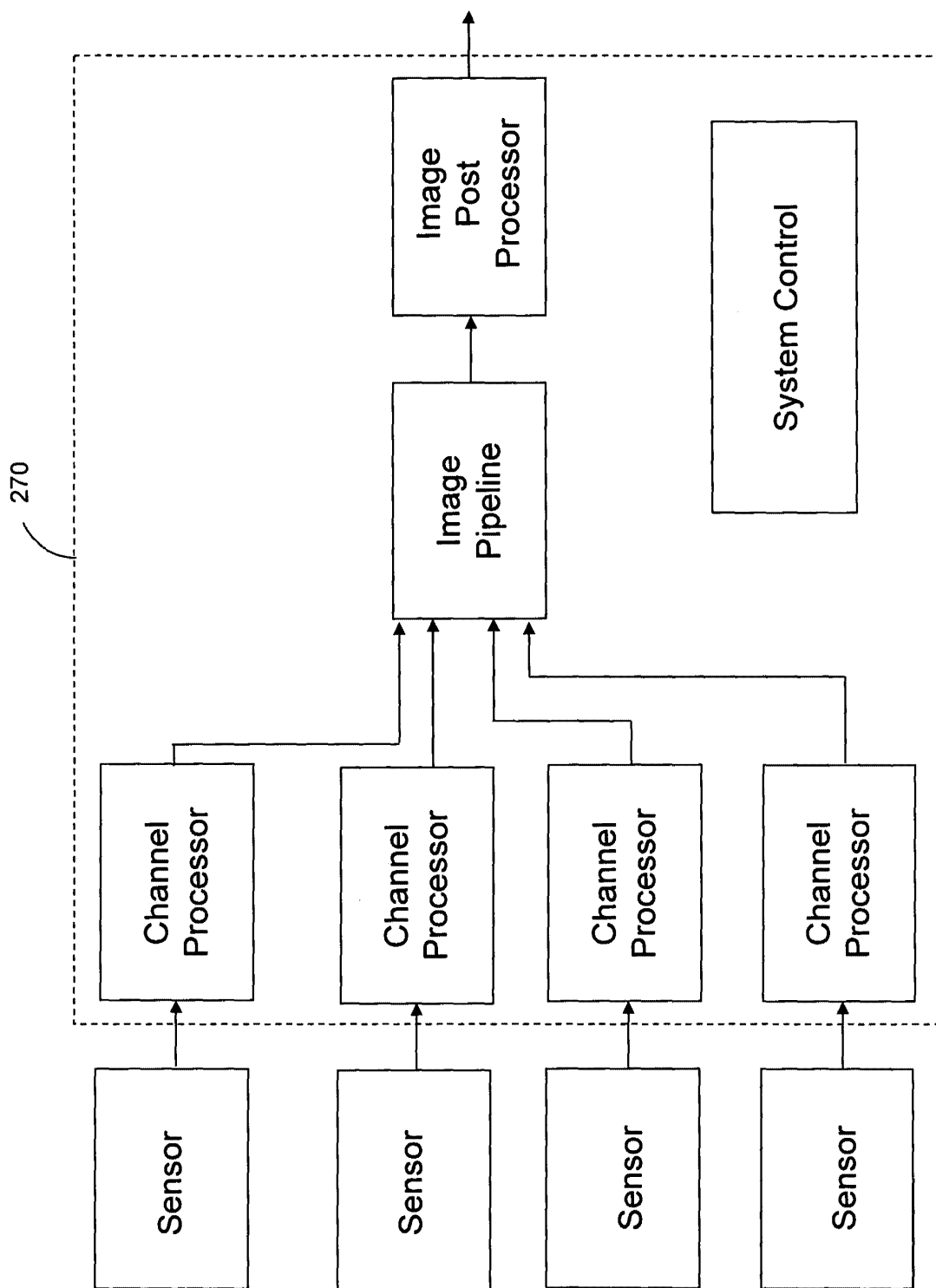


Figure 36A

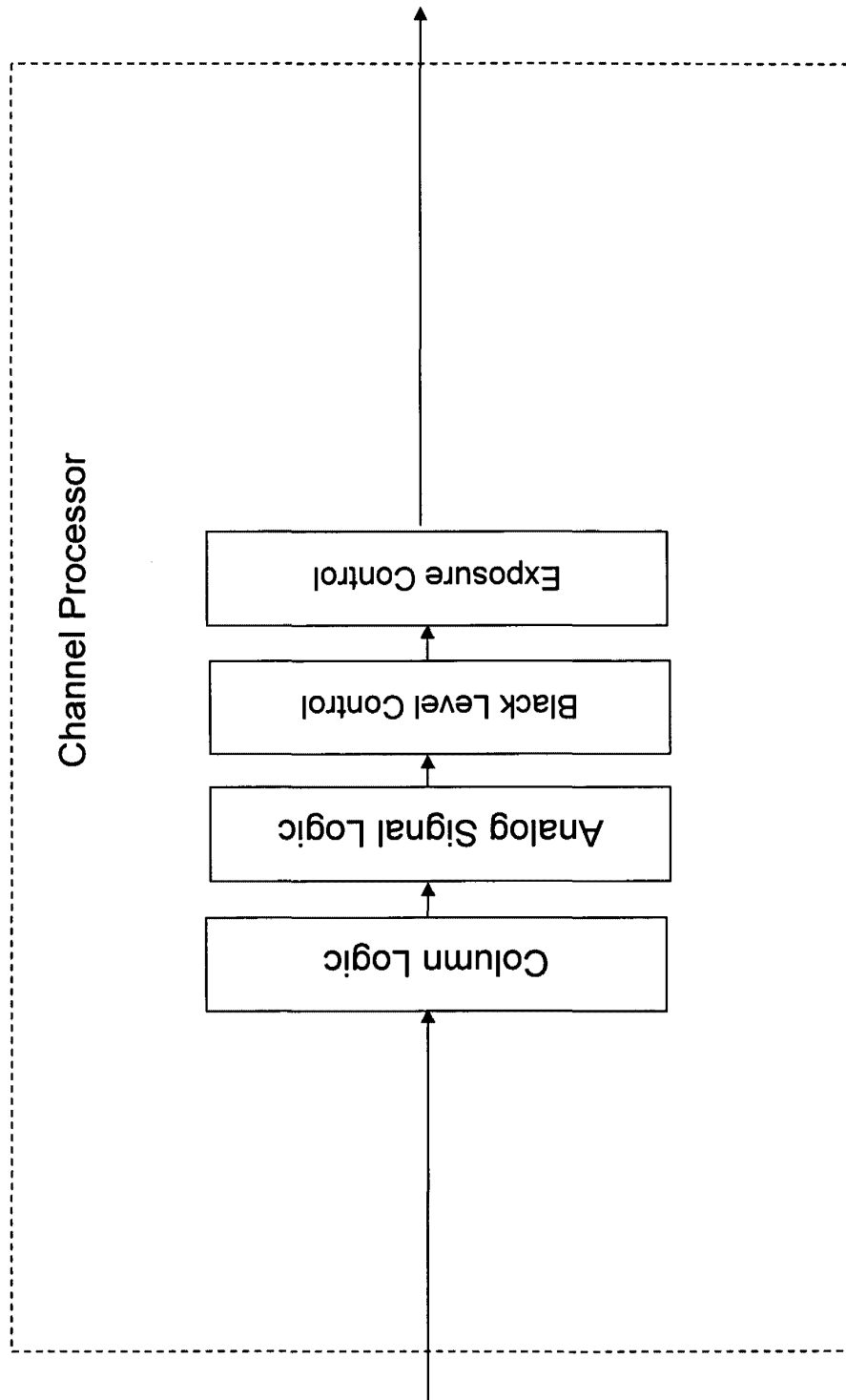


Figure 36B

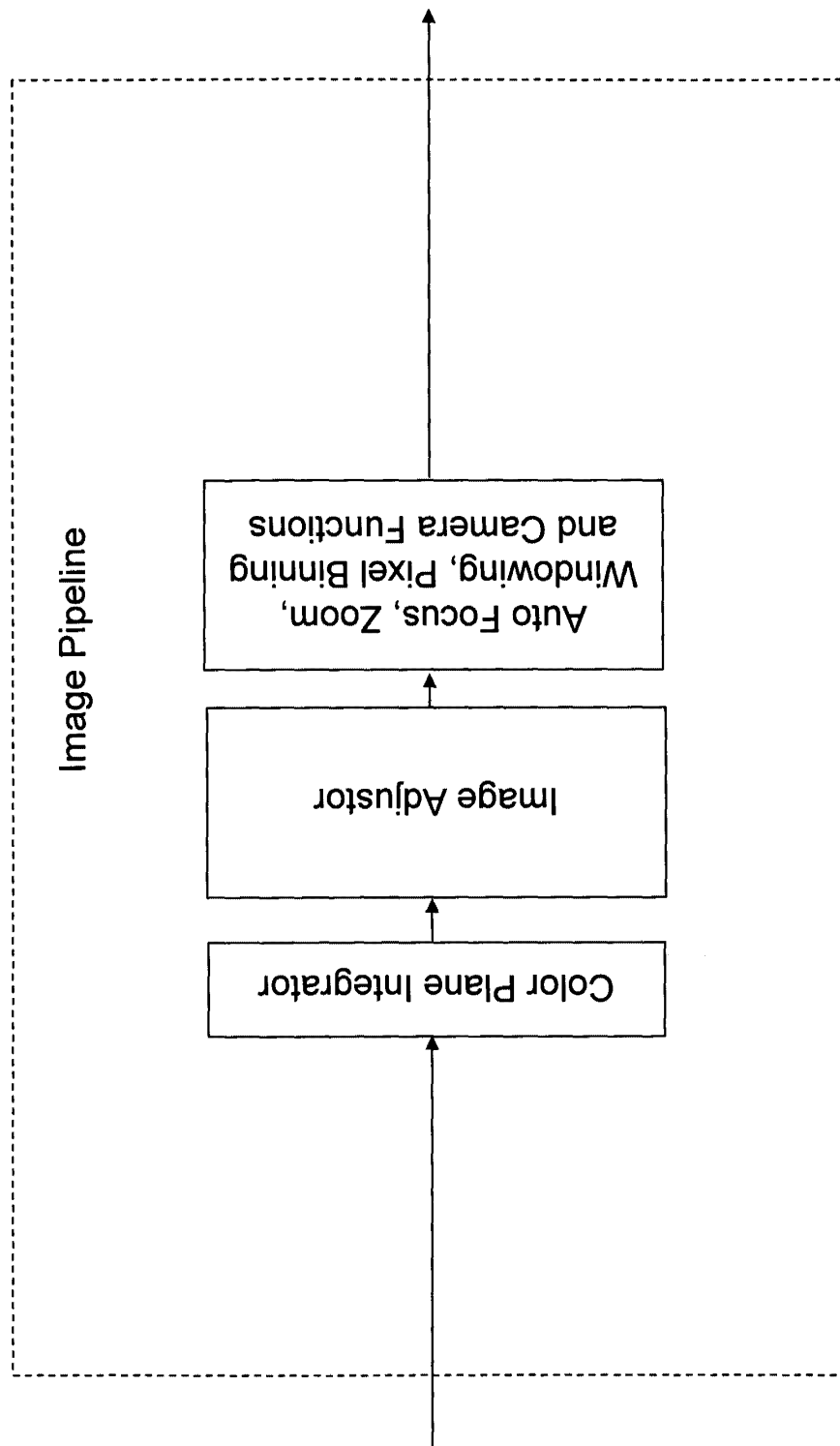


Figure 36C

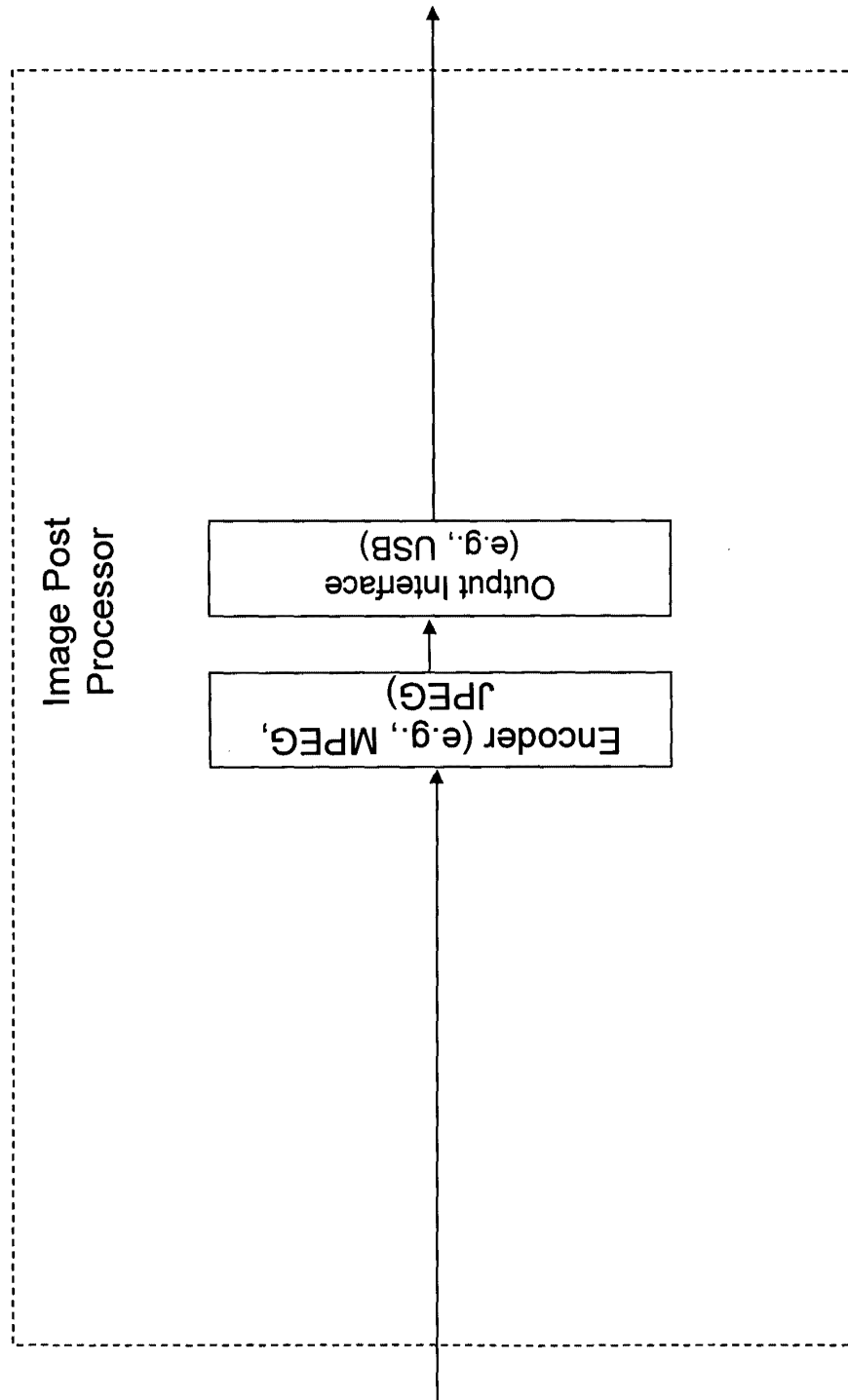


Figure 36D

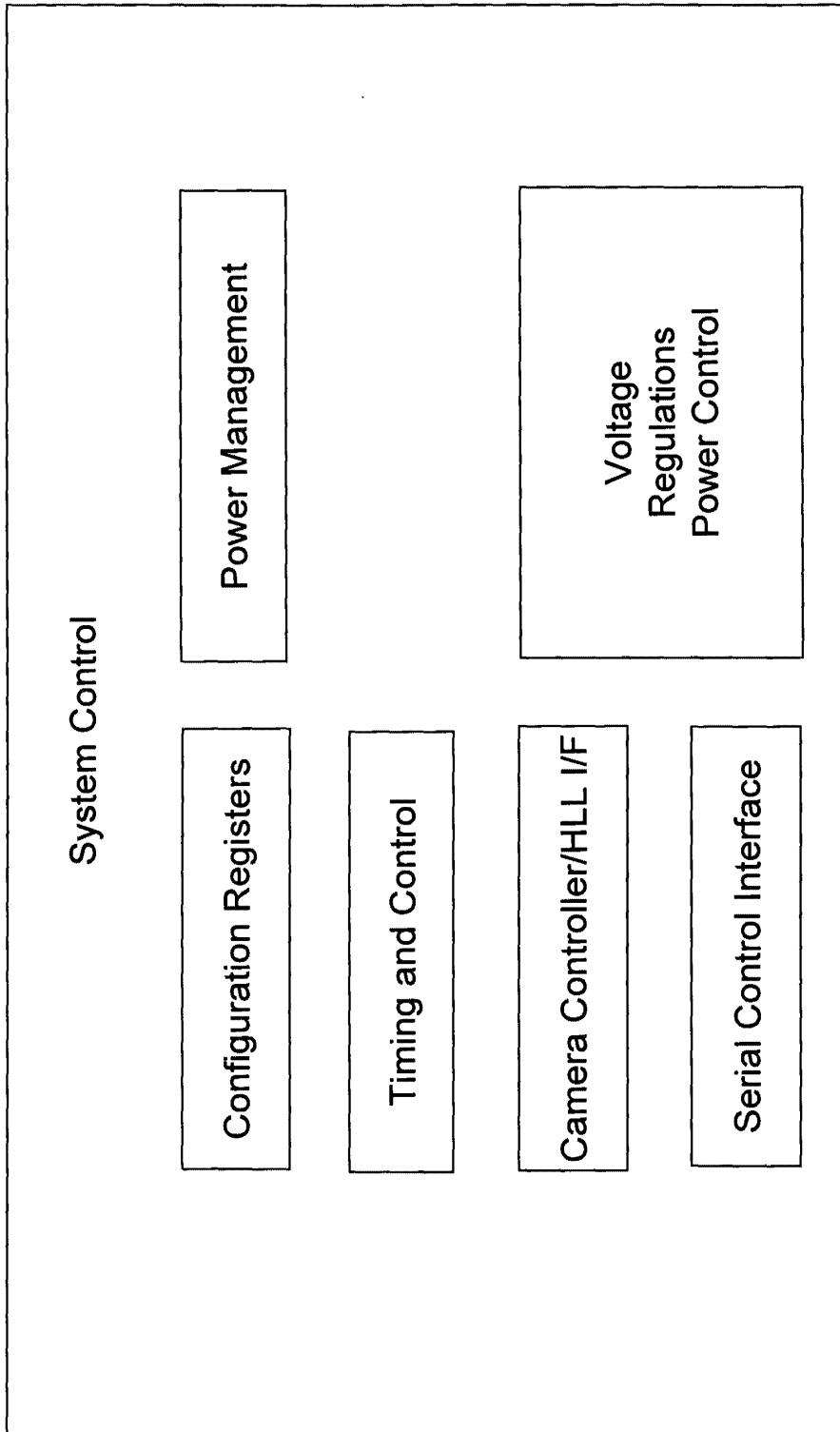


Figure 36E

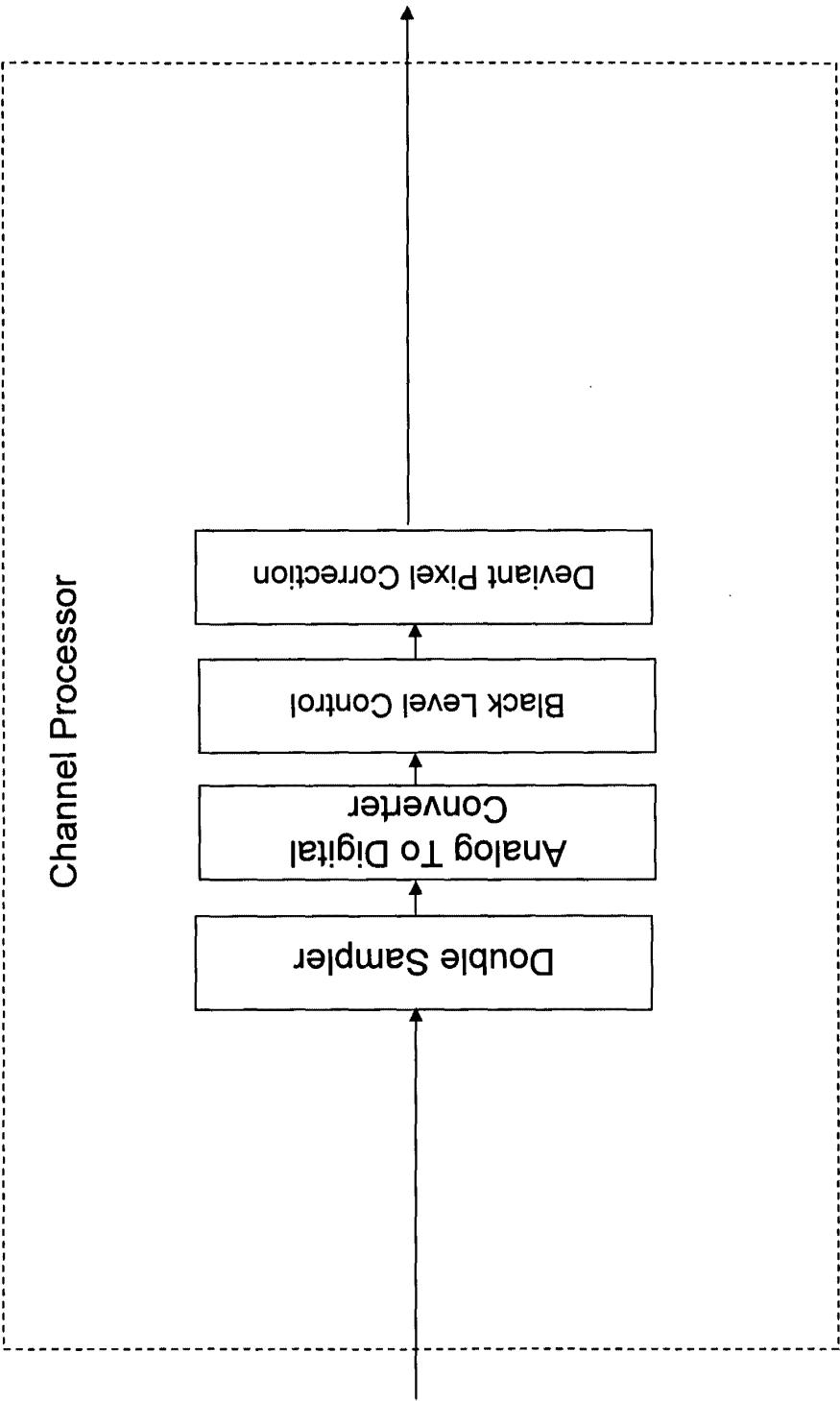


Figure 37A

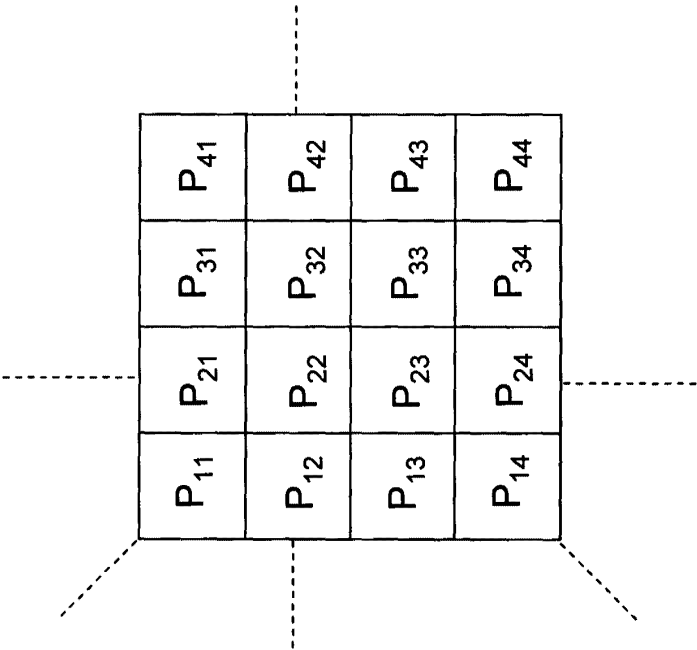


Figure 37B

Double Sampler

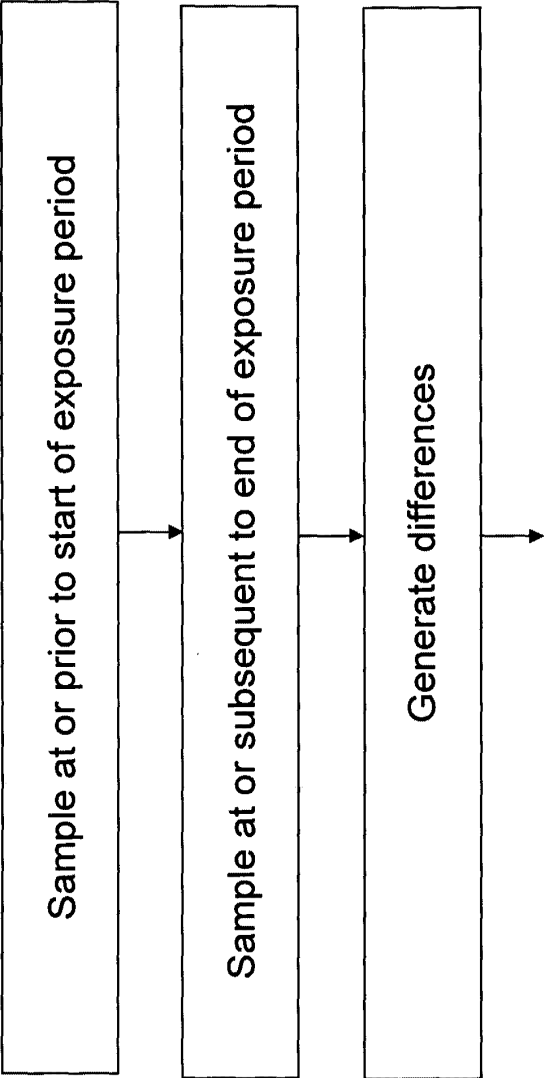


Figure 37C

Deviant Pixel

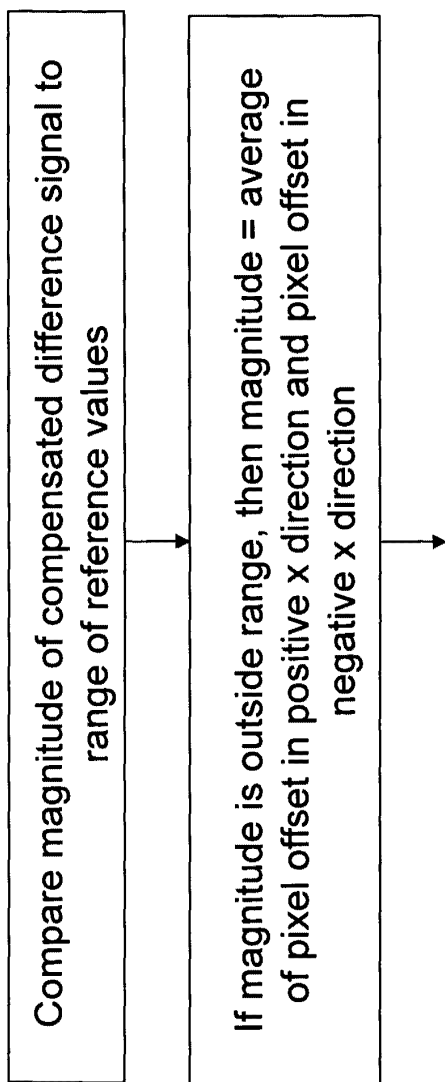
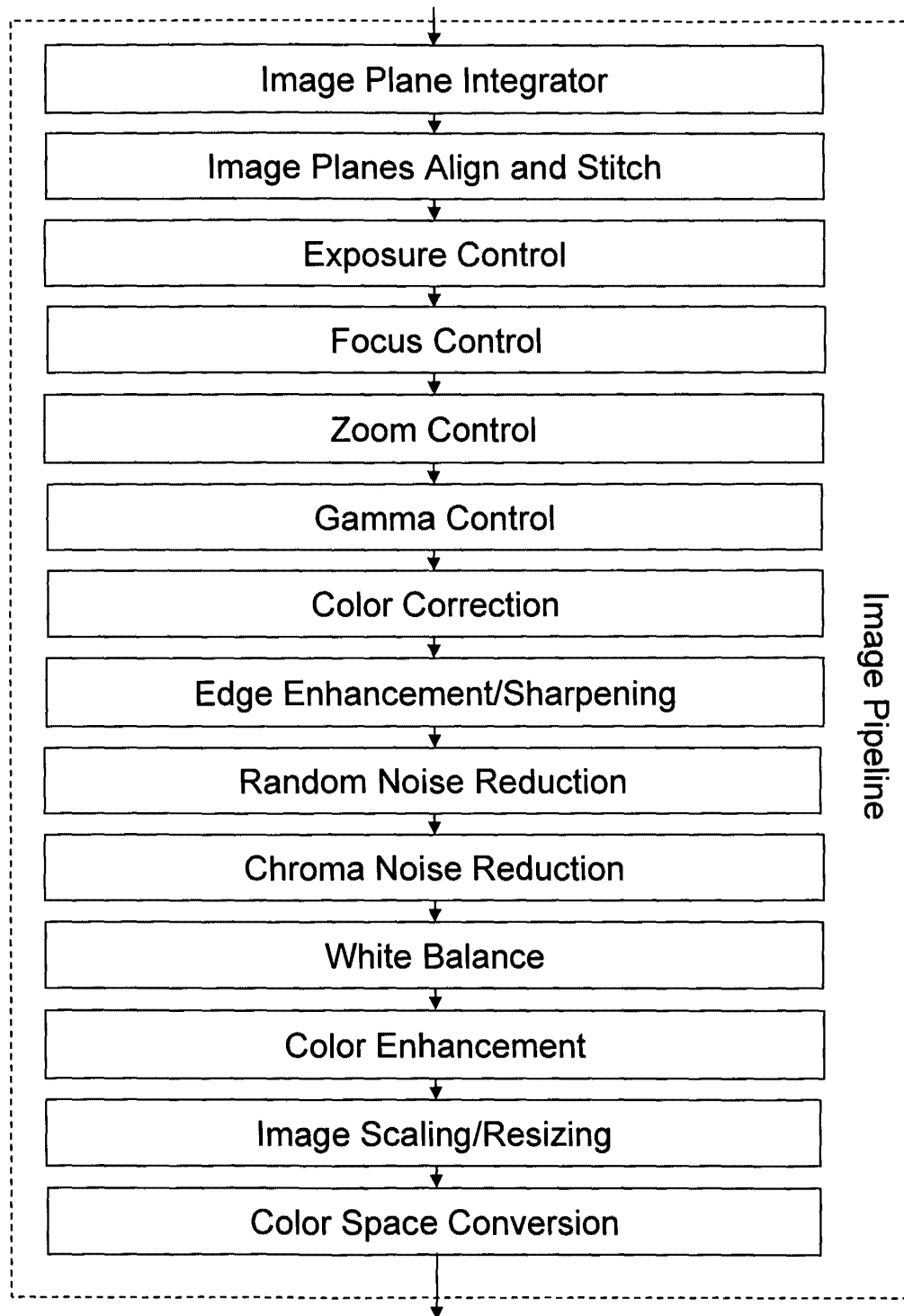


Figure 37D

Figure 37E



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Integrator

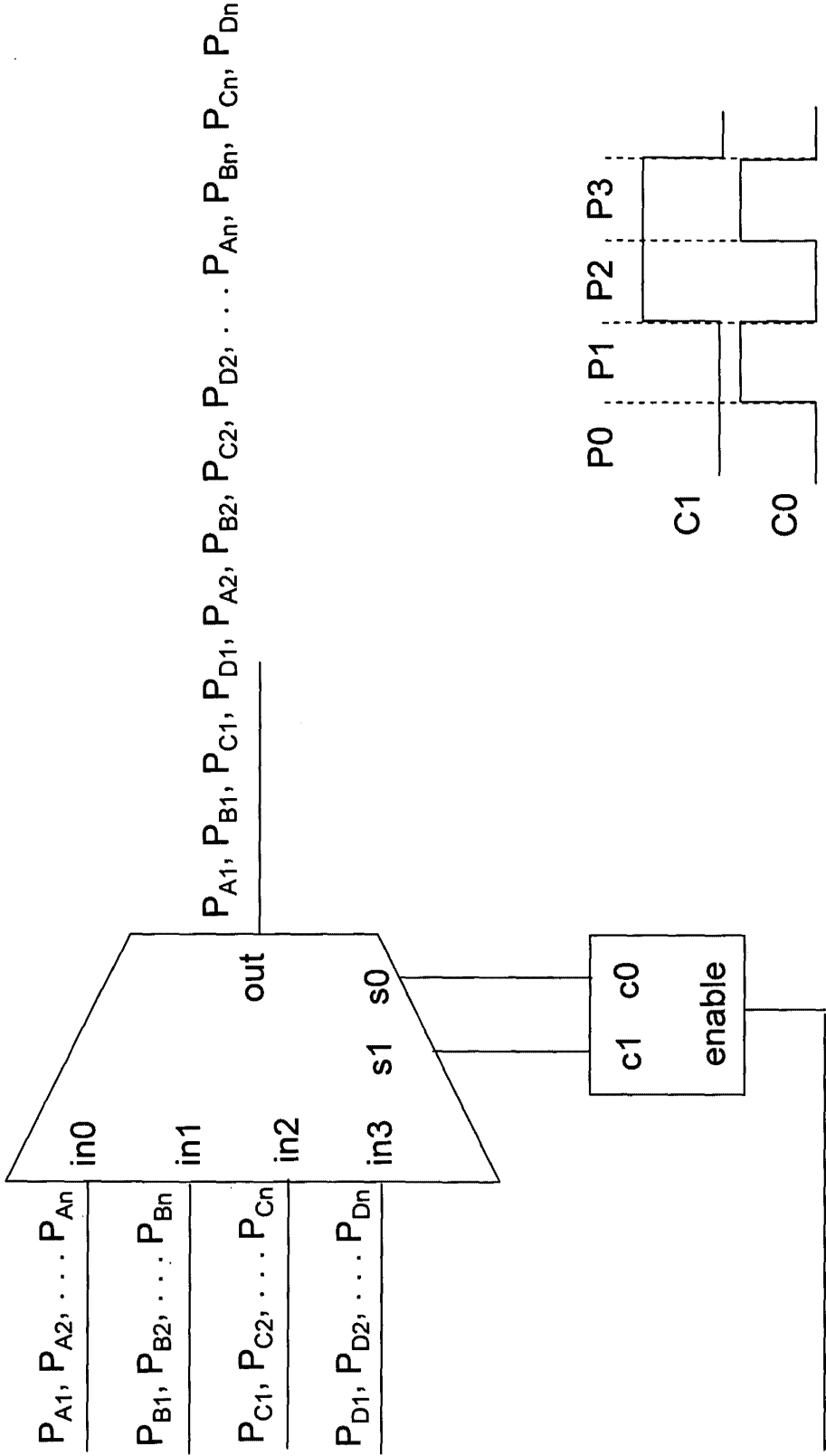


Figure 37G

Figure 37F

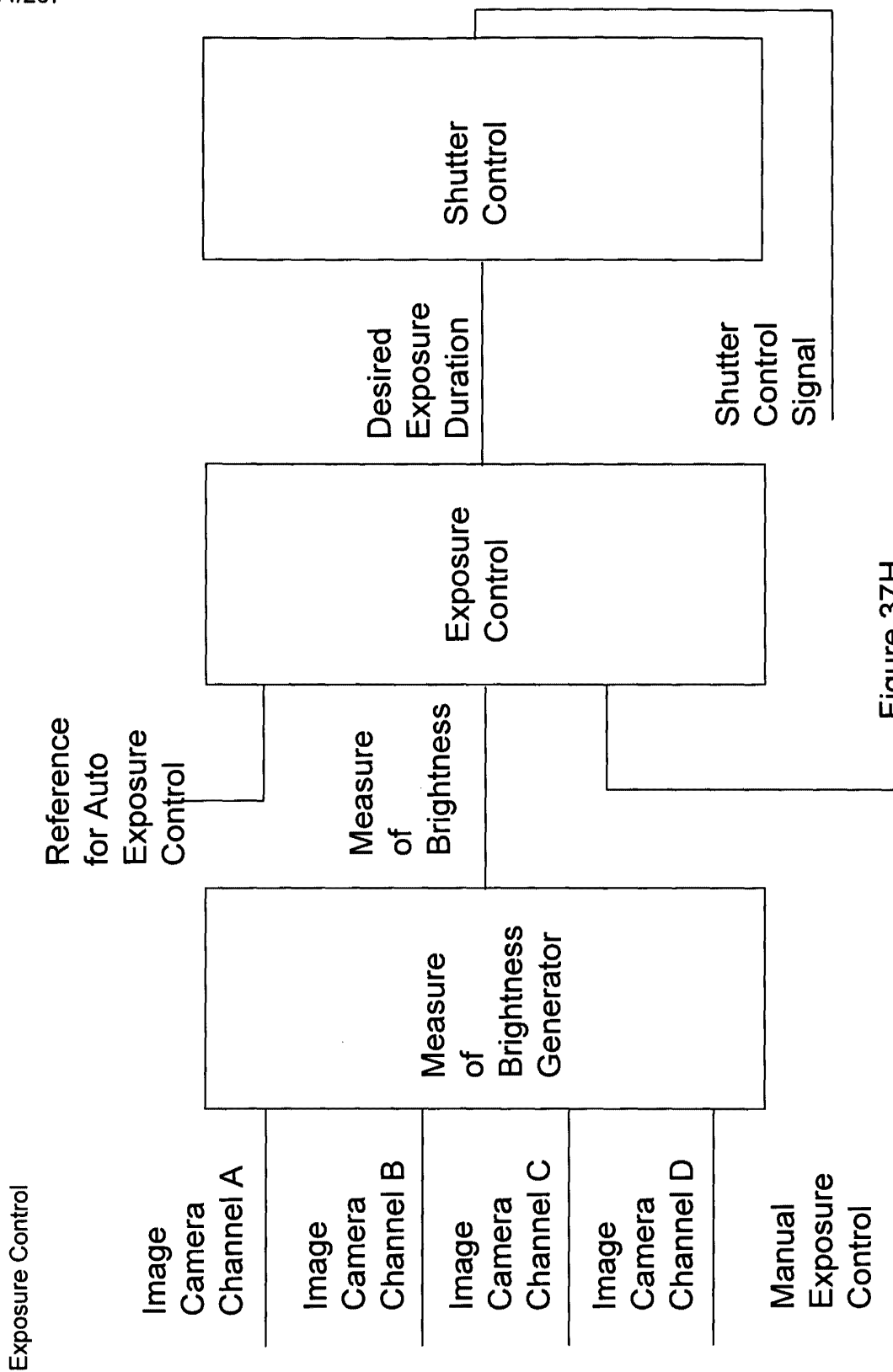


Figure 37H

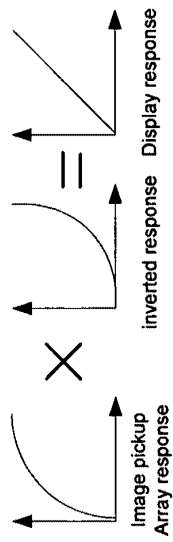


Figure 371

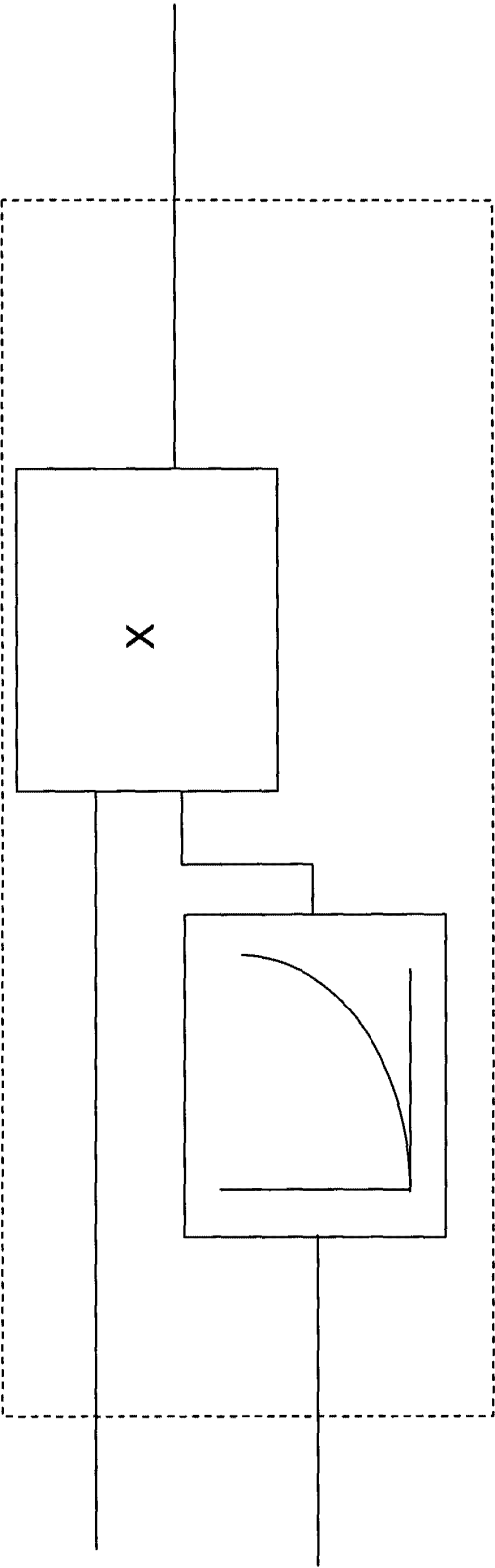


Figure 37J

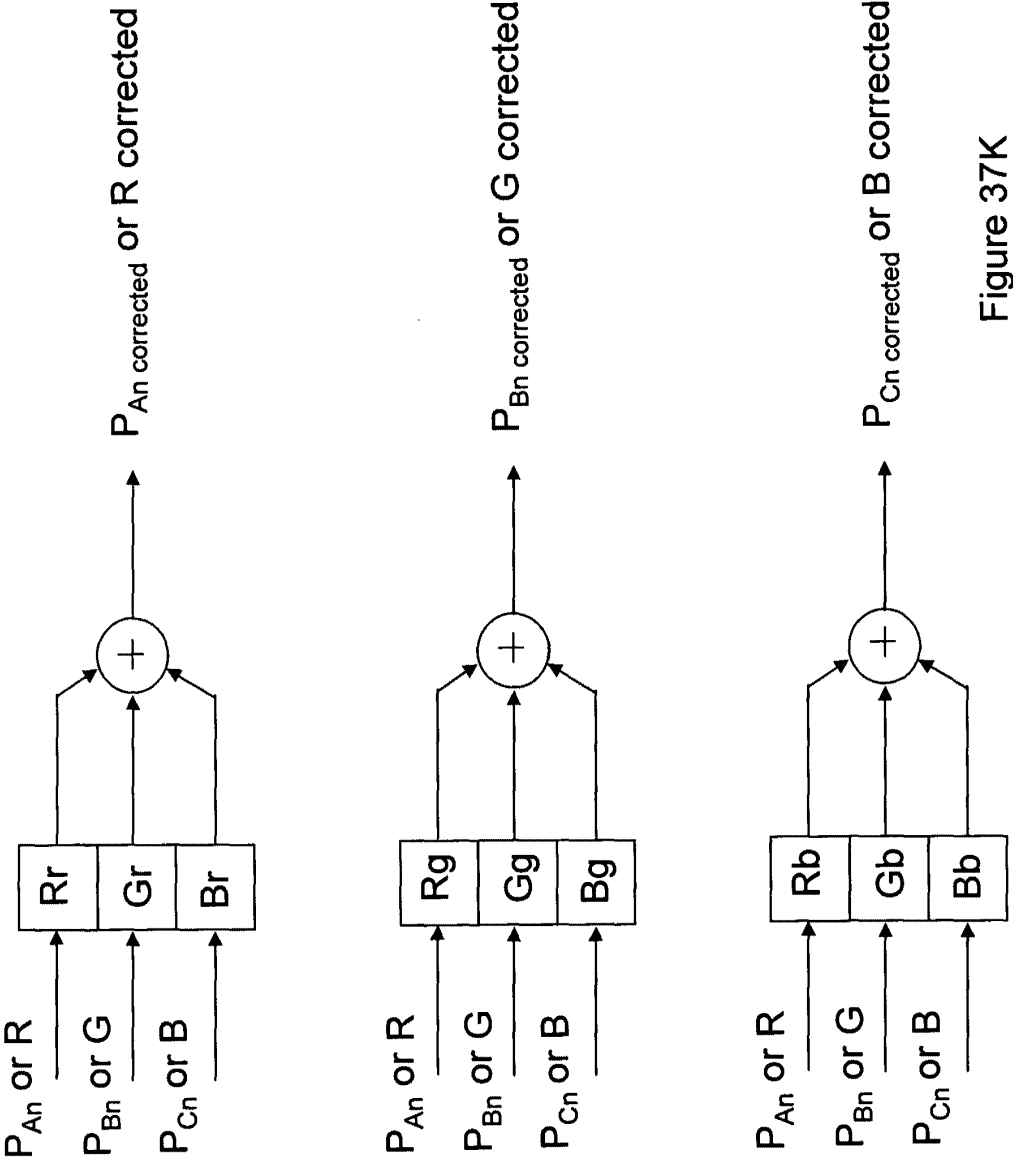


Figure 37K

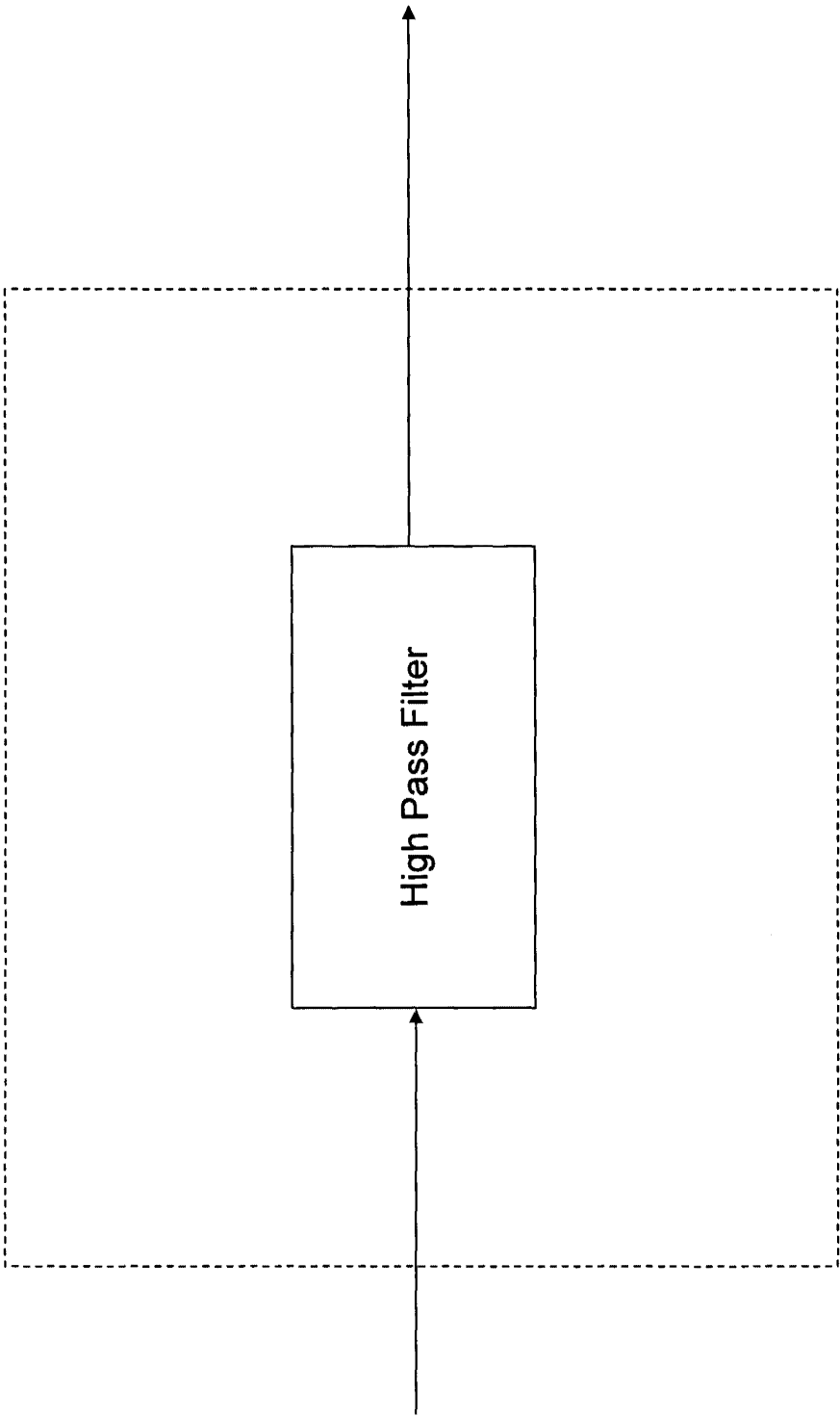
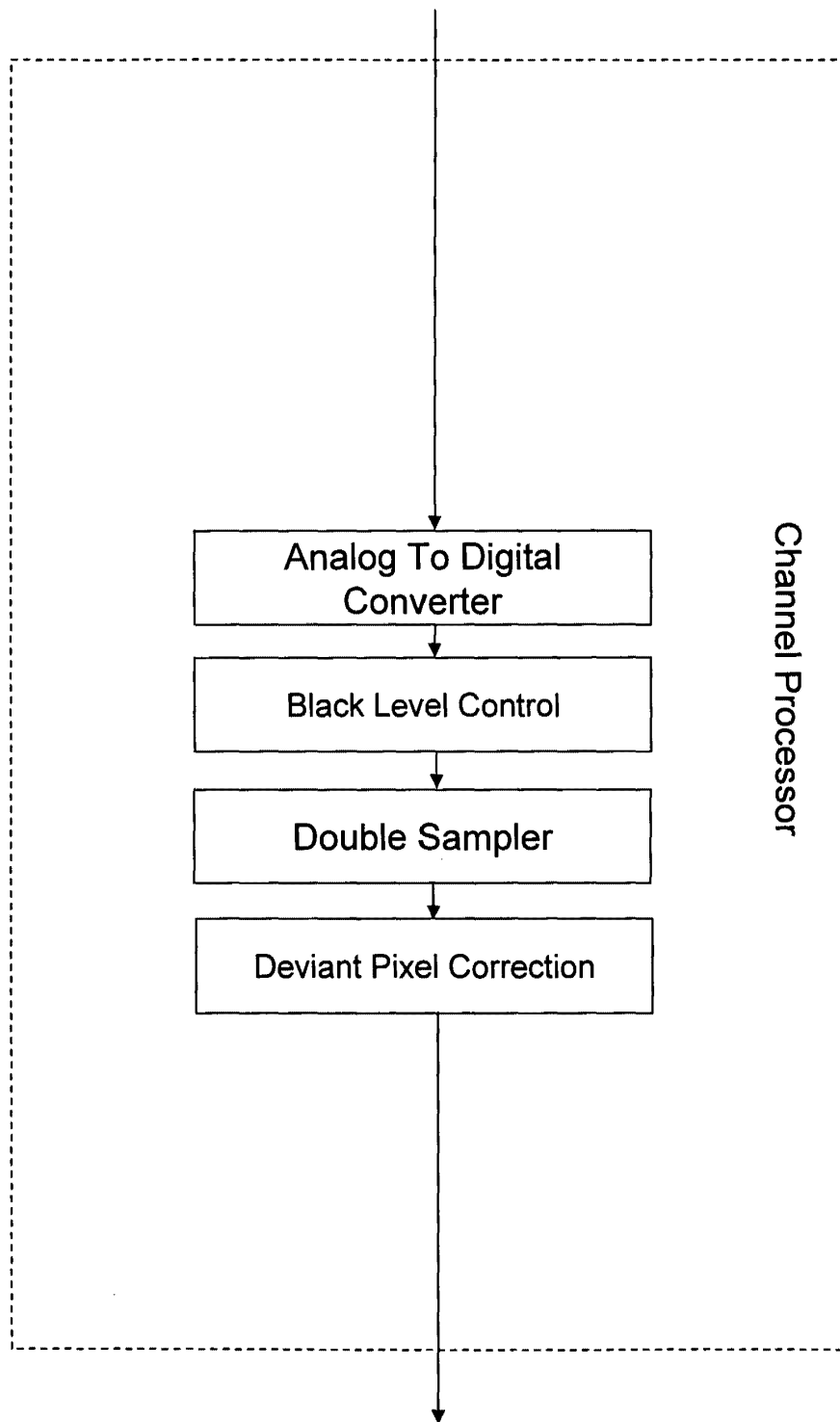


