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Rowe

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(54) **HIGH DUTY CYCLE SYNCHRONIZED MULTI-LINE SCANNER**

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(52) **U.S. Cl.** **359/204**; 359/17; 359/216
(58) **Field of Search** 359/204, 216, 359/219, 209, 17, 18

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(57) **ABSTRACT**

A scanner includes a single scanning element such as a holographic disc or a polygon mirror and an illumination system that provides a plurality of input beams that are directed to different areas on the scanning element. In one embodiment, a light source provides a single beam that is alternately directed to a first area and a second area. While an input beam is incident on the first area, a first scan line forms. While an input beam is incident on the second area, a second scan line forms. Duty-cycle and energy efficiency of this embodiment are high because the beam from the source is switched from one area to the other during dead time when a scan beam would not otherwise have been directed to the desired scan aperture. Separate scan lines are automatically synchronized since they originate from the same source. Thus, alignment of multiple scan lines to form an extended scan line is simplified. Another embodiment simultaneously directs input beams to different areas of a scanning element to generate a plurality of synchronized scan lines suitable for alignment to form extended scan lines or for use separately in applications such as color printing.

31 Claims, 10 Drawing Sheets

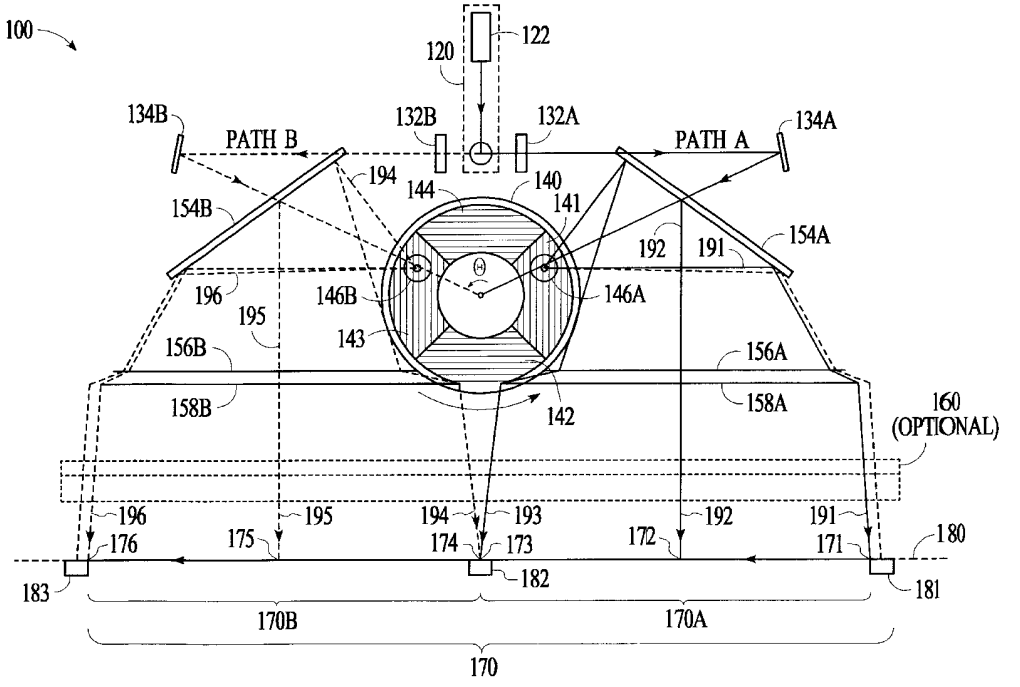
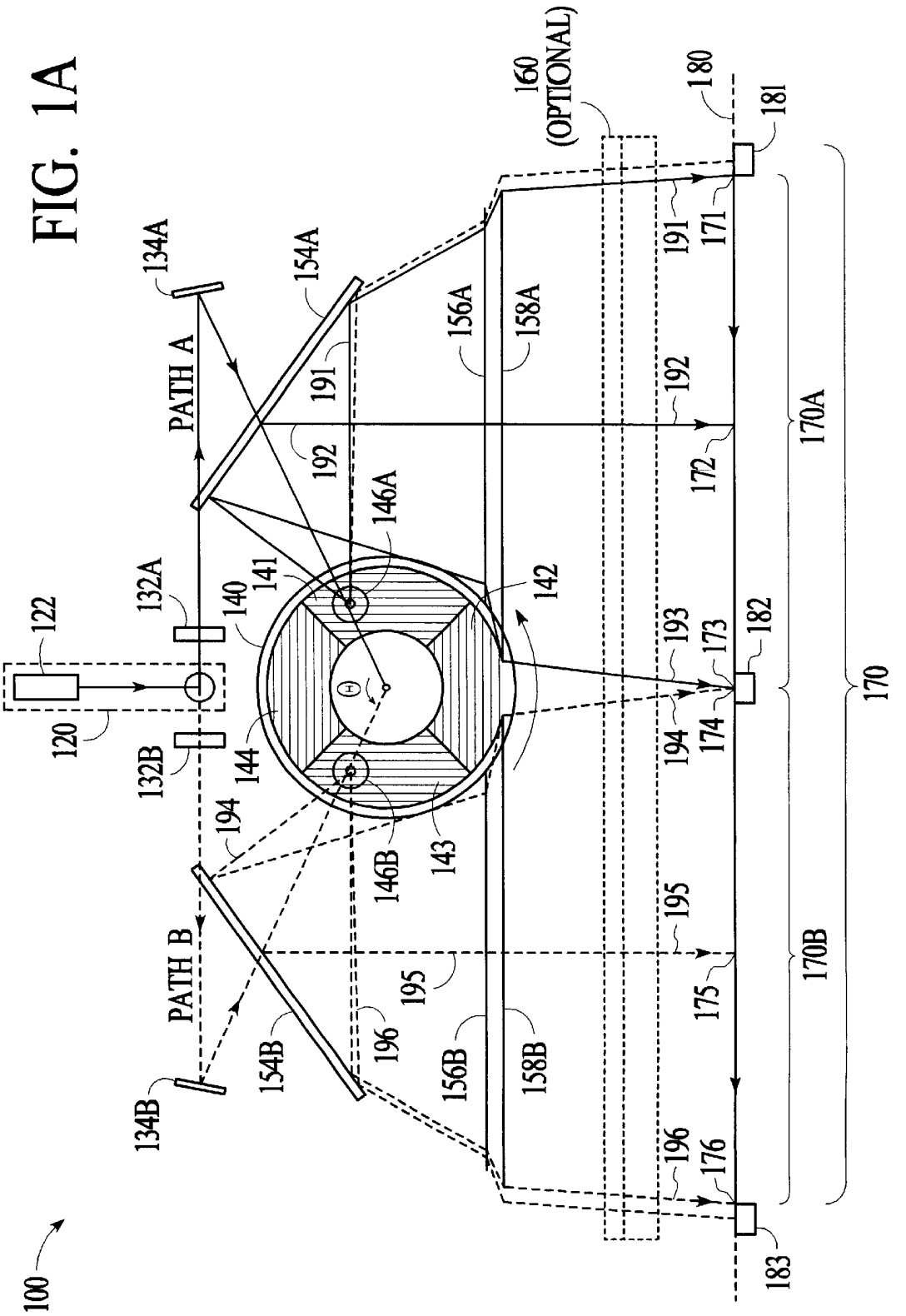


FIG. 1A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120
122
132A
132B
134A
134B
140
141
142
143
144
146A
146B
154A
154B
156A
156B
158A
158B
160 (OPTIONAL)
170
170A
170B
171
172
173
174
175
176
180
181
182
183
191
192
193
194
195
196
PATH A
PATH B