Figure 37L

Figure 38



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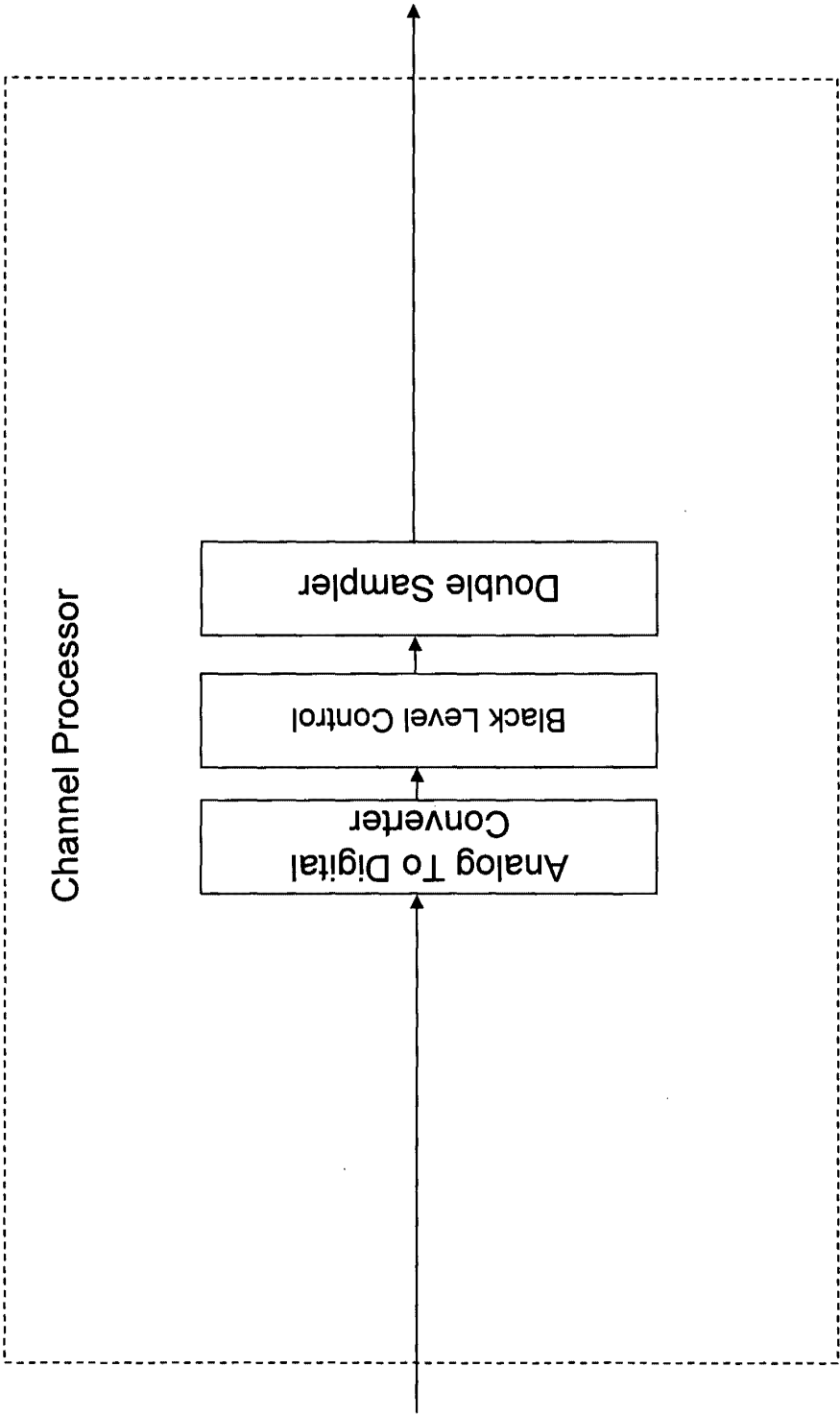


Figure 39

Figure 40

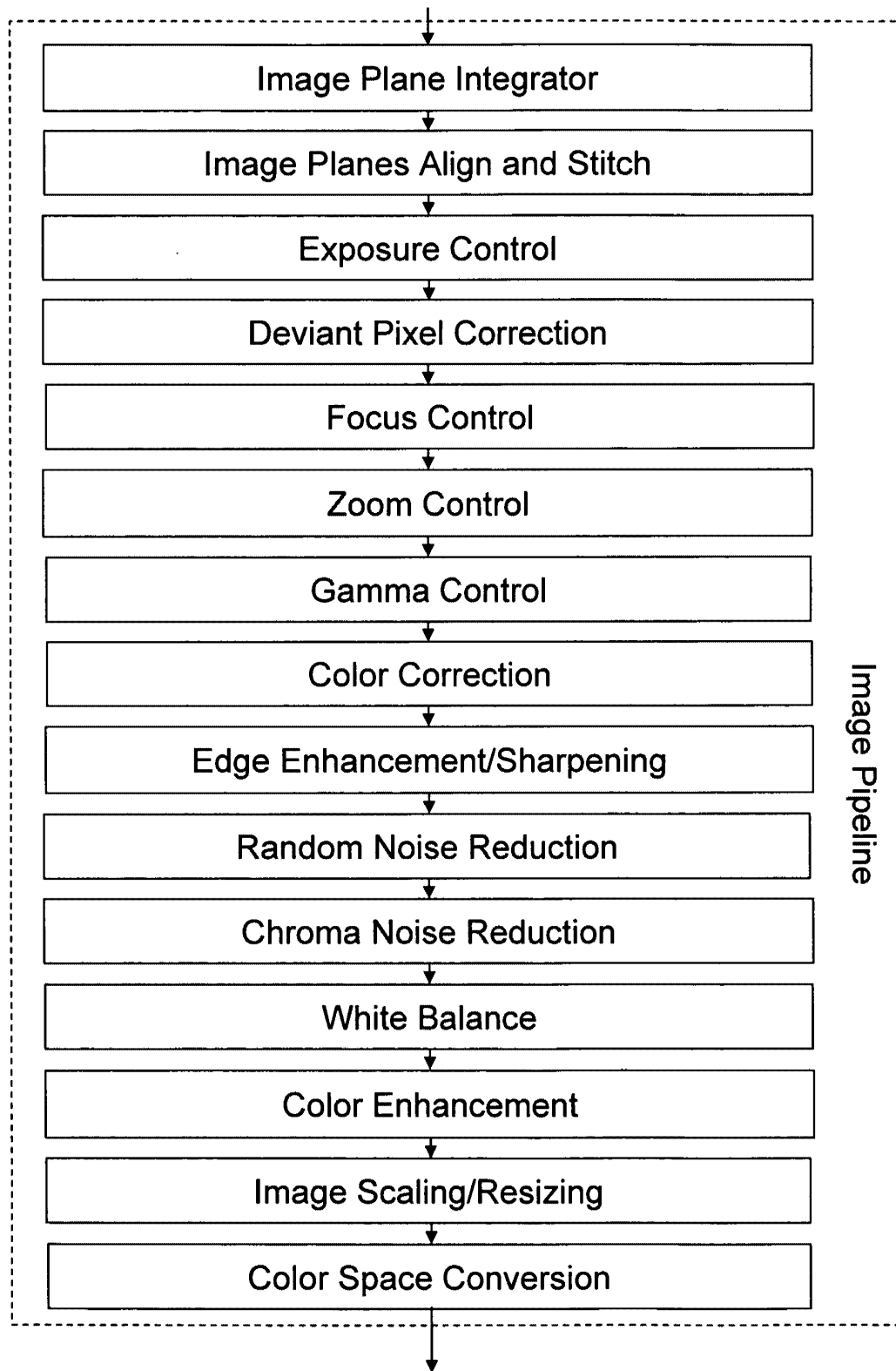


Image Pipeline

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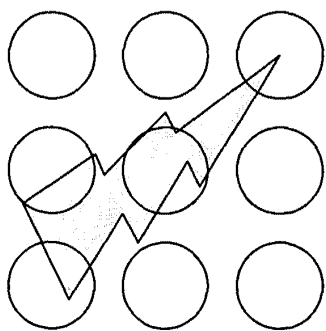


Figure 41A

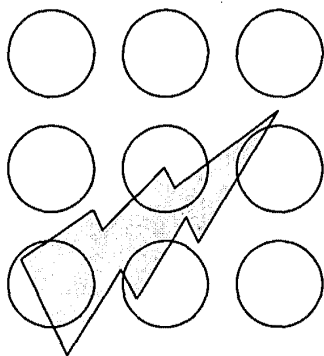


Figure 41C

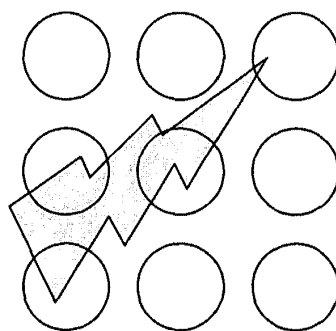


Figure 41G

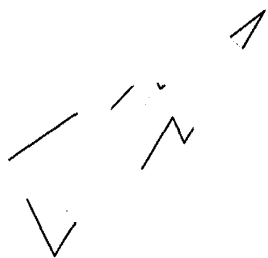


Figure 41B

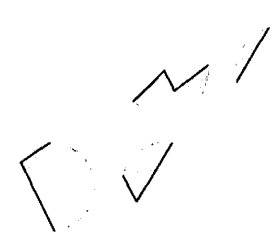


Figure 41D

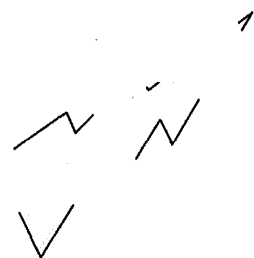


Figure 41H

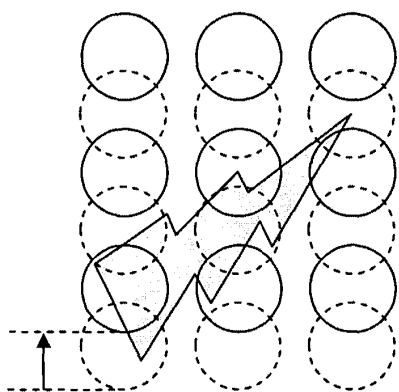


Figure 41E

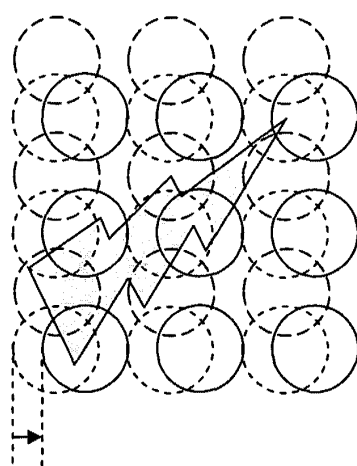


Figure 41I

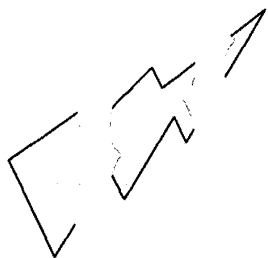


Figure 41F

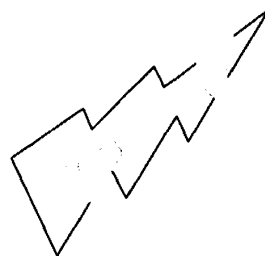


Figure 41J

<table><tr><td>$P_{1\ 11}$</td><td>$P_{1\ 21}$</td><td>$P_{1\ m1}$</td></tr><tr><td>$P_{1\ 12}$</td><td>$P_{1\ 22}$</td><td>$P_{1\ m2}$</td></tr><tr><td></td><td></td><td></td></tr><tr><td>$P_{1\ 1n}$</td><td>$P_{1\ 2n}$</td><td>$P_{1\ mn}$</td></tr></table>	$P_{1\ 11}$	$P_{1\ 21}$	$P_{1\ m1}$	$P_{1\ 12}$	$P_{1\ 22}$	$P_{1\ m2}$				$P_{1\ 1n}$	$P_{1\ 2n}$	$P_{1\ mn}$	<table><tr><td>P_{B11}</td><td>P_{B21}</td><td>P_{Bm1}</td></tr><tr><td>P_{B12}</td><td>P_{B22}</td><td>P_{Bm2}</td></tr><tr><td></td><td></td><td></td></tr><tr><td>P_{B1n}</td><td>P_{B2n}</td><td>P_{Bmn}</td></tr></table>	P_{B11}	P_{B21}	P_{Bm1}	P_{B12}	P_{B22}	P_{Bm2}				P_{B1n}	P_{B2n}	P_{Bmn}	<table><tr><td>$P_{1\ 11}$</td><td>$P_{2\ 11}$</td><td>$P_{1\ 21}$</td><td>$P_{2\ 21}$</td><td>$P_{1\ m1}$</td><td>$P_{2\ m1}$</td></tr><tr><td>$P_{3\ 11}$</td><td>$P_{4\ 11}$</td><td>$P_{3\ 21}$</td><td>$P_{4\ 21}$</td><td>$P_{3\ m1}$</td><td>$P_{4\ m1}$</td></tr><tr><td>$P_{1\ 11}$</td><td>$P_{2\ 11}$</td><td>$P_{1\ 22}$</td><td>$P_{2\ 22}$</td><td>$P_{1\ m2}$</td><td>$P_{2\ m2}$</td></tr><tr><td>$P_{3\ 12}$</td><td>$P_{4\ 12}$</td><td>$P_{3\ 22}$</td><td>$P_{4\ 22}$</td><td>$P_{3\ m2}$</td><td>$P_{4\ m2}$</td></tr><tr><td></td><td></td><td></td><td></td><td></td><td></td></tr></table>	$P_{1\ 11}$	$P_{2\ 11}$	$P_{1\ 21}$	$P_{2\ 21}$	$P_{1\ m1}$	$P_{2\ m1}$	$P_{3\ 11}$	$P_{4\ 11}$	$P_{3\ 21}$	$P_{4\ 21}$	$P_{3\ m1}$	$P_{4\ m1}$	$P_{1\ 11}$	$P_{2\ 11}$	$P_{1\ 22}$	$P_{2\ 22}$	$P_{1\ m2}$	$P_{2\ m2}$	$P_{3\ 12}$	$P_{4\ 12}$	$P_{3\ 22}$	$P_{4\ 22}$	$P_{3\ m2}$	$P_{4\ m2}$							<table><tr><td>$P_{3\ 11}$</td><td>$P_{3\ 21}$</td><td>$P_{3\ m1}$</td></tr><tr><td>$P_{3\ 12}$</td><td>$P_{3\ 22}$</td><td>$P_{3\ m2}$</td></tr><tr><td></td><td></td><td></td></tr><tr><td>$P_{3\ 1n}$</td><td>$P_{3\ 2n}$</td><td>$P_{3\ mn}$</td></tr></table>	$P_{3\ 11}$	$P_{3\ 21}$	$P_{3\ m1}$	$P_{3\ 12}$	$P_{3\ 22}$	$P_{3\ m2}$				$P_{3\ 1n}$	$P_{3\ 2n}$	$P_{3\ mn}$	<table><tr><td>$P_{4\ 11}$</td><td>$P_{4\ 21}$</td><td>$P_{4\ m1}$</td></tr><tr><td>$P_{4\ 12}$</td><td>$P_{4\ 22}$</td><td>$P_{4\ m2}$</td></tr><tr><td></td><td></td><td></td></tr><tr><td>$P_{4\ 1n}$</td><td>$P_{4\ 2n}$</td><td>$P_{4\ mn}$</td></tr></table>	$P_{4\ 11}$	$P_{4\ 21}$	$P_{4\ m1}$	$P_{4\ 12}$	$P_{4\ 22}$	$P_{4\ m2}$				$P_{4\ 1n}$	$P_{4\ 2n}$	$P_{4\ mn}$
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Figure 42B