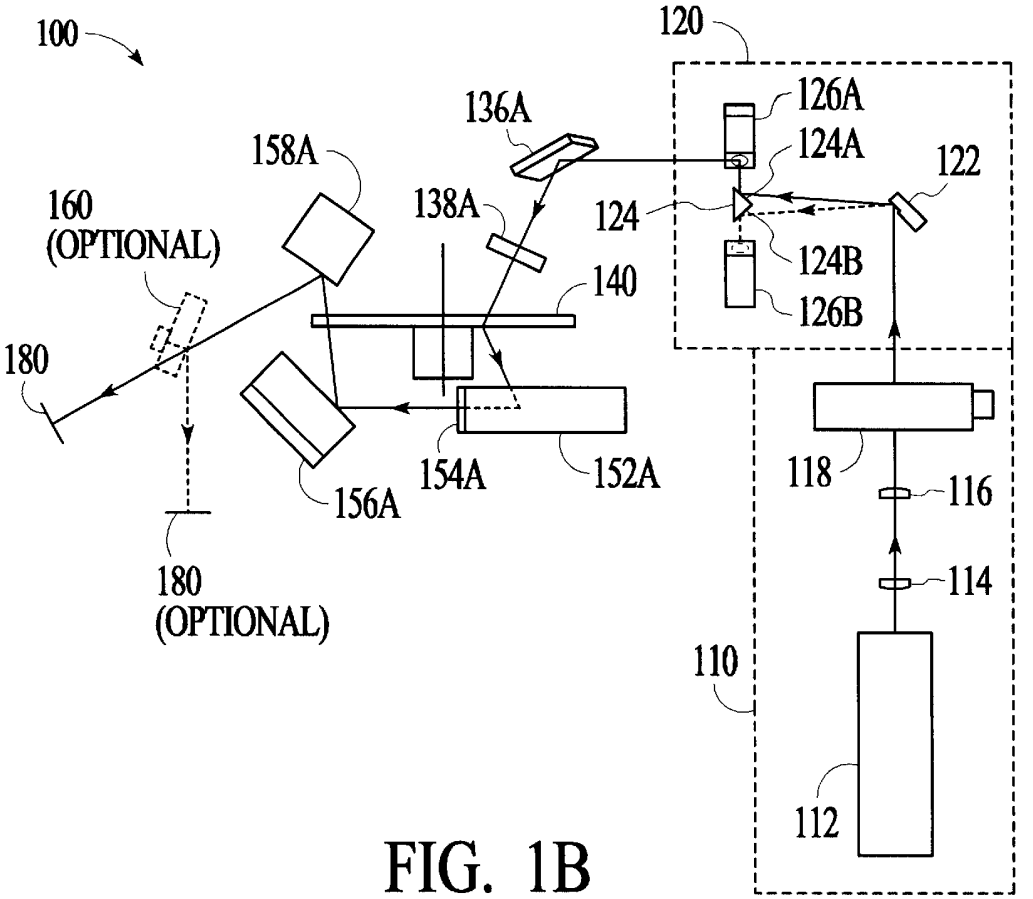

100
120
126A
136A
124A
158A
122
160
(OPTIONAL)
138A
124
140
124B
126B
180
118
116
154A
152A
156A
114
180
(OPTIONAL)
110
112

FIG. 1B

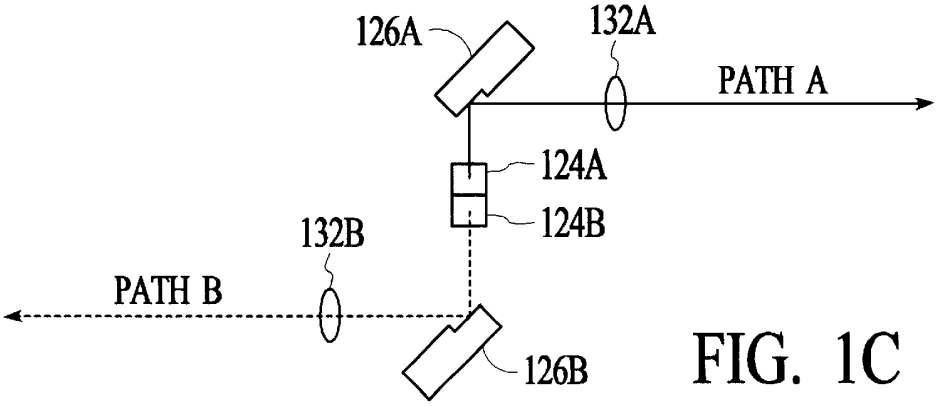

126A
132A
PATH A
124A
124B
132B
PATH B
126B

FIG. 1C

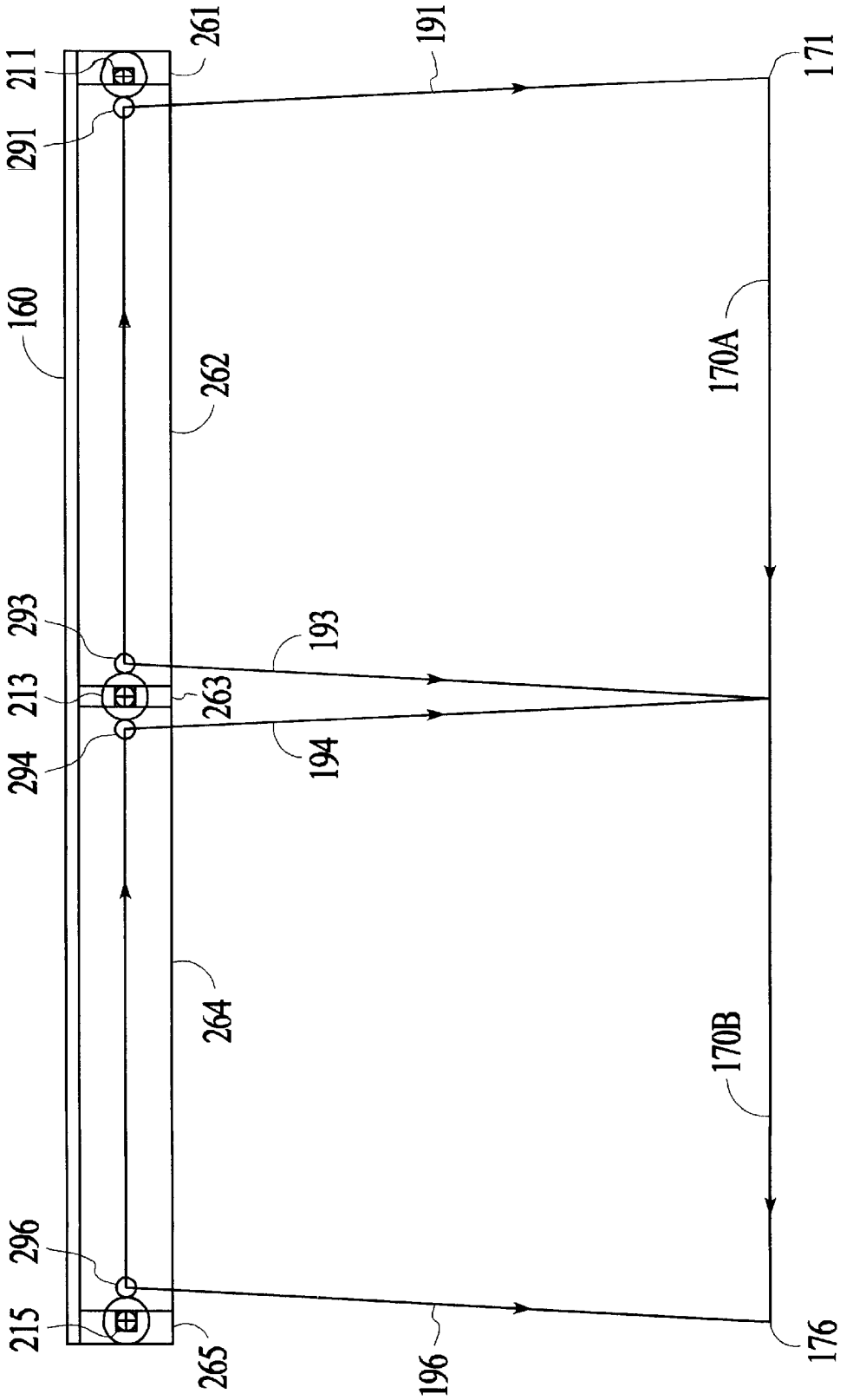

211
261
191
171
291
160
262
170A
293
193
213
263
294
194
264
170B
296
215
265
196
176

FIG. 2

FIG. 3

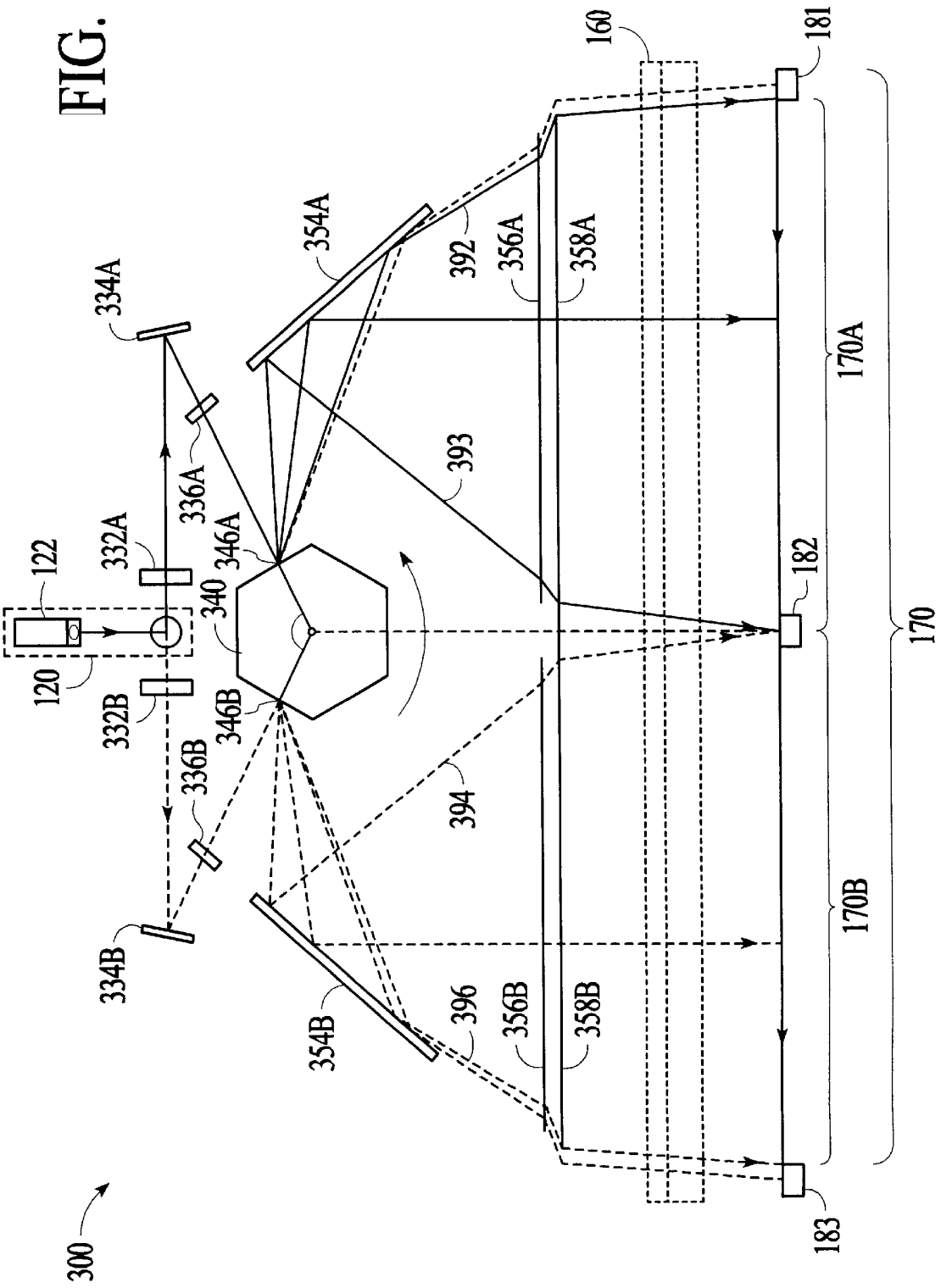
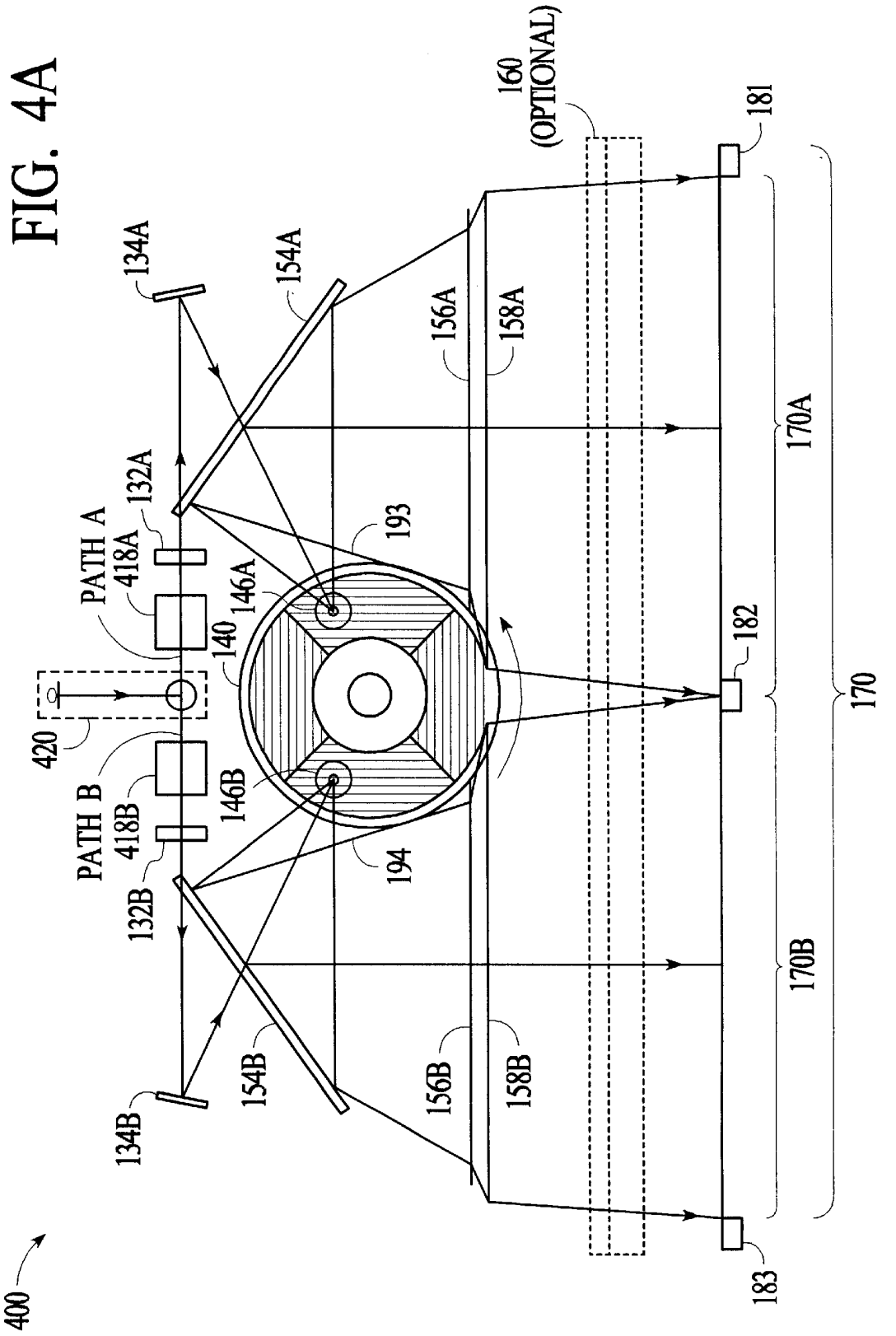

300
120
122
332A
332B
334A
334B
336A
336B
340
346A
346B
354A
354B
356A
356B
358A
358B
392
393
394
396
160
181
182
183
170
170A
170B

FIG. 4A


400
420
PATH A
PATH B
418A
418B
132A
132B
134A
134B
140
146A
146B
154A
154B
156A
156B
158A
158B
160
(OPTIONAL)
181
182
183
193
194
170A
170B
170

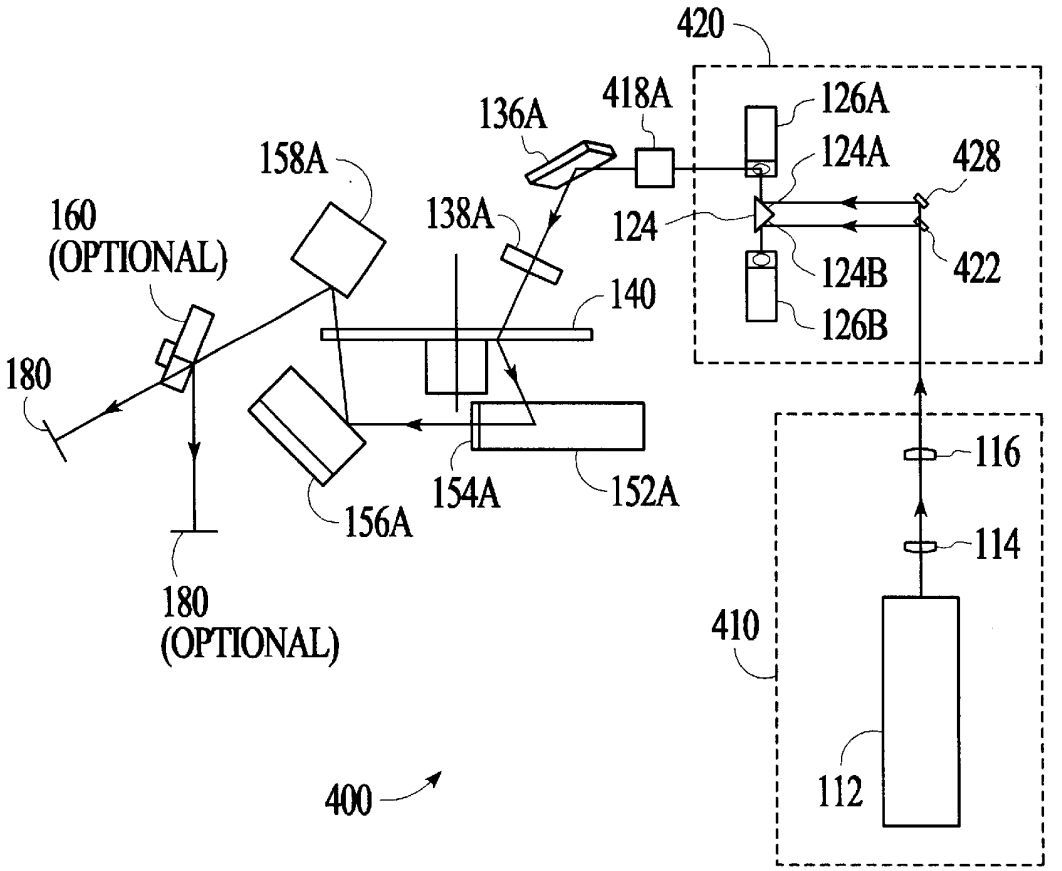

420
418A
126A
136A
124A
428
158A
160
(OPTIONAL)
138A
124
140
124B
422
126B
180
116
154A
152A
156A
114
180
(OPTIONAL)
410
112
400