Resolution Enhancement

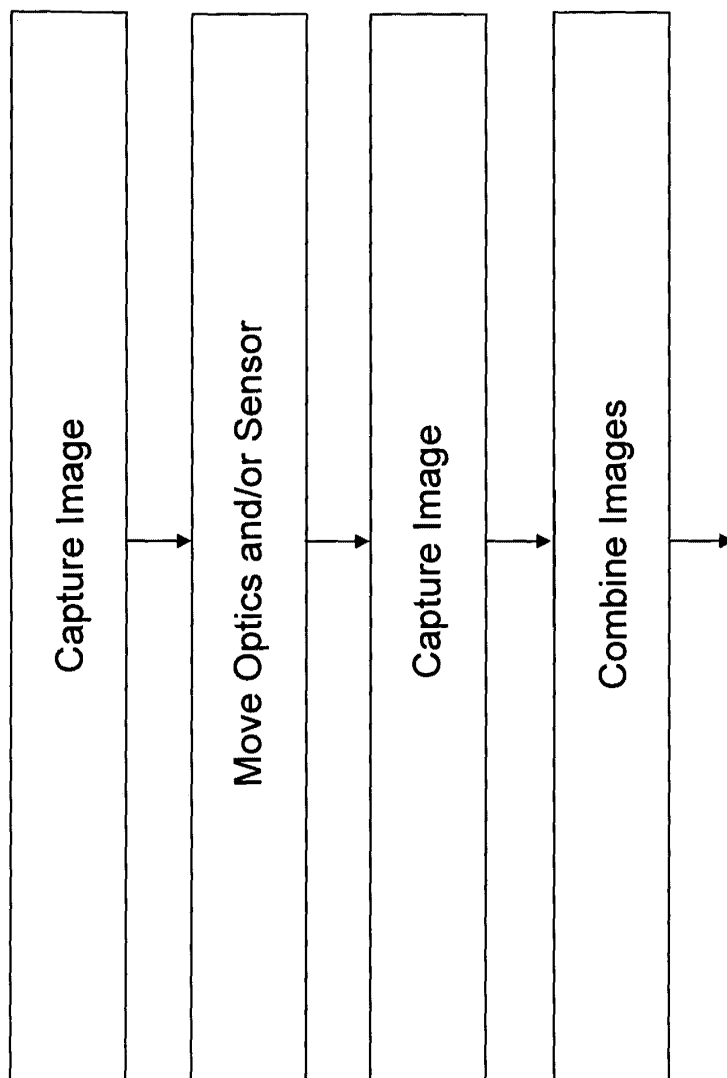


Figure 42A

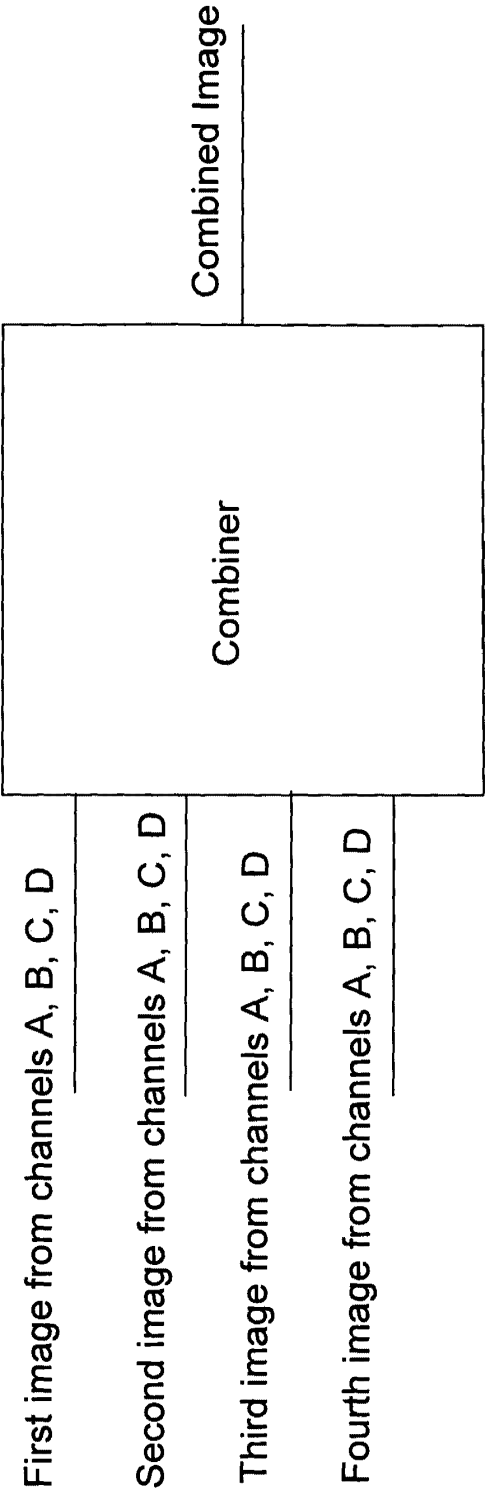


Figure 42C

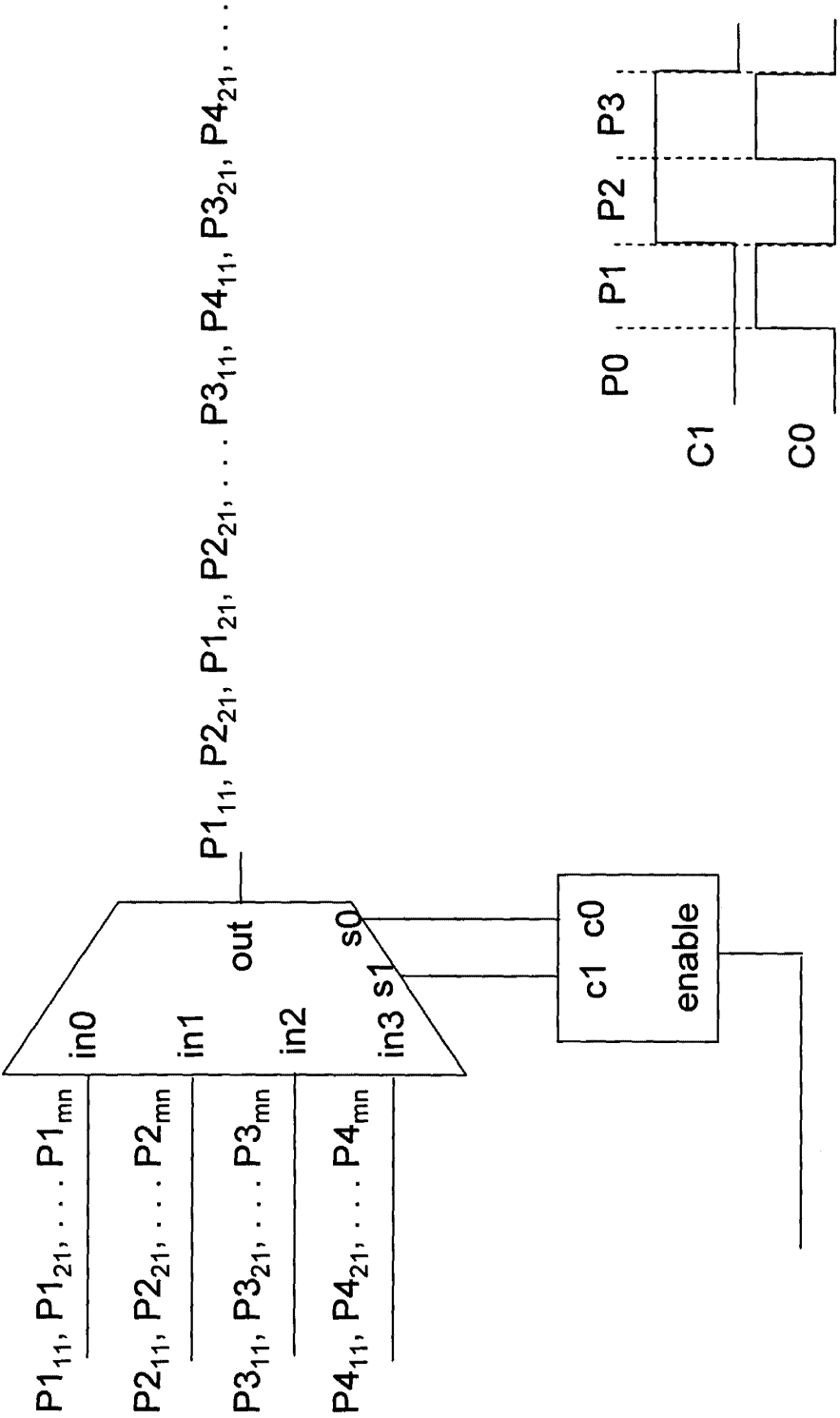


Figure 42D

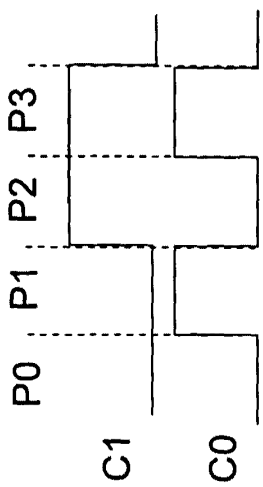


Figure 42E

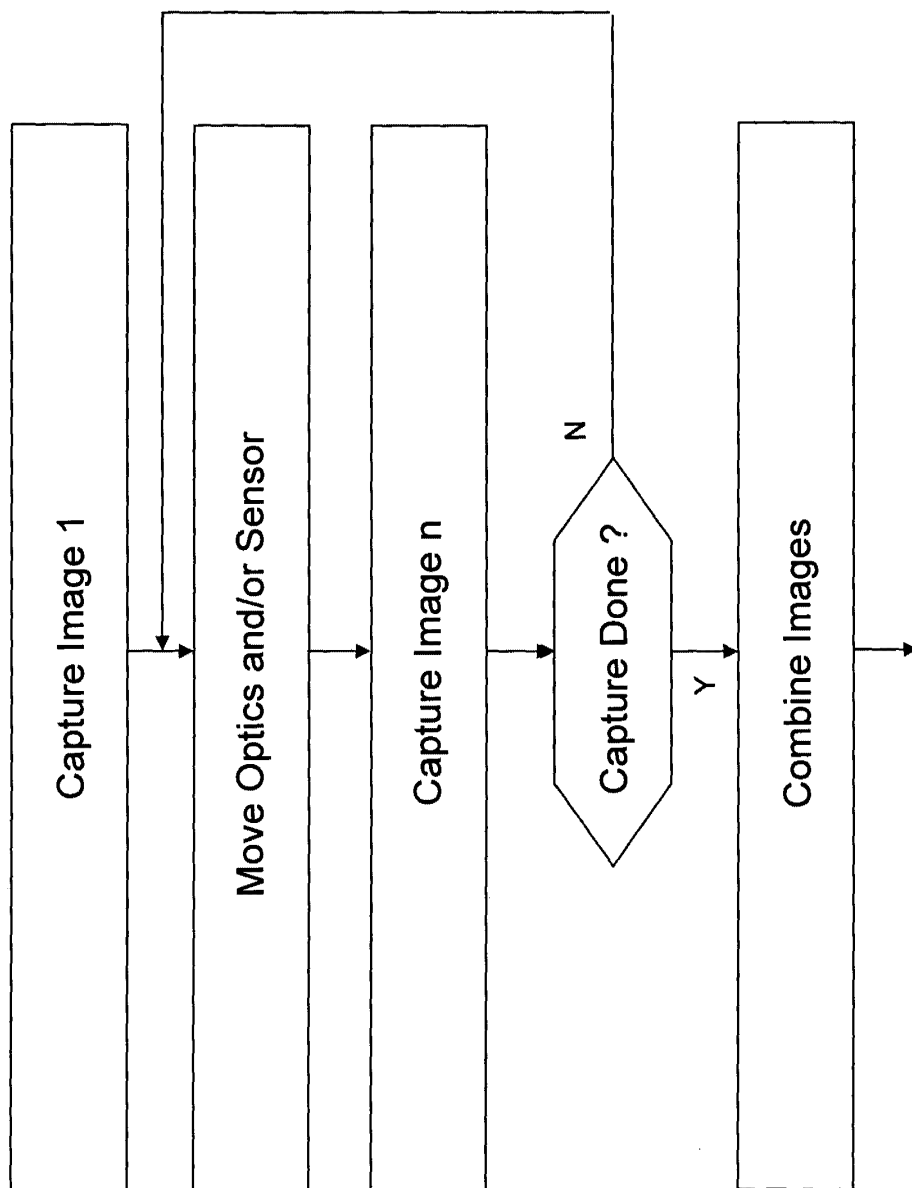


Figure 43

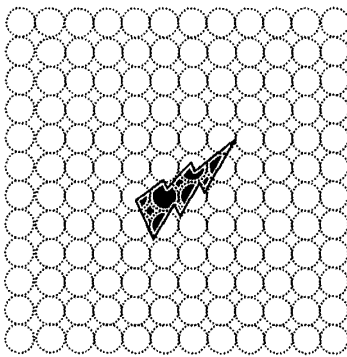


Figure 44A

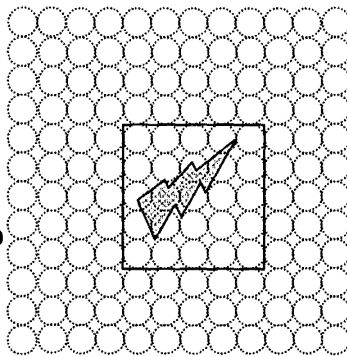


Figure 44C

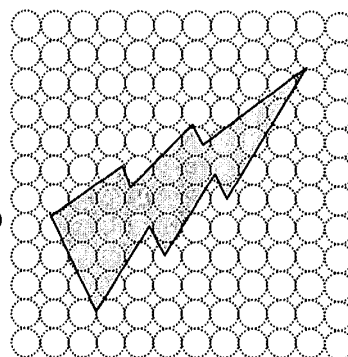


Figure 44F



Figure 44B

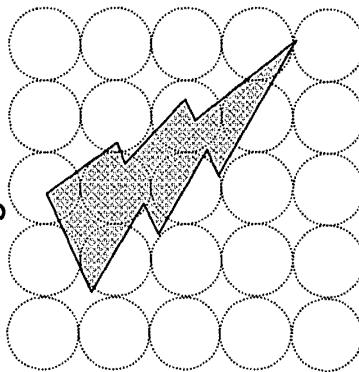


Figure 44D

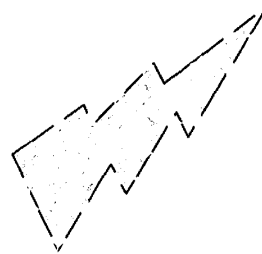


Figure 44G

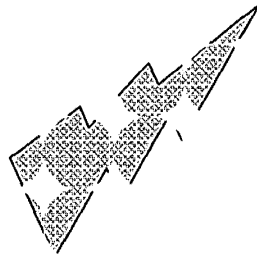


Figure 44E

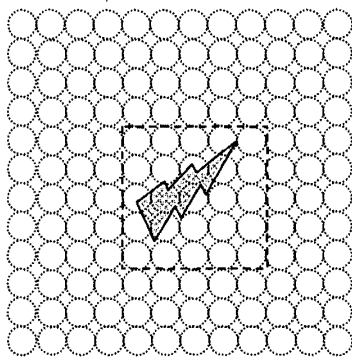


Figure 45A

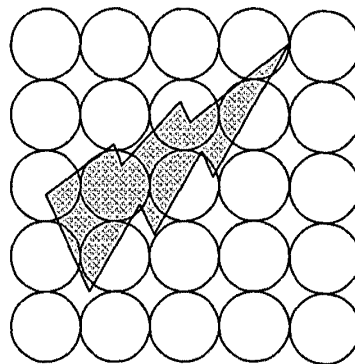


Figure 45C



Figure 45B

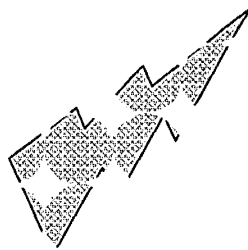


Figure 45D

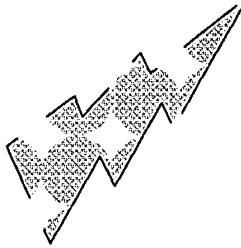


Figure 45F

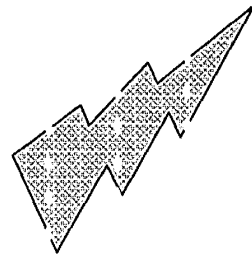


Figure 45H

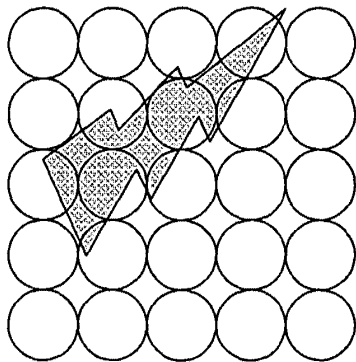


Figure 45E

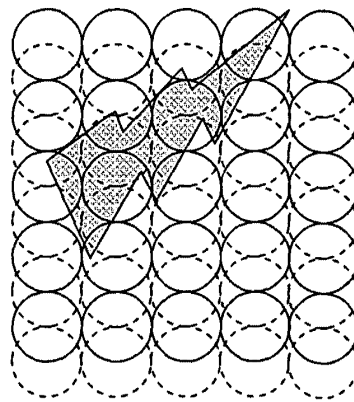


Figure 45G

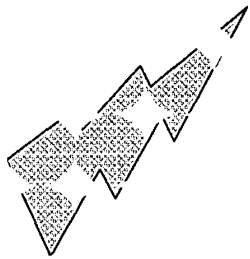


Figure 45J

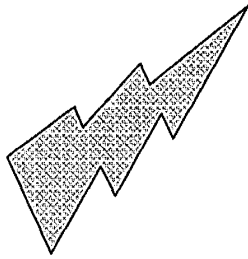


Figure 45L

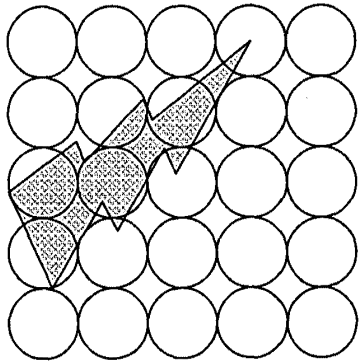


Figure 45I

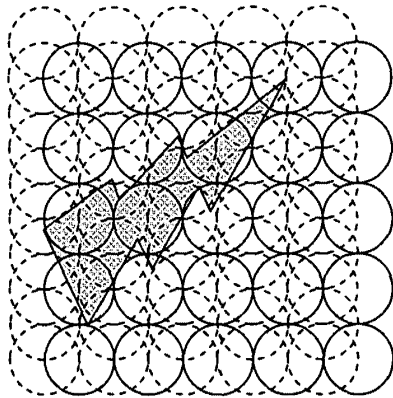


Figure 45K

Zoom

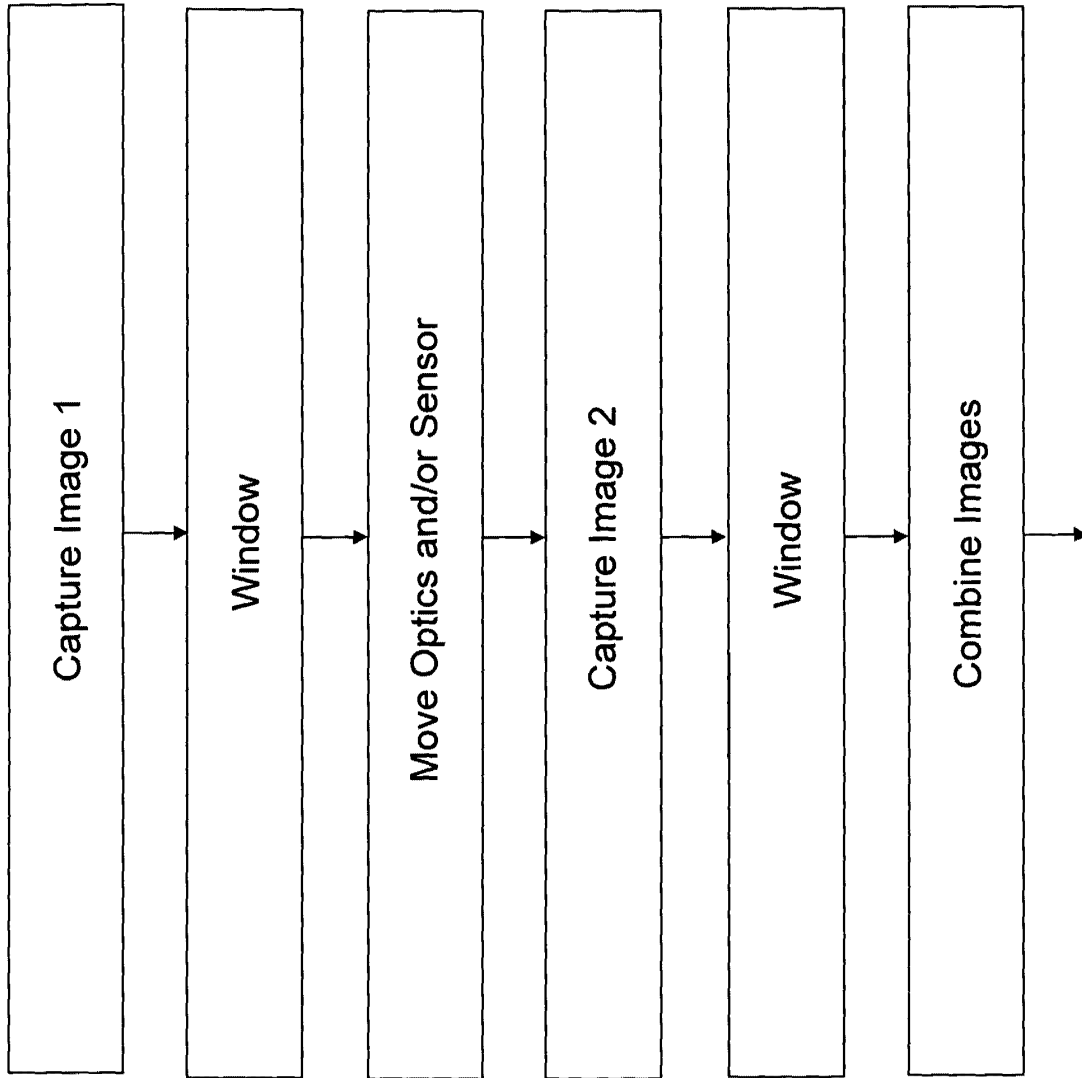


Figure 46A

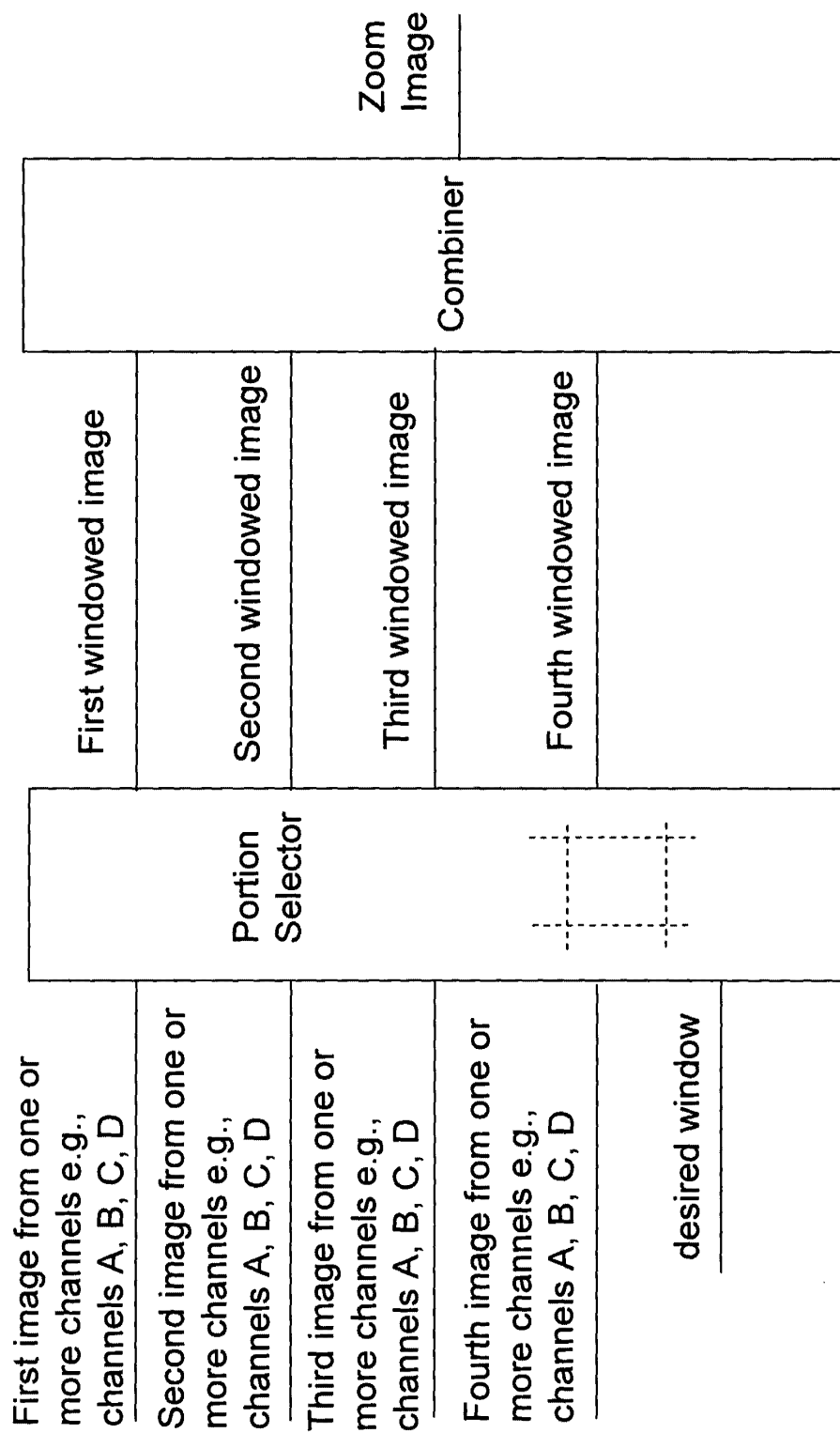


Figure 46B

Zoom

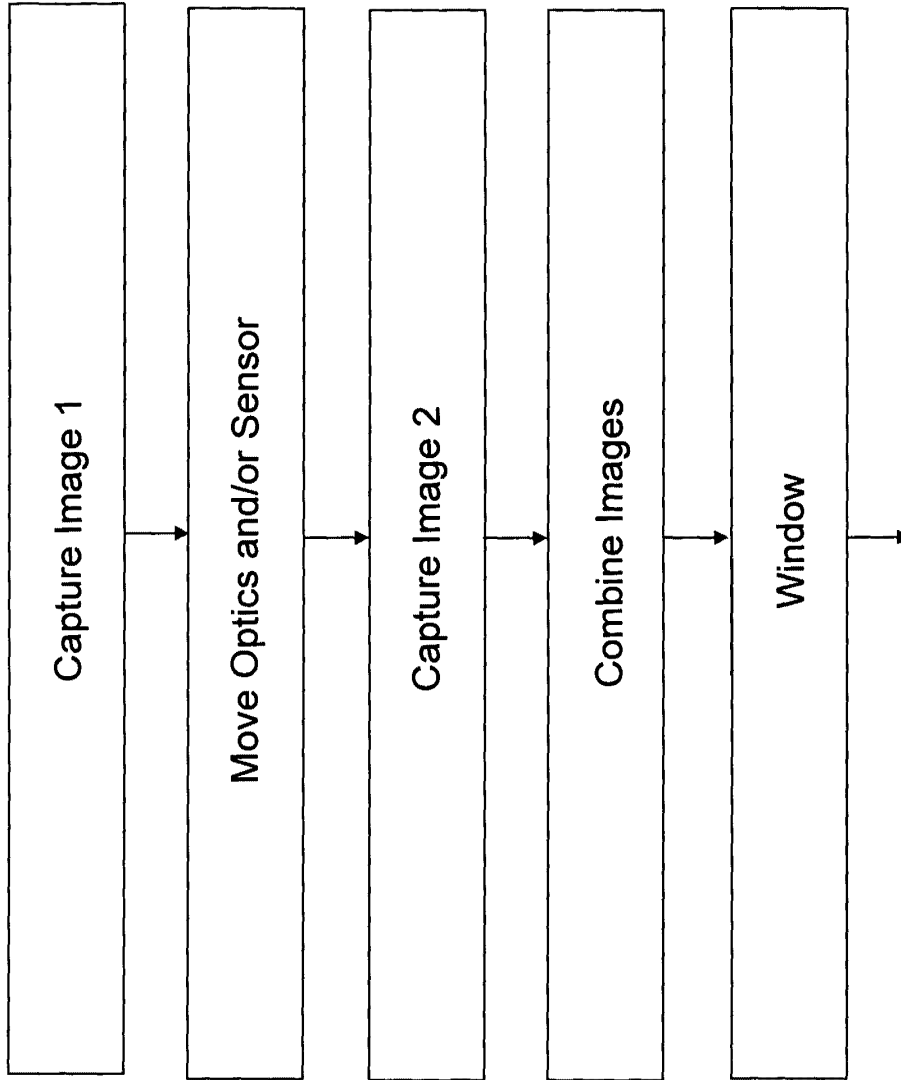


Figure 47A

Zoom

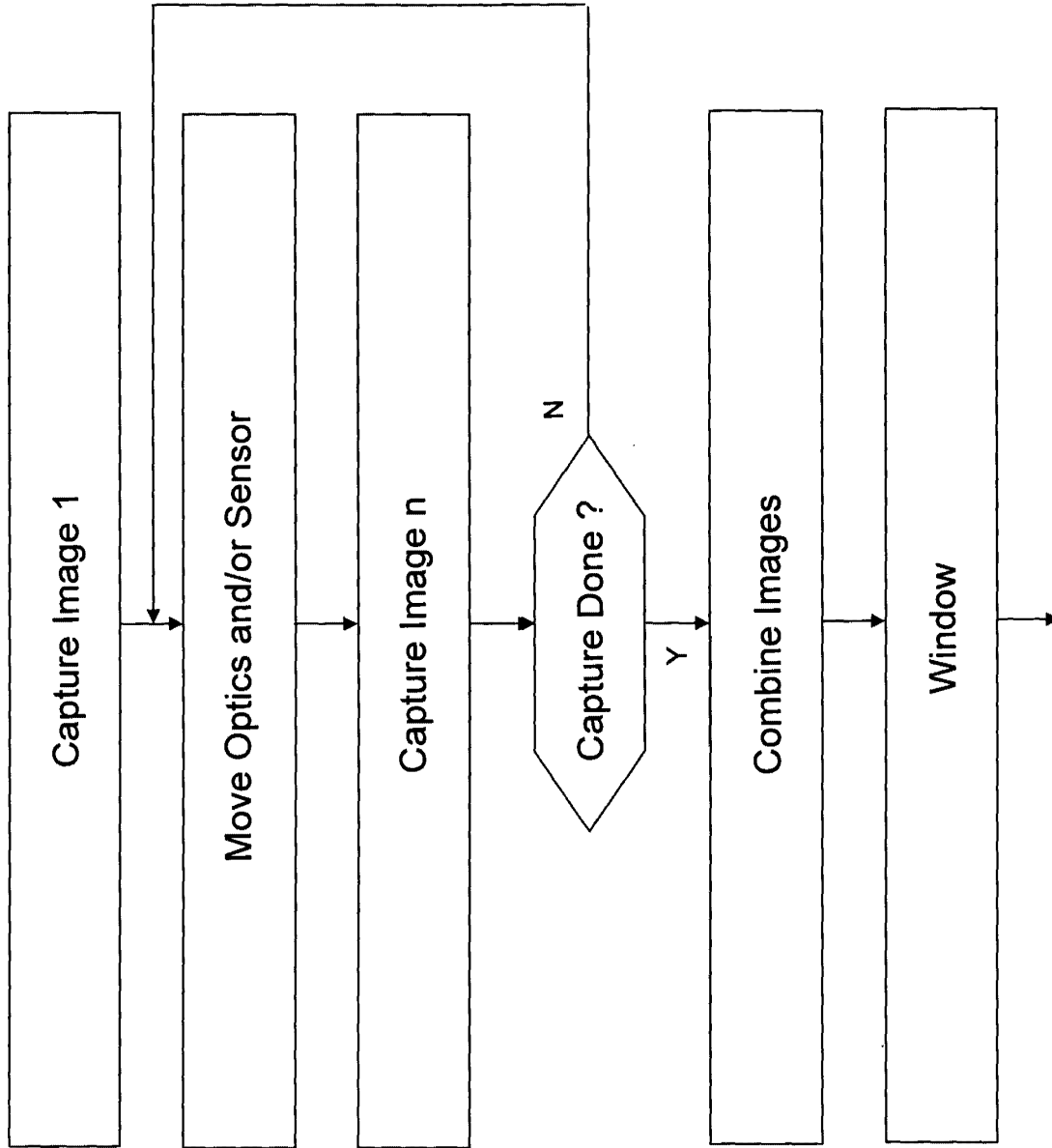


Figure 47B

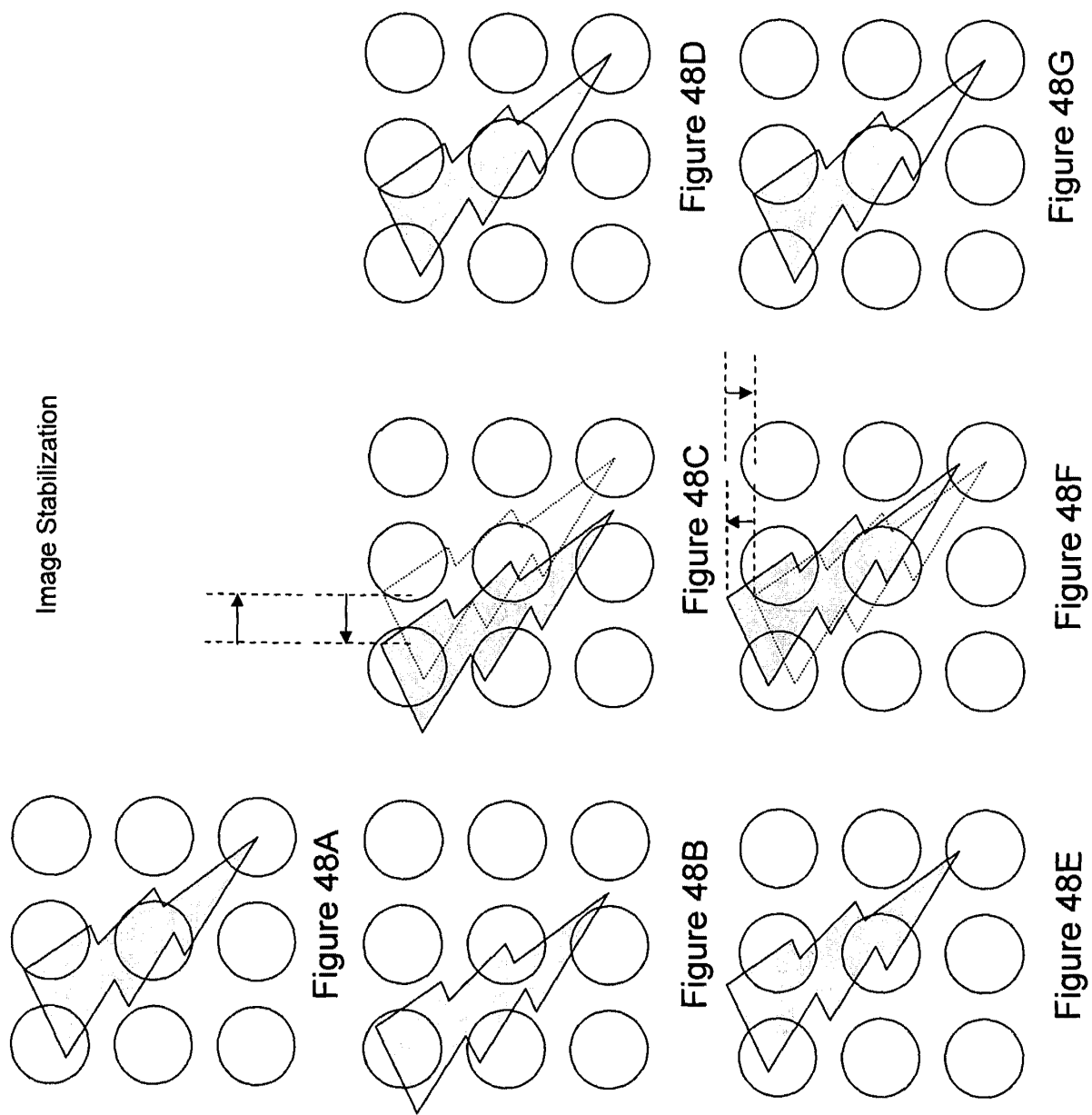


Image Stabilization

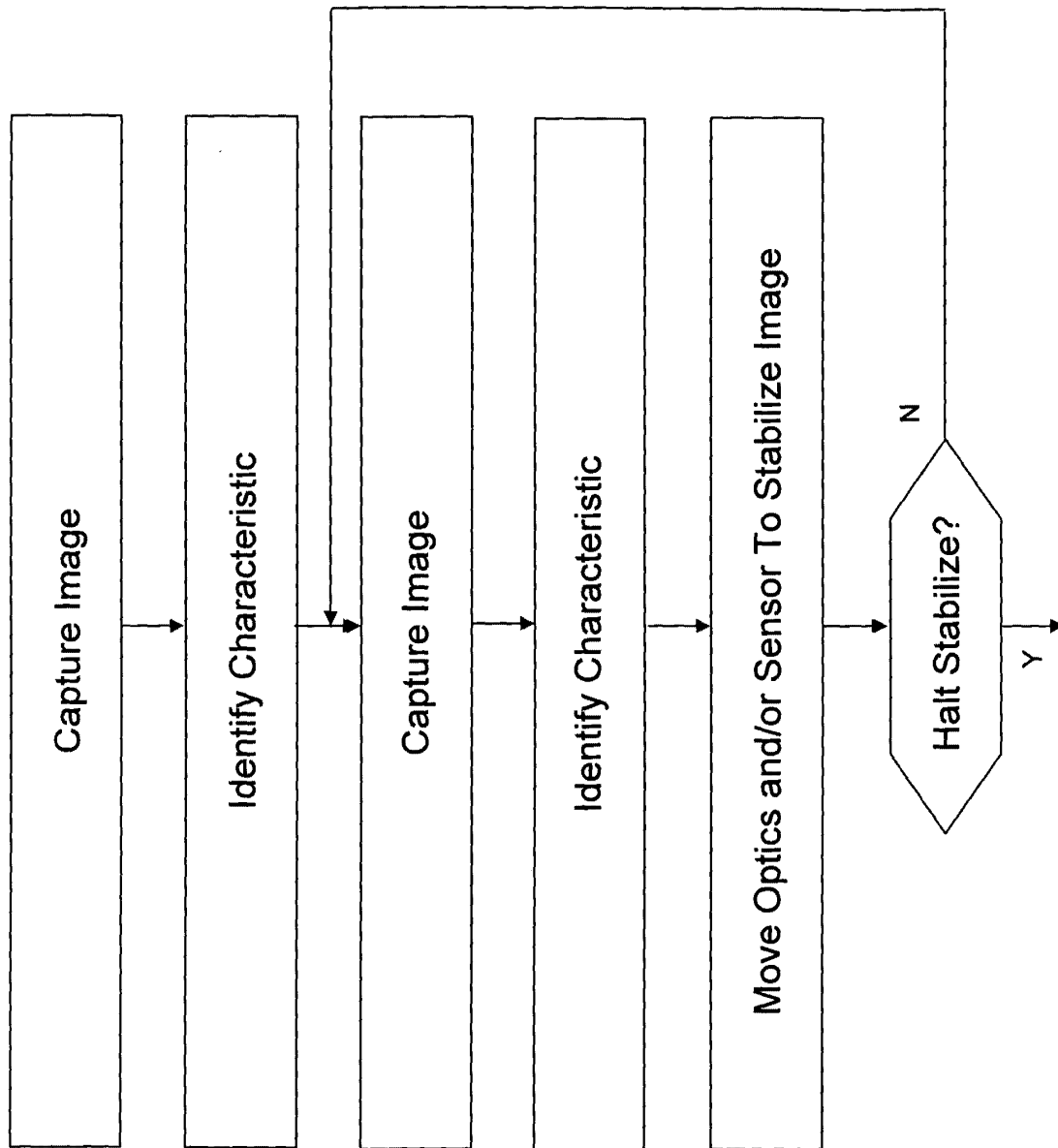
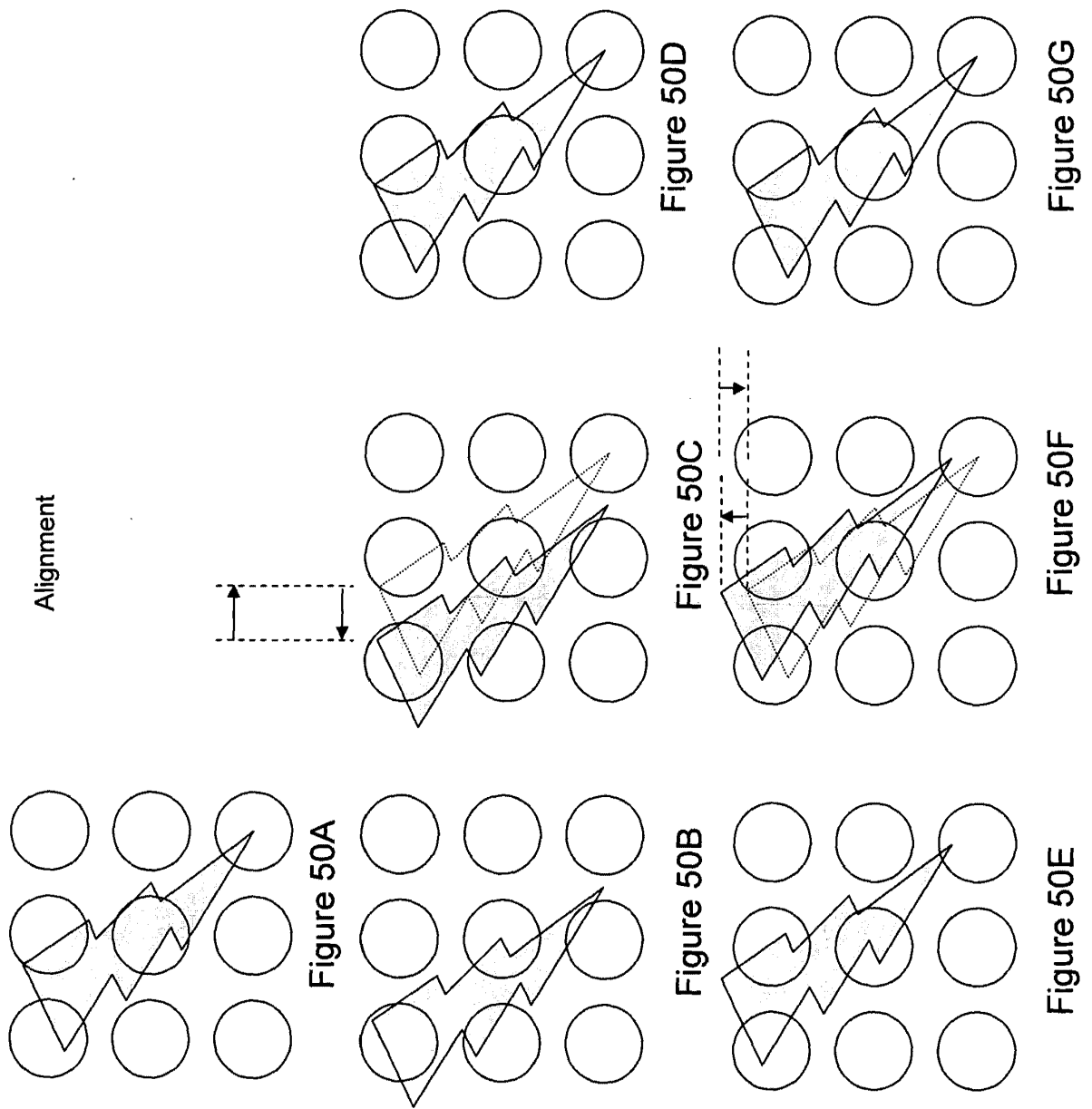
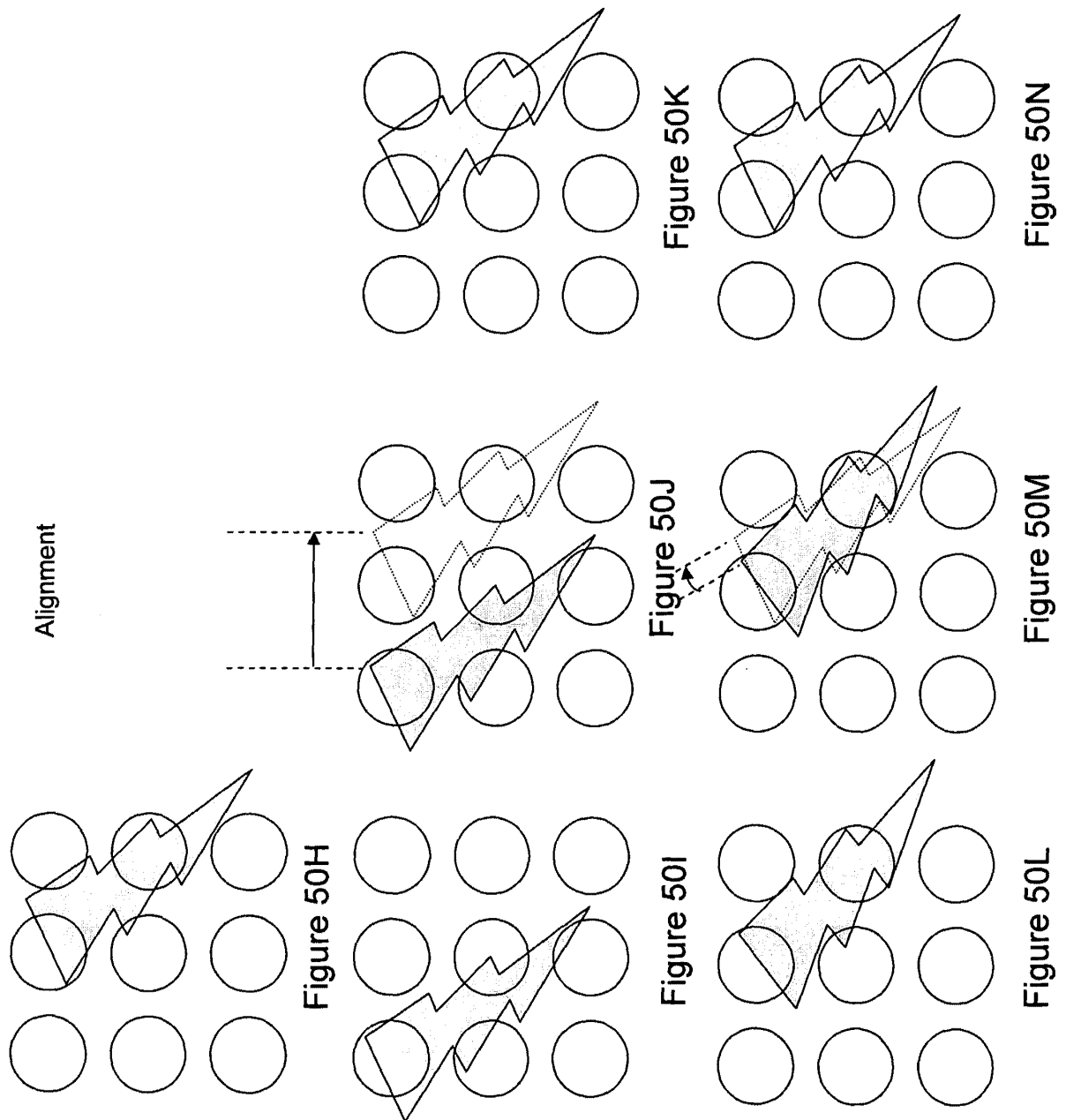


Figure 49





Alignment

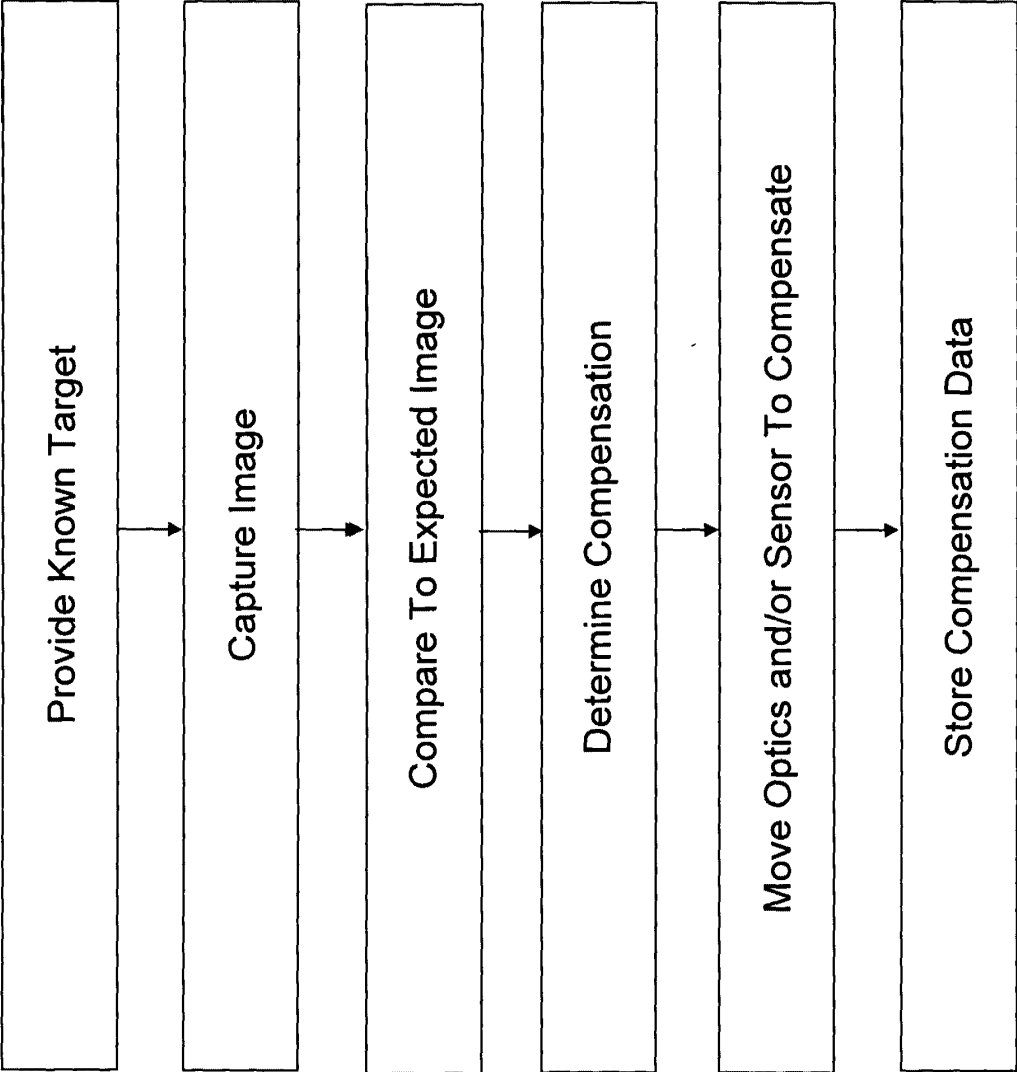


Figure 51

Alignment

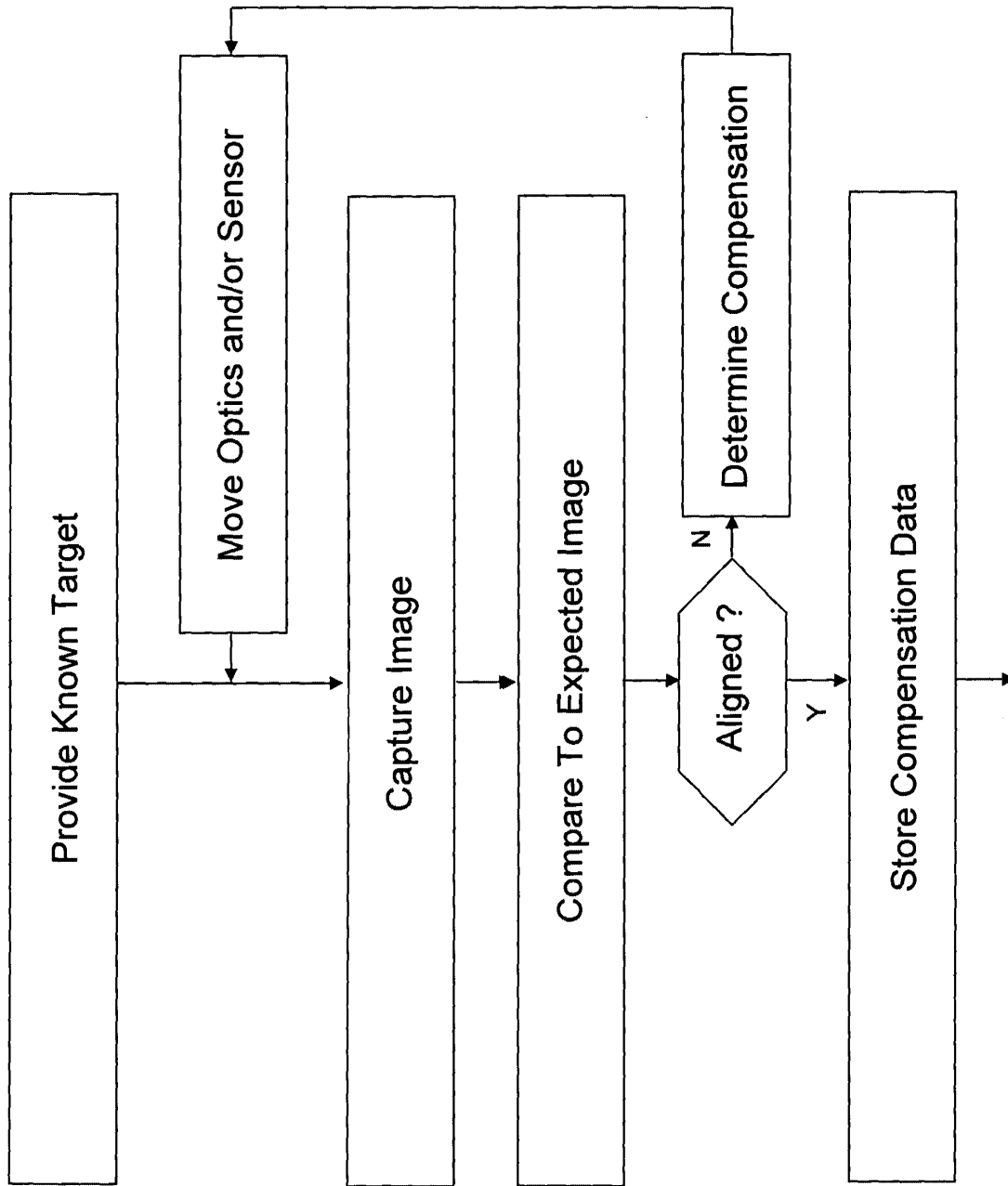
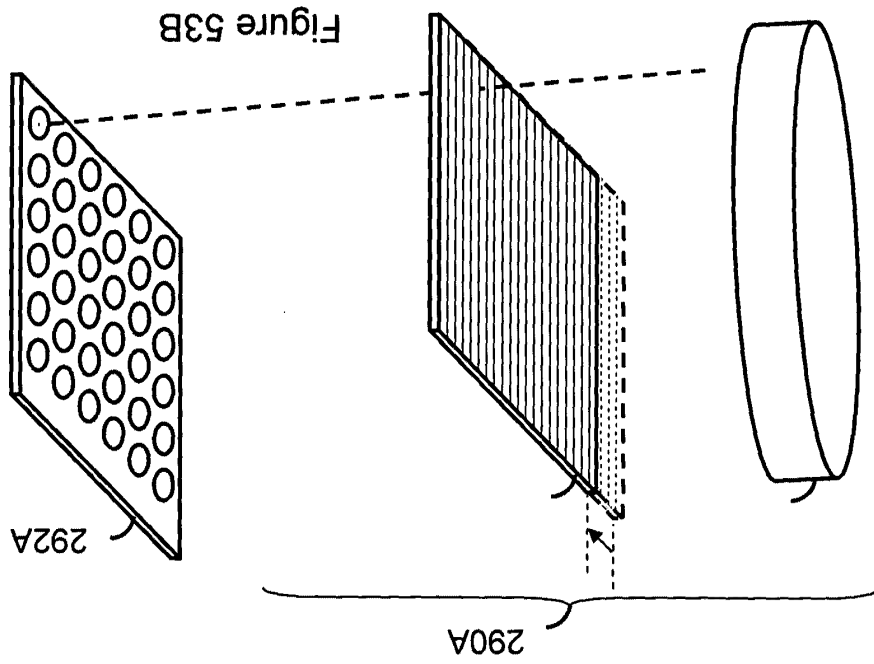
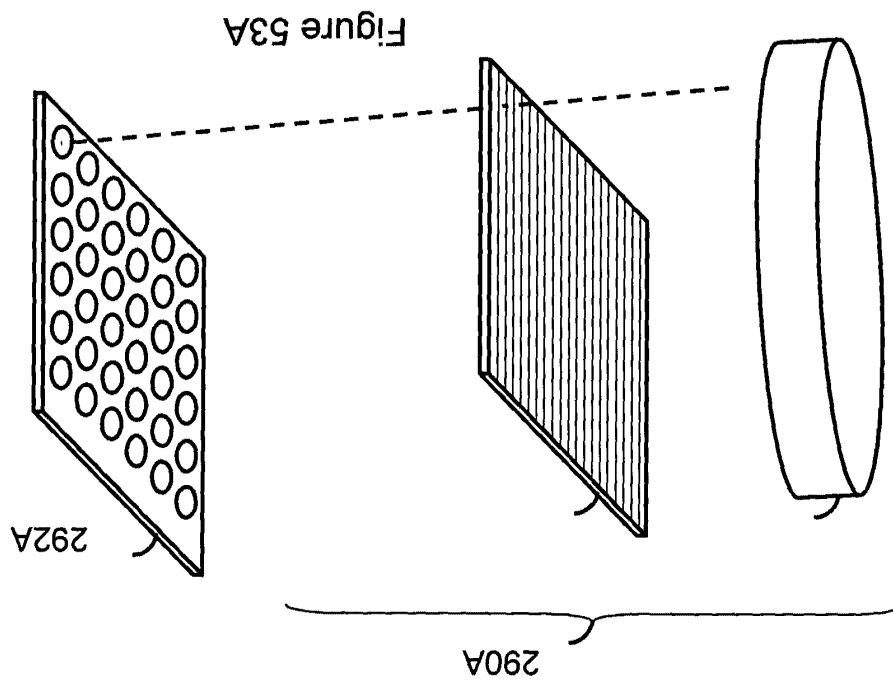
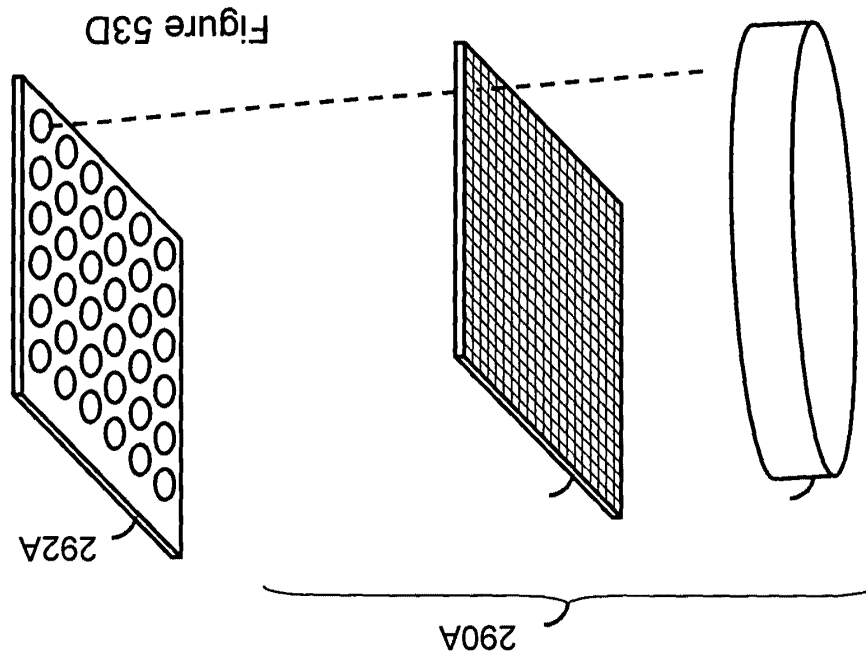
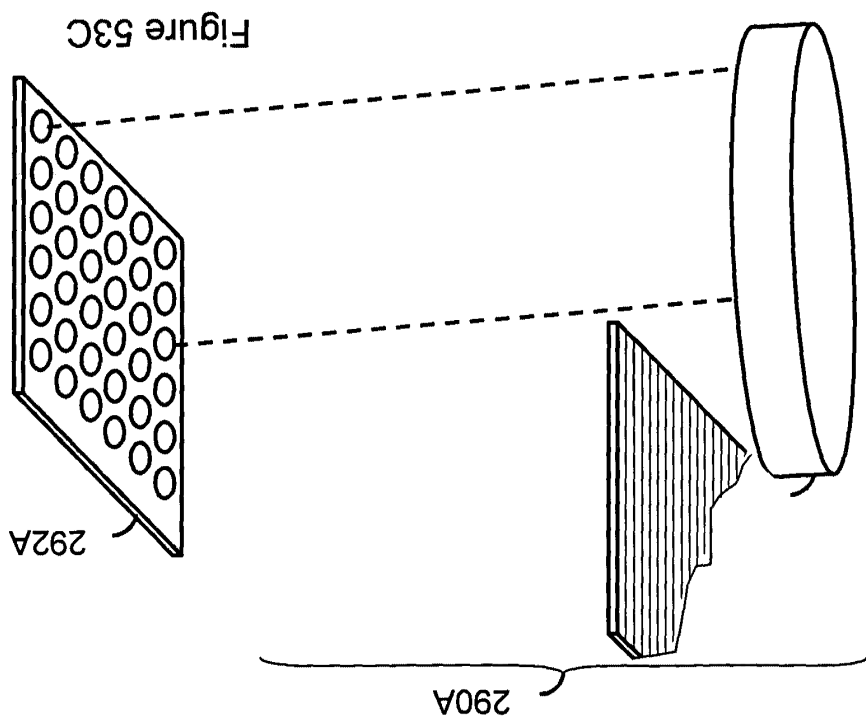


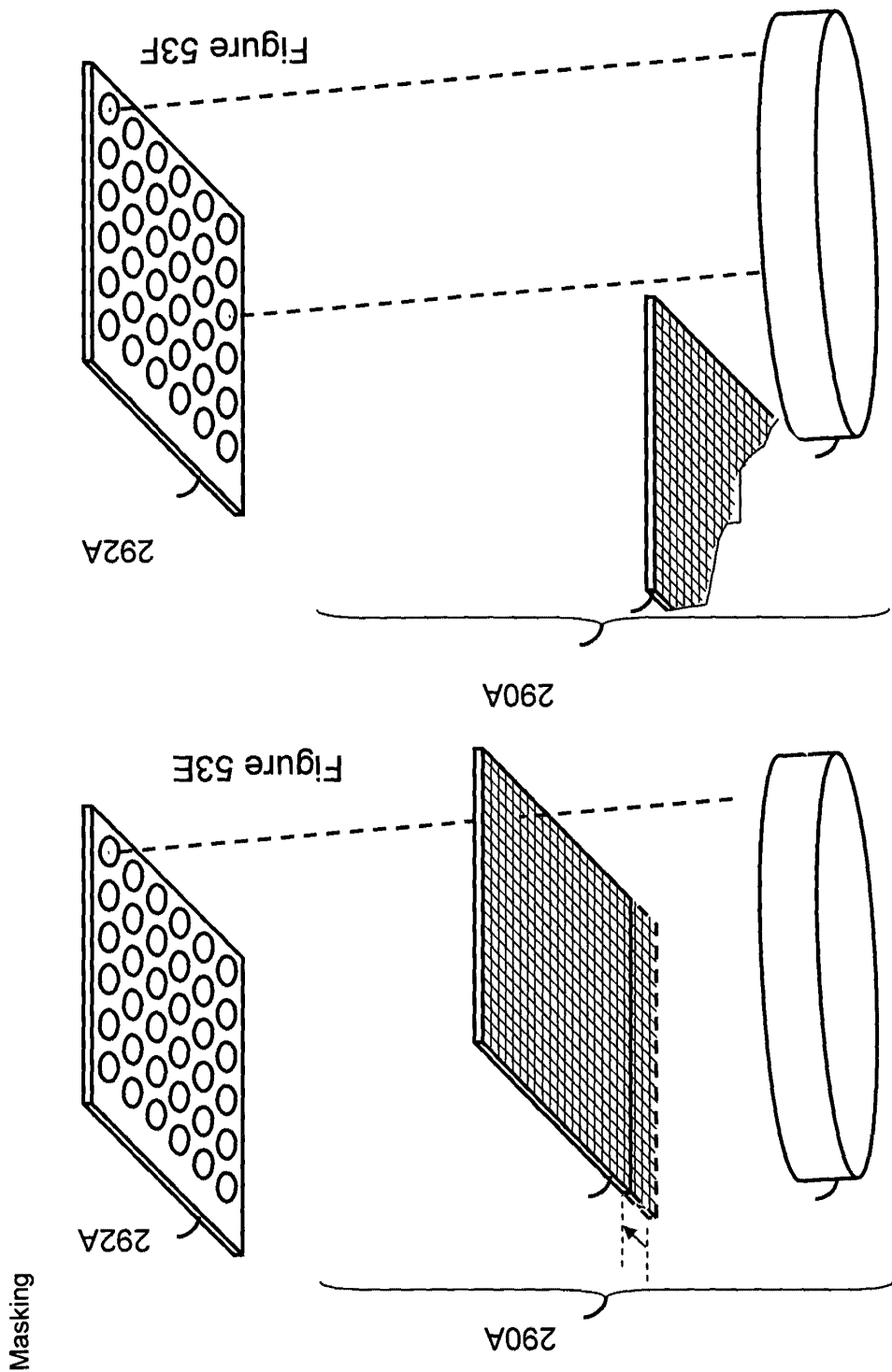
Figure 52

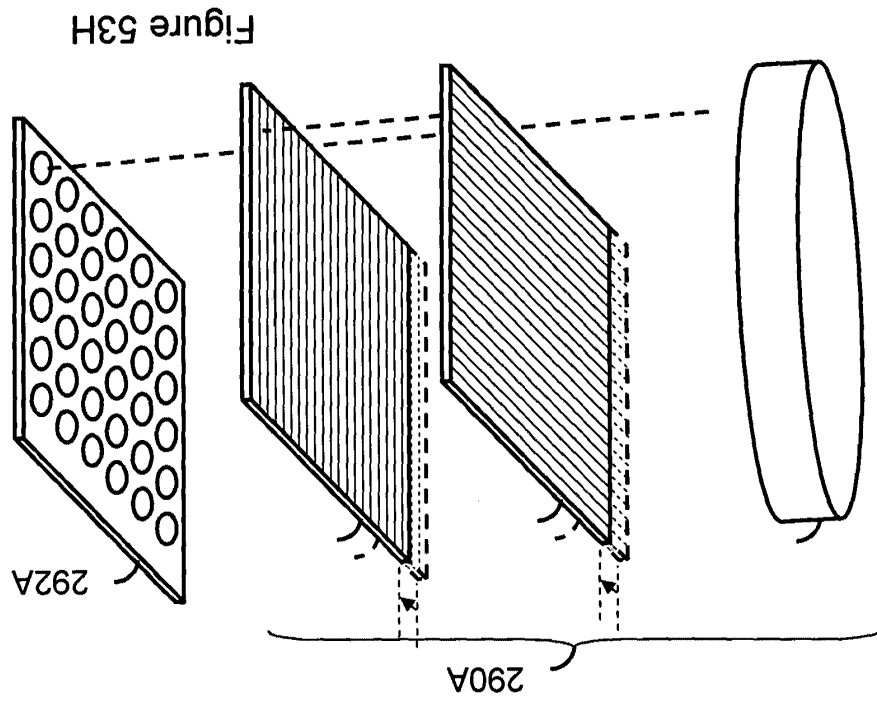
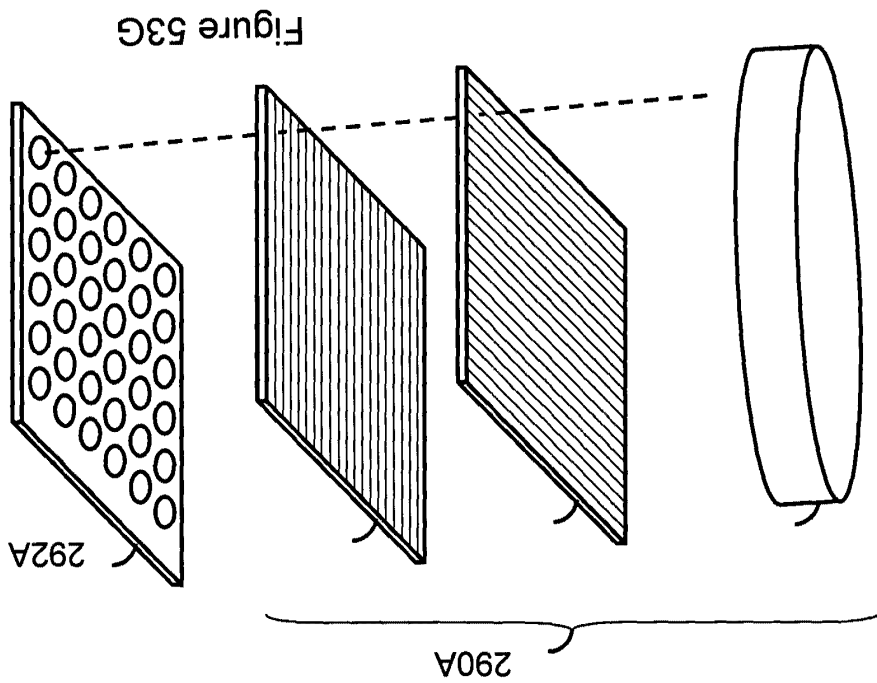


Masking



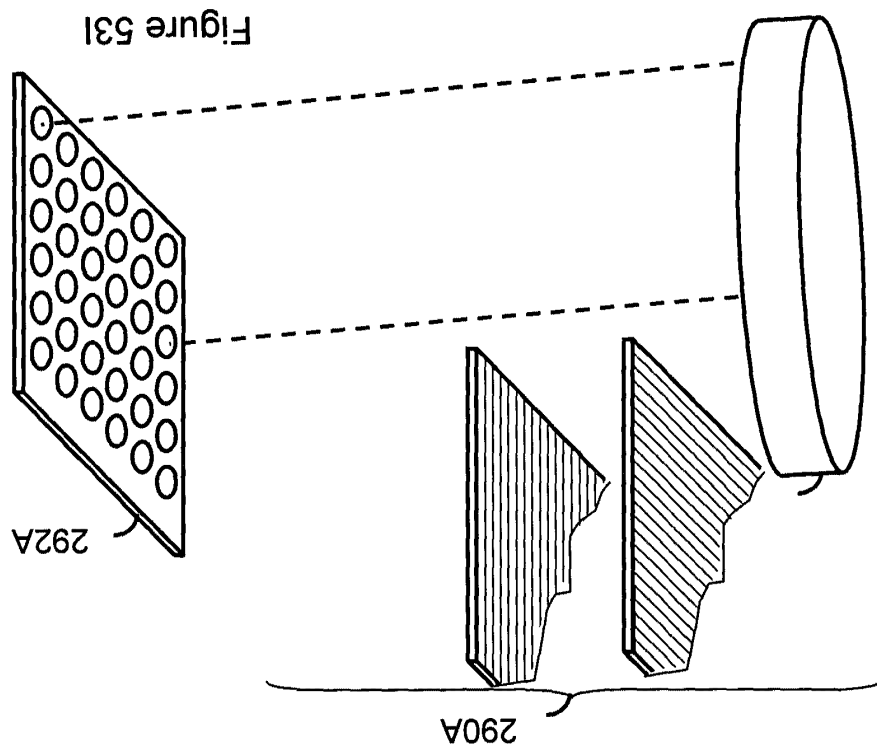
Masking





Masking

Masking



Masking

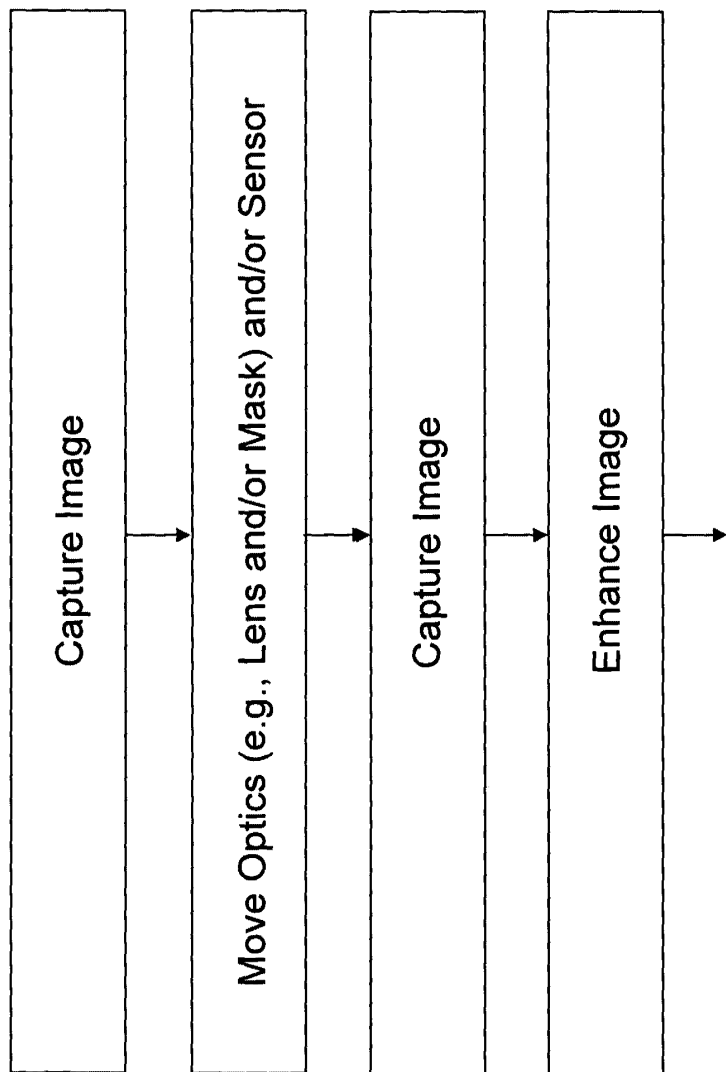


Figure 54

Mechanical Shutter

290A

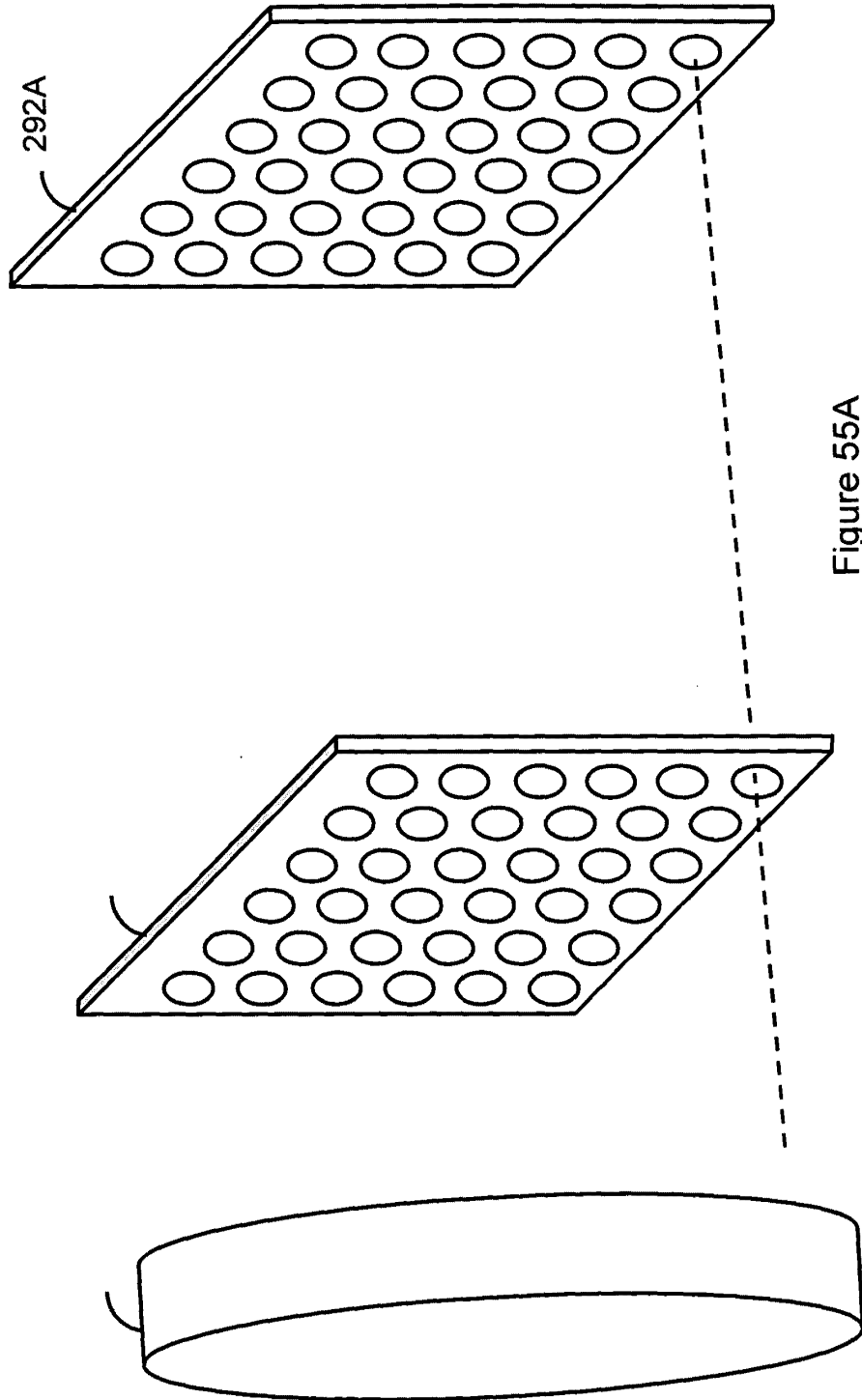


Figure 55A

Mechanical Shutter

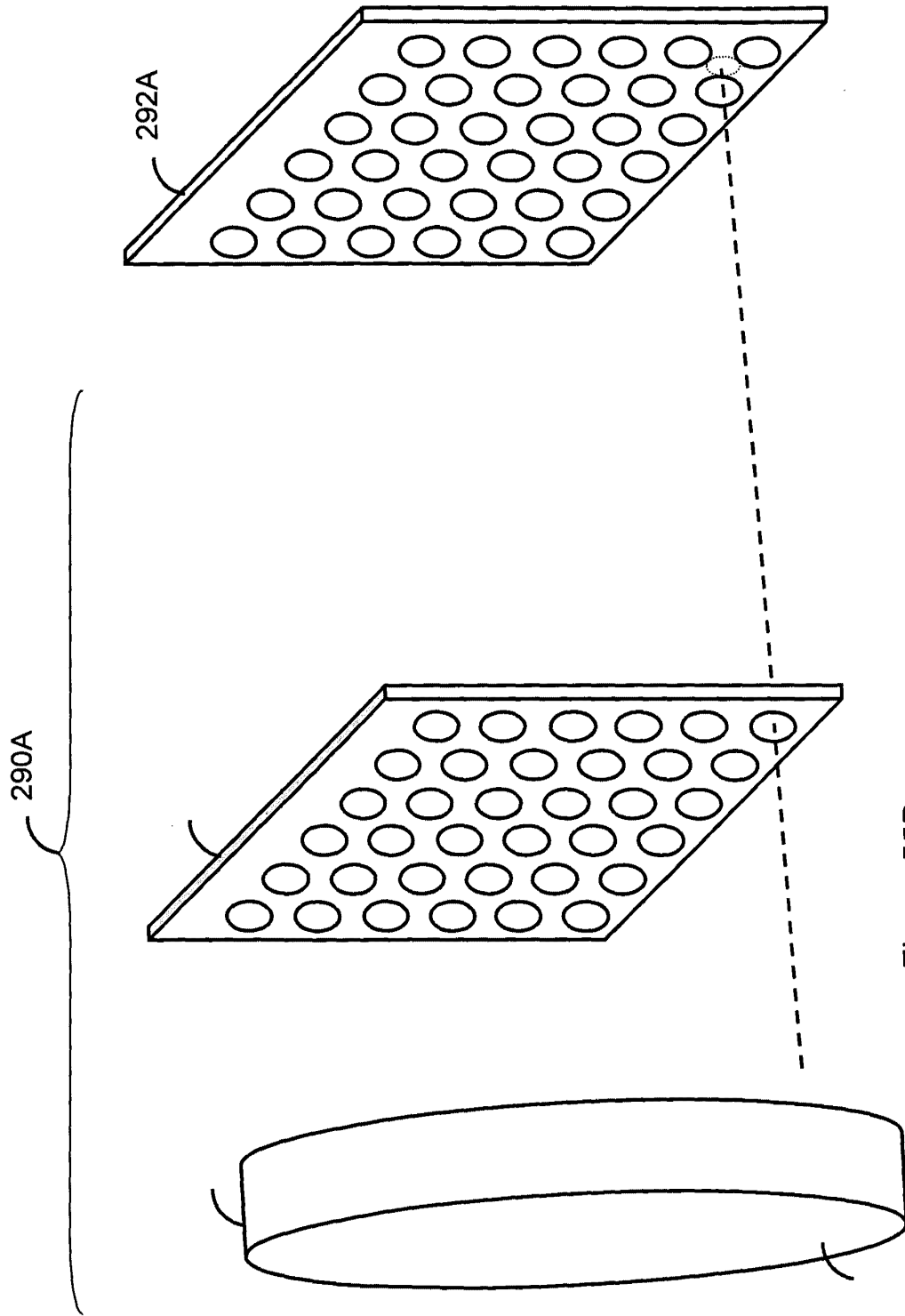


Figure 55B

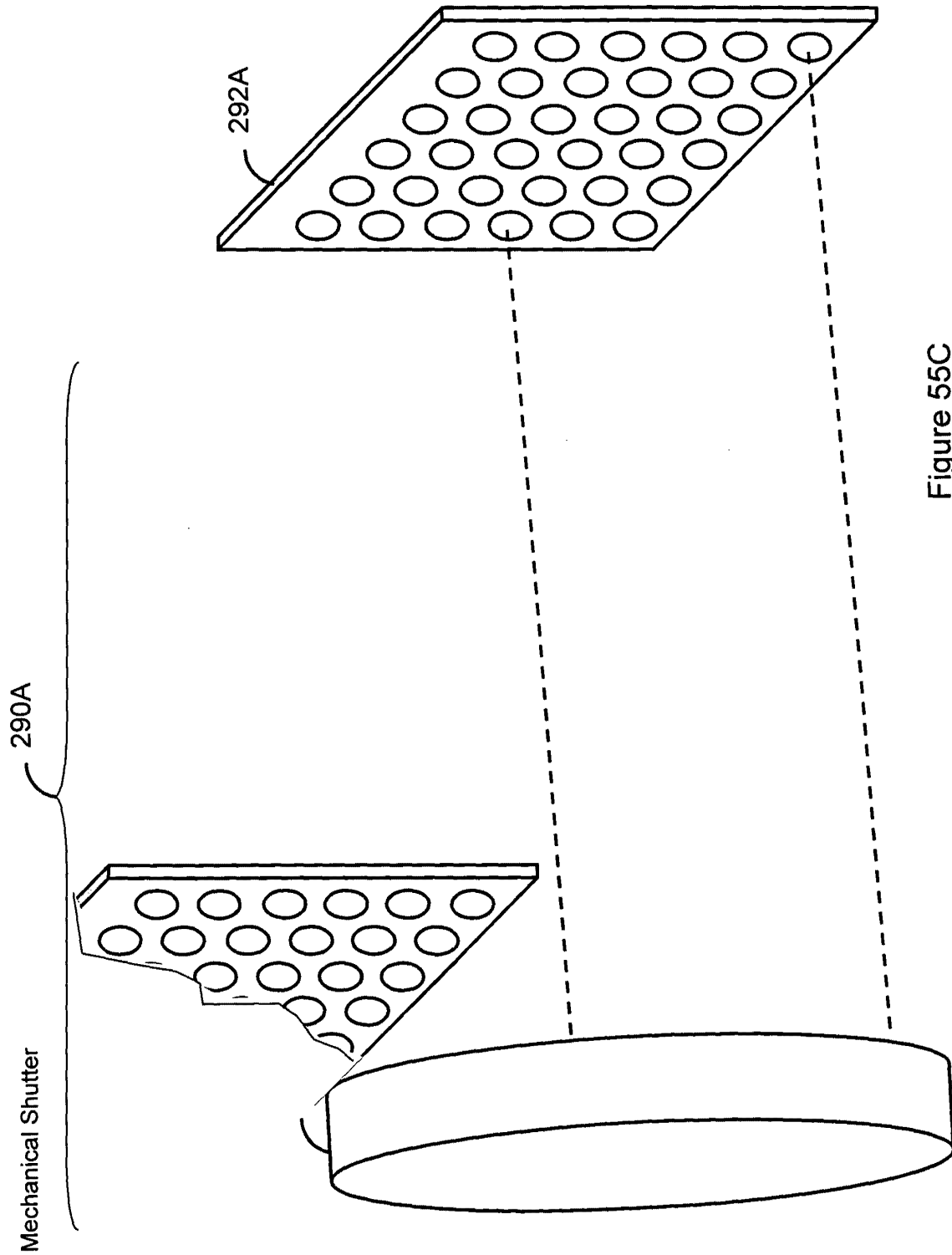


Figure 55C

Mechanical Shutter

290A

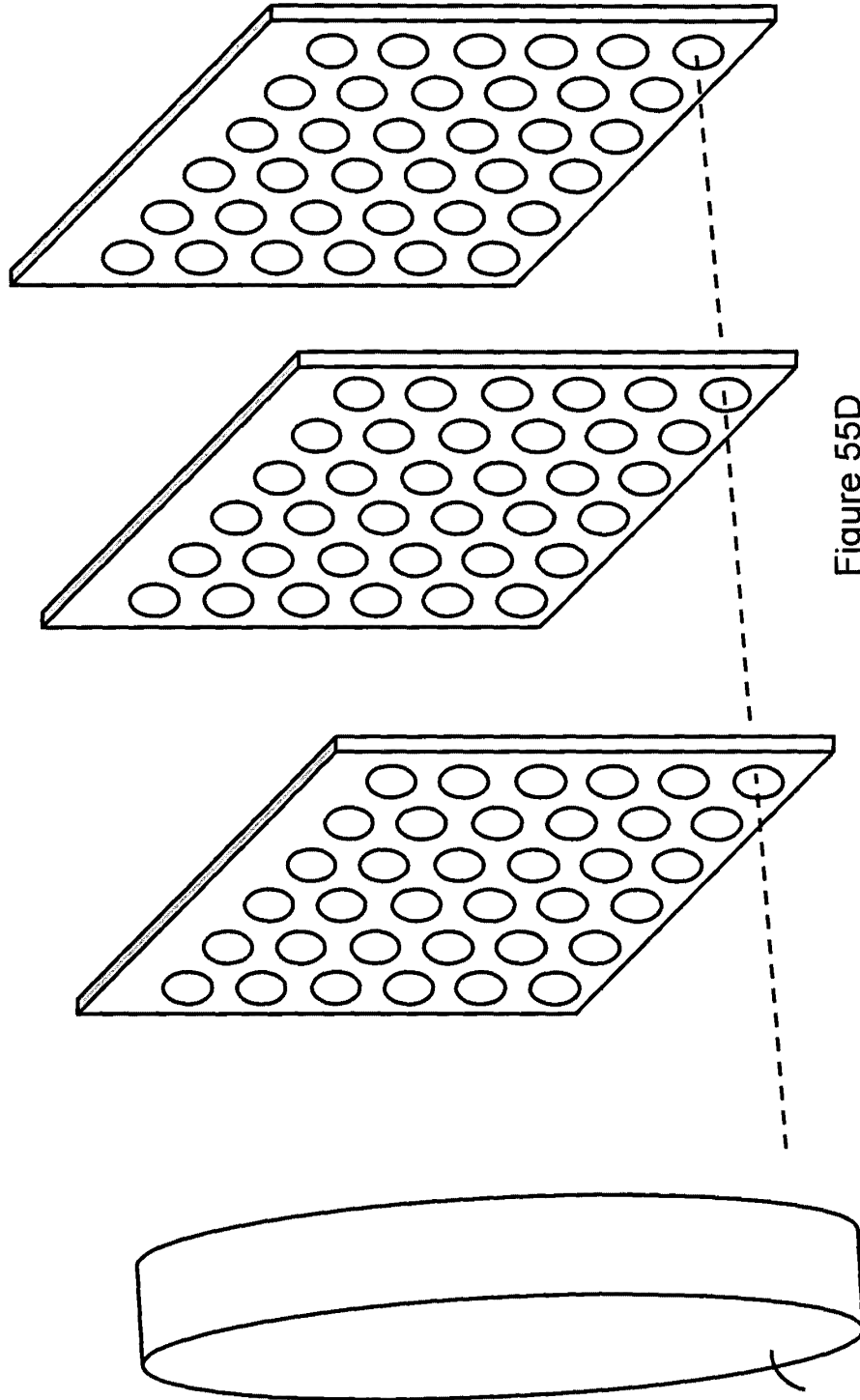


Figure 55D

Mechanical Shutter

290A

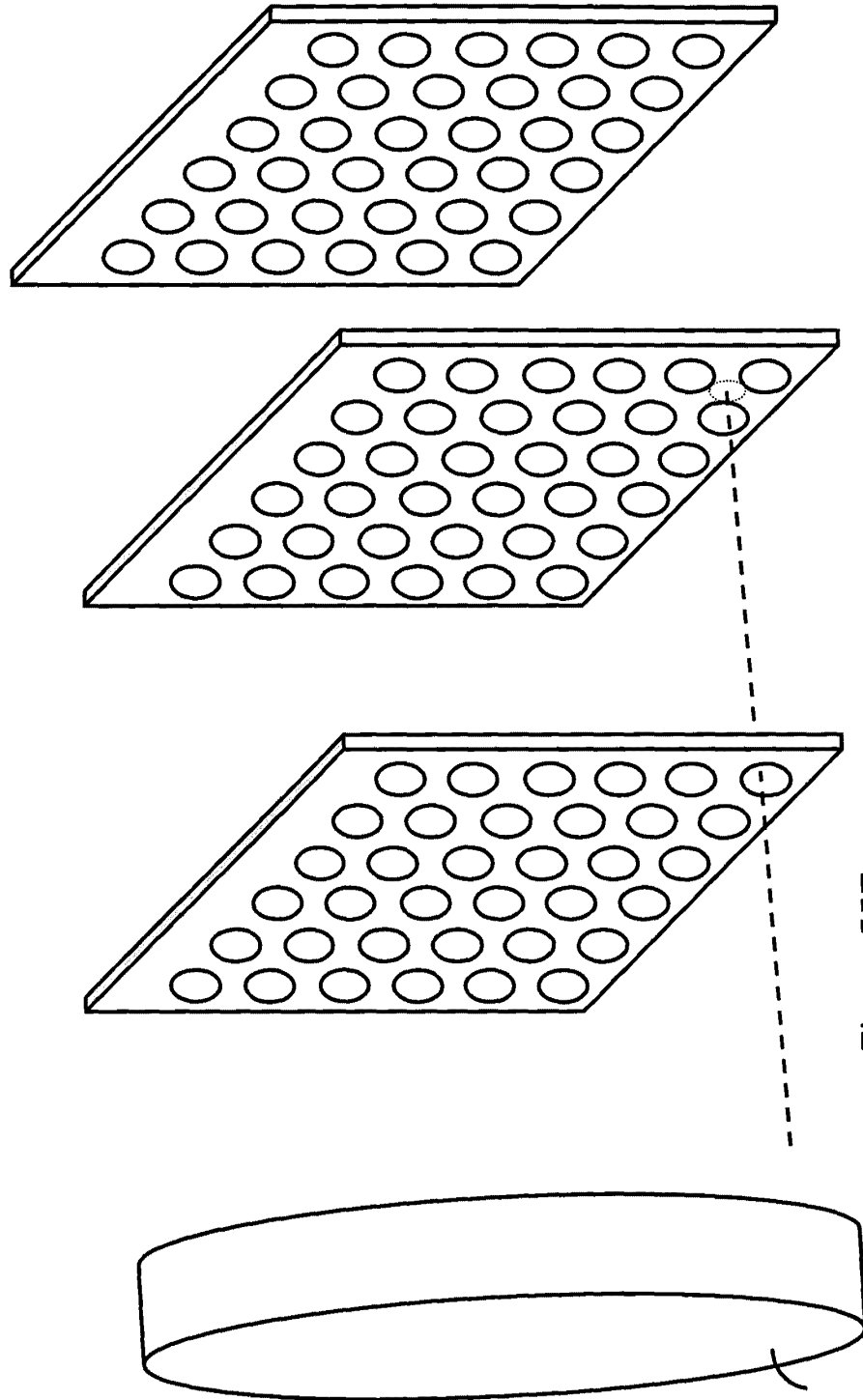


Figure 55E

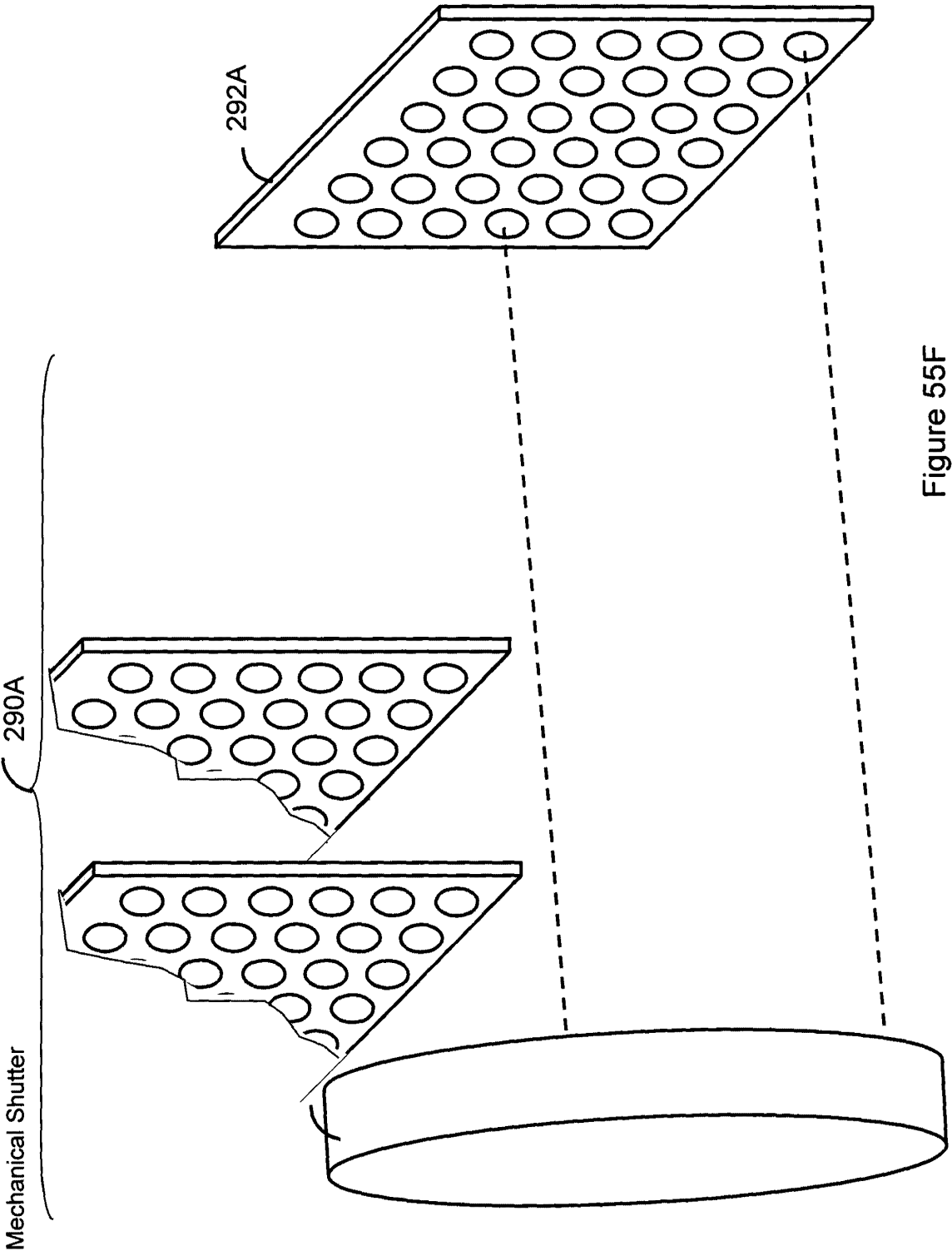


Figure 55F

Mechanical Shutter

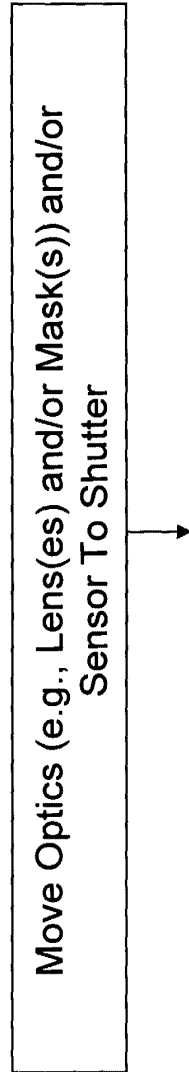


Figure 56

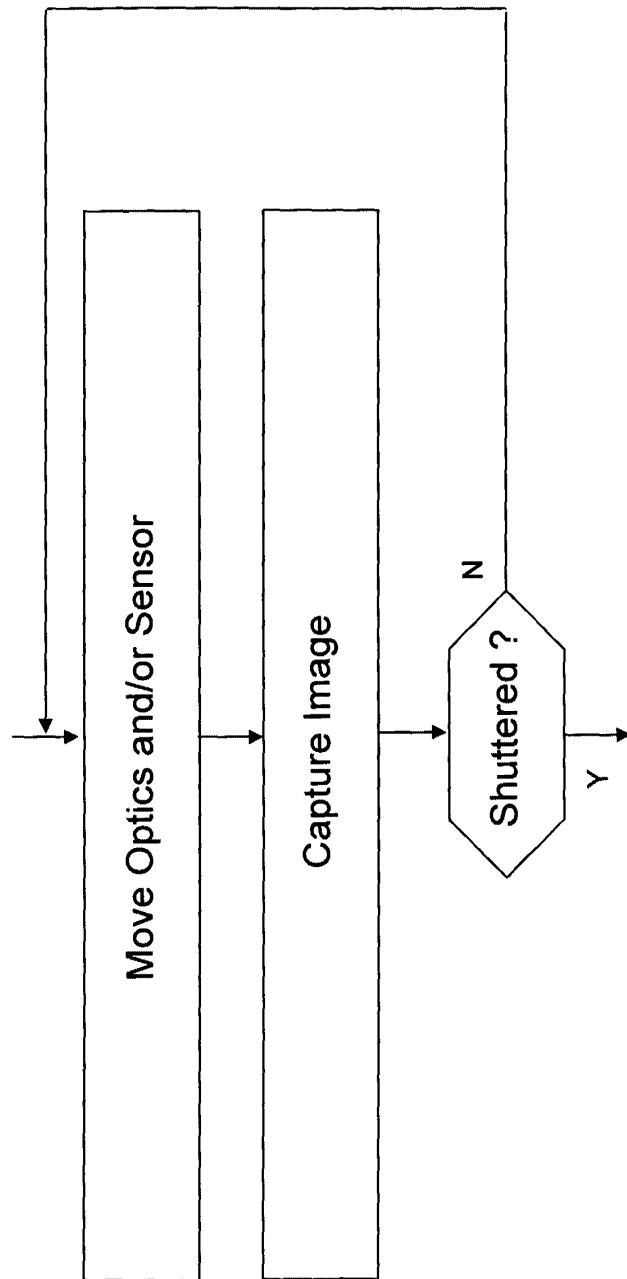


Figure 57

Mechanical Iris

290A

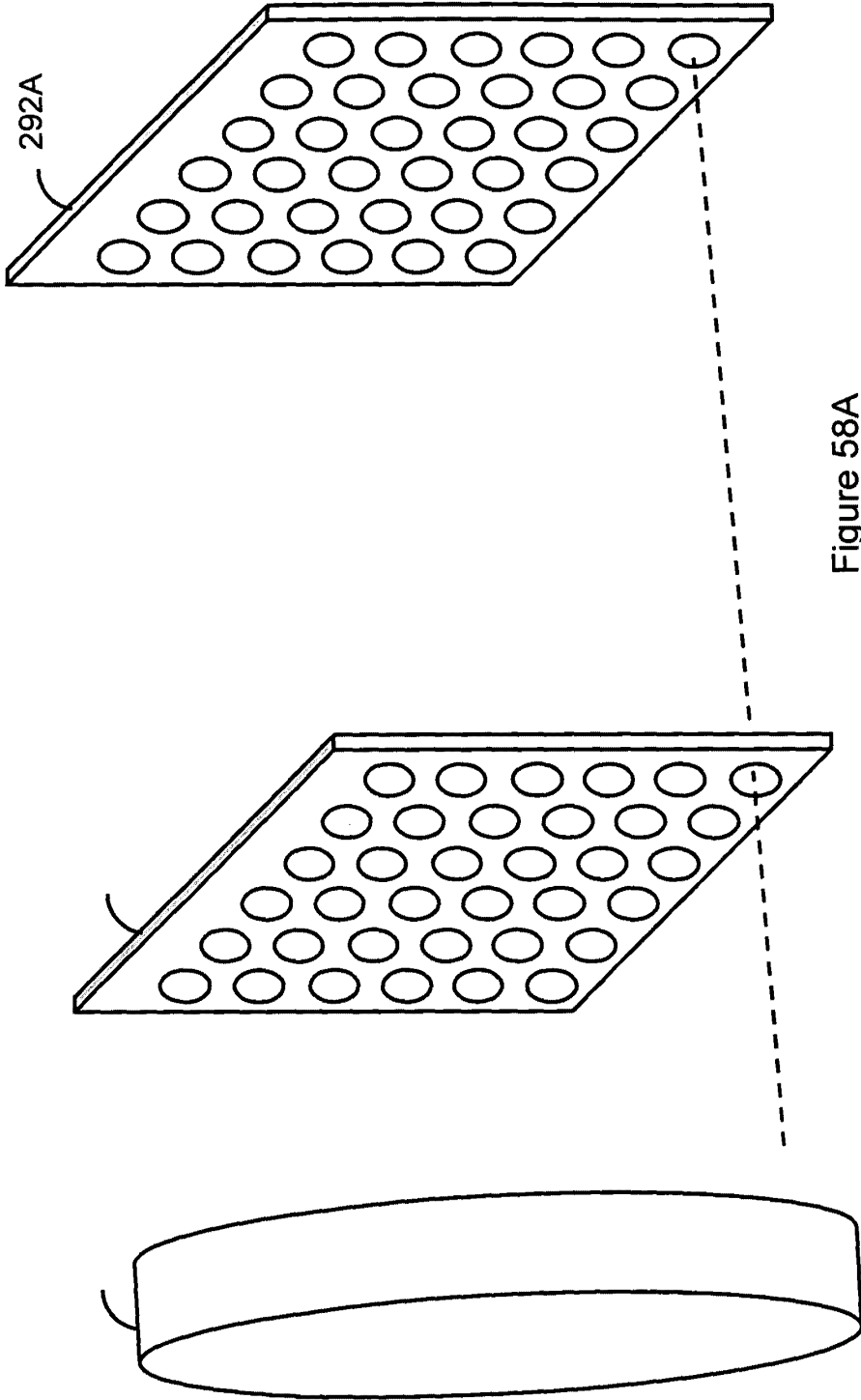
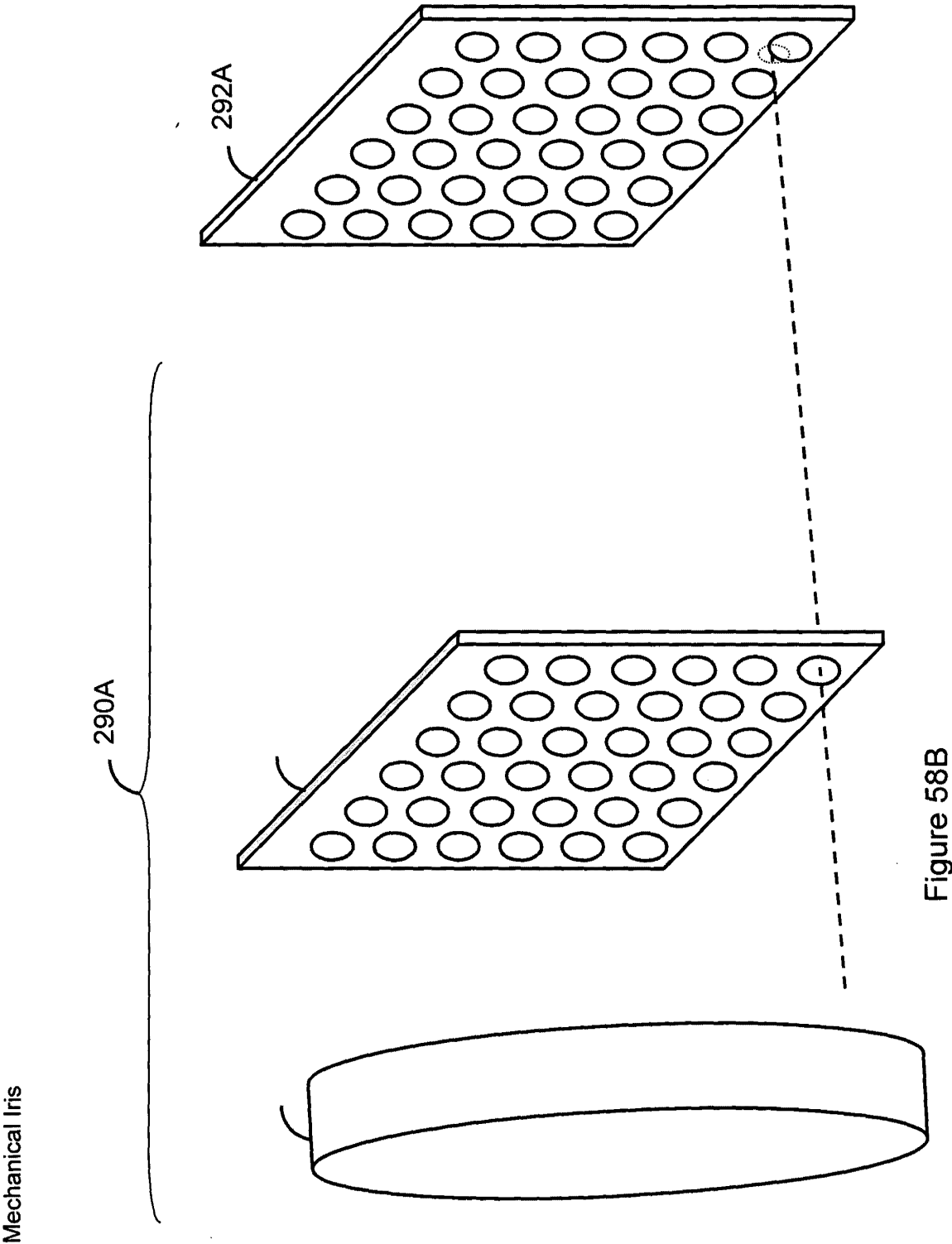
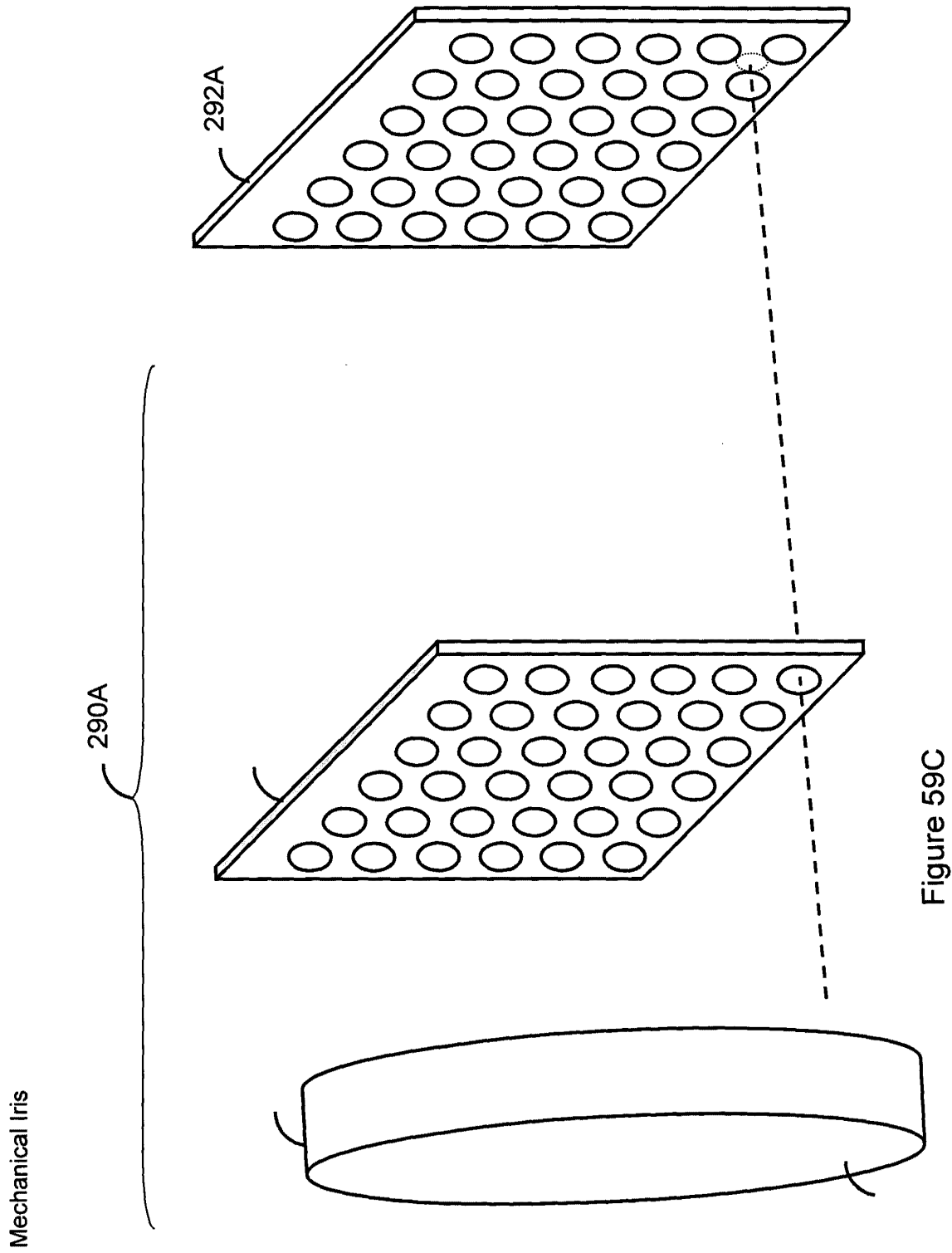