FIG. 4B

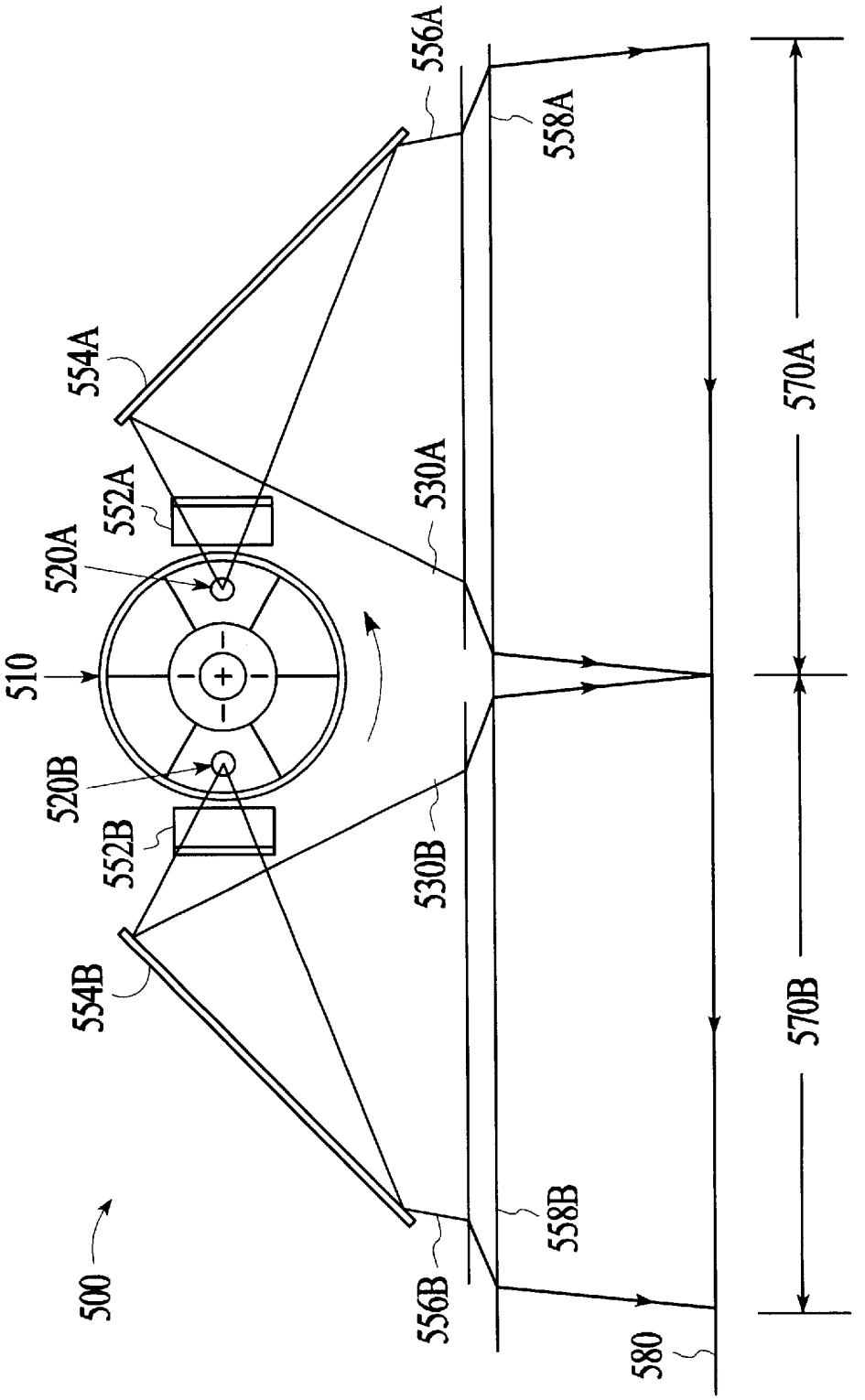

500
510
520A
520B
552A
552B
554A
554B
556A
556B
558A
558B
530A
530B
570A
570B
580

FIG. 5

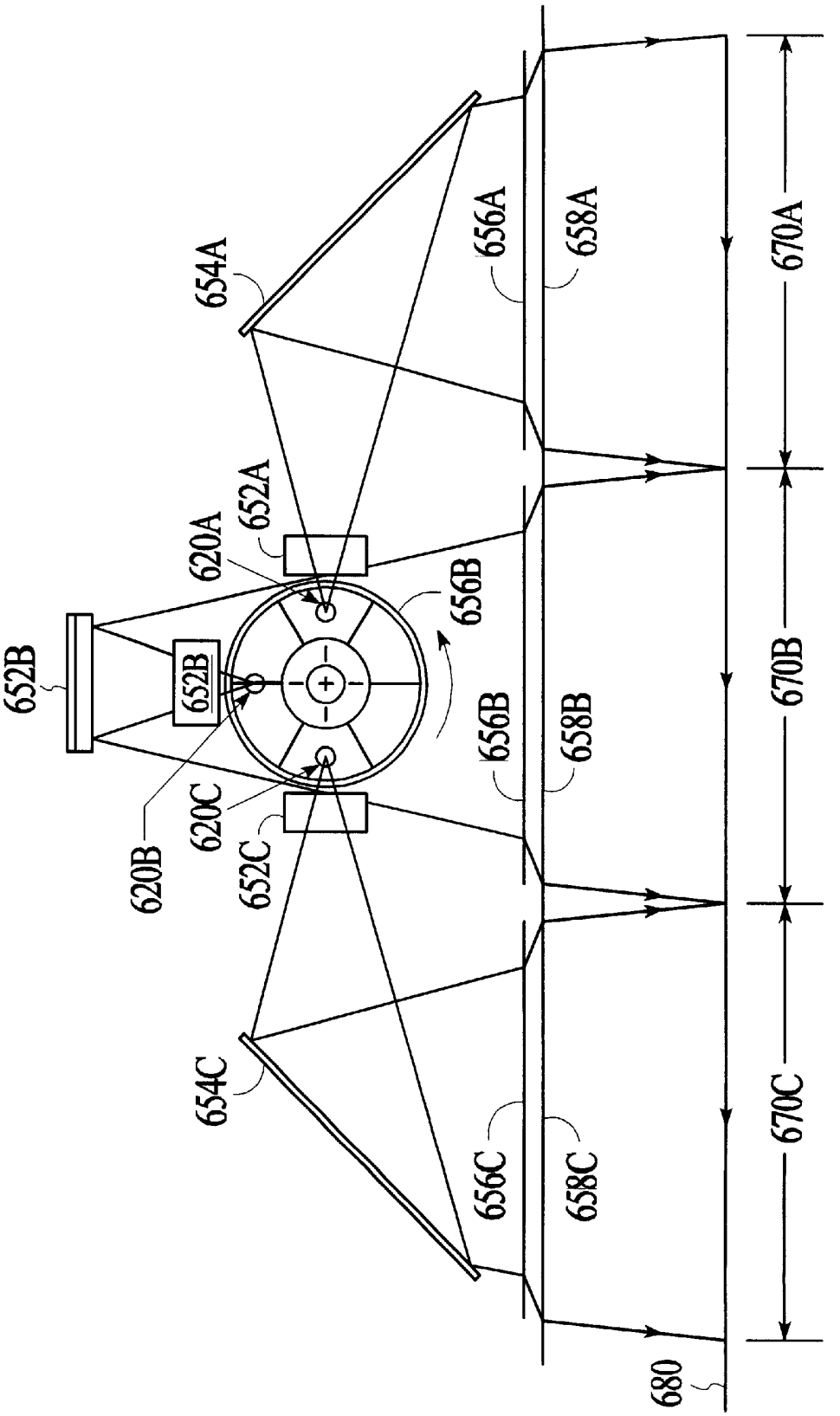

654A
656A
658A
670A
652A
620A
656B
652B
652B
620B
620C
652C
656B
658B
670B
654C
656C
658C
670C
680

FIG. 6

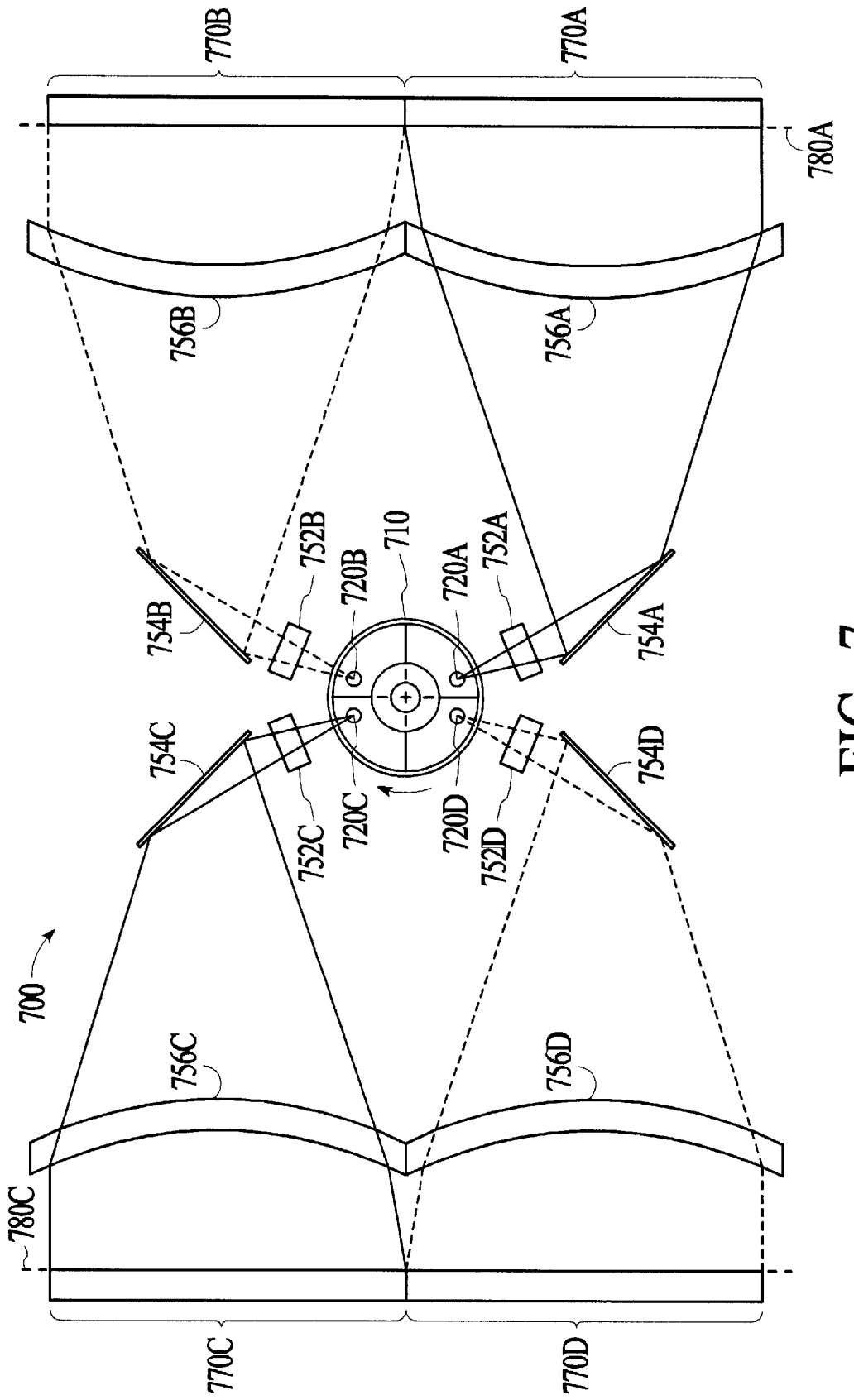

770B
770A
780A
756B
756A
752B
720B
710
720A
752A
754B
754A
754C
754D
752C
720C
720D
752D
700
756C
756D
780C
770C
770D

FIG. 7

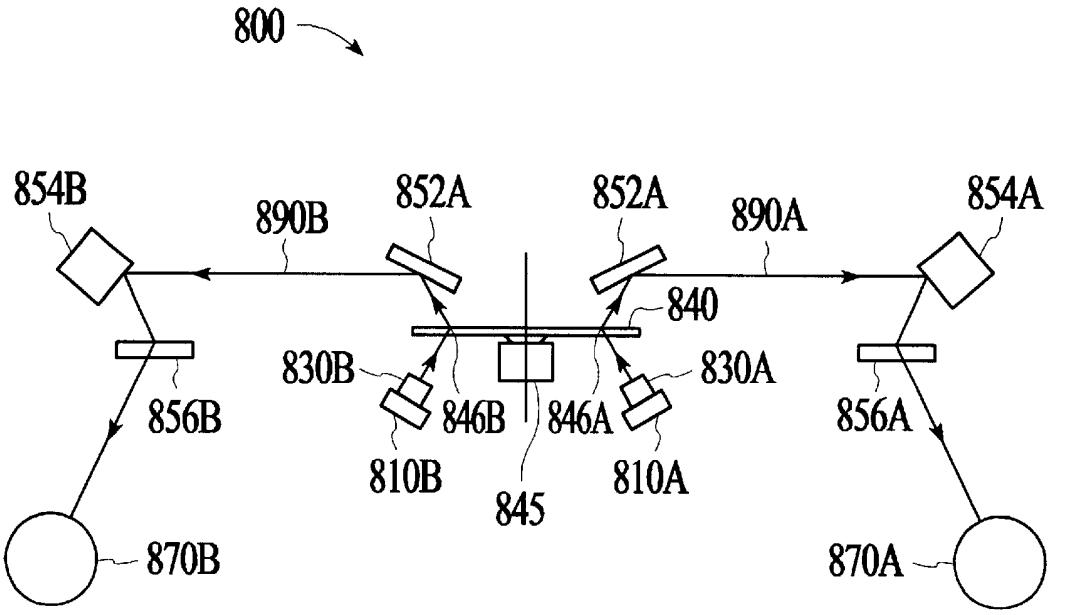

800
854B
890B
852A
852A
890A
854A
840
830B
830A
856B
846B
846A
856A
810B
845
810A
870B
870A

FIG. 8

HIGH DUTY CYCLE SYNCHRONIZED MULTI-LINE SCANNER

BACKGROUND

1. Field of the Invention

This invention relates to line scanners and methods for scanning multiple synchronized scan lines using scanners having high duty cycles that conserve illumination source energy.

2. Description of Related Art

Many devices such as printers, inspection devices, and medical equipment contain line scanners. For example, a typical laser printer contains a line scanner that scans a digitally modulated laser beam to form an image on a media such as paper, film, or plates, and in the medical industry, a line scanner in an X-ray machine scans an X-ray beam through a patient or sample to form lines of an image. A typical line scanner includes a scanning element such as a polygon mirror or a holographic disc on which an input beam from a laser or other light source is incident. The scanning element redirects the input beam, for example, by reflection or diffraction, to project a scan beam. Movement such as rotation or oscillation of the scanning element moves or scans the scan beam along a scan line in an image area. Line scanners often include pre-scan and post-scan optical systems that adjust the focus or collimation of the input and scan beams as well the linearity of the scan line and the uniformity of scan rate.

An important property of a line scanner is the duty cycle which is defined by the ratio of the time that the scan beam is imaging to the total operating time. Generally, a line scanner has a periodic motion that includes a dead time during which the line scanner is not directing the scan beam toward the image area. Thus, duty cycles for line scanners are generally less than 100% and typically range from about 20% to 70%. The duty cycle of a line scanner can limit the useful output illumination per unit of input power from a laser or other light source. Accordingly, a low duty cycle line scanner requires either a higher power light source, more efficient optics, or a slower scan rate to provide a fixed amount of useful illuminating energy density. Accordingly, line scanners having high duty cycles are sought.