Figure 58A





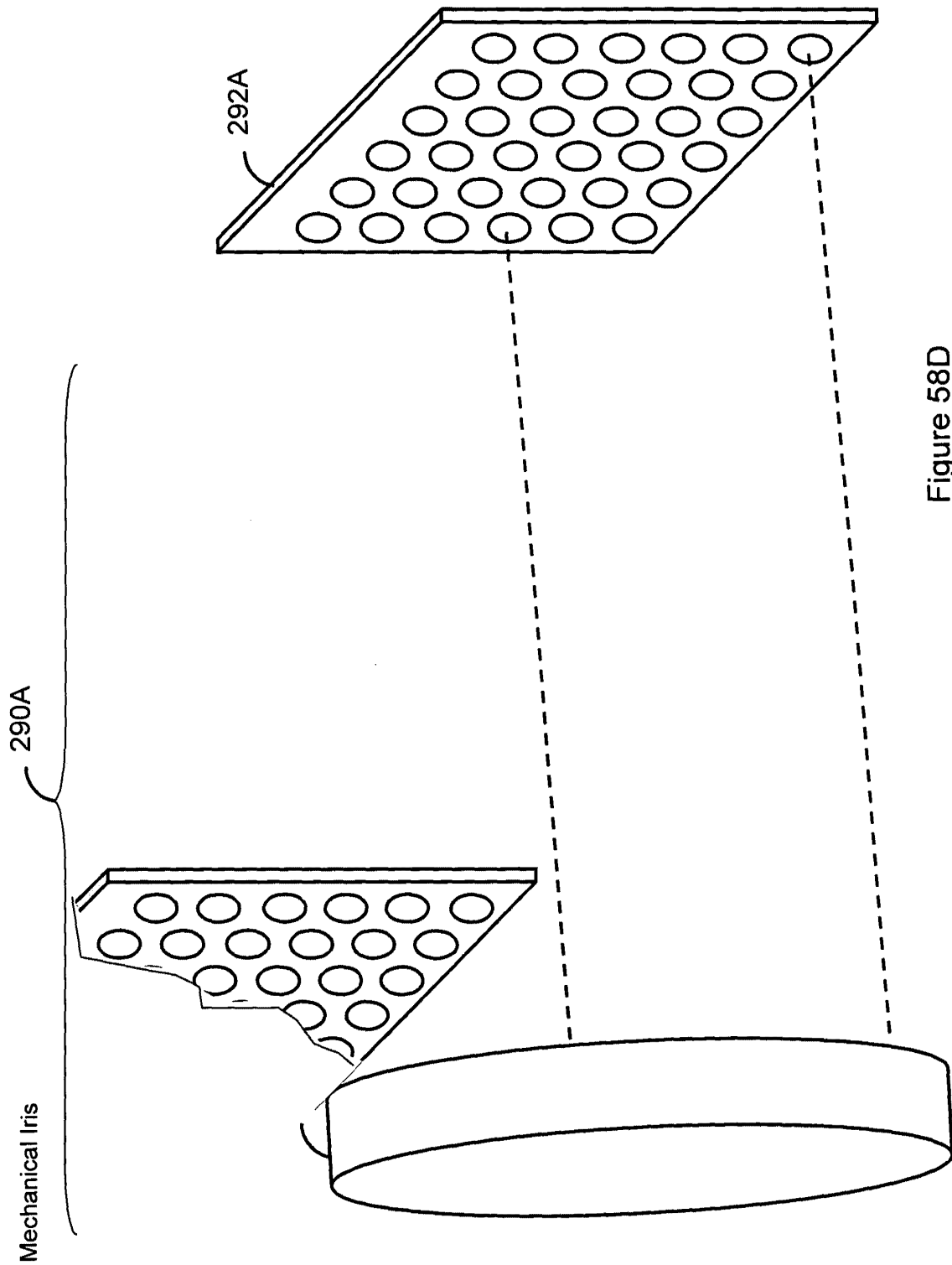


Figure 58D

Mechanical Iris

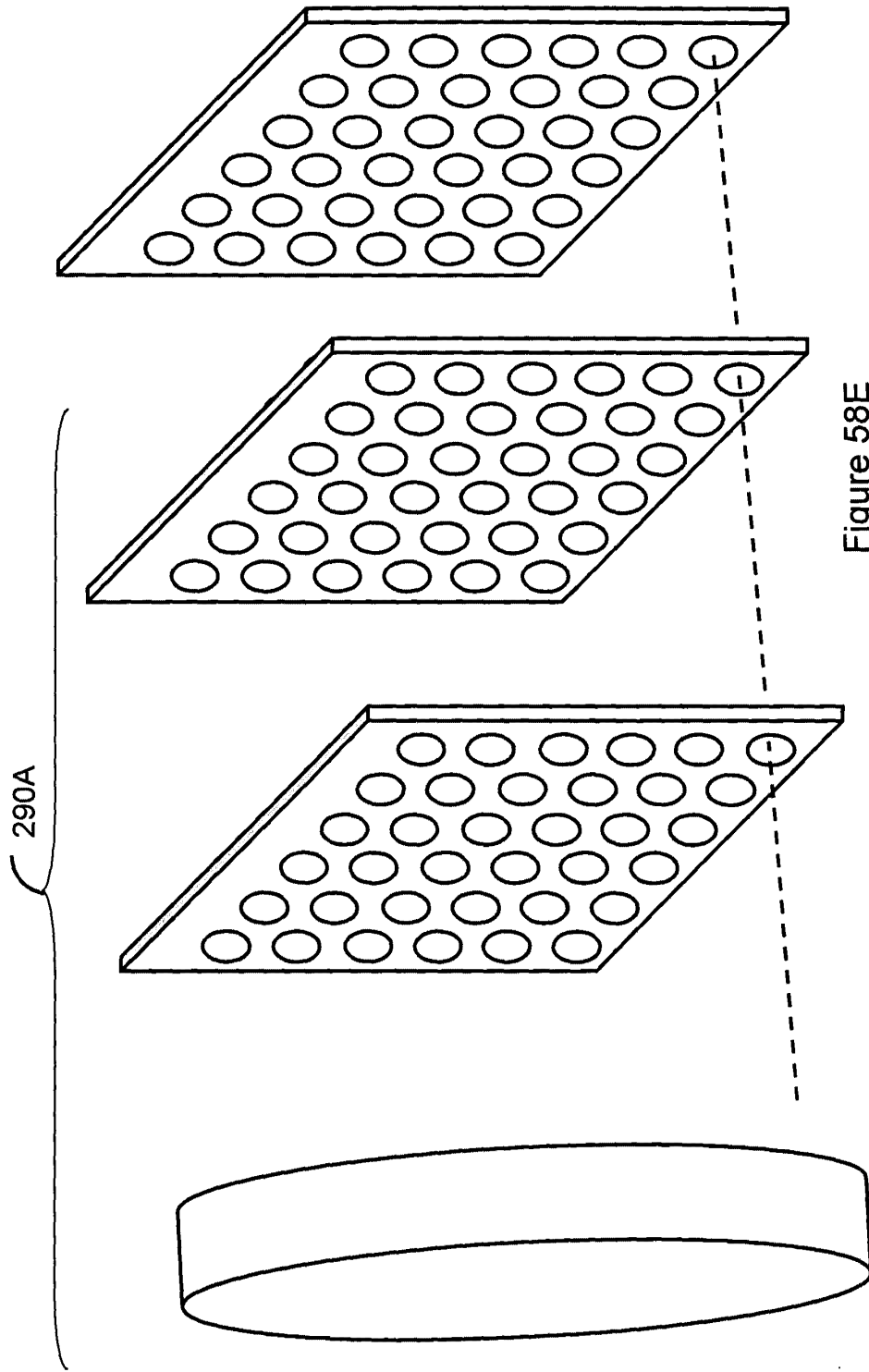


Figure 58E

Mechanical Iris

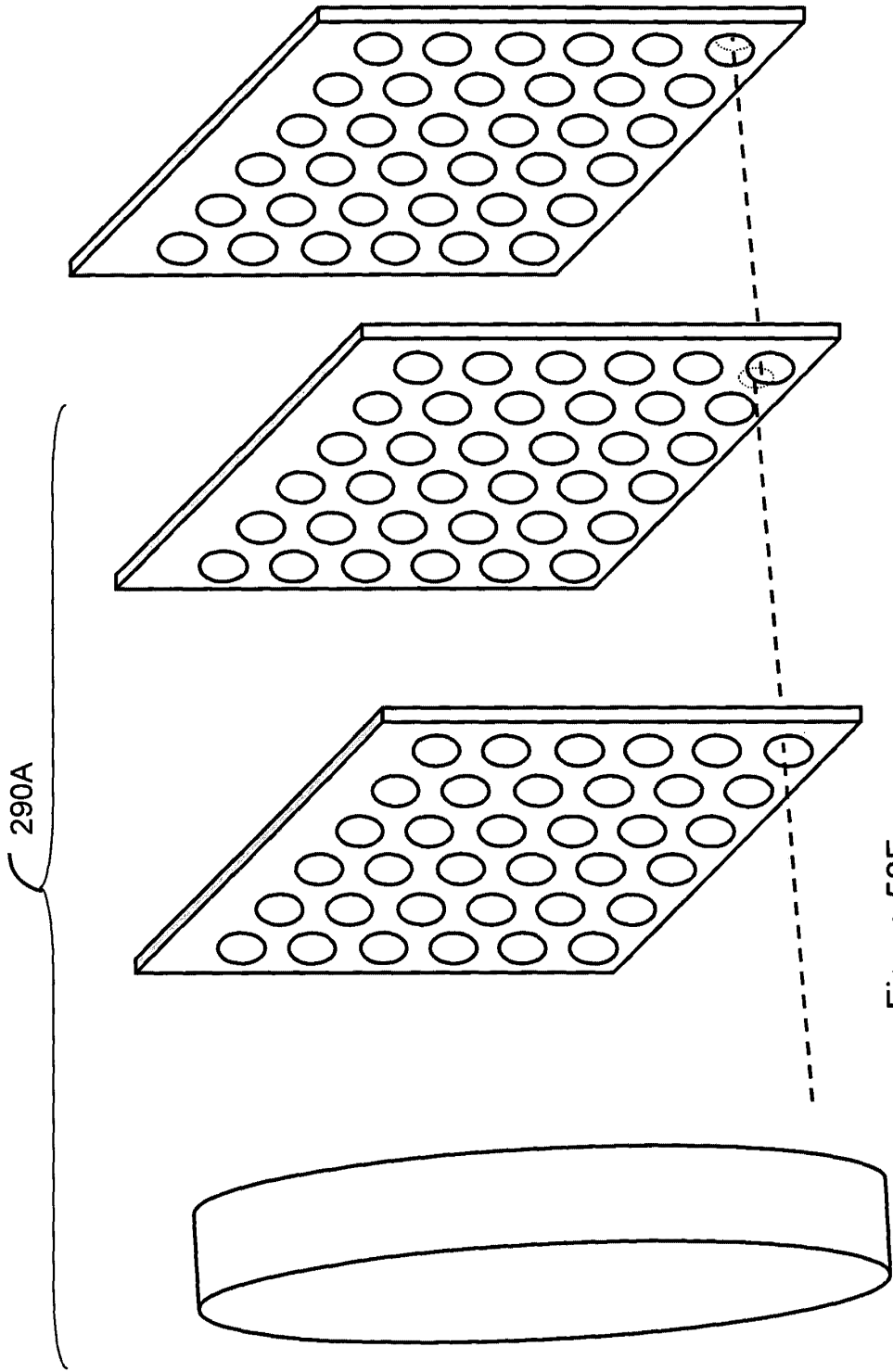


Figure 58F

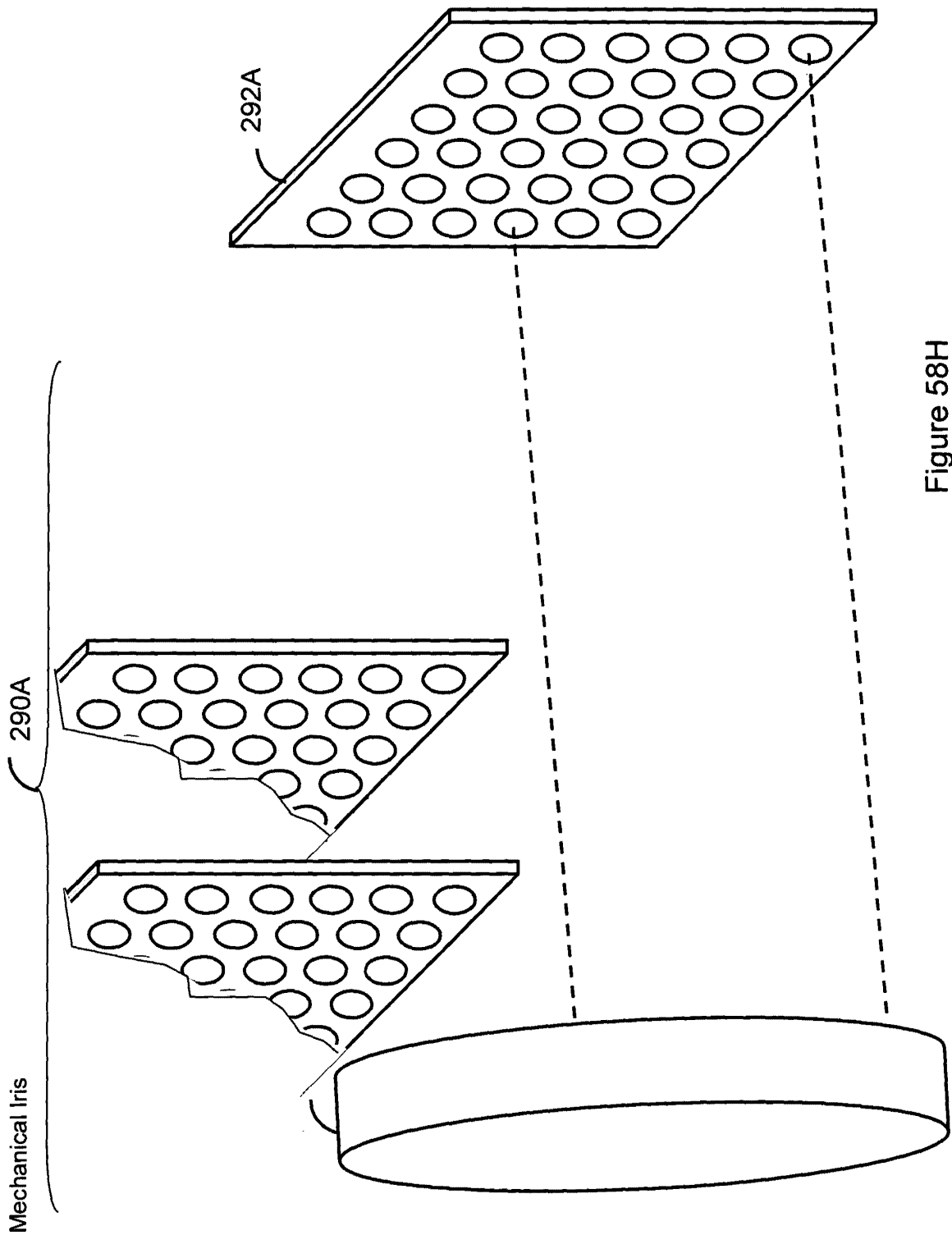


Figure 58H

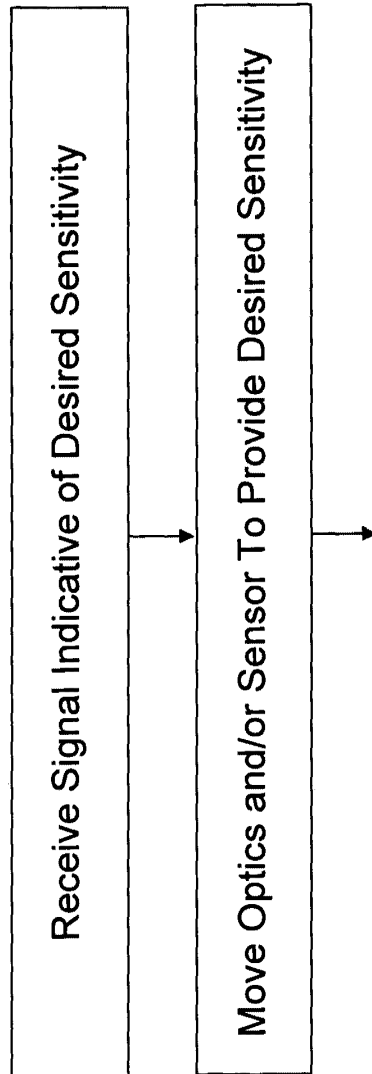


Figure 59

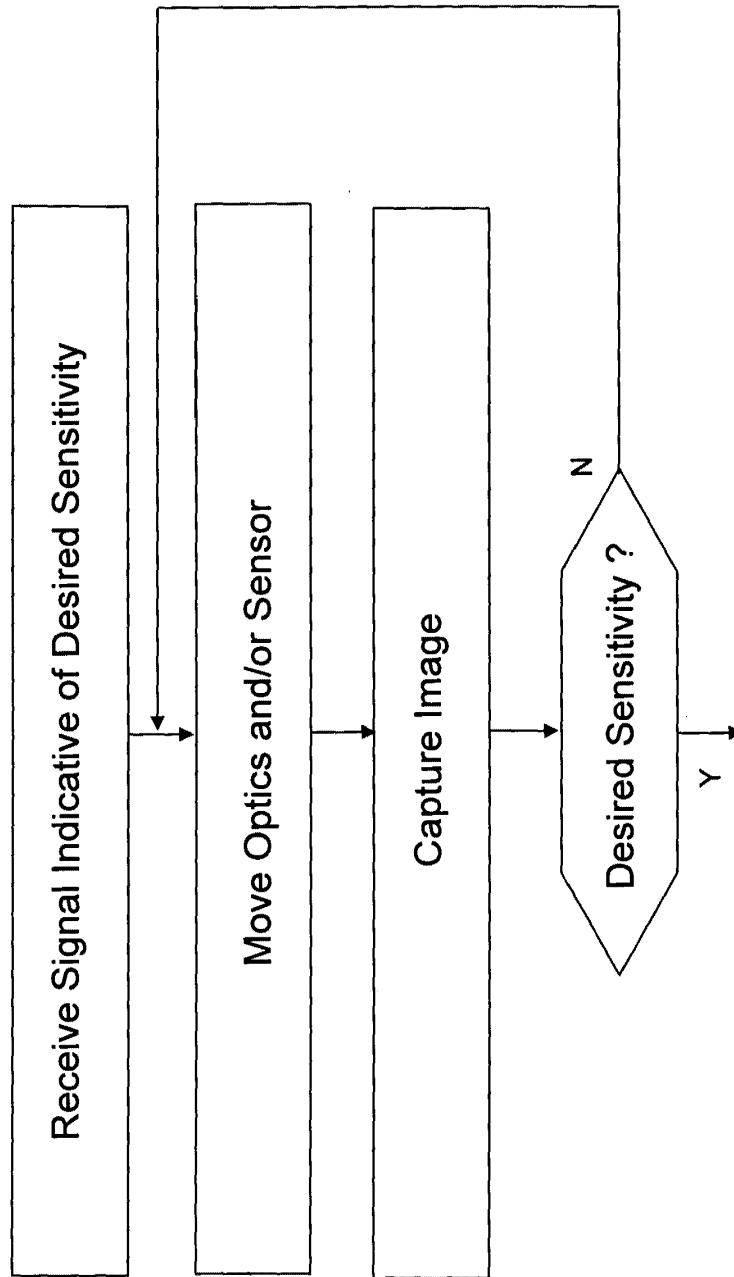


Figure 60

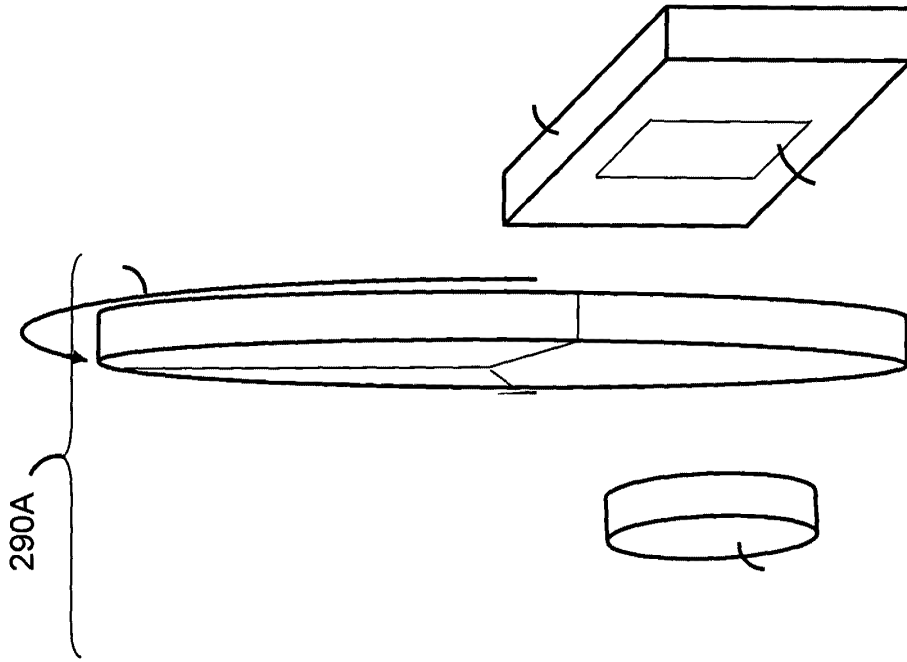


Figure 61B

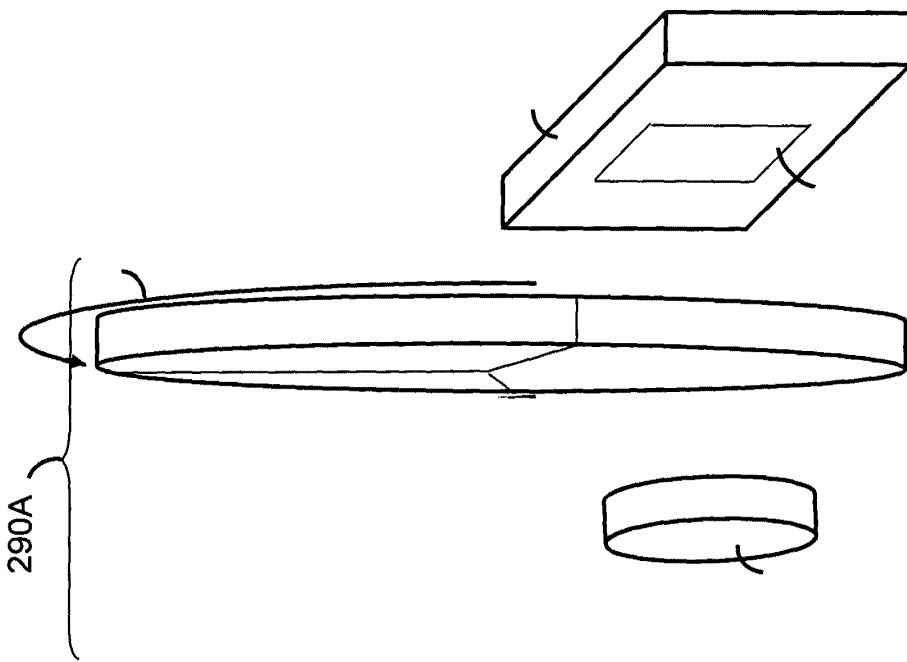
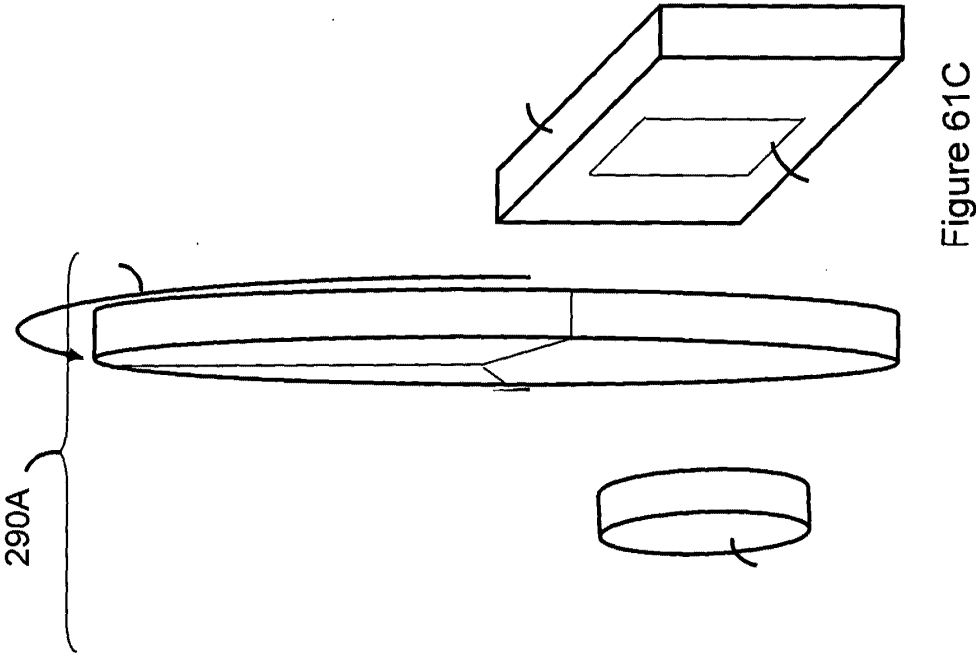


Figure 61A



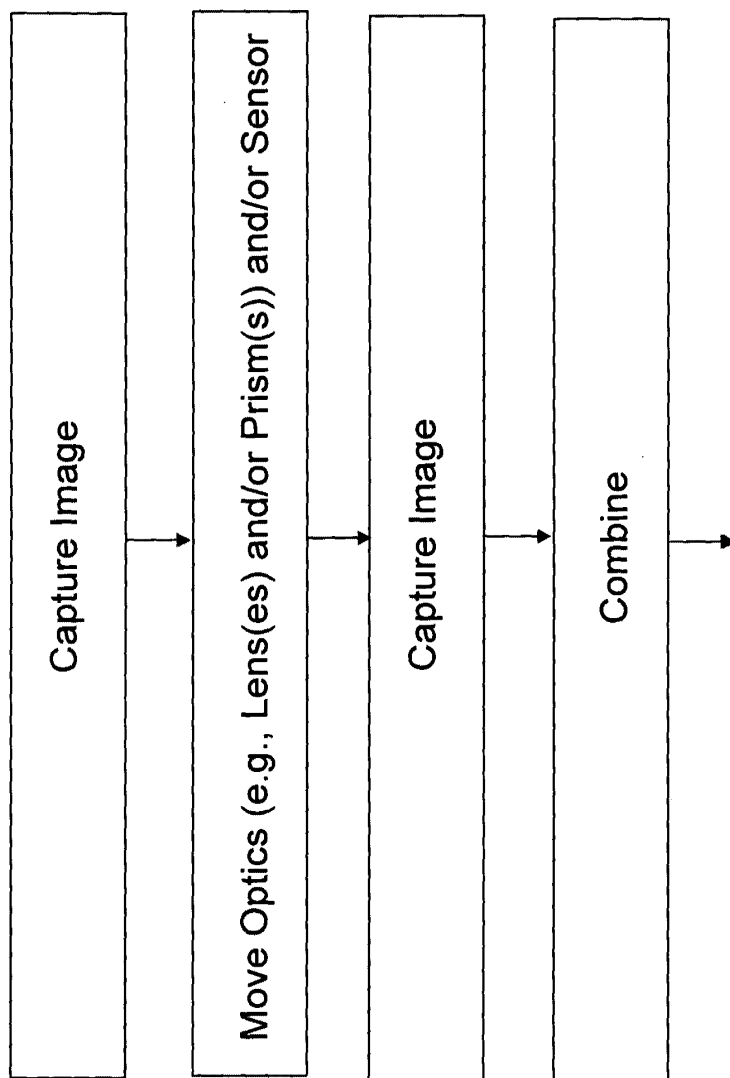


Figure 62A

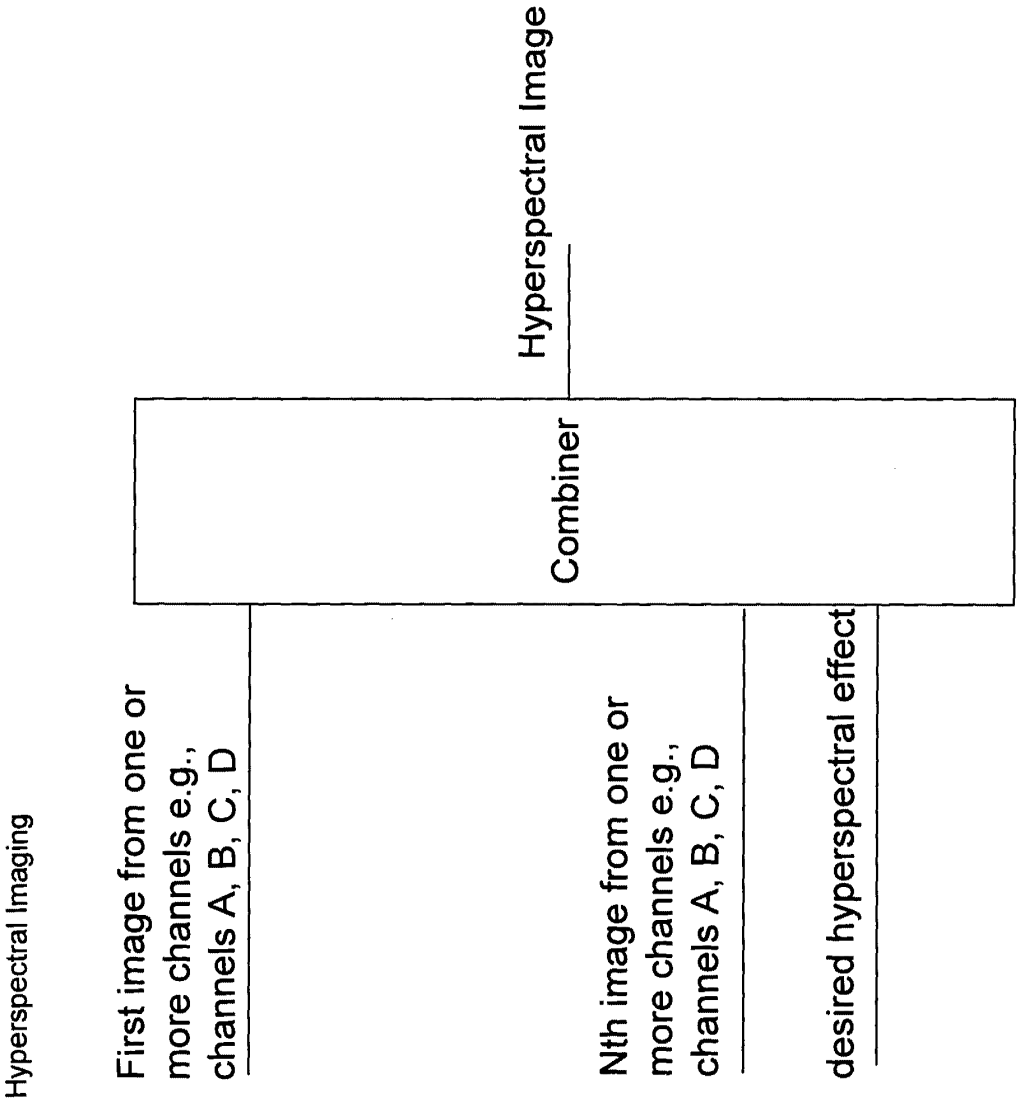


Figure 62B

Hyperspectral Imaging

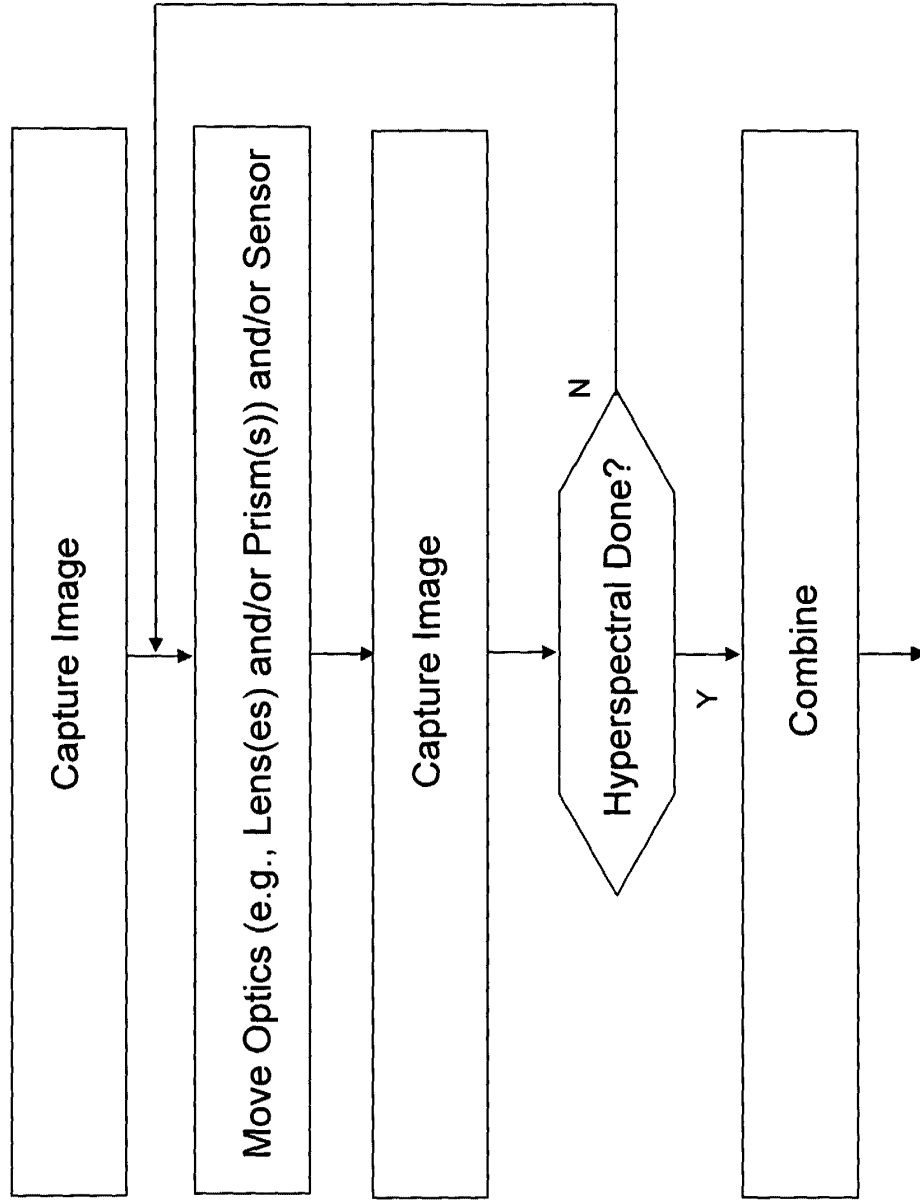


Figure 63

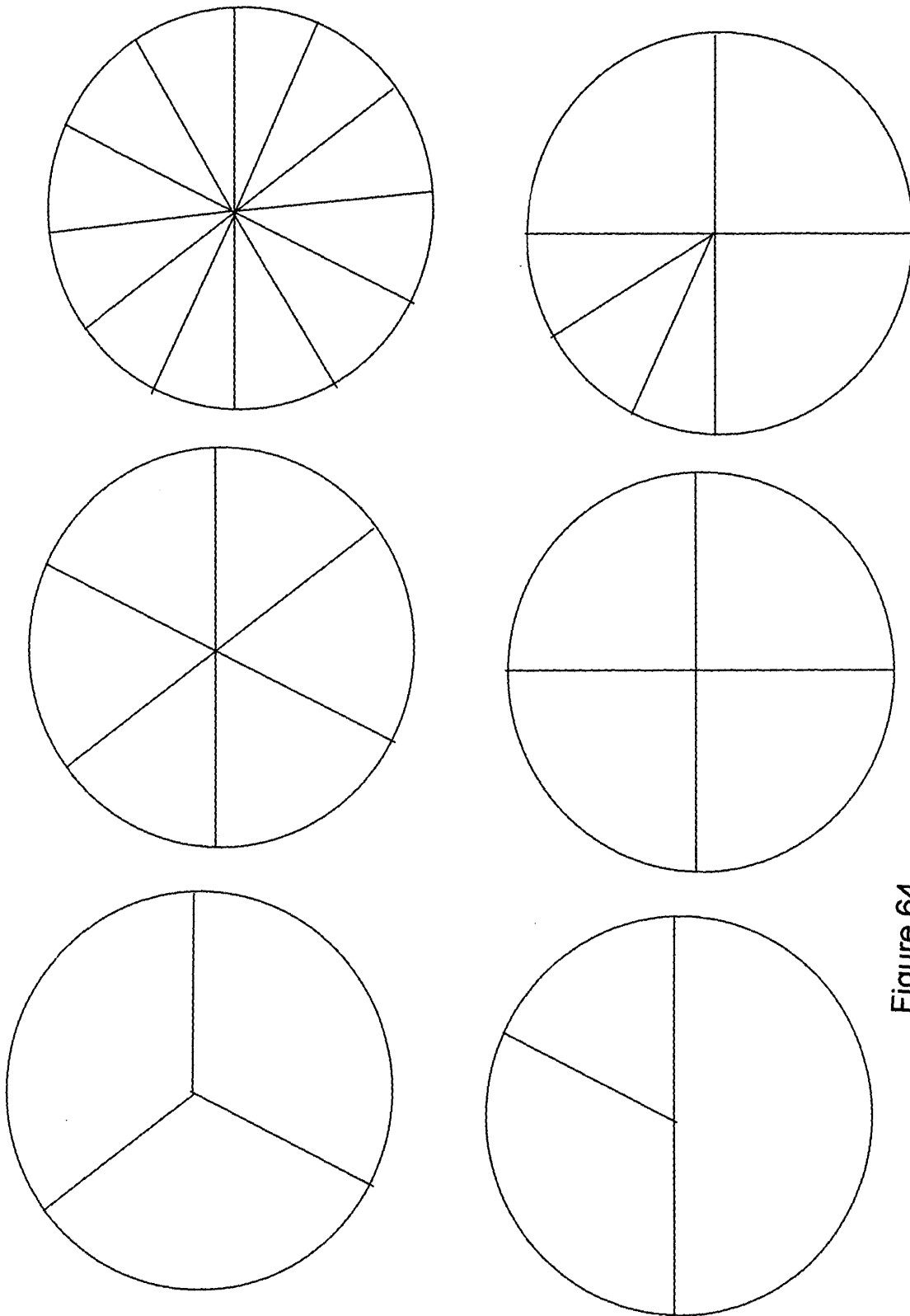


Figure 64

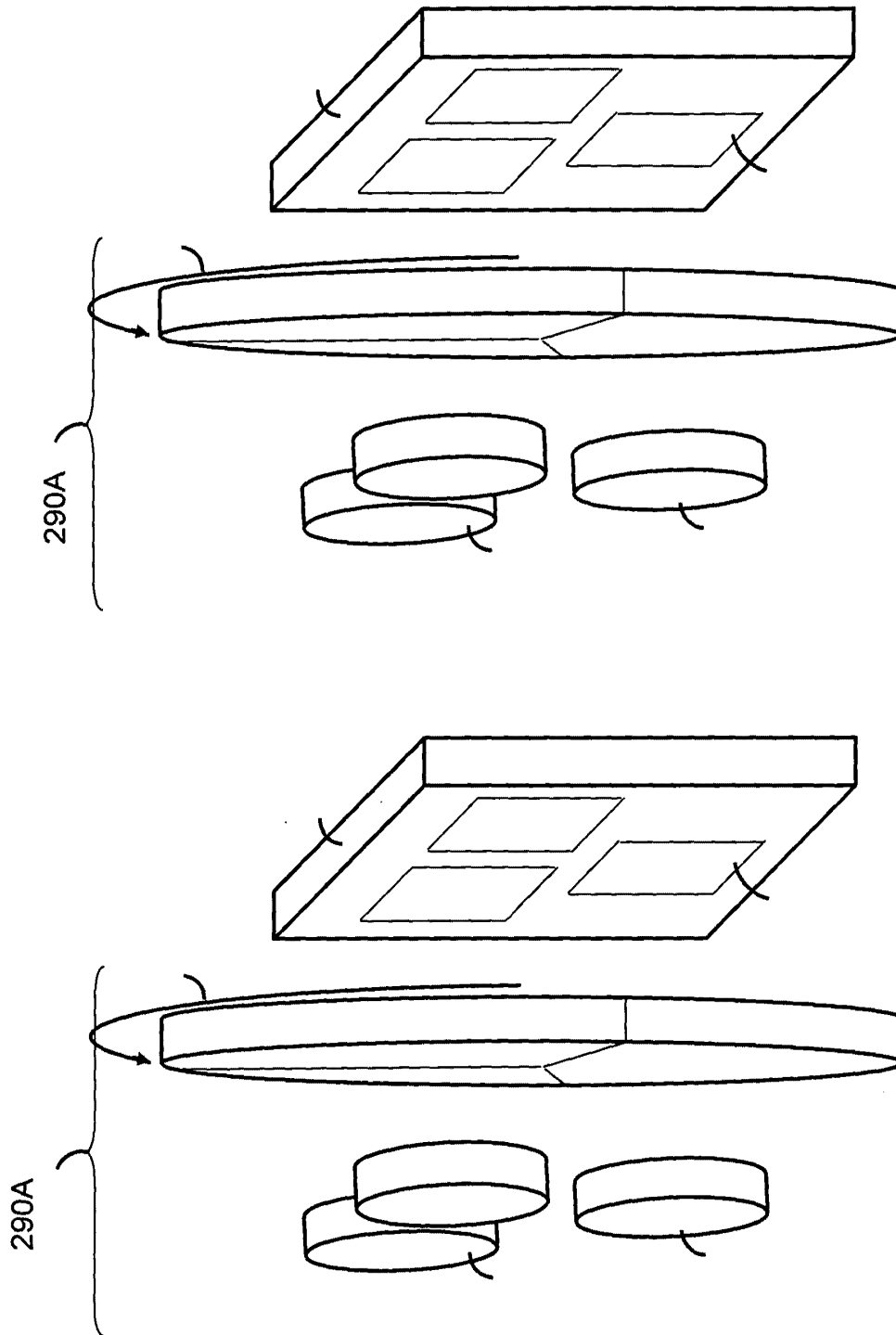


Figure 65B

Figure 65A

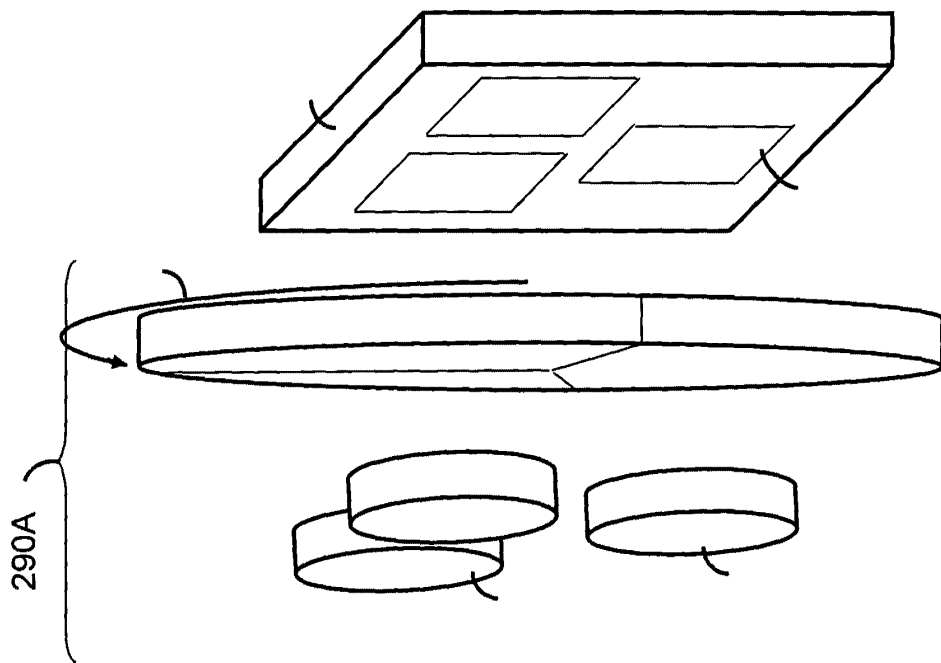


Figure 65D

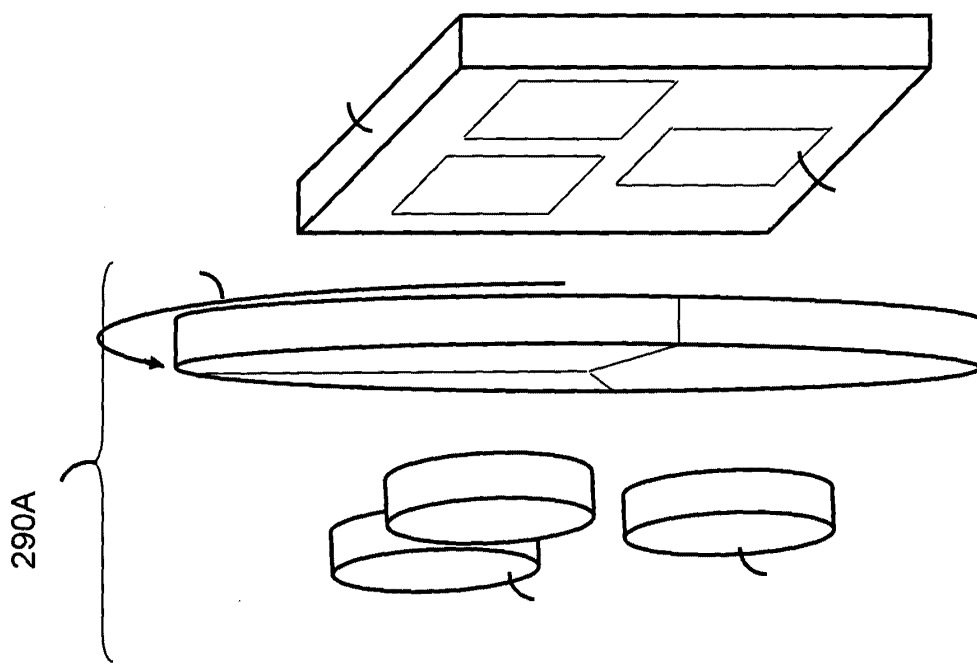


Figure 65C

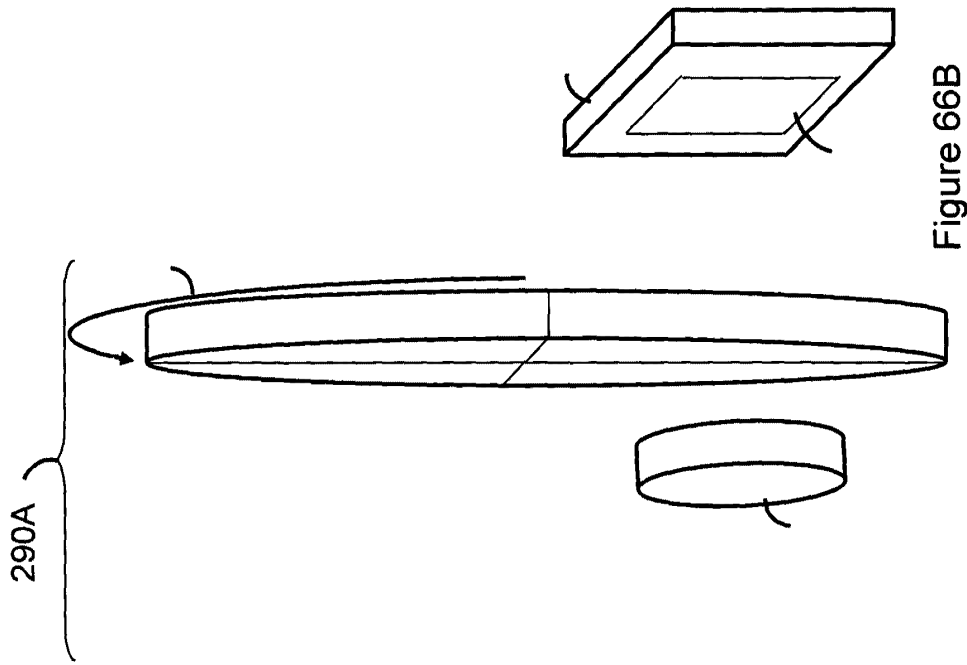


Figure 66B

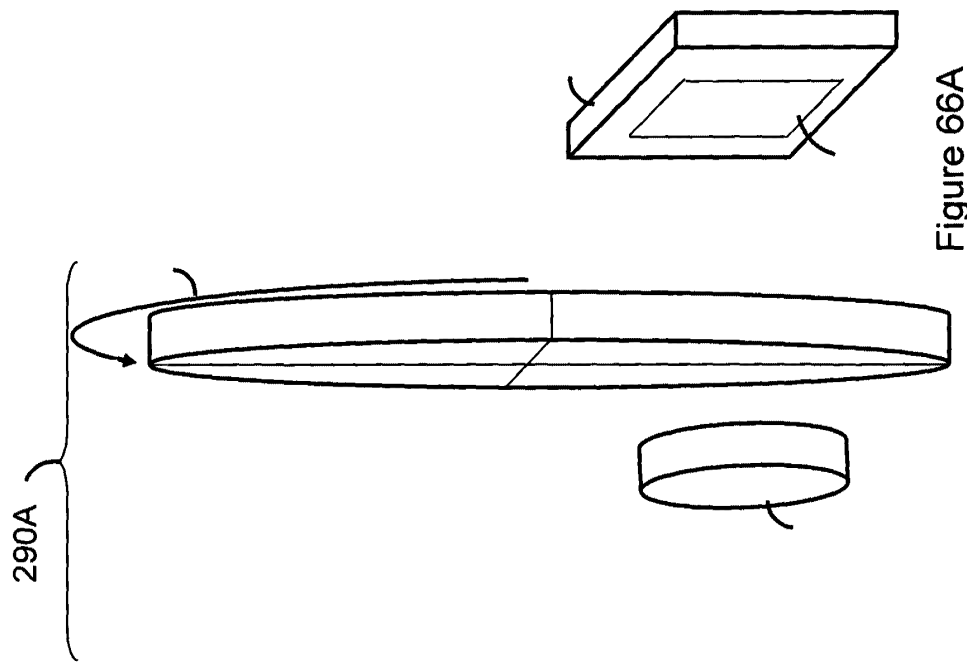


Figure 66A

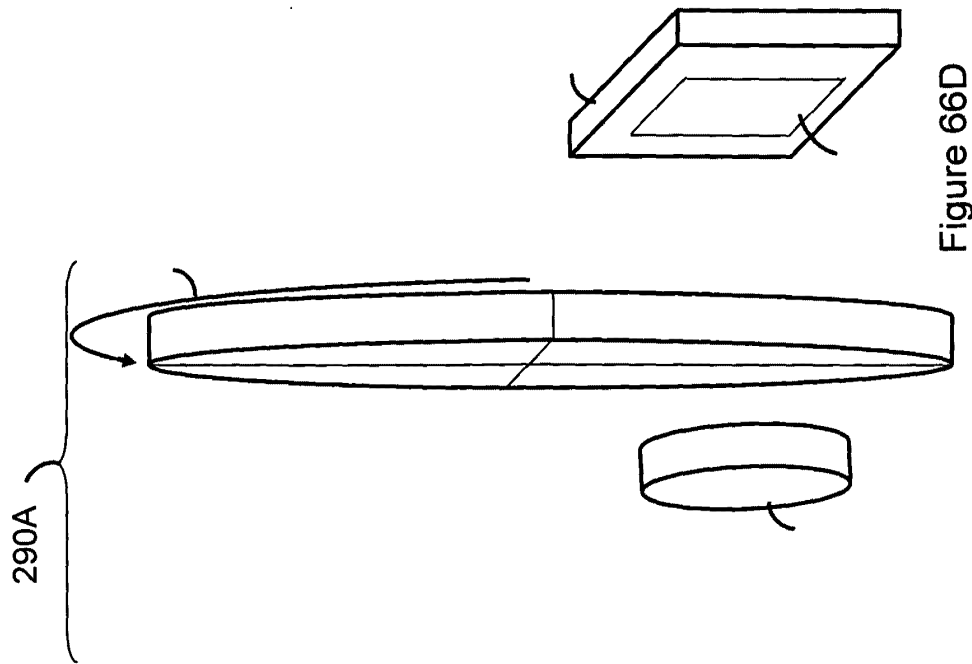


Figure 66D

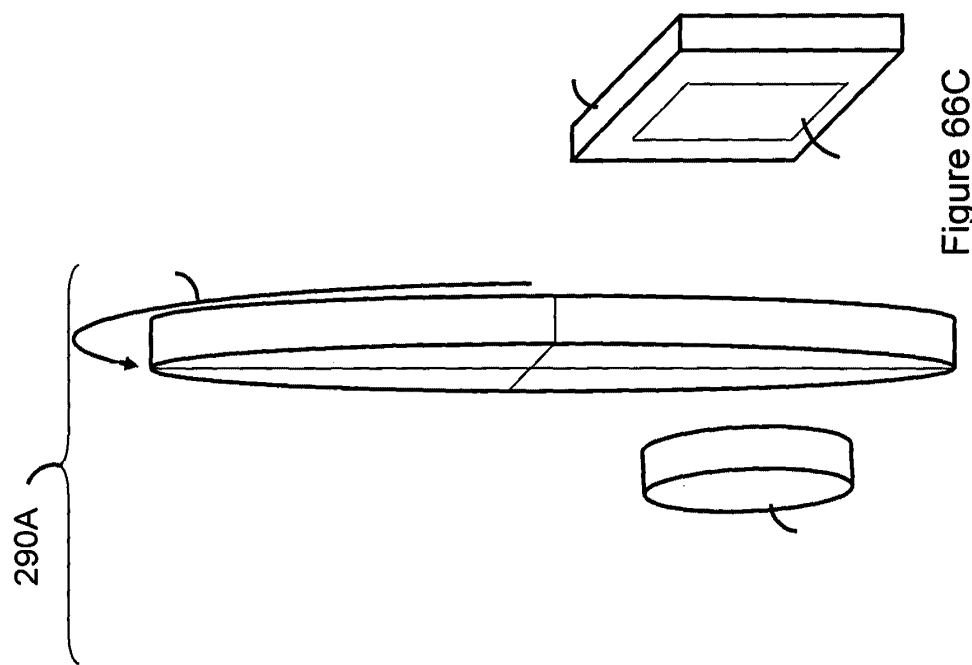


Figure 66C

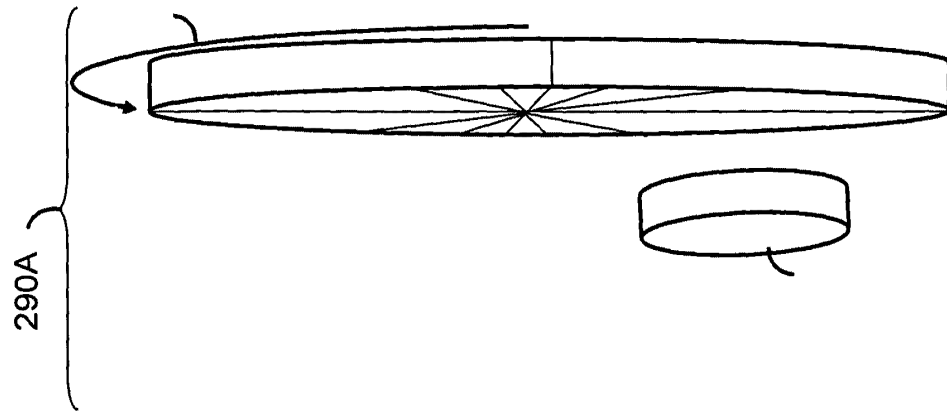


Figure 66F

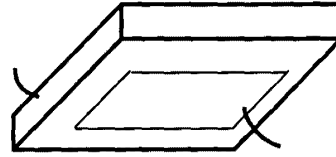
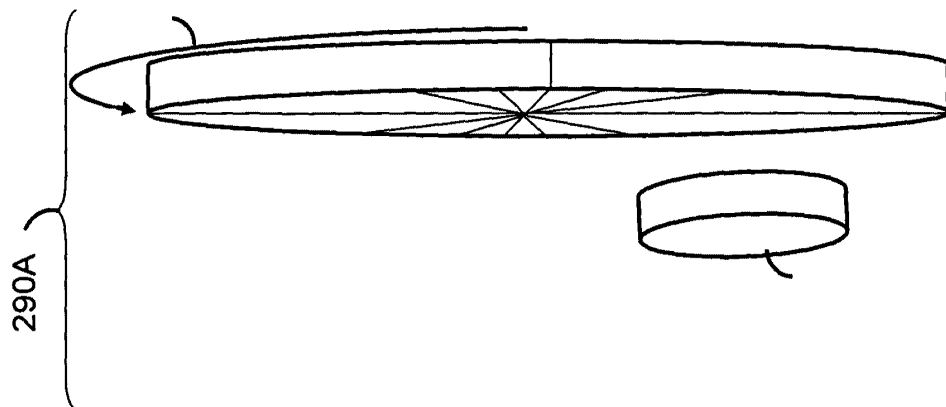
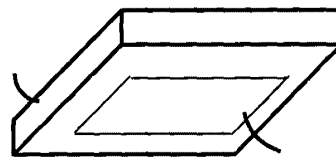


Figure 66E



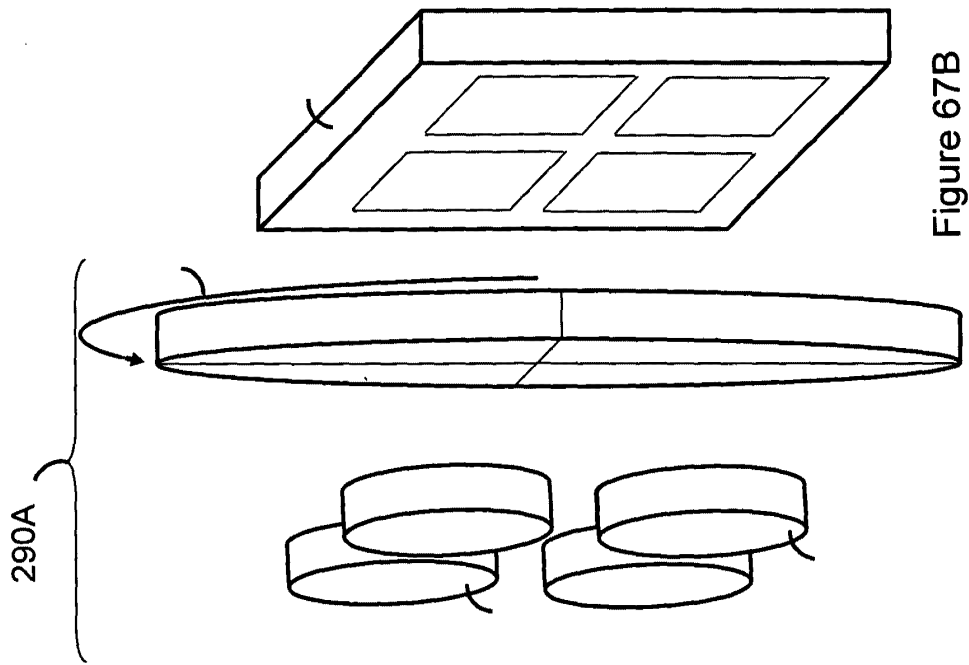


Figure 67B

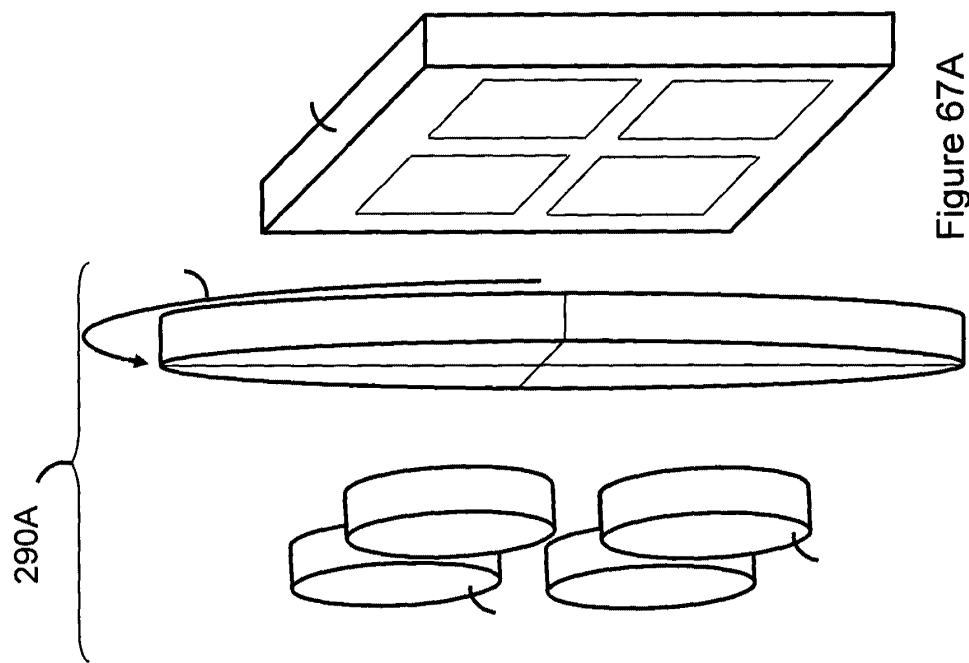


Figure 67A

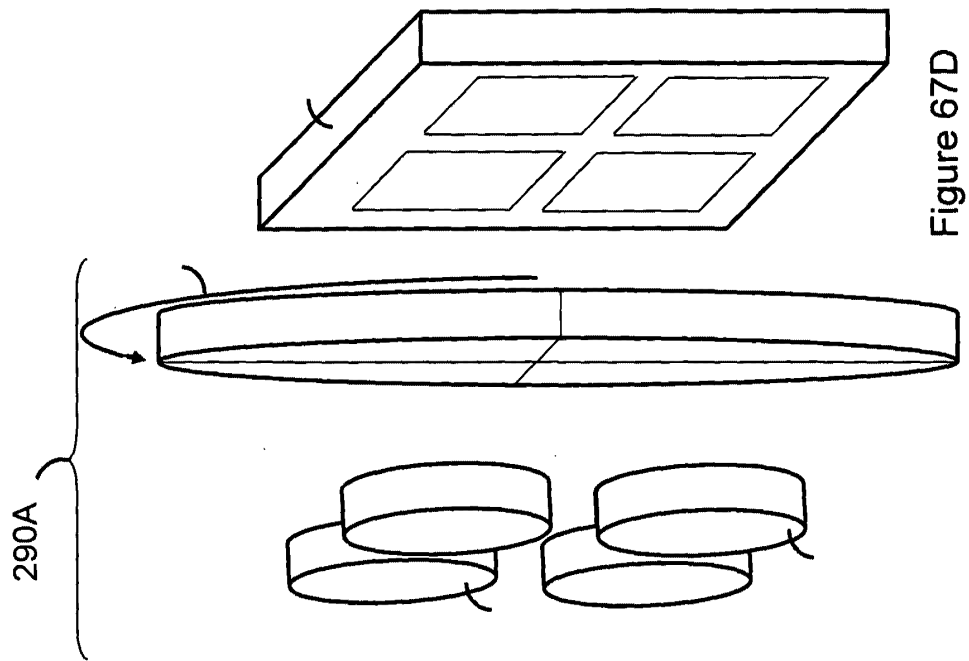


Figure 67D

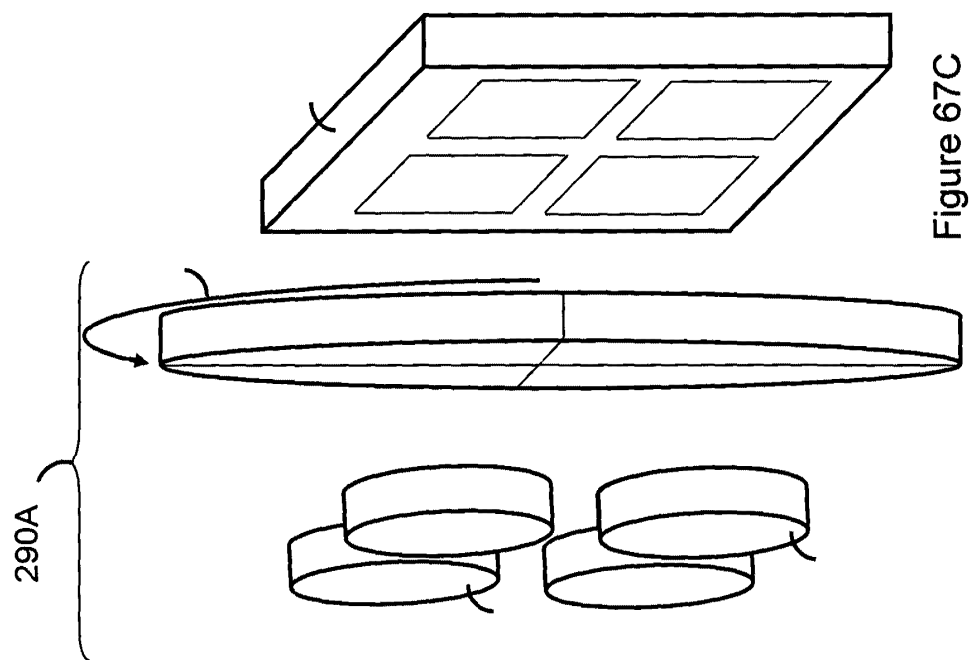
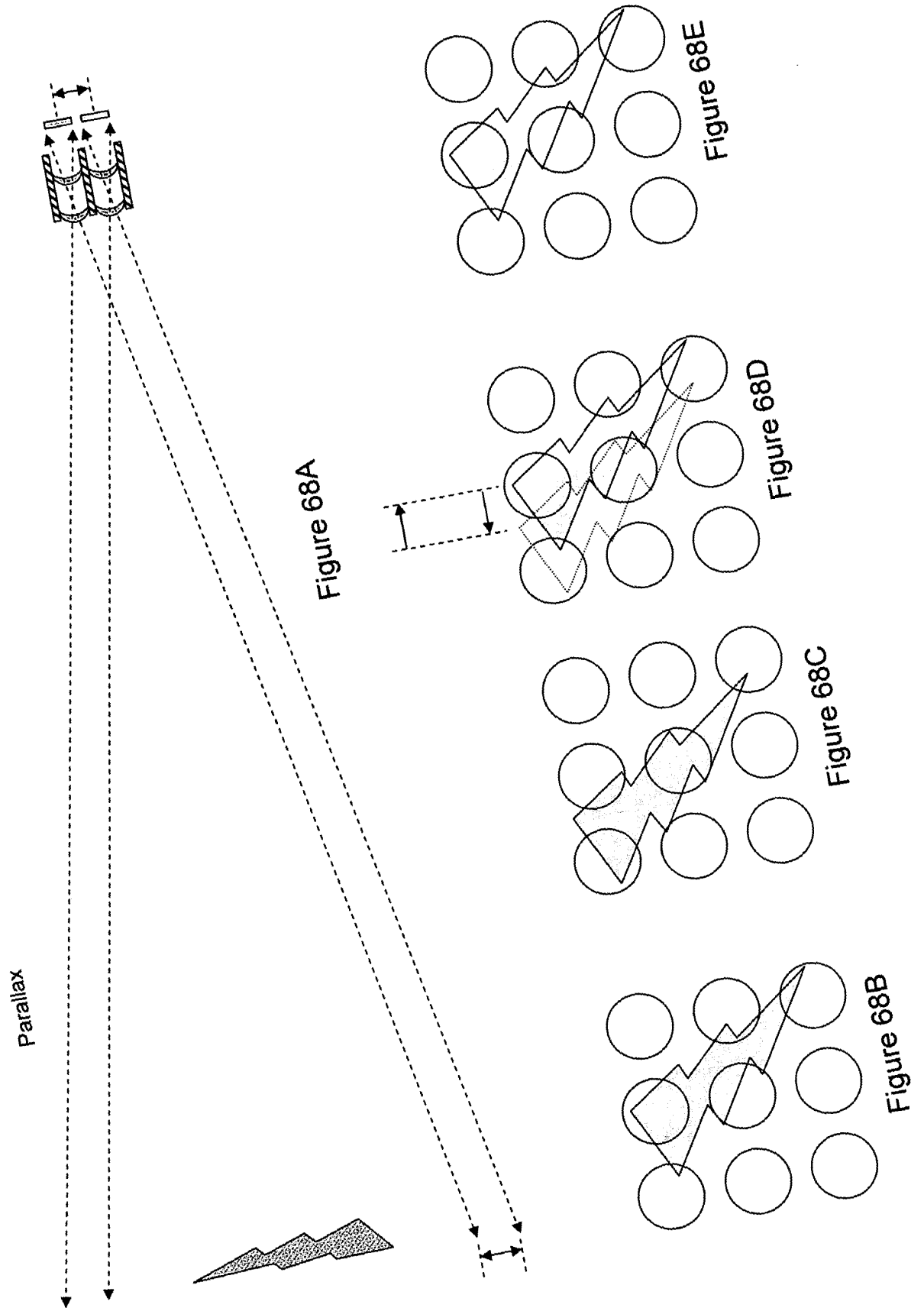


Figure 67C



Parallax

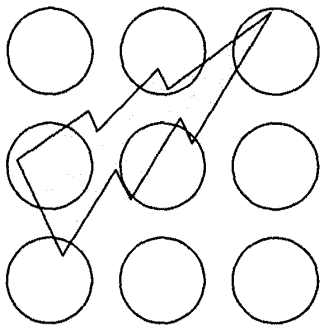


Figure 68F

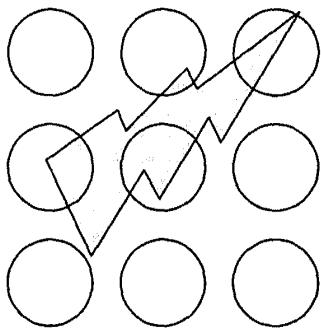


Figure 68G

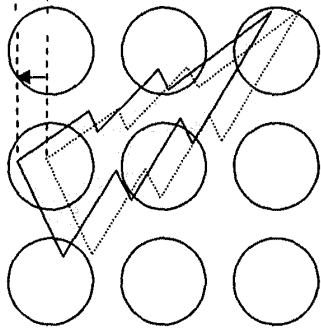


Figure 68H

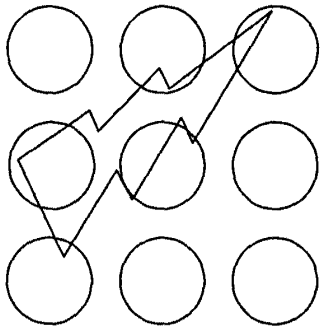


Figure 68I

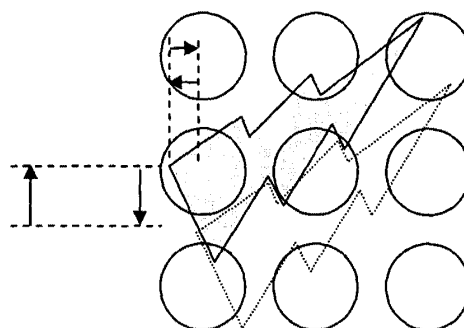


Figure 68L

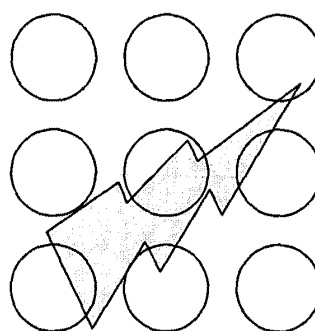


Figure 68K

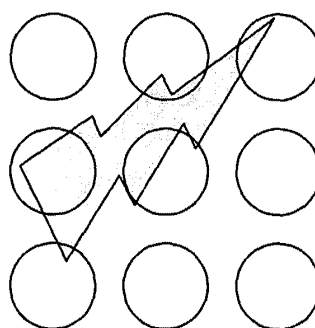


Figure 68J

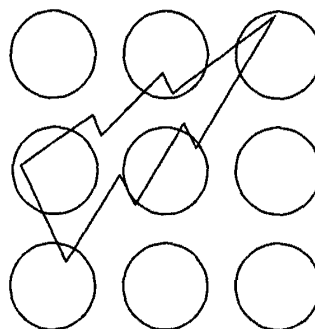


Figure 68M

0/267

Decreasing Parallax

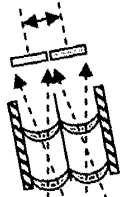


Figure 68N

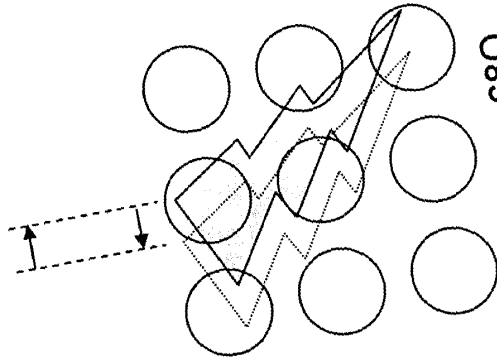


Figure 68Q

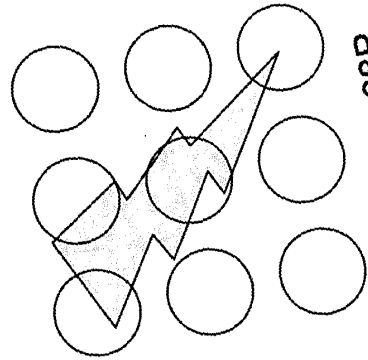


Figure 68P

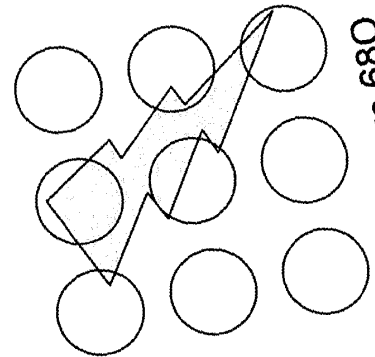


Figure 68O

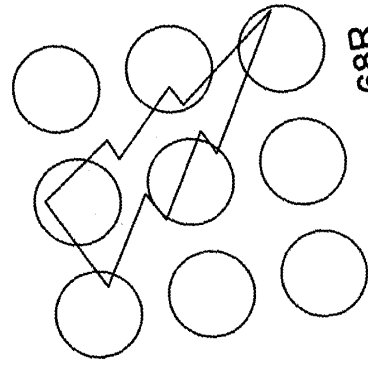


Figure 68R

Increasing Parallax

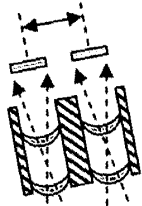


Figure 68S

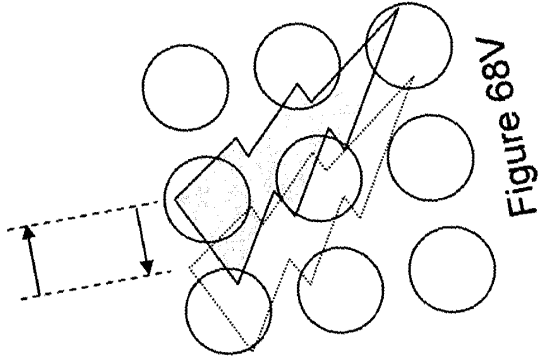


Figure 68V

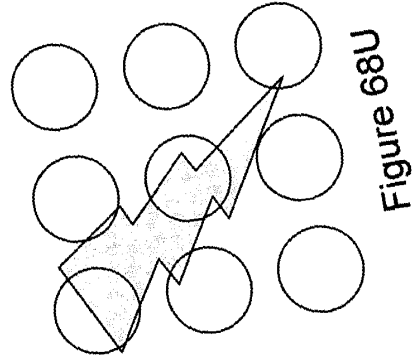


Figure 68U

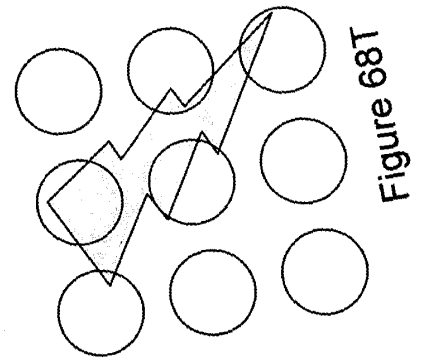


Figure 68T

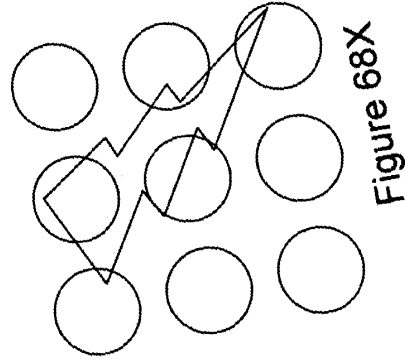


Figure 68X

Parallax

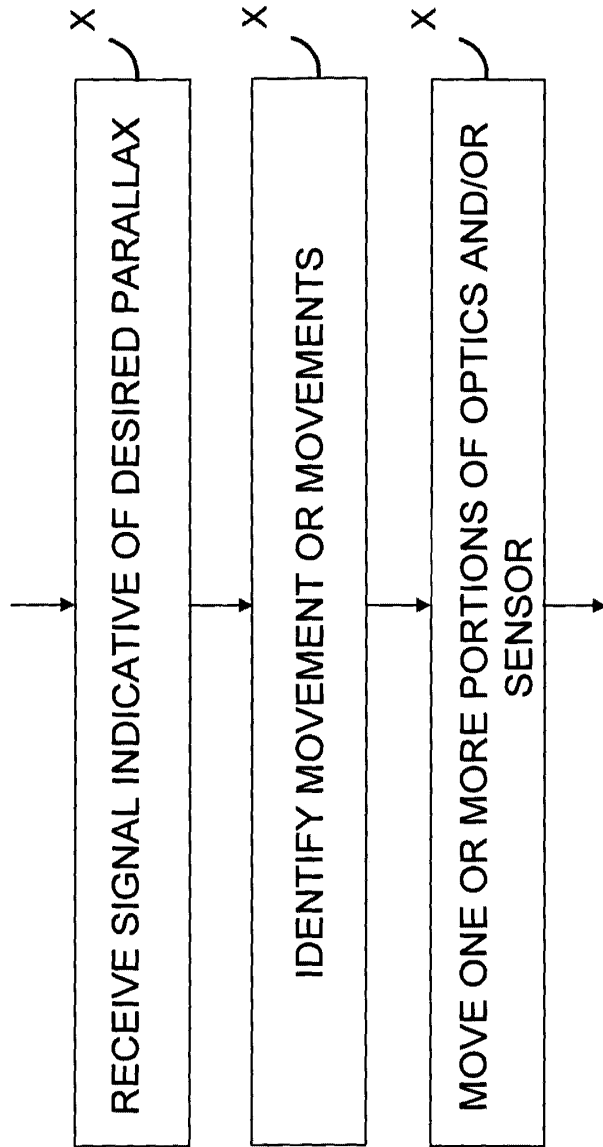


Figure 70

Parallax

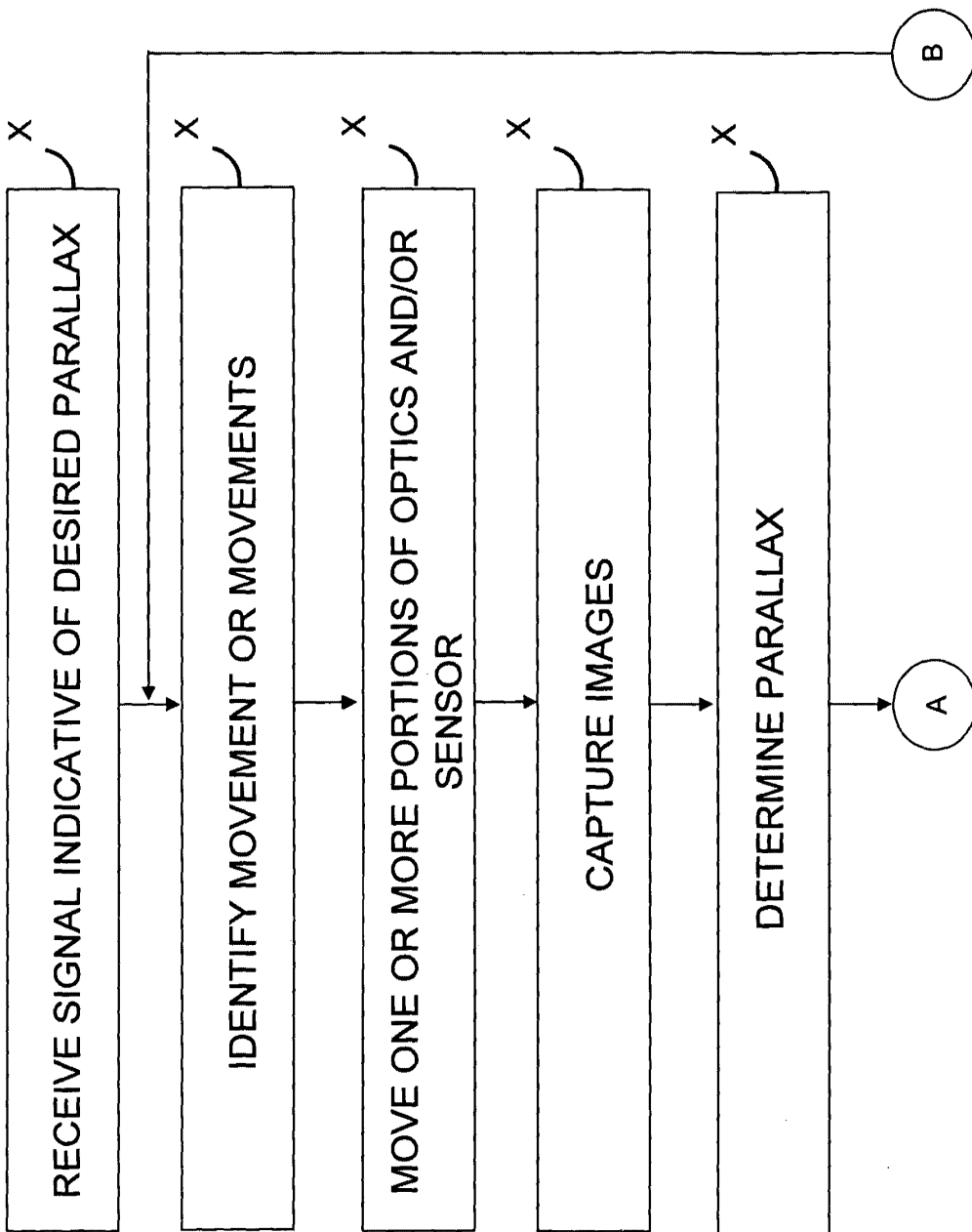


Figure 71A

Parallax

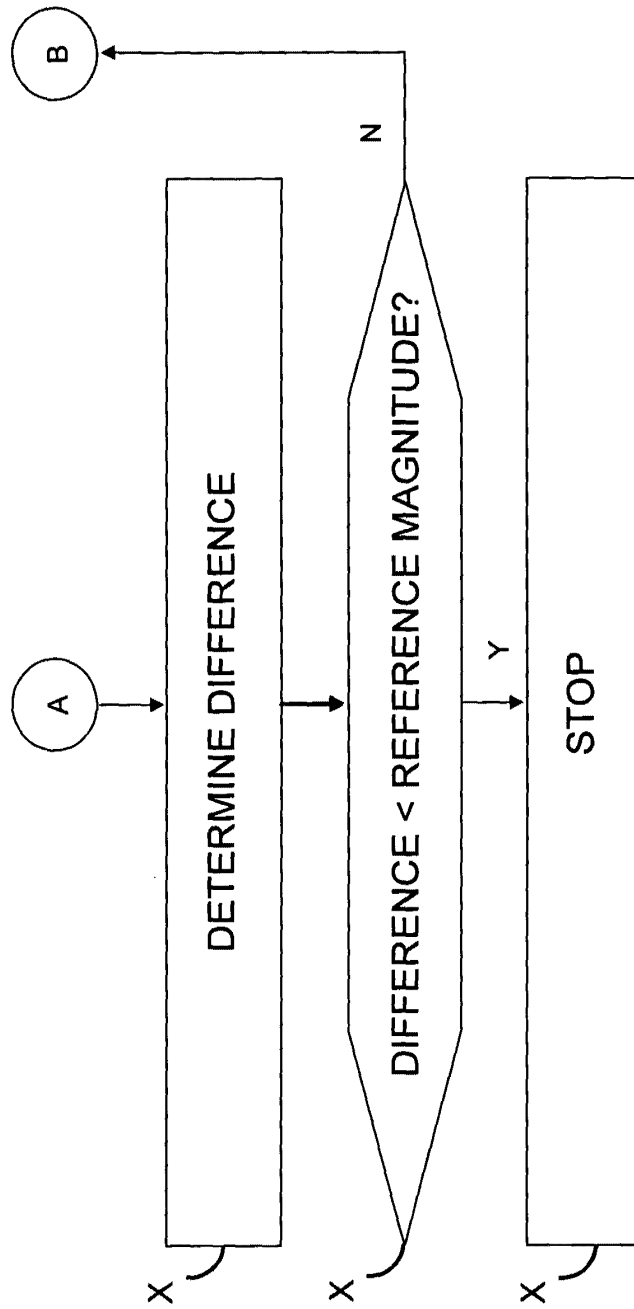


Figure 71B

Range Finding

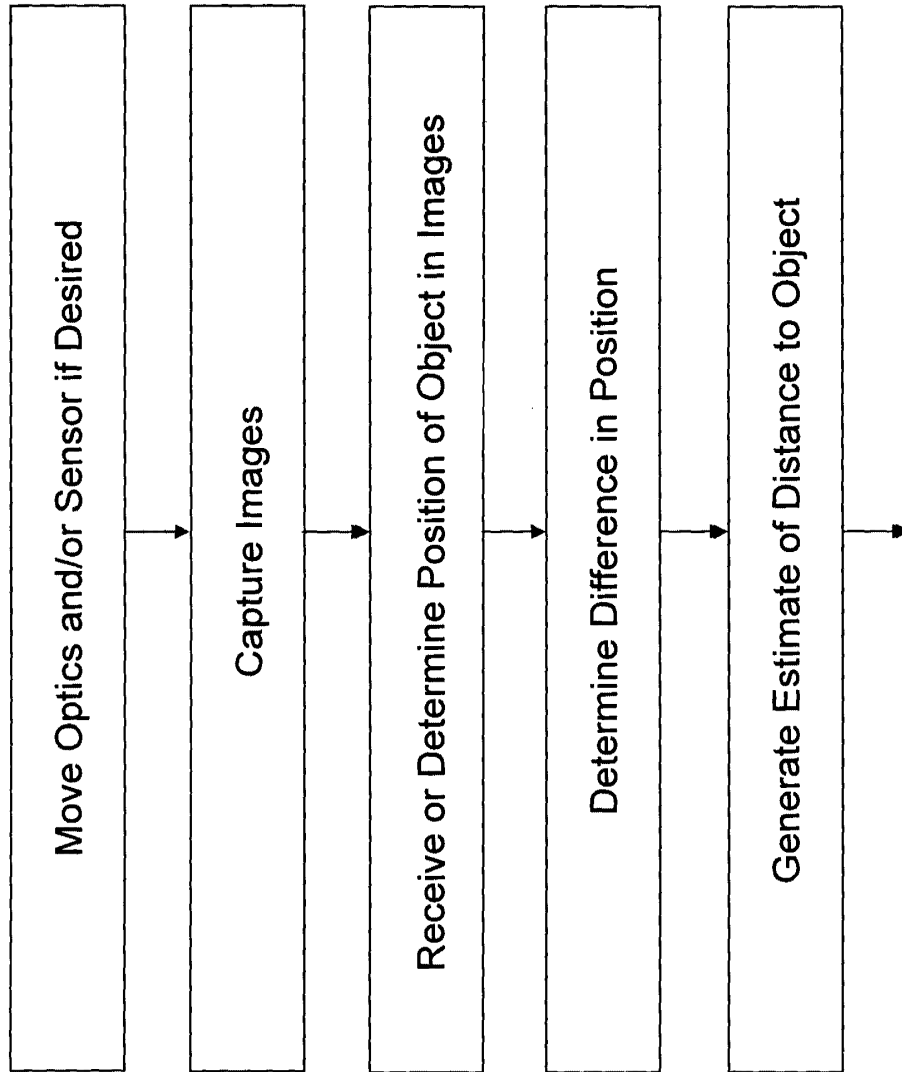


Figure 72

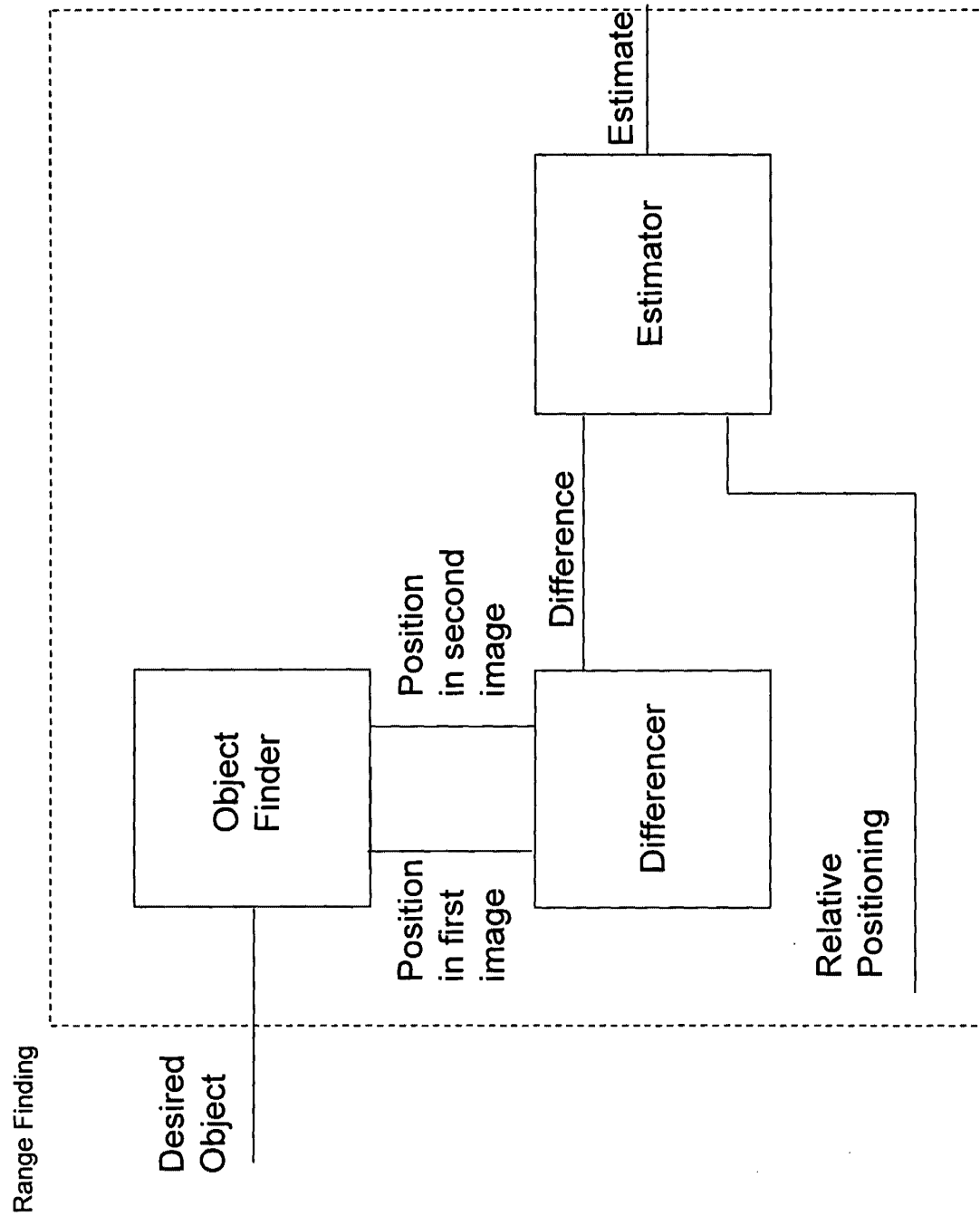


Figure 73

Range Finding

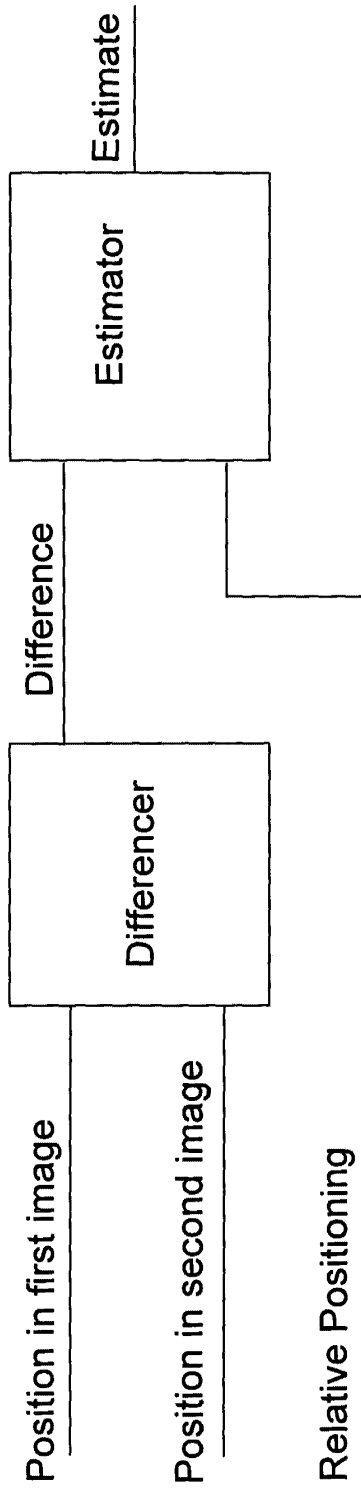


Figure 74

3D Imaging

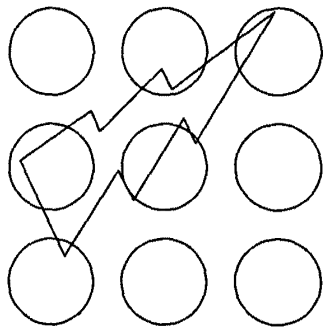


Figure 75A

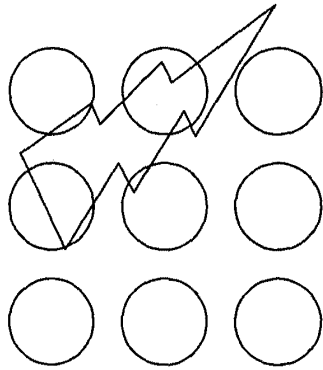


Figure 75B

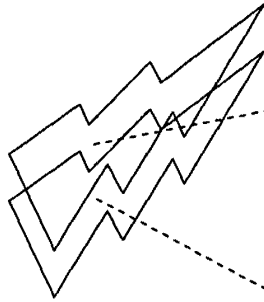
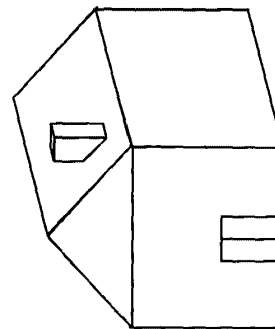