Another important property of line scanners is the imaging area or scan line length. Conventionally, creating long scan lines to cover a large imaging area requires either a large line scanner or multiple smaller line scanners operated in series. Using multiple line scanners (or scan heads) to create a long scan line has a number of advantages including the ability to design smaller or more compact systems with less expensive scanning heads. However, multiple-head systems often require elaborate and expensive line-connecting optics or electronics to control the relative positions of the scan lines from the various scan heads and to synchronize the independently operating scan heads. This is due in part to the lack of synchronization of the motion of the light sources and the scanning optics in the multiple scan heads. U.S. Pat. No. 5,654,817 describes a system employing multiple scan heads for large area imaging. Line scanners that are compact and do not require expensive line connecting optics or electronics are desired.

SUMMARY

In accordance with an embodiment of the invention, a high duty scanner has a single compact scan head capable of creating multiple synchronized scan lines. The scan lines are easily connected because a single scanning element provides a common reference for the multiple scan lines and in some embodiments because a common light source is oriented relative to each input beam so that motion of the light source manifests itself in each scan line in both the same direction and magnitude to provide synchronization. One embodiment of the invention redirects an input beam to increase the duty cycle of a scanner. In particular, pre-scan optics move an input beam from a first area for incidence on a scanning element to a second area for incidence on a scanning element. In alternate embodiments, the first and second areas contain portions of a single scanning element or alternatively portions of two separate scanning elements. Moving the input beam from the first to the second area occurs when the scanning beam reaches the end of a scan line but the scanning element has not positioned another facet in the first area for the start of another scan line. Upon movement of the input beam, the second facet immediately directs the scan beam into the image area for another scan line or for an extension of a scan line originated from the first facet. Moving the input beam thus can increase the duty cycle by increasing the time during which the scan beam is in the image area. The scan line length increases when second facet extends a scan line the first facet previously started.

Alternatively, multiple input beams either derived from a common light source and beam splitters or from multiple light sources, are directed to multiple separated areas on a single scanning element to generate multiple synchronized scan lines. Timing of the multiple scan lines depends on the relative positions of the incident areas of the multiple input beams so that scan lines can be simultaneously or sequentially scan.

The synchronized scan lines can be used separately in applications such as color laser printing or can be aligned for formation of a single extended scan line. Whether simultaneous input beams or alternating input beams are used, a single scanning element and/or light source simplifies alignment of multiple scan lines for formation of an extended scan line because many variations of the scanning element and light source are common to all of the scan lines that constitute the extended scan line.