Figure 76

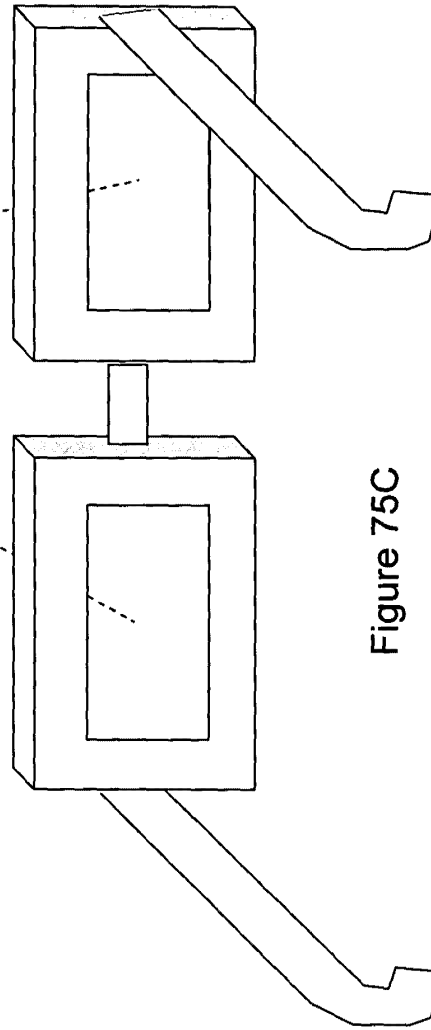


Figure 75C

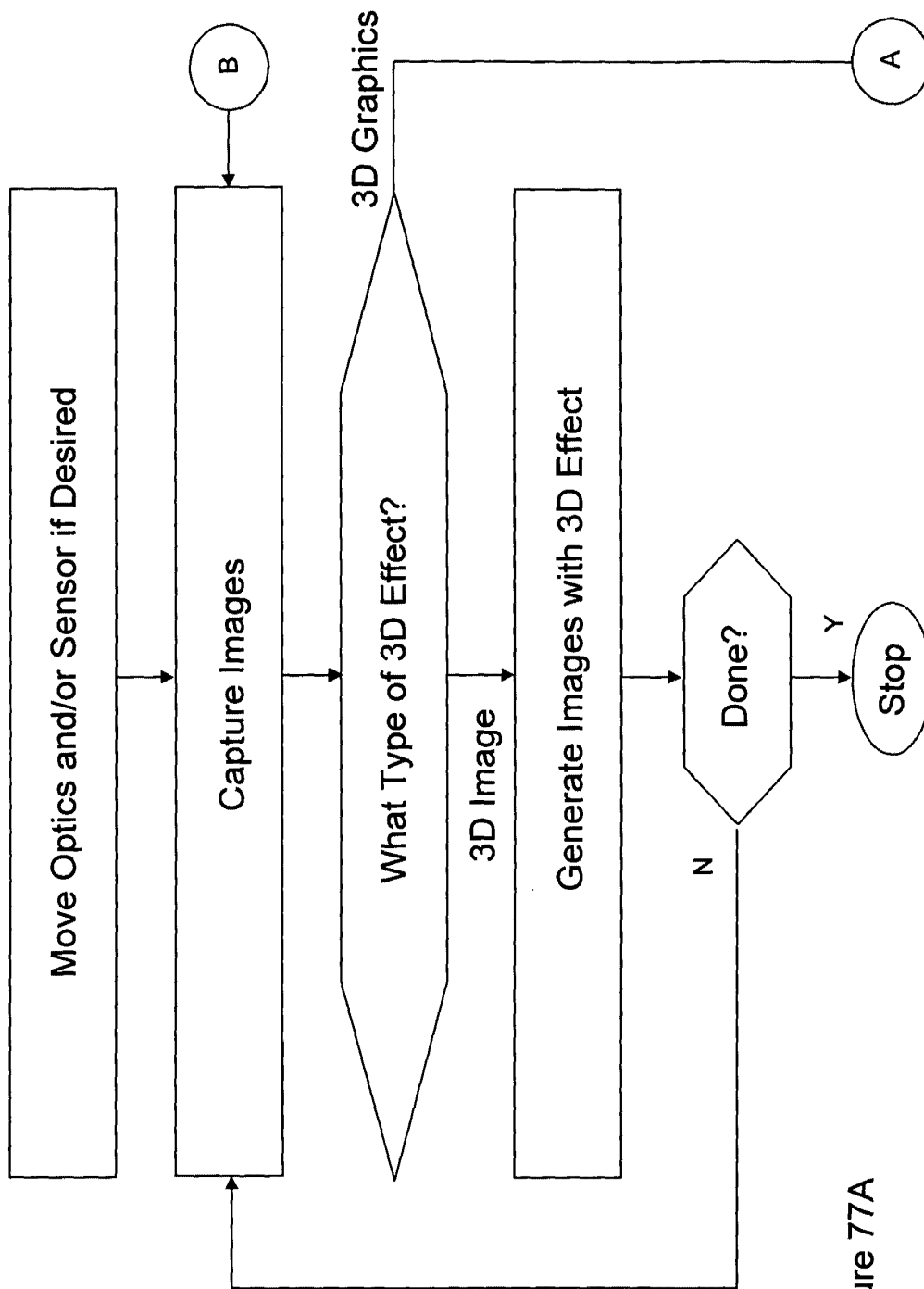


Figure 77A

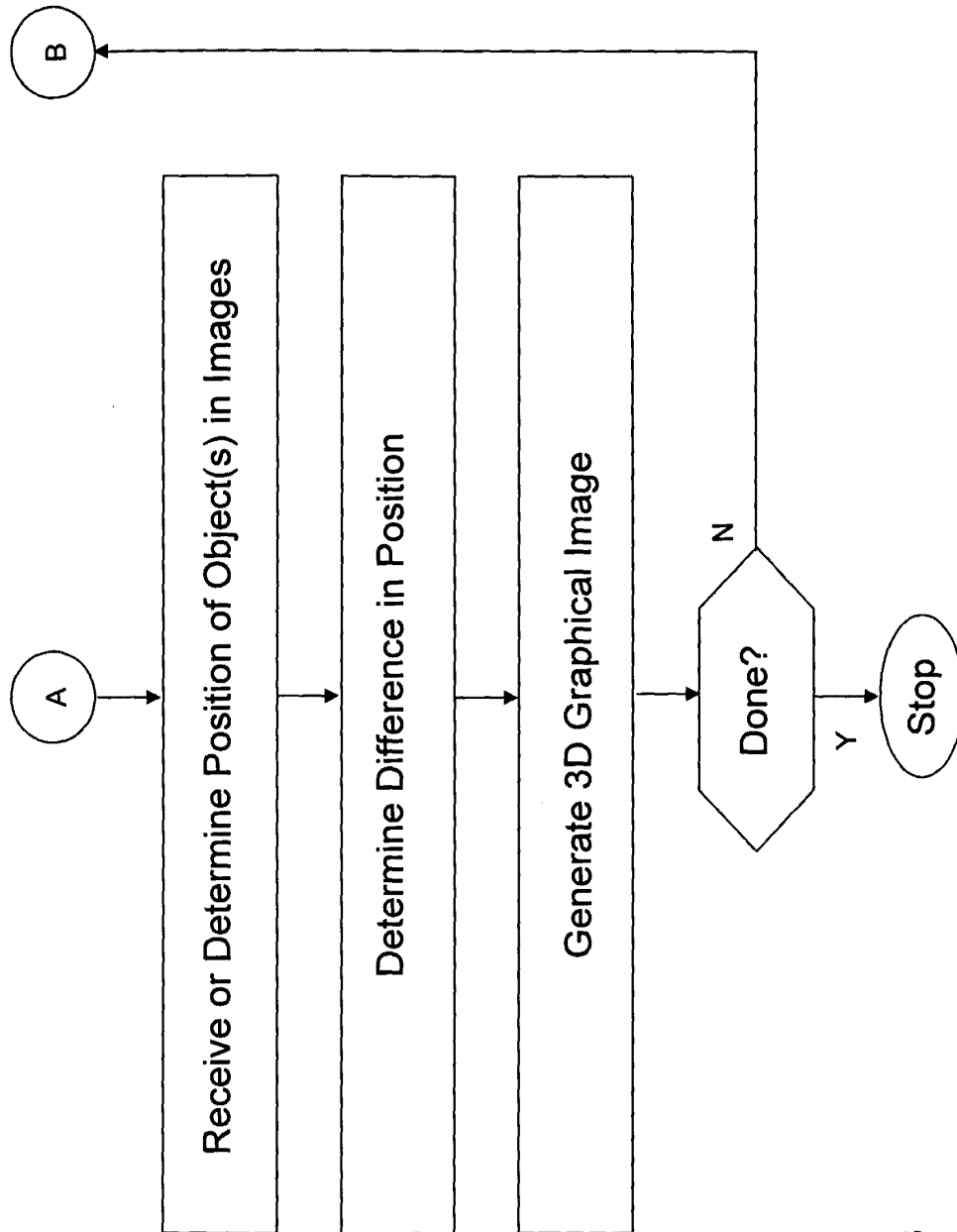


Figure 77B

3D Imaging

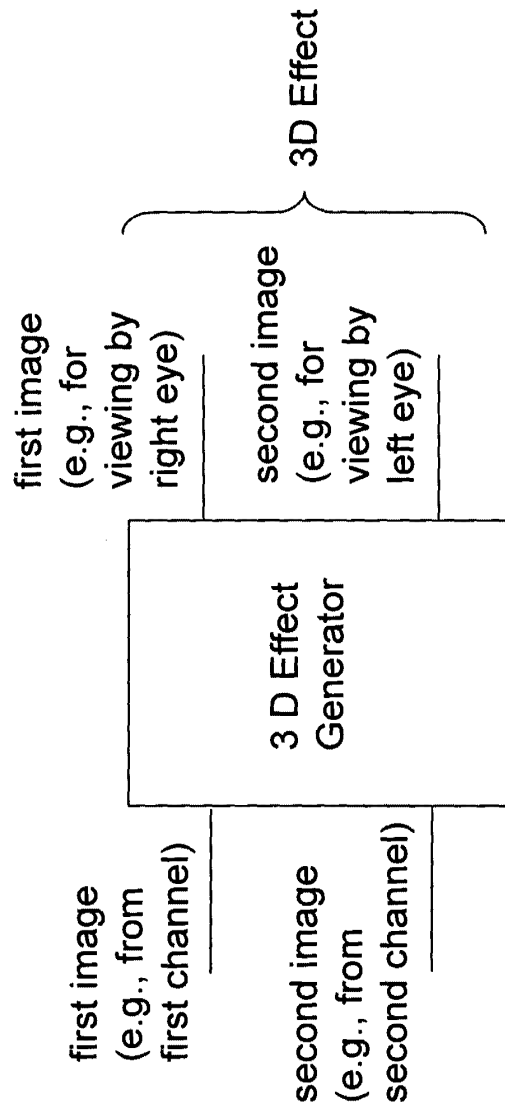


Figure 78

3D Imaging

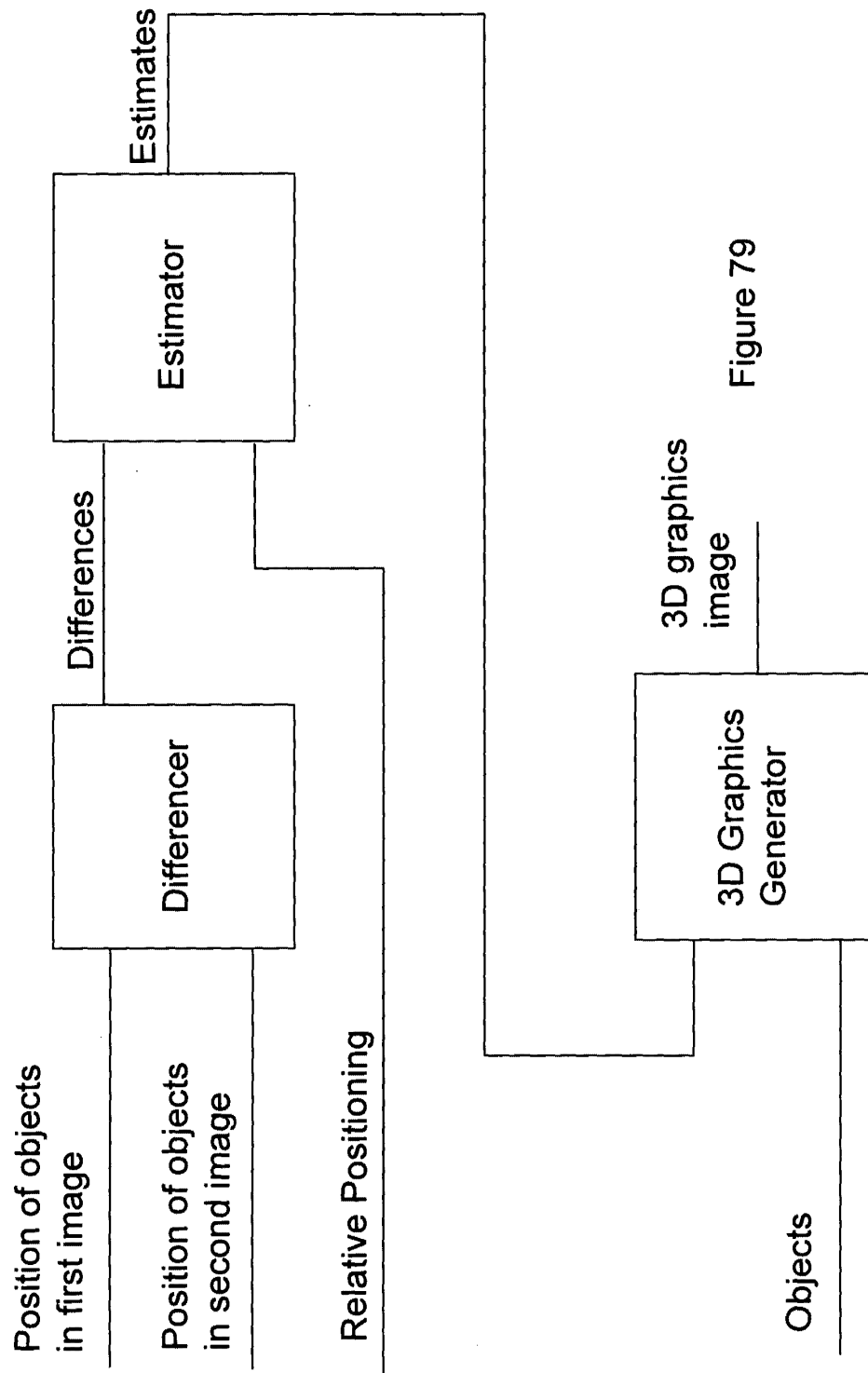


Figure 79

Image Discrimination

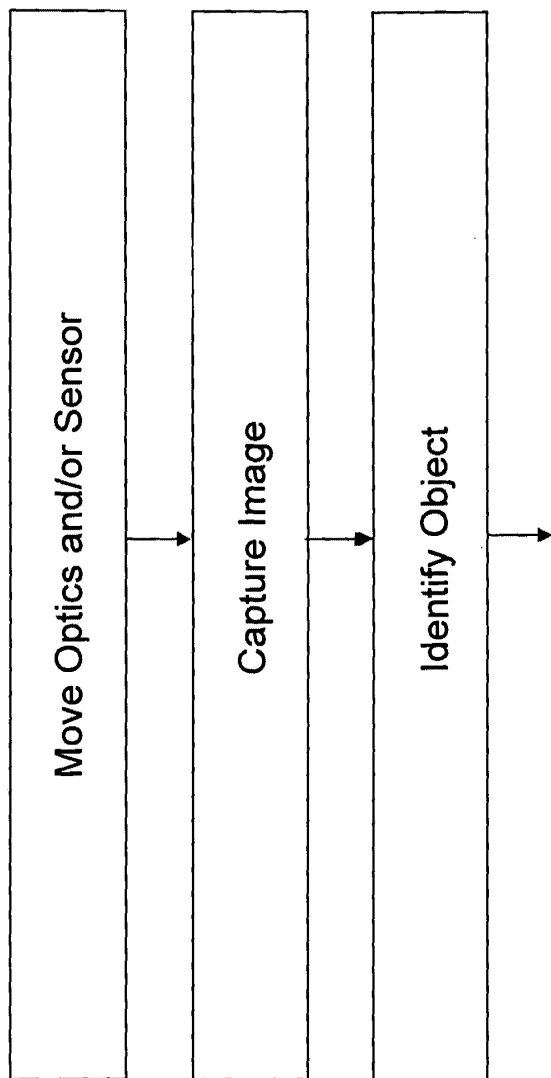


Figure 80

Image Discrimination 1 of 2

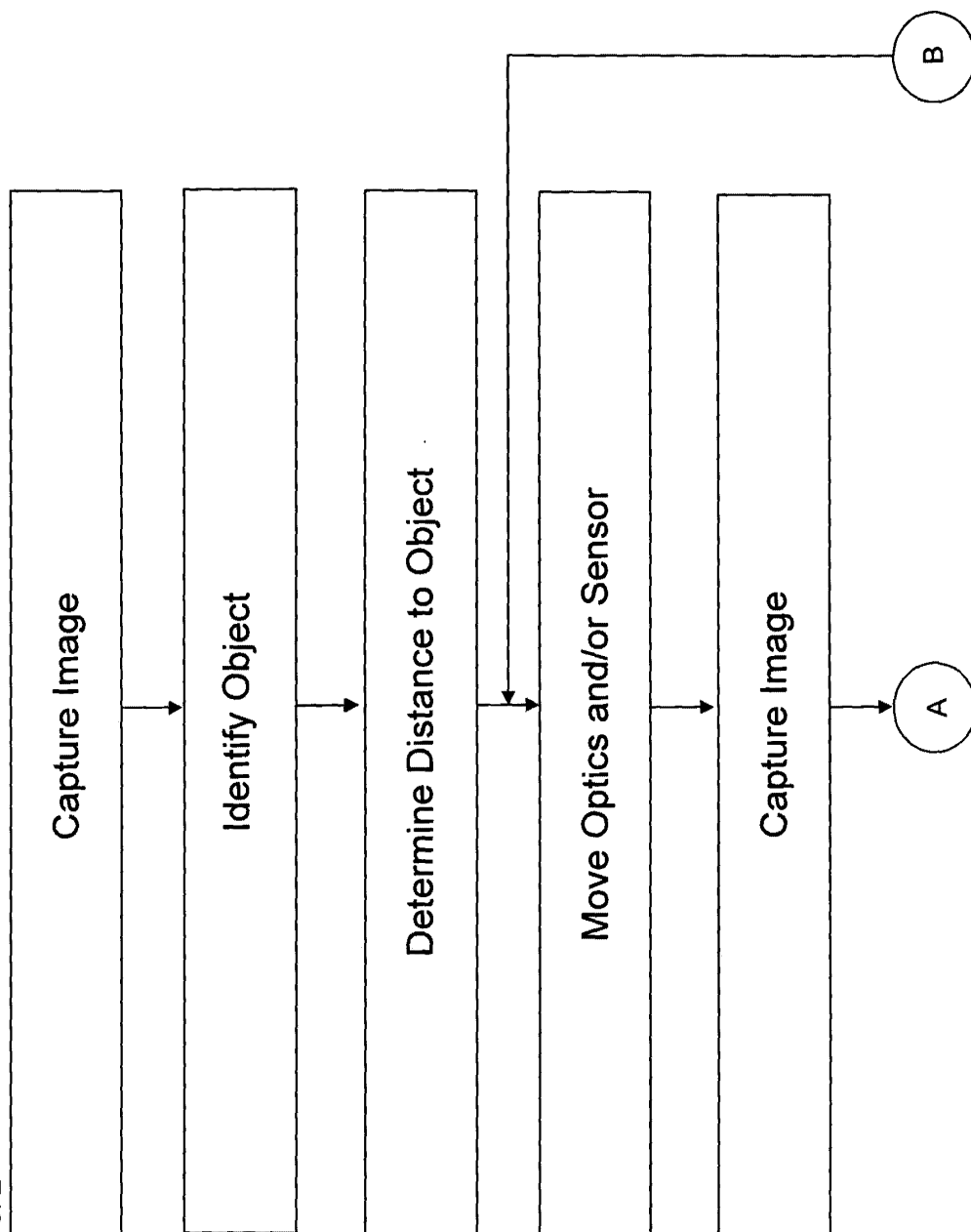


Figure 81A

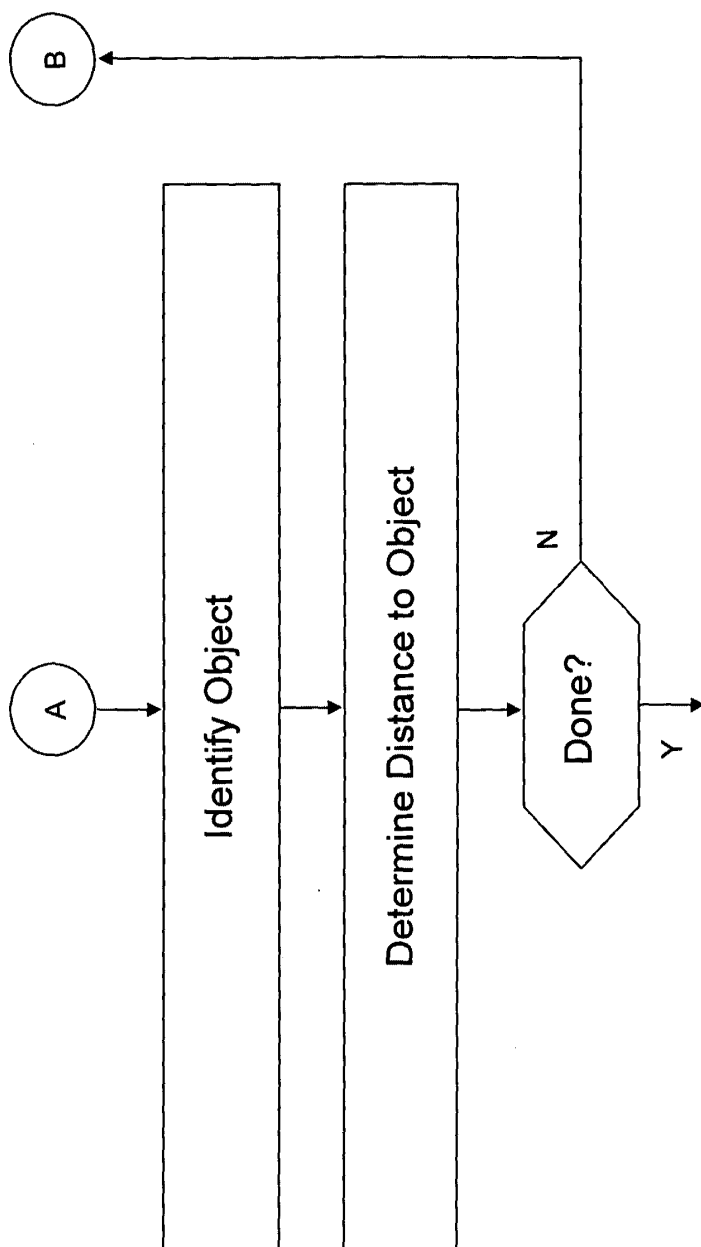


Figure 81B

Auto Focus

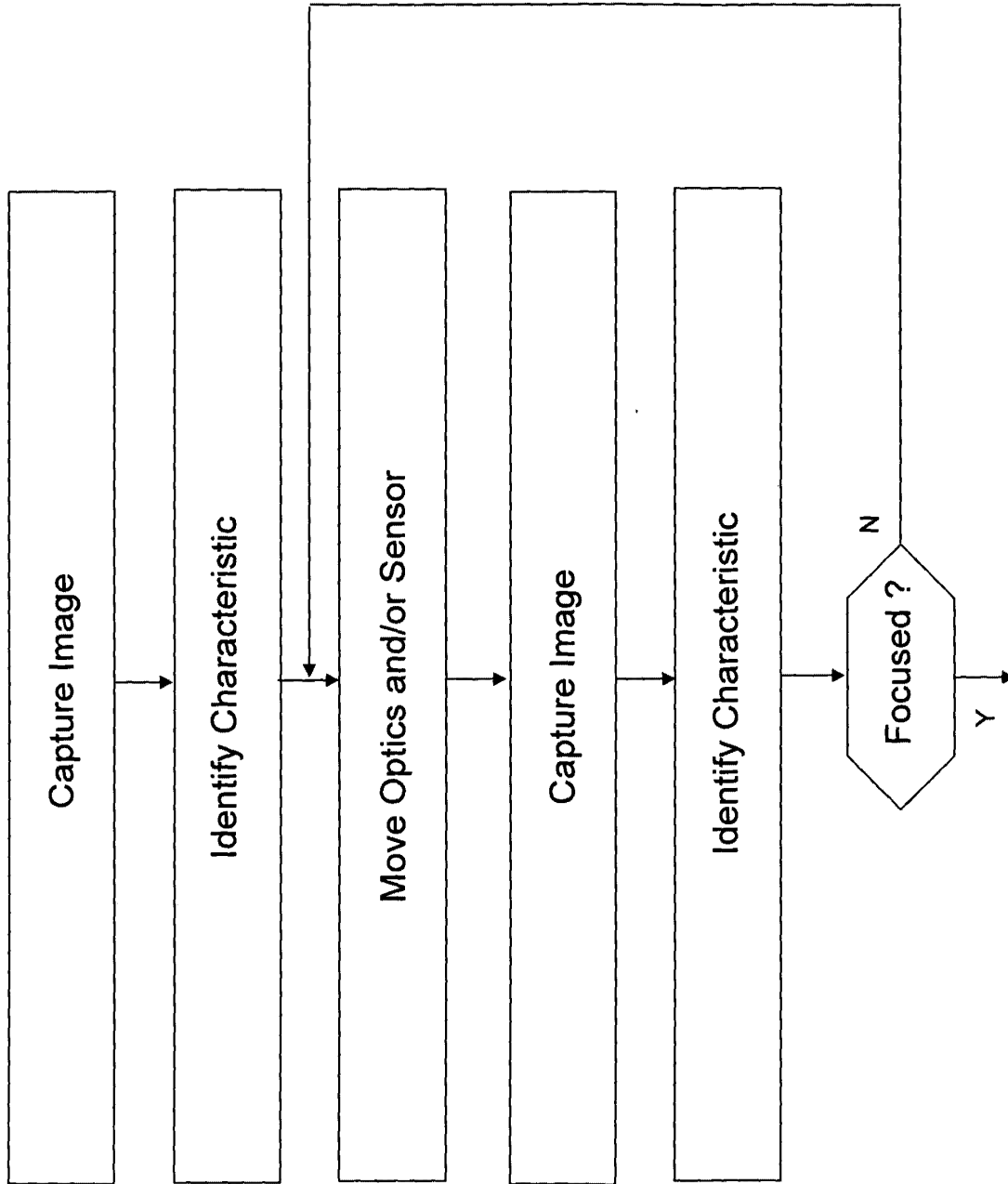


Figure 82

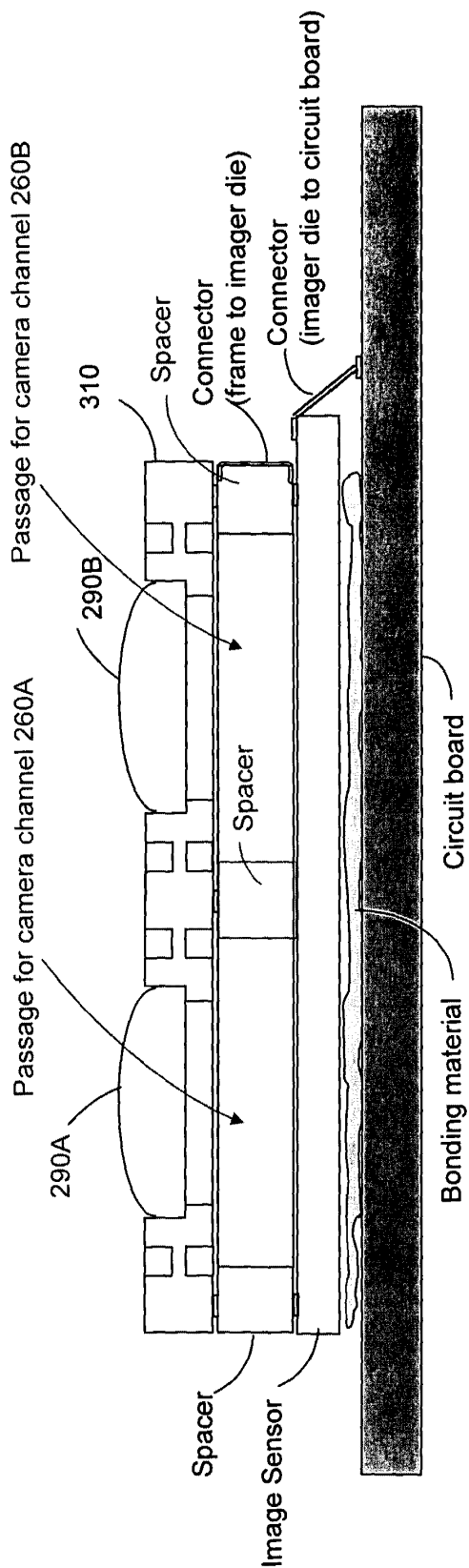


Figure 83A

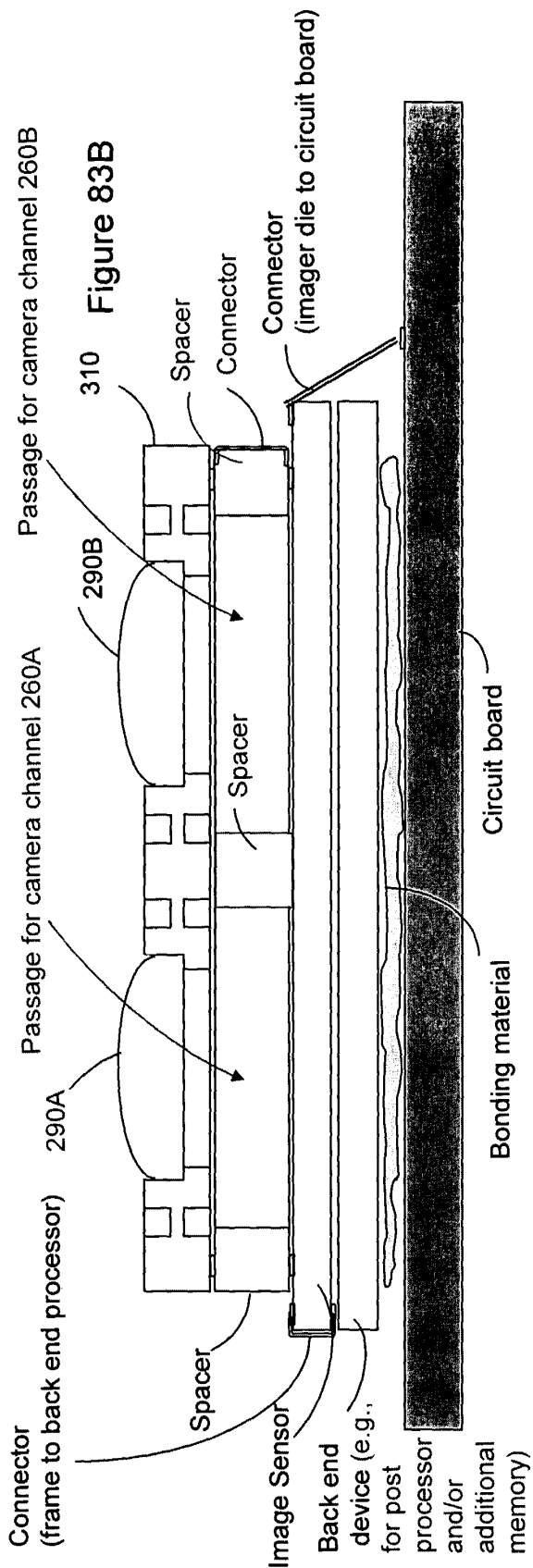


Figure 83B

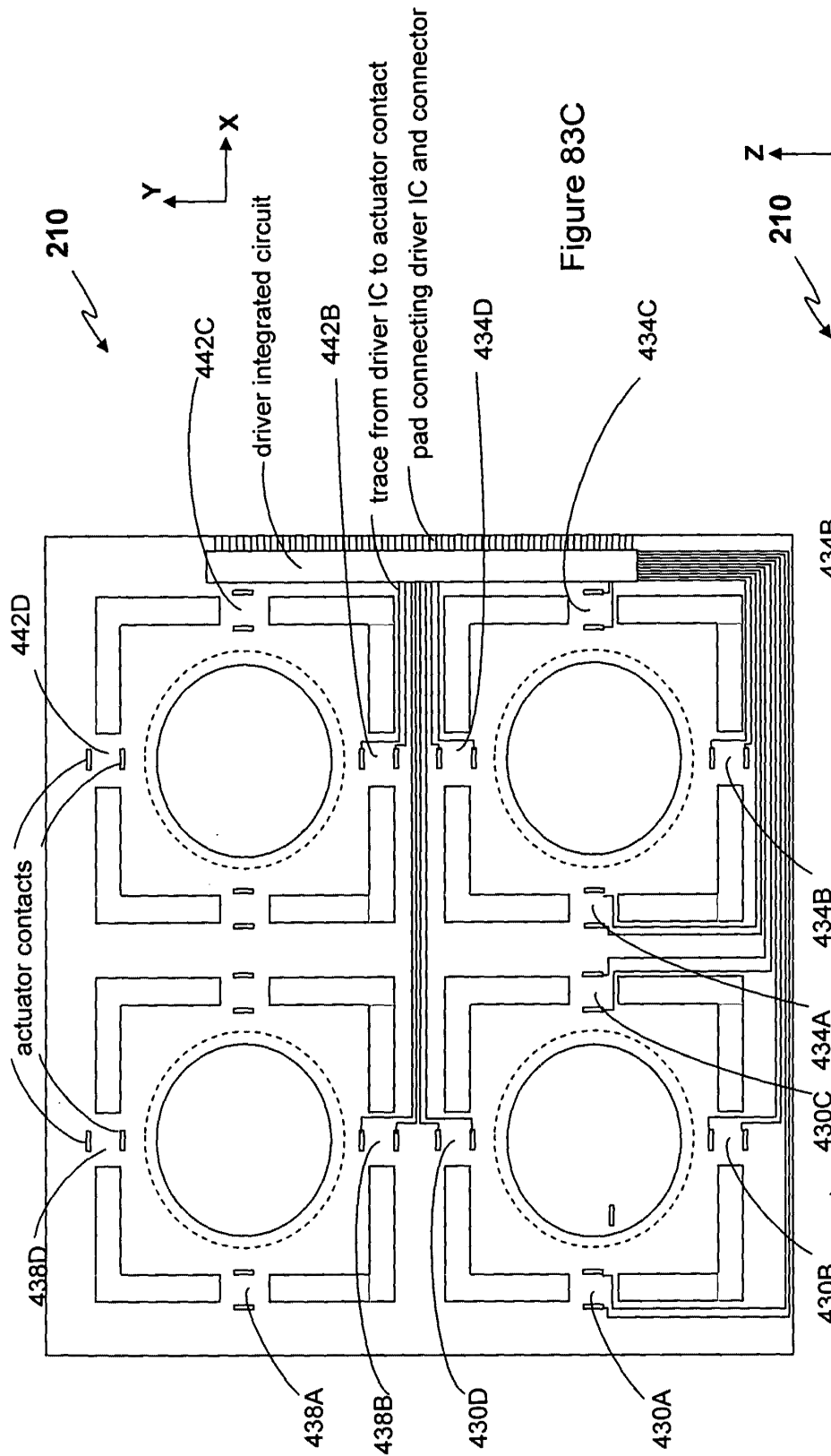


Figure 83C

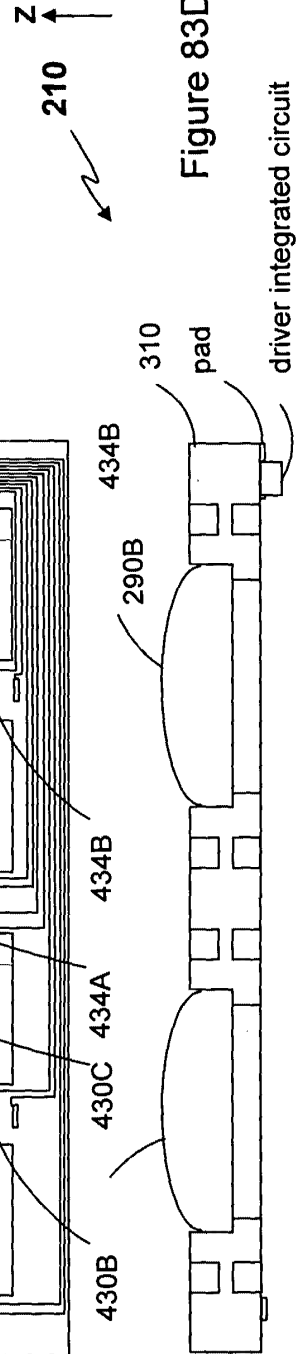


Figure 83D

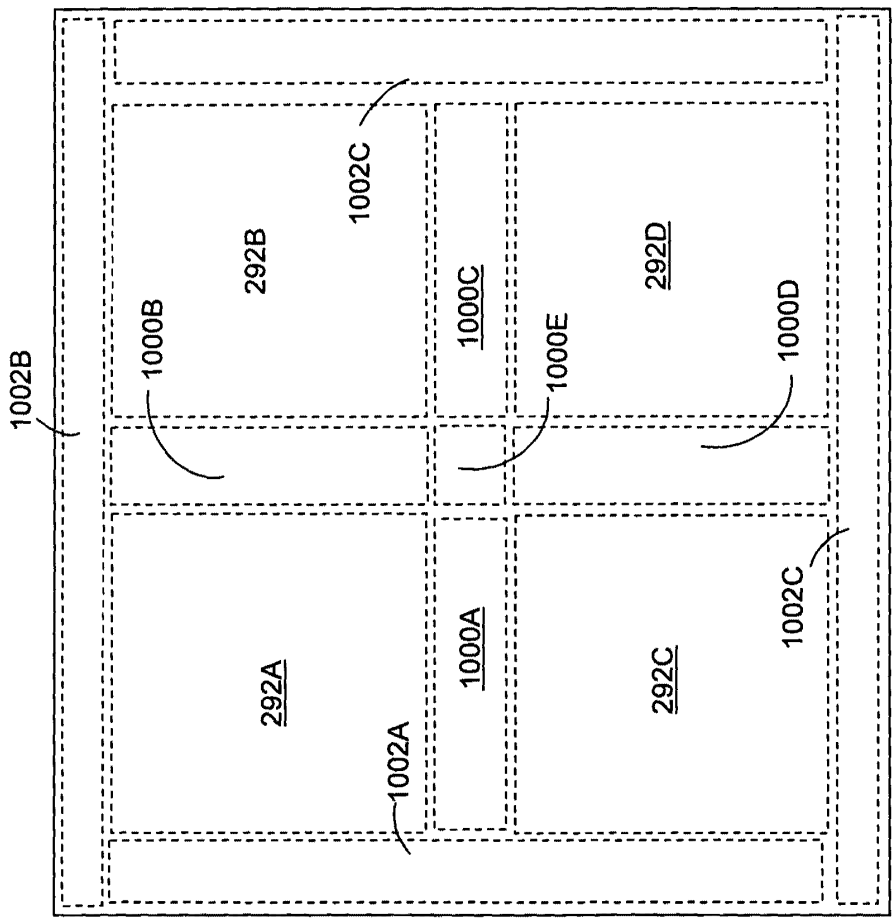


Figure 83E



Figure 83F

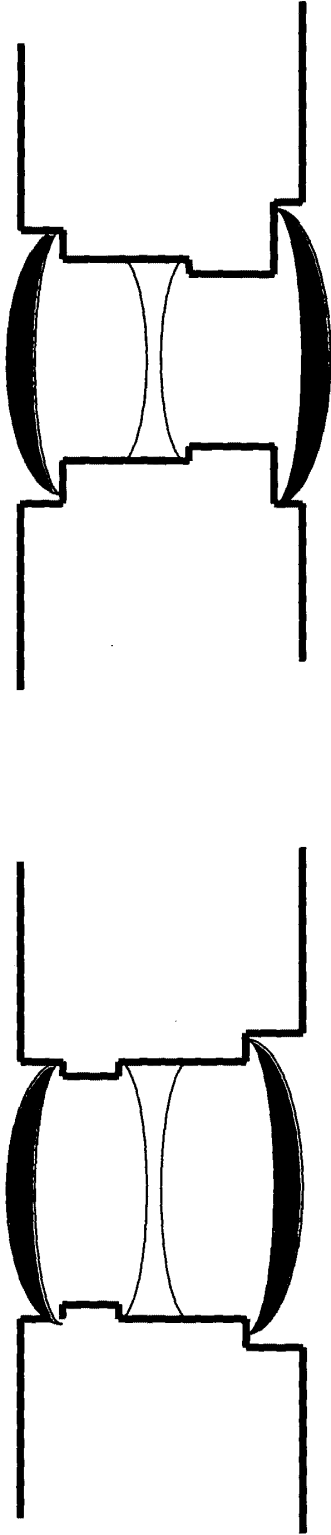


Figure 84A

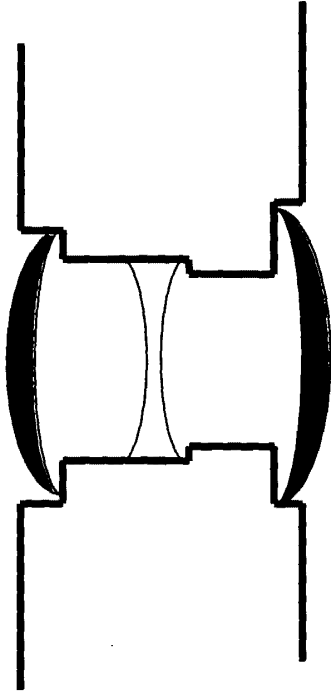


Figure 84B



Figure 84C

A couple examples of lens assy. In the left top case, the center lens is pushed in from the bottom. In the right top example the center lens is pushed in from the top. In the lower left case, if the lenses are built into one lens assembly (eg, one lens with 3 elements) the lens could be mounting from either direction employing only one stop. Method of attachment can be mechanical (press fit) chemical (glue) or electronic (bonding)

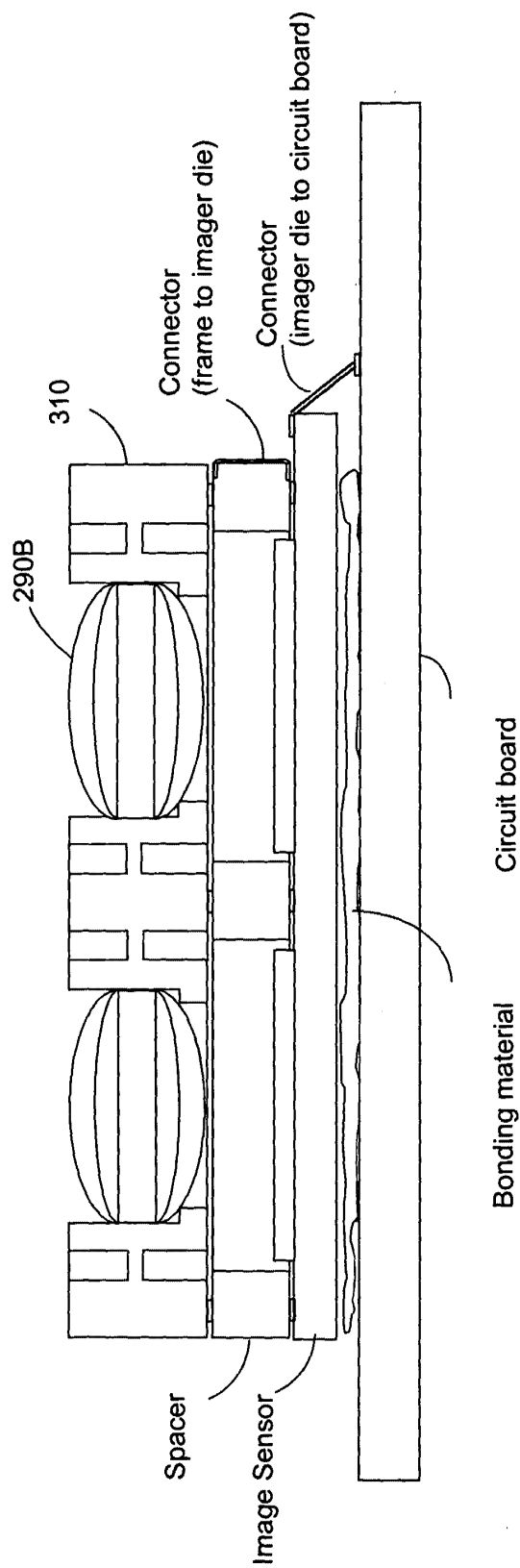


Figure 85A

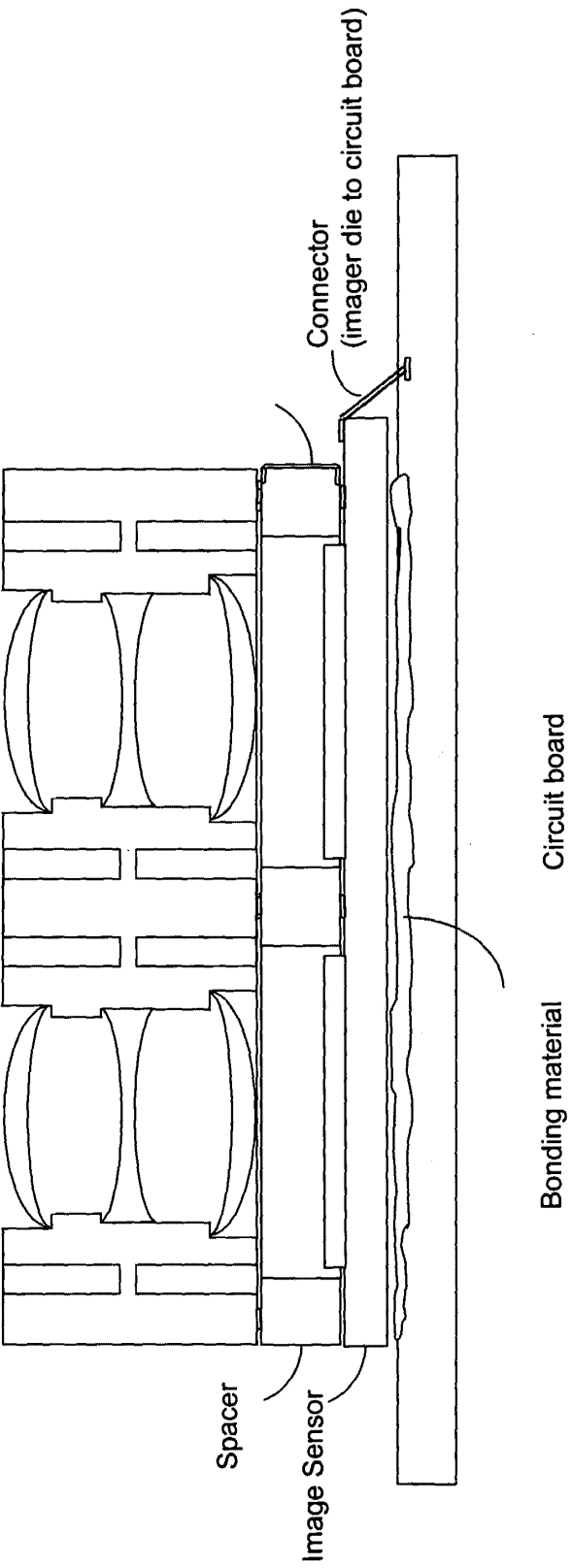


Figure 85B

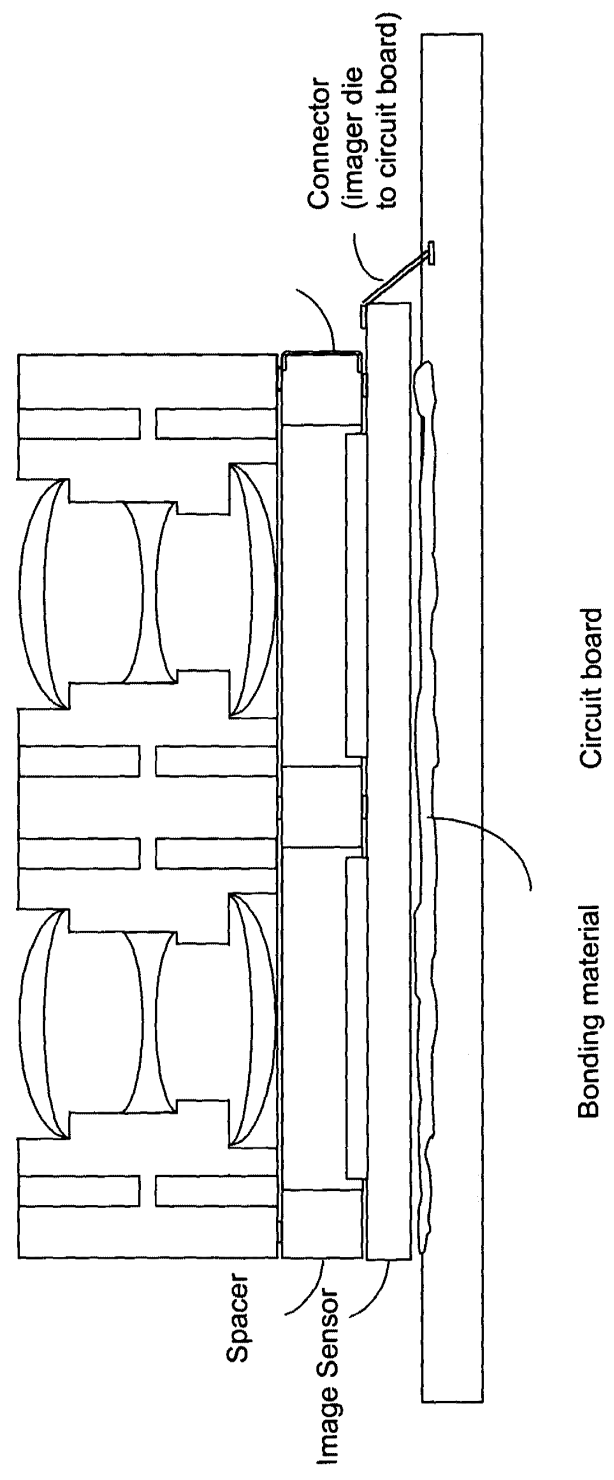


Figure 85C

Image Sensor & Post Processor Overview

Example shown: red, green, blue

3 individual arrays

Other colors, quantities, shapes & sizes optional

Image processing software located between individual arrays

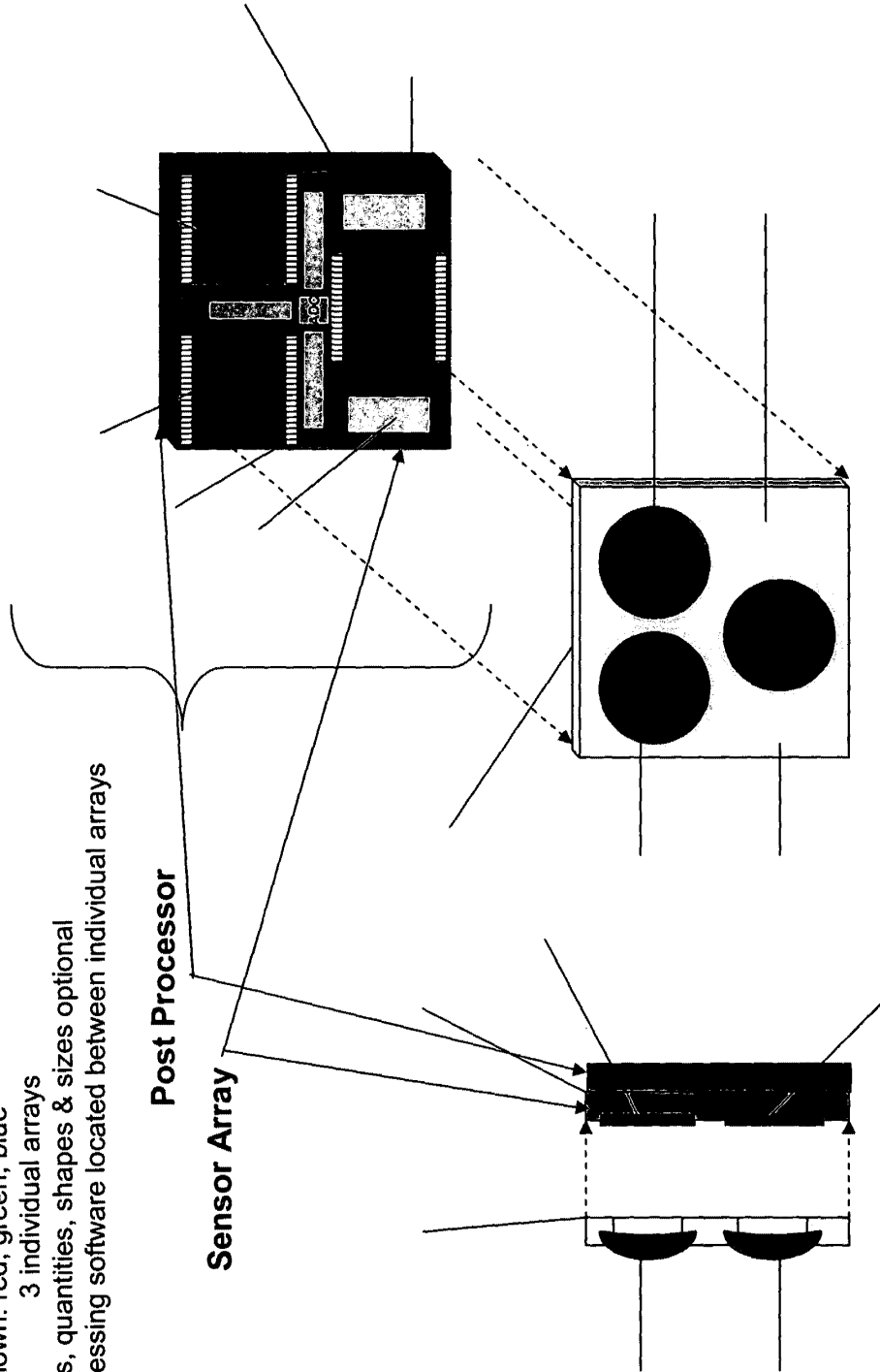
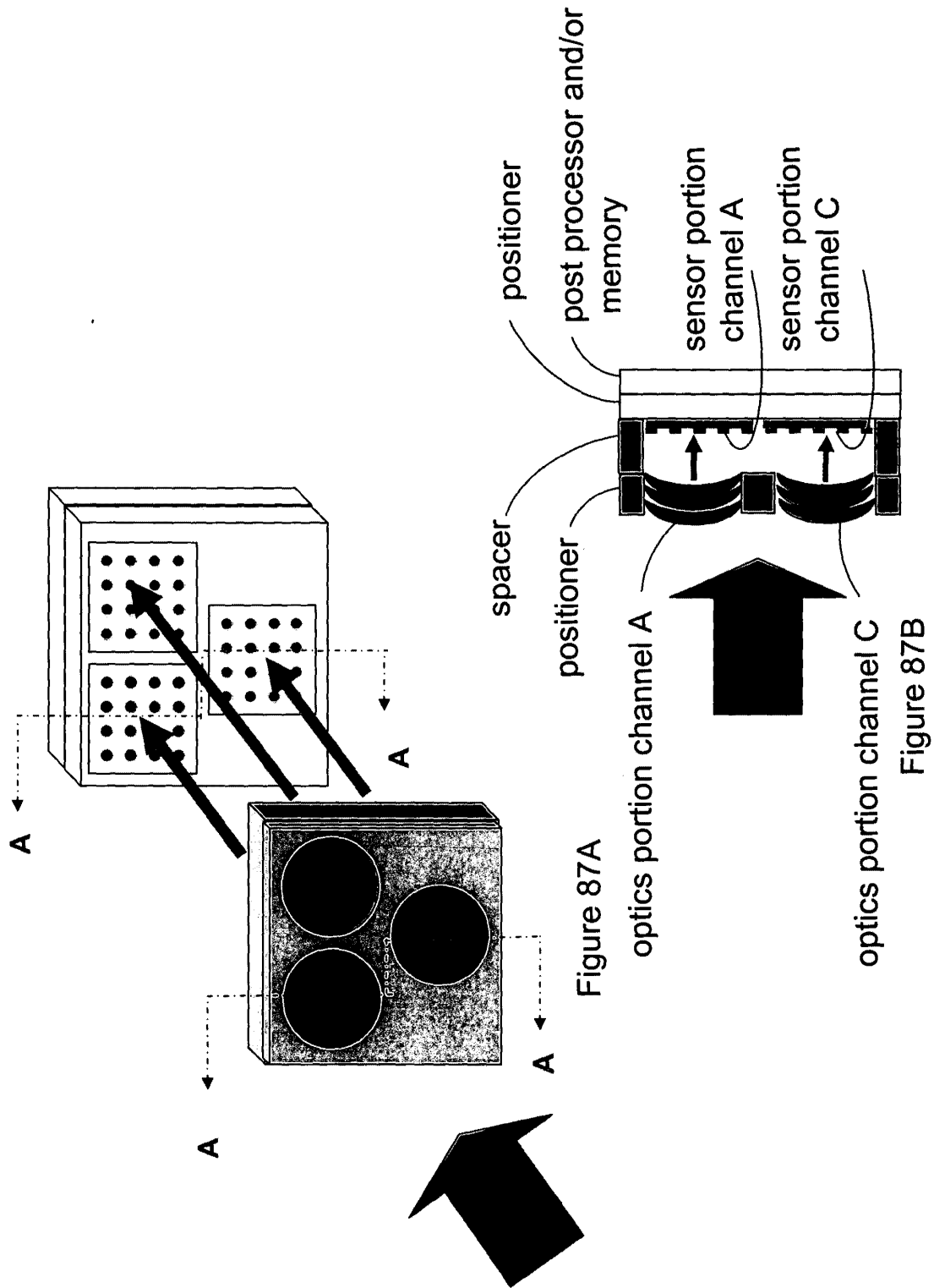


Figure 86B

Figure 86A



Solid State Camera Basic Components

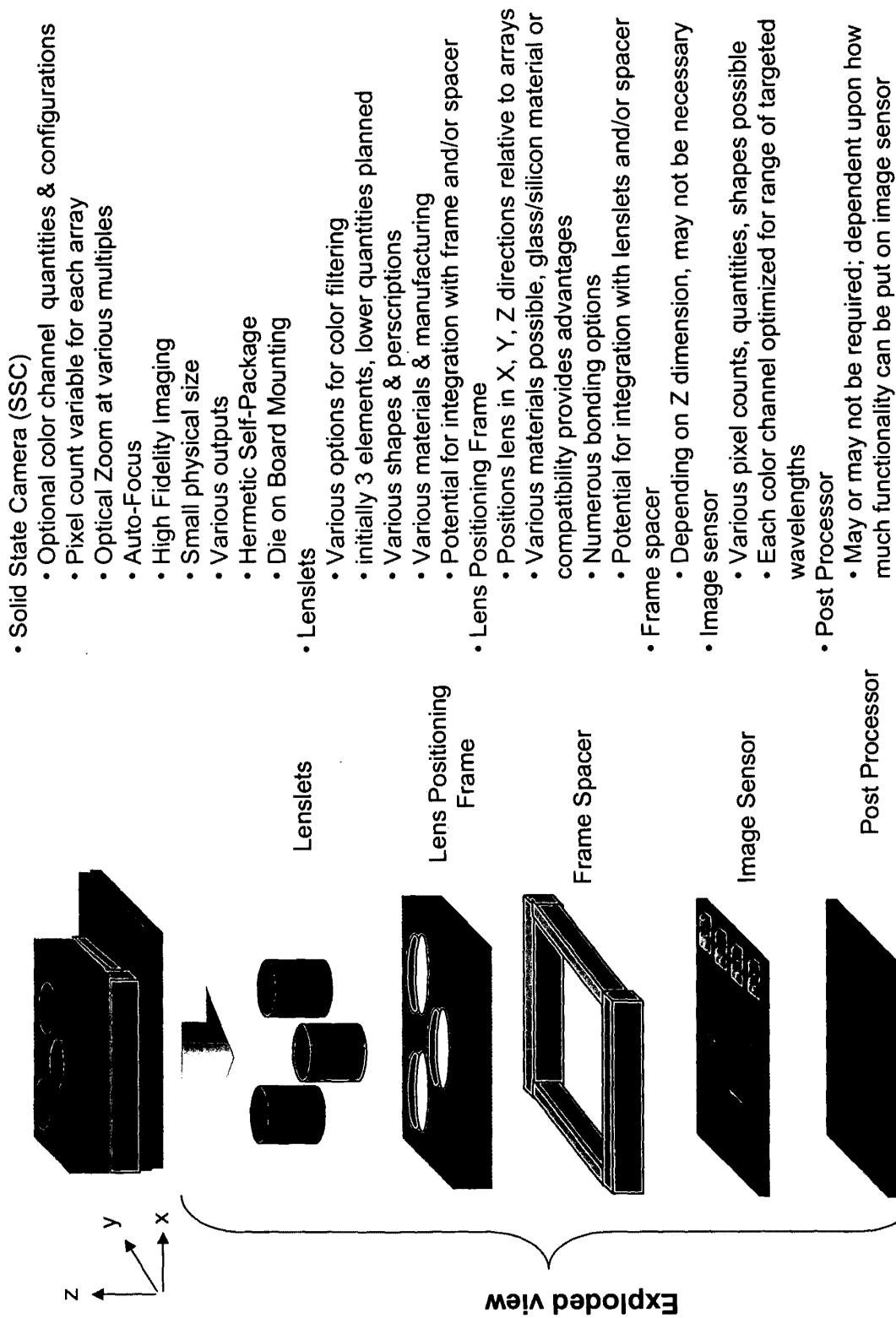
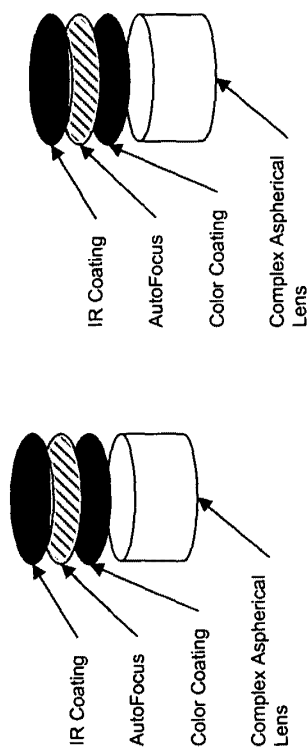


Figure 88

Lens configurations



Other embodiments for adapting a camera channel to a color (or band of colors) or a wavelength (or band of wavelengths)

- Coating on top of optics
- Dye in the lens
- Filter below lens
- Filter on array

A lens may have any number of elements or lenslets, e.g., 1, 2 or 3

Figure 89

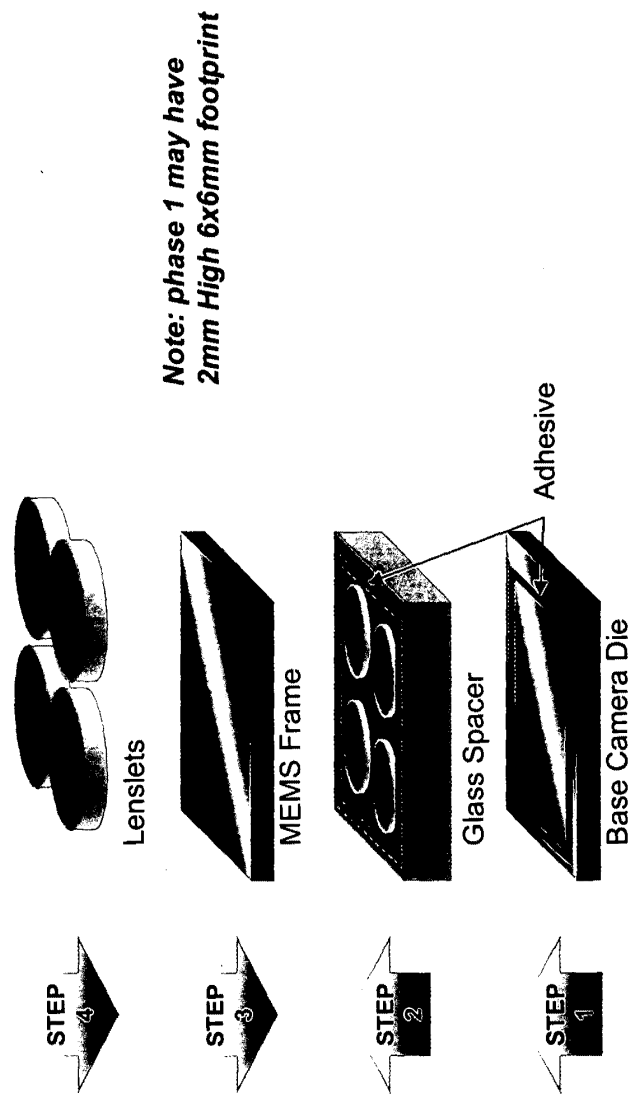


Figure 90

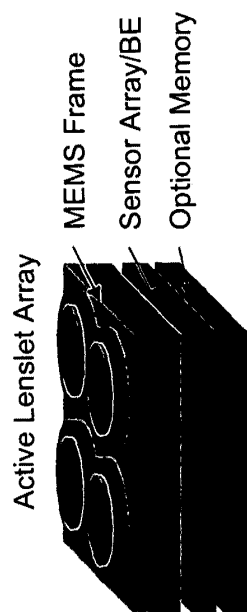


Figure 91

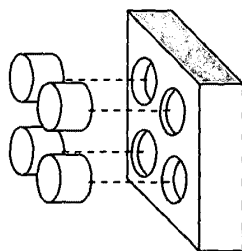


Figure 92A

- Examples of methods for affixing optics to frame
 - Mechanical
 - press fit
 - physical stops
 - Chemical
 - glue
 - Electronic
 - Other
 - Lenslets and frame manufactured as one mold
 - Lens “tabs” (from mfr process) used to create frame

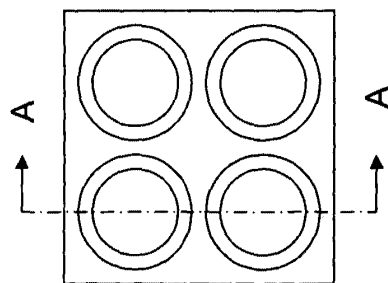


Figure 92B

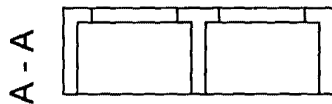
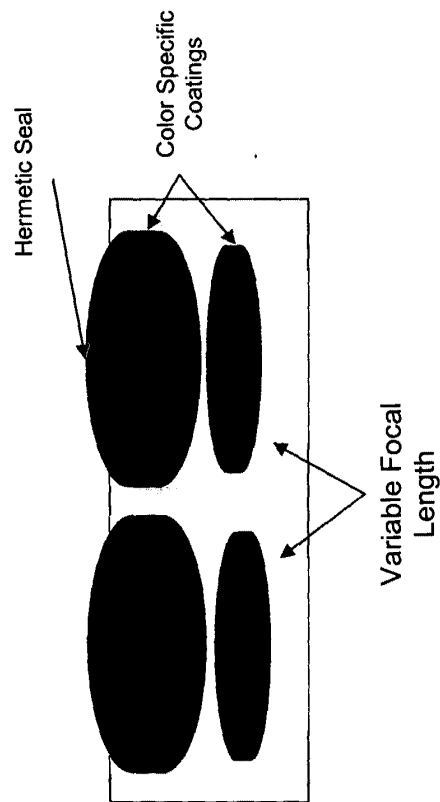


Figure 92C



Figure 92D

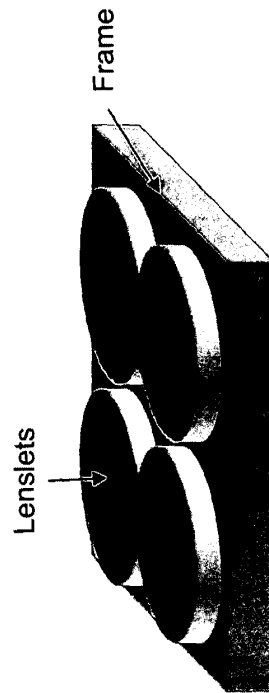


Assembly:

- Passive DL Structure is Wafer Attached
- Lenslets are Press fit: no adhesive out-gassing
- Stops built into MEMS Frame ensure alignment
- Lenslets are color and IR coated
- Multiple Lens combinations can be realized
- Wafer to Wafer alignment done via IR alignment marks
- Tolerances to 1.0um
- High Volume manufacturing process

Figure 93

Passive Frame



Potential Advantages:

- Eliminates Color Filters and uLens
- Eliminates Conventional Lens System
- Eliminates Package
- Eliminates multiple test operations
- Hermetic without the package
- Eliminates Lens and Lens to sensor Alignment
- Reduces total camera Height to 2.5mm
- Total Device goes to 6x6x2.5mm for 1.3Meg Camera

Figure 94

Other Embodiments

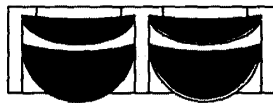


Figure 95A



Figure 95B

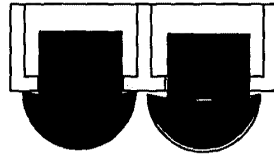


Figure 95C

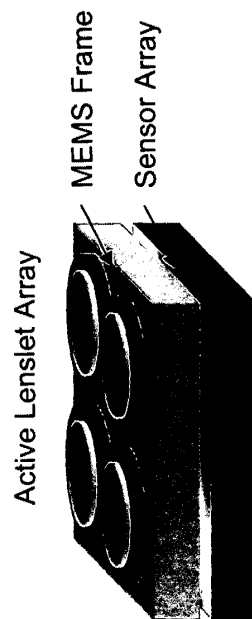


Figure 96

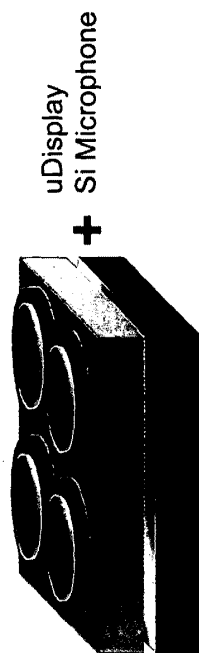


Figure 97

Bare Die:

- Chip on board and Chip in board
- Die bonding
- NO package cost
- Single sided contacts
- **Back to back cameras**
- Hermetic Package
- Plastic/Glass Lens

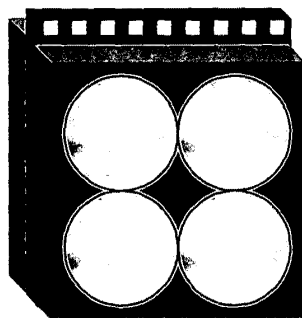


Figure 98



Molded Plastic:

- Lead frame supports Die/MEMS structure
- Lens Caps isolation during molding
- Single or dual sided frame
- Very Low Package cost
- PLCC, TQFP, DIP (Japan)

Figure 99

- Ceramic:**
- Cavity supports Die/MEMS structure
 - Harsh environment protection
 - Single or Dual sided frame
 - High Package Cost

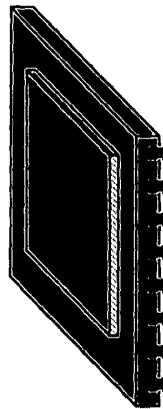
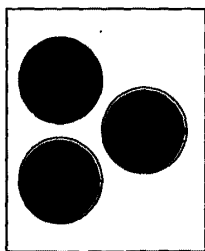


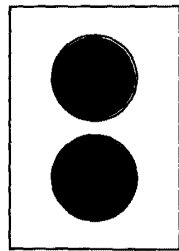
Figure 100

Solid State Camera Symmetric Configurations



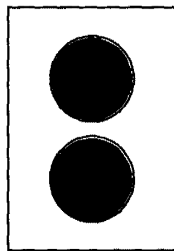
Three color channels; discrete or multiple colors
Example shown: Discrete red, green, blue
Other color options can be used

Figure 101A



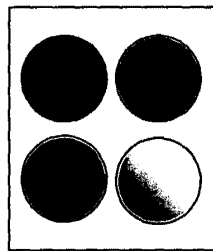
Two color channels
Example shown: Discrete red & green
Other color options can be used, including polarizing effect

Figure 101B



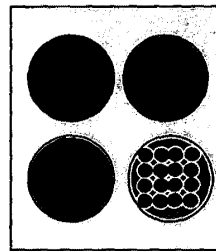
Two channels; one or both with multiple colors
Example shown: red & blue combined, discrete green
Other color options can be used

Figure 101C



Four color channels; discrete or multiple colors
Example shown: Discrete red, green, blue & infrared (for low light sensitivity)
Other color options can be used, including complementary colors (CYMK (K = clear))

Figure 101D



Four color channels; discrete or multiple colors, and /or full spectrum array (for image processing and close-up images)
Example shown: Discrete red, green, blue & "Bayer" pattern array
Other color options can be used

Figure 101E

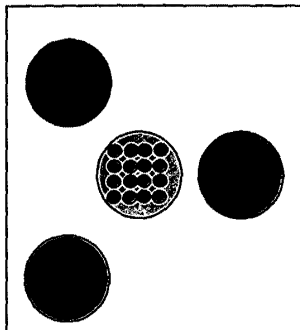
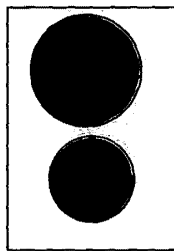


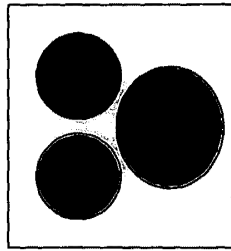
Figure 101F

Solid State Camera Asymmetric Configurations



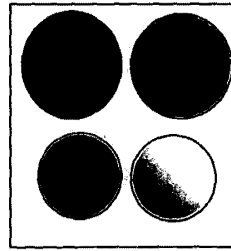
Mixed Topology camera
Example shown: red/blue vertical camera, extended resolution green narrow band camera
Each color channel optimized for its purpose

Figure 102A



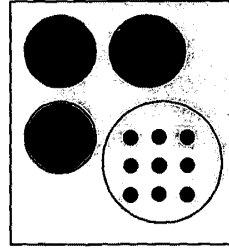
Mixed Resolution cameras: Two standard resolution narrow band cameras with one or more higher resolution narrow band cameras

Figure 102B



Mixed Architecture Cameras: Cameras with same resolution but optimized/custom spectrum specific Architectures. Different pixel sizes, architectures and readouts per band.

Figure 102C



Mixed Mode Cameras: Several narrow band cameras integrated with alternative resolution and mode of operation cameras. Narrow band with Bayer pattern wideband

Figure 102D

Other Embodiments

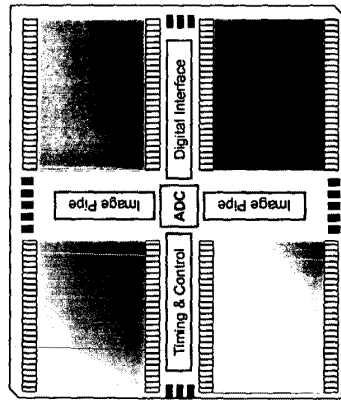


Figure 103A

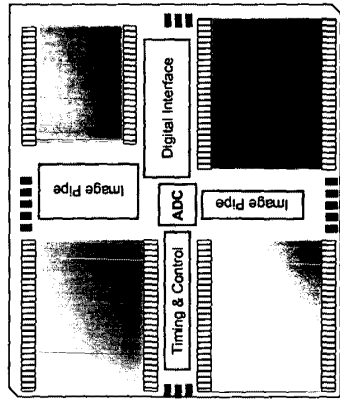


Figure 103B

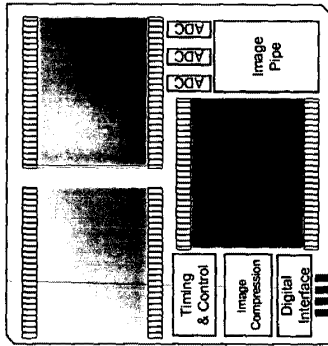


Figure 103C

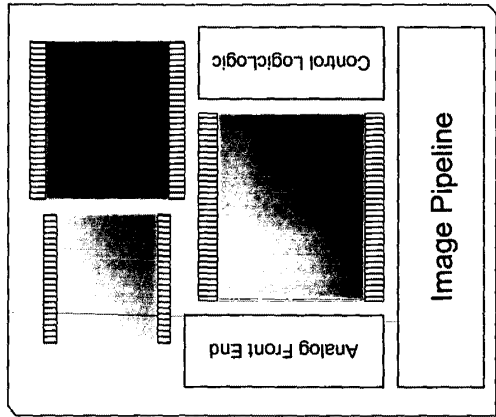


Figure 103D

Focal Plane Structure

Example shown: 3 array configuration
red/blue/green
different sized arrays

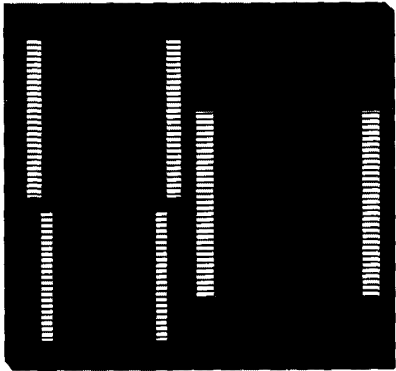


Figure 104A

Narrow Band Focal Planes

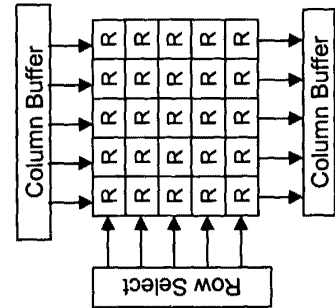
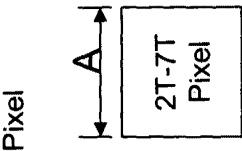


Figure 104B



Pixel

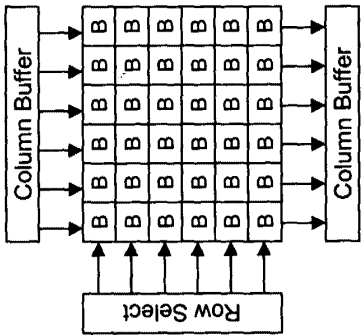


Figure 104C

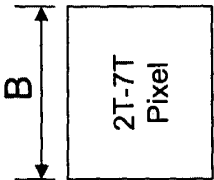
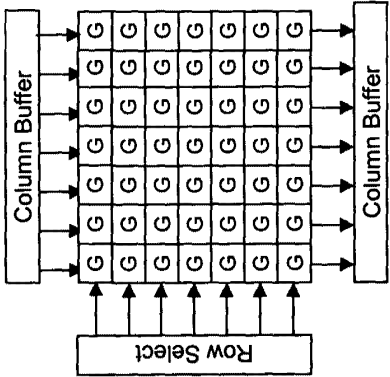


Figure 104D

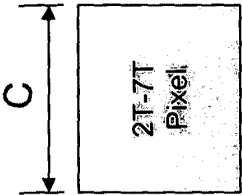


Image Pipeline

Example shown: 3 array configuration

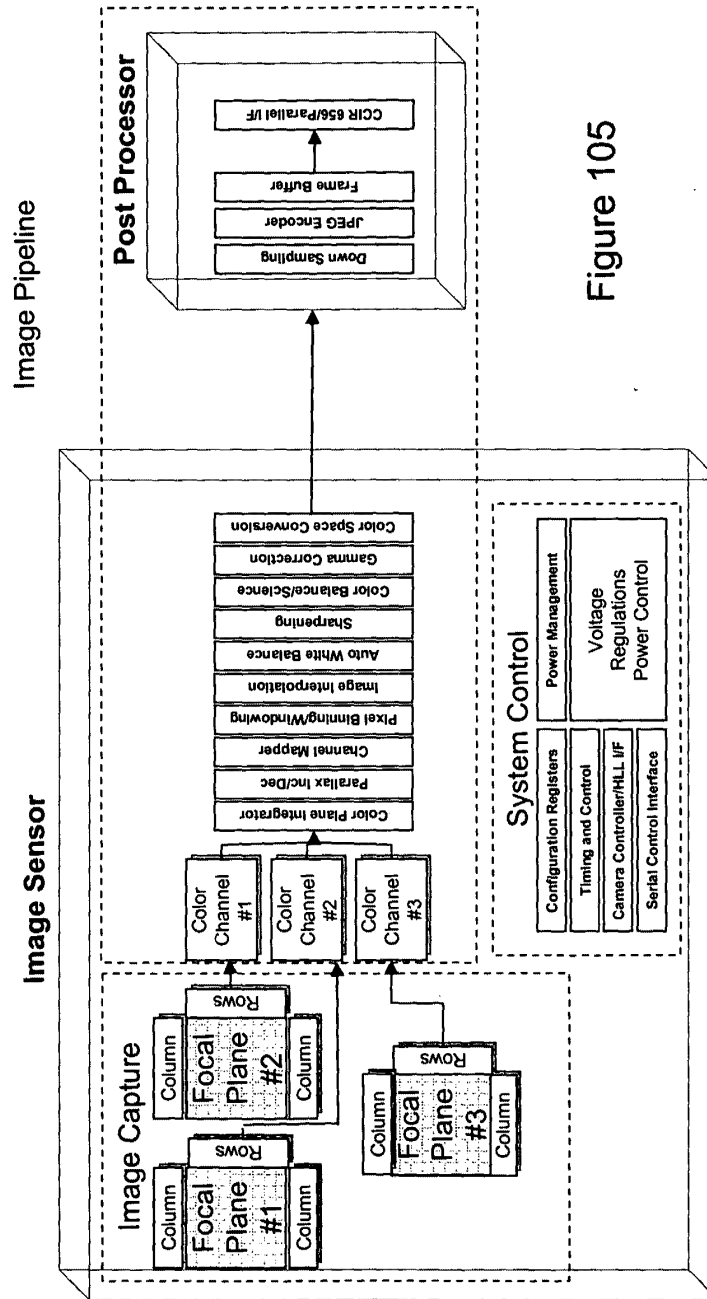


Figure 105

Image Pipeline

Note: Radical inc. Experiment for Asymmetric FPA

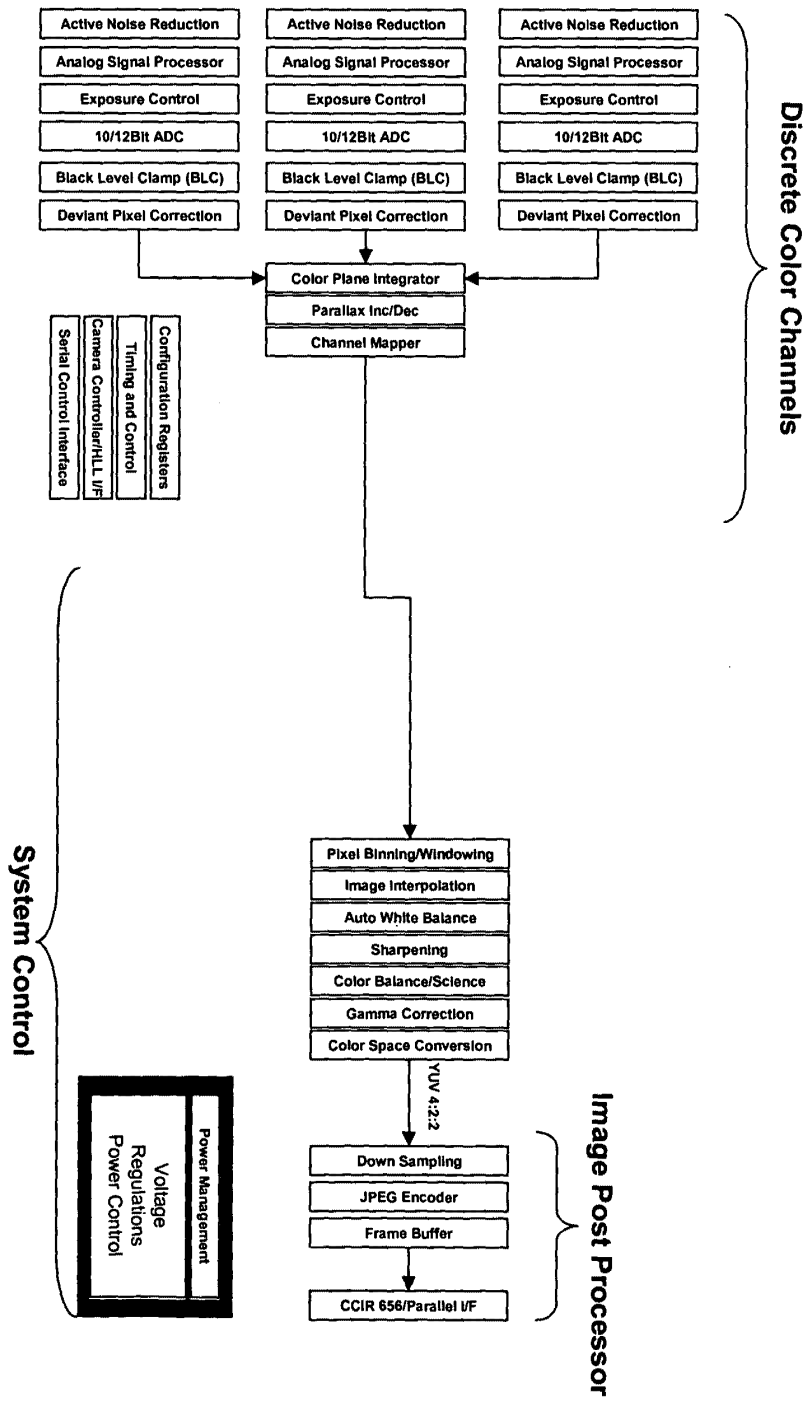


Figure 106

264/267

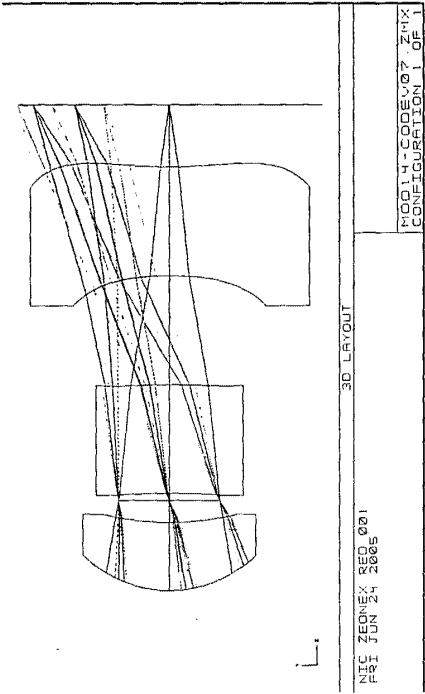


Figure 107A

Lens for RED band-3D Layout

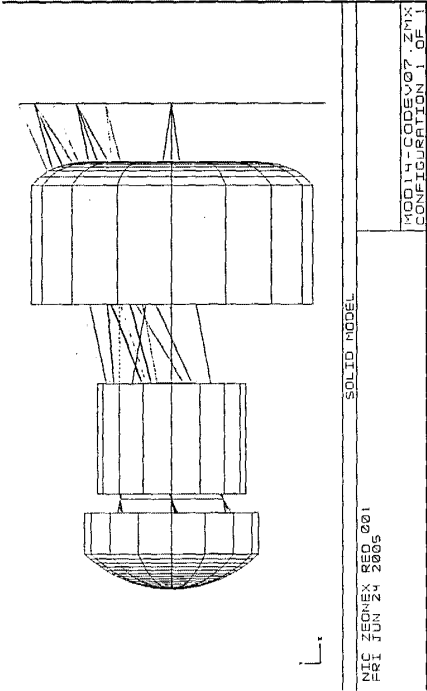


Figure 107B

Lens for RED band-Solid Model

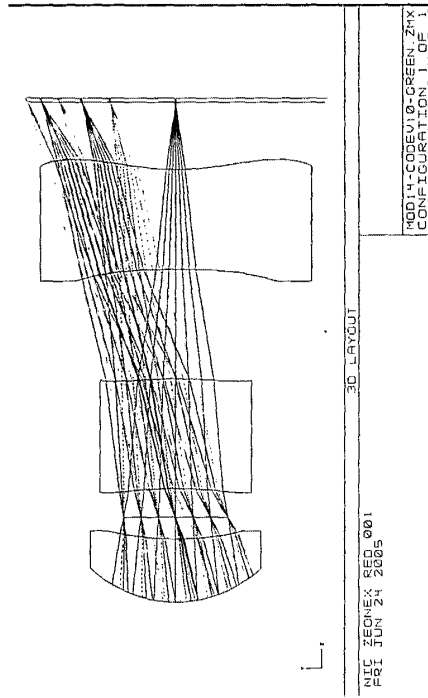


Figure 108A

Lens for GREEN band-3D Layout

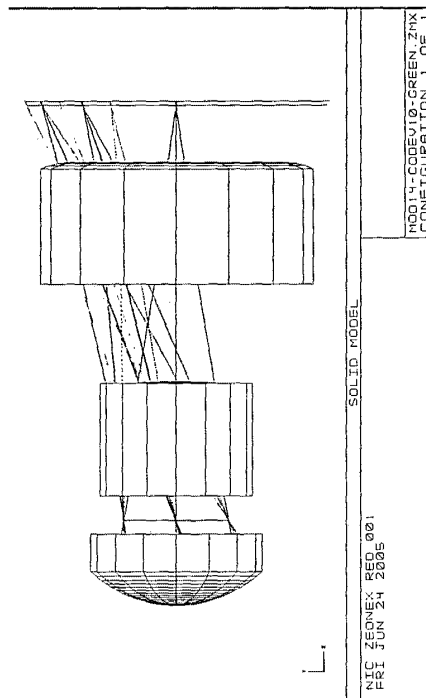


Figure 108B

Lens for GREEN band-Solid Model

Figure 109A

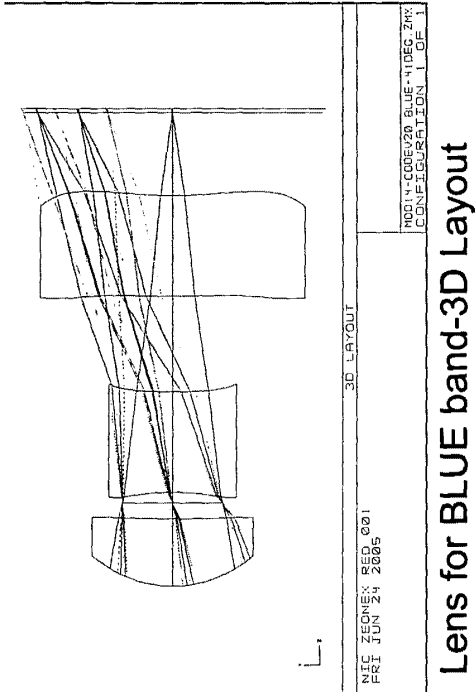


Figure 109B