In one embodiment of the invention a scanner includes a scanning element such as a holographic disc or a polygon mirror and an illumination system that directs a first input beam to a first area and a second input beam to a second area. The first and second areas are separated from each other and situated so that portions of the scanning element move through the first and second areas during a scanning operation. First and second scan beams respectively originate from deflections of the first and second input beam by portions of the scanning element in the first and second areas. The input beams encountering the scanning element are oriented so that motion of both scan beams are synchronized for a given light source motion, and thus motion of the light source does not affect synchronization or alignment of the scan beams. Post-scan optics direct the first and second scan beams to illuminate first and second scan lines which can be used separately or aligned for joining that forms of an extended scan line. When the scan lines are aligned, a beam detector assembly can be positioned between the scanning element and an image plane in which the extended scan line is formed and in a gap between a path of the first scan beam to the end of the first scan line and a path of the second scan beam to the start of the second scan line. In one embodiment, the detector assembly is mounted on the back of a mirror having a first mirrored section positioned to reflect the first scan beam, a second mirrored section positioned to reflect

the second scan beam, and a transparent section between the first and second mirrored sections.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1A** shows a top view of a line scanner including a holographic disc as a scanning element that forms multiple scan lines in accordance with an embodiment of the invention.

FIGS. **1B** and **1C** show side views of portions of the line scanner of FIG. **1A**.

FIG. **2** shows an optional mirror and sensor system for aligning scan lines in the line scanner of FIG. **1A**.

FIG. **3** shows a top view of a line scanner including a polygon mirror as a scanning element that forms multiple scan lines in accordance with an embodiment of the invention.

FIGS. **4A** and **4B** respectively show a top view and a side view of a line scanner using a single light source and a beam splitter to provide multiple input beams in accordance with an embodiment of the invention.

FIG. **5** illustrates a scanner in accordance with an embodiment of the invention that uses a single scanning element to scan two scan lines.

FIG. **6** illustrates a scanner in accordance with an embodiment of the invention that uses a single scanning element to scan three scan lines.

FIG. **7** illustrates a scanner in accordance with an embodiment of the invention that uses a single scanning element and two simultaneous beams with path switching to an four scan lines.

FIG. **8** illustrates a scanner in accordance with an embodiment of the invention that causes a single scan element with multiple light sources to generate multiple synchronized scan lines.

Use of the same reference symbols in different figures indicates similar or identical items.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In accordance with an embodiment of the invention, a high duty cycle scanner uses a single scanning element such as a polygon mirror or holographic disc, to create multiple synchronized scan lines. The synchronized scan lines are easily connected to create an extended scan lines of greater length because the multiple scan lines have common characteristics that arise from the common scanning element and the common orientation of the light source. The scanner can switch an input beam from one area containing a portion of the scanning element to another area during a "dead zone" when a scan beam would not be directed into the image area. As used herein, the dead zone is defined as the period of time between the end of one scan line and the start of the next scan line, and the downtime is defined as the time during which the laser beam is performing no useful function. Redirecting the input beam from one area to another can place a scan beam back in the image area and thus reduce the downtime of the scanner. The incident areas could contain portions of the same scanning element or correspond to and contain portions of different scanning elements. By deflecting the input beam from a first area to a second area during the dead zone of the first area and back to the first area during the dead zone of the second area, a scanner can exhibit a duty cycle of greater than 90%.

If the input beam switches to an area containing another facet of the same scanning element, the two scan lines are synchronized. In addition, if the same light source generates the input beams to multiple areas, the motion of each scan line due to pointing error of the light source is synchronized. Synchronized scanning and light source pointing allow for better in-scan and cross-scan control of where scan lines connect. Thus, less costly correction techniques can align the multiple scan lines.

FIGS. **1A** and **1B** respectively show a top view and a side view of a line scanner **100**. Line scanner **100** includes a light source **110**, path selection optics **120**, pre-scan optics, a scanning element **140**, and post-scan optics. Light source **110** generates an input beam such as a laser beam which path selection optics **120** and the pre-scan optics direct onto scanning element **140** with proper input beam orientation. In the specific embodiment shown in FIG. **1B**, light source **110** includes a laser **112**, beam shaping elements **114** and **116**, and an acousto-optic modulator (AOM) **118** that digitally modulates the input beam's intensity. Such light sources are well known for line scanners used in laser printers. An alternative embodiment of the invention uses laser diode light sources that can be modulated internally, eliminating the need for the AOM **118**. An alternative embodiment of the invention uses a light source other than lasers, for example, an LED (light emitting diode) or an x-ray source and eliminates AOM **118** if modulation of the input beam is not required. Beam shaping elements **114** and **116** are selected as required to provide a beam profile for the application of line scanner **100**.

Path selection optics **120** switch the input beam back and forth between two paths, path A and path B. In the embodiment shown, path selection optics **120** include an adjustable deflector **122** and a fixed deflector **124** having two facets **124A** and **124B**. Adjustable deflector **122** can be a piezo-electrically driven deflector mirror, acousto-optical deflector (AOD) or any device that allows control over the exit angle of a light beam. Fixed deflector **124** is a prism, a pair of mirrors oriented at a 90° angle, or any device that deflects a beam along sufficiently separated paths. In operation, deflector mirror **122** deflects the beam from source **110** onto one or the other of facets **124A** and **124B** of defector **124**. From facet **124A**, the beam reflects to an adjustable deflector **126A** and along path A. From facet **124B**, the beam reflects to an adjustable deflector **126B** and along path B. FIG. **1C** illustrates how path A and path B are widely separated, e.g., in opposite directions. Light source **110** and path selection optics **120** are oriented so that movement of or changes in light source **110** or path selection optics **120** causes synchronized movement of path A and path B at the image plane. In particular, the images of light source **110** formed from beams along path A and path B should have the same orientation, for example, both upright or both inverted. In scanner embodiments employing a common light source for multiple beams, optics that synchronize movement of the scan beams reduce the effects of pointing error because movement of the light source causes matching changes in all of the scan beams.

A control circuit (not shown) periodically switches the orientation of adjustable deflector **122** from a configuration directing the input beam along path A to a configuration directing the input beam along path B. As described further below, the orientation of adjustable deflector **122** for the two configurations is selected to align a scan line generated when the beam is incident scanning element **140** from path A with a scan line produced when the beam is incident on scanning element **140** from path B. Deflector **122** selects a path A or B by positioning the beam on facet **124A** or **124B** and positions the beam on the selected facet for alignment along

the in-scan direction. Deflectors **126**A and **126**B position their respective beams for cross-scan alignment of the two scanned lines A and B relative to each other.

From selection optics **120**, the input beam travels through pre-scan optics along the selected path. For path A or B, the beam passes through a first beam shaping lenses **132**A or **132**B, reflects from two fold-mirrors **134**A and **136**A or **134**B and **136**B, and then passes through a second beam shaping lens **138**A or **138**B before reaching holographic scan element **140**. FIG. **1**A does not show mirrors **136**A and **136**B and lenses **138**A and **138** which overlie and would obscure the top view of scanning element **140**. For simplicity of illustration, FIG. **1**B omits lens **132**A, mirror **134**A, and the pre-scan optical elements along path B.

The input beam is incident on a portion of scanning element **140** that is currently within an area **146**A or **146**B, depending on whether optics **120** selected path A or B. During scanning, scanning element **140** rotates so that the portions of scanning element **140** within areas **146**A and **146**B constantly change. Changes in the properties of the portions of scanning element **140** within areas **146**A and **146**B change the angle at which the scan beam emerges and scan the scan beam along a scan line. Adjusting the orientations of deflectors **122** and **126**A or **126**B selects the location of incident area **146**A or **146**B, the radius at which the input beam strikes scanning element **140**, and the cross-scan position of a scan line **170** in an image plane **180**.

In the post-scan optics, the scan beam initially reflects from fold mirrors **152**A and **154**A or **152**B and **154**B onto a first aspheric curved mirror **156**A or **156**B. Mirror **156**A or **156**B in turn reflects the scan beam onto a second aspheric curved mirror **158**A or **158**B. The size of mirrors **156**A, **156**B, **158**A, and **158**B and gaps between mirrors **156**A and **156**B or mirrors **158**A and **158**B along with the property of the portions of scanning element **140**, control scan line apertures and the lengths of scan lines **170**A and **170**B. The focusing properties of curved mirrors **156**A, **156**B, **158**A, and **158**B are selected according to the application of line scanner **100**. In particular, curved mirrors **156**A, **156**B, **158**A, and **158**B provide a linear scan (i.e., a constant scan speed at a constant rotation speed of scanning element **140**), correct bow caused by scanning element **140**, flatten the focus field (so that all points along the scan line are in focus), and create a quasi-telecentric scanned beam at the focal plane. Many alternative embodiments of the post-scan optics are known in the art or can be created. For example, curved mirrors **156**A, **156**B, **158**A, and **158**B could be replaced by more complex reflective and/or transmissive optics that provide scan lines of any desired characteristics.

Curved mirrors **158**A and **158**B form scan lines **170**A and **170**B on the same image plane **180**. An optional line-correction mirror **160** which monitors the position of the scan beams and the resulting scan lines is inserted between image plane **180** and mirrors **158**A and **158**B. If line-correction mirror **160** is used, the scan beam reflects from correction mirror **160** to image plane **180**.

In the exemplary embodiment, scanning element **140** is a multi-faceted holographic scan disc attached to a motor assembly. The holographic scan disc has four facets **141**, **142**, **143**, and **144**, each of which spans 90° and diffracts the beam into post-scan optics when selection optics **120** select a portion of the facet in area **146**A or **146**B. Of the 90° of each facet, about 40.5° beginning about 24.75° from a leading edge of the facet is for scanning and directs the beam to a path ending in a desired portion of the image plane. For the exemplary embodiment, scanning of extended scan line **170** requires a rotation of about 90° (one facet of scanning element **140**). Each extended scan line **170** includes two scan lines **170**A and **170**B that two separate facets of scanning element **140** provide.

In an example scanning process, facets **141** and **144** scan the scan beam respectively along scan lines **170**A and **170**B which are aligned and concatenated to create extended scan line **170**. Selection optics **120** select area **146**A when scanning element **140** is oriented so that facet **141** is in area **146**A and directs a scan beam along a path **191** to the start **171** of scan line **170**A. At this point, the portion of facet **141** in area **146**A is about 24.75° from the edge of facet **141** in the exemplary embodiment. Scanning element **140** then rotates about 20.25° while the scan beam in image plane **180** moves until facet **141** directs the scan beam along a path **192** to the midpoint **172** of scan line **170**A. Rotation through the next 20.25° moves the scan beam the same distance further to the end point **173** of scan line **170**A where the scan beam is along a path **193** passing under scanning element **140**. At this point, scan line **170**A from facet **141** is complete, and path selection optics **120** switch the input beam from path A to path B.

Areas **146**A and **146**B are separate from each other by an odd number of half facets, which in FIG. **1**A is an angle θ of 135°. Scanning element **140** must rotate another 4.5° before facet **144** is in position to direct the scan beam to the start of scan line **170**B. Accordingly, path selection optics **120** have the time required for a 4.5° rotation to switch the path of the input beam. The portion of facet **144** is in area **146**B, at that point, directs the scan beam along a path **194** which ends at the starting point **174** of scan line **170**B. Accordingly, scanning element **140** rotates through 45° (half a facet) between the start of scan line **170**A and the start of scan line **170**B. If scanner **100** is properly adjusted, the start point **174** of scan line **170**B is at substantially the same location as the end point **173** of scan line **170**A. Adjustment of the positions of the scan lines is discussed below. The scan beam moves from starting point **174** to end point **176** of scan line **170**B while scanning element **140** rotates through 40.5°. At this point, extended scan line **170** is complete, and path selection optics **120** switch the input beam back to path A for the start of the next scan line. For the next extended scan line **170**, facet **142** sweeps the image beam across scan line **170**A, and facet **141** sweeps the image beam across scan line **170**B.

Alternative systems and methods are available for monitoring the position of scan lines **170**A and **170**B. One system uses a start-of-scan (SOS) position detector assembly **181**, a central position detector assembly **182**, and an end-of-scan (EOS) position detector assembly **183**, which are located at or near the image plane **180**. Detector assemblies **181**, **182**, and **183** can be mounted above scan line **170** to allow mounting in the dual head casting which is a frame for mounting of the various optical components. SOS detector assembly **181** and EOS detector assembly **183** are located outside of the scan aperture (i.e., the boundaries of scan line **170**) and are similar or identical to SOS and EOS detector assemblies found in conventional laser printers, image setters and many other scanning devices. Central position detector assembly **182** is at or near the center of scan line **170**. During typical operation of scanner **100**, media being scanned blocks central position detector assembly **182**. However, prior to scanning media, central detector assembly **182** can accurately determine the relative positions of the end of scan line **170**A and the start of scan line **170**B in both the cross-scan and in-scan directions. Detector assemblies **181** and **183** then control the pixel clock data rate and the scan rate of scan lines **170**A and **170**B when scanning media.

Another system for monitoring scan line position includes optional line correction mirror **160** which is between a final focusing element of scanner **100** and the image plane containing scan line **170**. FIG. **2** shows an embodiment of mirror **160** which includes two mirrored sections **262** and **264** and three transparent sections **261**, **263**, and **265**. Mirror **160** can be made up of two separate mirrors mounted on a rigid platform with transparent sections between the mirrors or one continuous mirror that is silvered in only the desired sections. Mirrored section **262** reflects the scan beam during formation of scan line **170**A and lies between an area **291** where path **191** reflects from mirror **160** and an area **293** where path **193** reflects from mirror **160**. Mirrored section **264** reflects the scan beam during formation of scan line **170**B and lies between an area **294** where path **194** reflects and an area **296** where path **196** reflects. Scanner **100** is not perfectly telecentric and causes beam paths **191**, **193**, **194**, and **196** to "toe out." This allows transparent section **263** to be in the gap between areas **293** and **294**.

Beam position detector assemblies **211**, **213**, and **215** are mounted behind mirror **160** in transparent areas **261**, **263**, and **265**, respectively. Detector assemblies **211** and **215** are respectively the start-of-scan (SOS) and end-of-scan (EOS) detector assemblies. Detector assembly **213** is a central detector assembly that monitors the positions of the end of scan line **170**A and the start of scan line **170**B. An advantage of central detector assembly **213** when compared to central detector assembly **182** of FIG. **1**A, is that central detector assembly **213** is upstream of the image plane and not blocked by media in position for scanning. A control system (not shown) is connected to position detector assemblies **211**, **213**, and **215** and monitors the in-scan timing and the cross-scan positions of scan lines **170**A and **170**B. In particular, detector assemblies **211**, **213**, and **215** provide feedback on position and timing of the scan lines to the control system which in turn adjusts scanner **100** (e.g., deflectors **122**, **126**A and **126**B of FIG. **1** A) to align scan lines **170**A and **170**B. Based on the information from detector assemblies **211**, **263**, and **265**, the control system also provides a signal to the pixel clock to synchronize pixel speed and location within scanned beams **170**A and **170**B.

FIG. **3** illustrates a scanner **300** in accordance with another embodiment of the invention. Scanner **300** differs from scanner **100** primarily in that a scanning element **340** of scanner **300** is a polygon mirror instead of a holographic disc as used for scanning element **140** of scanner **100**. In scanner **300**, light source **110** and path selection optics **120** direct an input beam to pre-scan optics including lenses **332**A and **332**B and mirrors **334**A, **334**B, **336**A, and **336**B. As described below in regard to other embodiments of the invention, instead of selection optics **120** which switch the path of the input beam, input beams can be simultaneously directed along paths A and B using multiple light sources or a single light source and a beam splitter. In the embodiment shown in FIG. **3**, the pre-scan optics direct an input beam to an incident area **346**A or **346**B containing a portion of scanning element **340**. Scan element **340** directs a scan beam into post scan optics including flat mirrors **354**A and **354**B and focusing mirrors **356**A, **356**B, **358**A, and **358**B. The post scan optics may also include optional line correction mirror **160**. Scanning element **340** rotates so that while the input beam is incident area **346**A, the scan beam scans scan line **170**A. While the input beam is incident area **346**B, the scan beam scans scan line **170**B.

In an exemplary embodiment of the invention, scanning element **340** is hexagonal. For scan line **170**A, path selection optics **120** direct the input beam to area **146**A while scanning element rotates about 30° (i.e., about half the angular extent of a facet of scanning element **240**.) Path selection optics **120** then switch the input beam to area **146**B while scanning element **340** rotates through another 30° rotation (i.e., another half facet rotation). Path selection optics **120** then switch the input beam back to incident area **346** at which point another facet of scanning element **340** is back in position for the start of another scan line.

FIGS. **4**A and **4**B illustrate a line scanner **400** which simultaneously directs input beams along paths A and B. Scanner **400** includes a common light source **410** that contains a laser **112** and beam shaping elements **114** and **116** as described for light source **110** of FIG. **1**B but does not include an acousto-optical modulator. Light source **110** directs a source beam to beam separation optics **420** which split the source beam into two input beams, one directed along path A and another directed along path B. Beam separation optics **420** include a beam splitter **422** (e.g., a half silvered mirror or other means of dividing the source beam into two equal energy input beams) and deflectors **124**, **126**A, **126**B, and **428**. Beam splitter **422** simultaneously directs a first input beam via deflector **428** to facet **124**A of deflector **124** and a second input beam to facet **124**B of deflector **124**. The first and second beams respectively reflect from deflectors **126**A and **126**B and propagate along respective paths A and B. Acousto-optical modulators **418**A and **418**B are in respective paths A and B and control beam intensity into the pre-scan optics and the portions of scanning element **140** in respective areas **146**A and **146**B. In paths A and B, scanner **400** includes: pre-scan optical elements **132**A, **132**B, **134**A, **134**B, **136**A, **136**B, **138**A, and **138**B; scanning element **140**; and post-scan optical elements **152**A, **152**B, **154**A, **154**B, **156**A, **156**B, **158**A, and **158**B which are the same as the elements described above in regard to FIGS. **1**A and **1**B.

With scanning element **140** as described above and areas **146**A and **146**B separated by an odd number of half facets, only one of areas **146**A and **146**B at a time contain a portion of scanning element **140** that directs a scan beam into extended scan line **170**. Accordingly, separation optics **420** always directs one of the input beams down a path (A or B) that currently does not lead to scan line **170**. This reduces the percentage of illumination power utilized for imaging. However, scanning element **140** automatically alternates between directing a scan beam from area **146**A to scan line **170**A and directing a scan beam from area **146**B to scan line **170**B and does not require control logic and beam path switching that is synchronized with the rotation of scanning element **140**. The delay between the scan beam from area **146**A reaching the end of scan line **170**A and the scan beam from area **146**B starting scan line **170**B can be adjusted by changing the angle between areas **146**A and **146**B. In one embodiment, areas **146**A and **146**B are positioned so that area **146**A and area **146**B simultaneously direct scan beams along respective paths **193** and **194**. This eliminates the delay between the end of scan line **170**A and the start of scan line **170**B. The elimination of the delay can simplify cross-scan corrections required in applications where a medium moves at constant velocity in the cross-scan direction relative to scanner **400** during scanning. Larger changes in the relative positions of areas **146**A and **146**B can implement a variety of scanning options including simultaneous scanning of scan lines **170**A and **170**B.

FIG. **5** illustrates a scanner **500** which simultaneously scans scan lines **570**A and **570**B. Scanner **500** has two input beams derived from a common light source using separation optics such as describe in regard to FIG. **4**B, a scanning

element **510** with four substantially identical facets, and incident areas **520**A and **520**B that are an integer number of facets apart, e.g., 180° apart relative to a rotation axis of scanning element **510**. With this orientation, incident areas **520**A and **520**B simultaneously contain portions of scanning element **510** that direct scan beams to scan lines **570**A and **570**B. The post-scan optics include flat mirrors **552**A, **552**B, **554**A, and **554**B and focusing elements such as curved mirrors **556**A, **556**B, **558**A, and **558**B which simultaneously direct scan beams **530**A and **530**B from areas **520**A and **520**B to the same image plane **580**.

FIG. **6** illustrates a scanner **600** which has three input beams (not shown) that simultaneously illuminate three synchronized areas **620**A, **620**B, and **620**C. Either separate light sources or a common light source with a beam splitter can generate the three input beams. Areas **620**A, **620**B, and **620**C are situated so that identical portions of three different facets of a scanning element **610** are simultaneously in areas **620**A, **620**B, and **620**C. Post-scan optics direct scan beams from areas **620**A, **620**B, and **620**C to an image plane **680** where scan lines **670**A, **670**B, and **670**C form. The post-scan optics include six flat mirrors, **652**A, **652**B, **652**C, and **654**A, **654**B, and **654**C which direct scan beams from respective areas **620**A, **620**B, and **620**C to three identical focusing systems (curved mirrors) **656**A and **658**A, **656**B and **658**B, and **656**C and **658**C, respectively. Mirrors **652**A, **652**B, **652**C, and **654**A, **654**B, and **654**C are positioned so that the optical path length from areas **620**A, **620**B, and **620**C to respective focusing systems **656**A and **658**A, **656**B and **658**B, and **656**C and **658**C are the same. When a common light source is used, proper orientation of the input beams before deflection in area **620**A, **620**B or **620**C causes the image of the light source to have the same orientation at each of the scan lines **670**A, **670**B, and **670**C. This allows changes in the orientation of a common light source (not shown) to cause matching shifts in each of the scan lines **670**A, **670**B, and **670**C and thereby improves the scanner's tolerance of pointing error.

Systems similar to scanner **600** can generate four or more simultaneous synchronized scan beams in an image plane. For four or more simultaneous scan beams, an illumination system has pre-scan optics that direct four or more input beams to four or more respect incidence areas. The incidence areas simultaneously contain the same portions of different facets of a scanning element. Post-scan optics can include, for example, four or more similar or identical focusing systems and injection optics that direct scan beams from the incidence areas to corresponding focusing systems. The injection optics may differ for each incidence area but provide the same optical path lengths from incidence areas to the focusing systems. The geometry of the injection optics depends on the number of facets on the scanning element and the locations of the incidence areas relative to the scanning element. Pre-scan optics can compensate for differences in the injection optics so that each image formed by a scan beam has the same orientation as images formed by the other scan beams.

An advantage of above scanners where multiple scan beams simultaneously originate from a common light source and a scanning element/motor assembly is the high degree of synchronization of the scan beams. Known line-scanner effects such as wedge (deviation in parallelism of two surfaces of the disc), wobble of motor bearings, disc eccentricity, and variations in the rotational speed of the scanning element have substantially less effect on the synchronization of scan lines from a common scanning element and a common light source than on the synchronization of scan lines from separate scanning elements. Additionally, timing synchronization between the two scan lines is automatic for a single scanning element, whereas in the two element system, the rotational orientation of the two scanning elements must be synchronized every time the device is powered up. In particular, when starting a system having two scanning elements, the rotational speed of each element is adjusted in an iterative fashion to match not only the speeds but also the relative phases of the elements. A scanner using a single scanning element has the further advantages of being relatively compact and inexpensive because a single scanning head provides multiple scan beams without requiring costly components for scan line synchronization. Prior systems have required a separate scan head for each scan beam and complicated synchronization systems.

FIG. **7** shows a scanner **700** in accordance with an embodiment of the invention that incorporates multiple input beams and/or switching of the paths of the input beams to provide a high duty cycle. Scanner **700** includes a scanning element (holographic disc) **710** having four facets and an illumination system (not shown). In a first configuration, the illumination system simultaneously directs four input beams to incidence areas **720**A, **720**B, **720**C, and **720**D. In a second configuration, the illumination system simultaneously directs two input beams to two of four incidence areas **720**A, **720**B, **720**C, and **720**D at a time. In a third configuration, the illumination system serially directs a single input beam to areas **720**A, **720**B, **720**C, and **720**D. Post-scan optics direct scan beams from areas **720**A, **720**B, **720**C, and **720**D for formation of respective scan lines **770**A, **770**B, **770**C, and **770**D. In scanner **700**, scan lines **770**A and **770**B are aligned in an image plane **780**A to form an extended scan line. Similarly, the post scan optics form scan lines **770**C and **770**D in an image plane **780**C to form a second extended scan line. Alternatively, the post-scan optics can direct each scan line **770**A, **770**B, **770**C, and **770**D to four different image planes to form four separate scan lines or direct all four scan lines **770**A, **770**B, **770**C, and **770**D to the same image plane. Scan lines in a common image plane can be aligned and synchronized to form one long scan line or simultaneously illuminate two or more parallel scan lines.

In the first illumination configuration, each of areas **720**A, **720**B, **720**C, and **720**D directs a scan beam to the respective scan line only when a suitable portion of scanning element **710** is in the area. As illustrated, areas **720**A and **720**C are 180° apart on a four-facet scanning element and simultaneously direct scan beams to respective scan lines **770**A and **770**C. Similarly, areas **720**B and **720**D are 180° apart and simultaneously direct scan beams to respective scan lines **770**B and **770**D. Scanner **700** in the first illumination configuration automatically switches from starting scan lines **770**A and **770**C to starting scan lines **770**B and **770**D after about a one-half facet revolution of scanning element **710**.

In the second illumination configuration, areas **720**A, **720**B, **720**C, and **720**D are paired so that each input beam corresponds to a pair of areas, and the lighting system switches each input beam back and forth from a path to one incident area to path to the other incident area in the pair. For example, area **720**A or **720**D can be paired with area **720**B or **720**C. In the exemplary embodiment, areas **720**A and **720**B are paired, and areas **720**C and **720**D are paired so that aligned scan lines share the same light source and possible misalignments of that light source. In operation, when input beams are simultaneously directed to areas **720**A and **720**C, scanning element **710** directs scan beams to respective sets

of flat mirrors **752**A and **754**A and **752**C and **754**C which reflect scan beams to respective focusing systems **756**A and **756**C. Scanning element **710** rotates through about half the angular span of a facet (e.g., somewhat less than 45° for a four-facet scanning element) while the scan beams scan along scan lines **770**A and **770**C. The illumination system then switches the input beams to paths to areas **720**B and **720**D. Areas **720**B and **720**D are positioned so that portions of facets in areas **720**B and **720**D are the same as the portions that were in areas **720**A and **720**C before the rotation by one half of a facet. While the input beams are directed to areas **720**B and **720**D, scanning element **710** rotates through about half a facet, and scan beams sweep along scan lines **770**B and **770**D. Thus from the start of scan line **770**A or **770**C to the end of scan line **770**B or **770**D, scanning element **710** rotates by one facet and positions the next facets in areas **720**A and **720**C for the start of another scan line. The second illumination configuration utilizes illumination power more efficiently than the first illumination configuration but requires path selection optics and control circuits that are synchronized with the rotation of scanning element **710**.

In the third illumination configuration, path selection optics direct an input beam along a path to area **720**A for scanning of scan line **770**A. (This requires a one half facet rotation of scanning element **710**.) The path selection optics can then switch the input beam to a path to area **720**B or **720**D. Both areas **720**B and **720**D then contain the proper portions of scanning element **710** to begin scanning respective scan line **770**B or **770**D. Once the second scan line **770**B or **770**D is complete, the path selection optics direct the input beam to area **720**C for scanning of the third scan line **770**C. Following scanning of scan line **720**C, the path selection optics direct an input beam to area **720**D or **720**B for scanning of the last of the four scan lines **770**D or **770**B. The third illumination configuration has the advantage of high duty cycle without beam splitting since a single input beam (and a single light source) are used for all of scan lines **770**A, **770**B, **770**C, and **770**D, but the third illumination configuration is slower than the first or second illumination configurations because scan lines are scanned serially (one at a time). However, this illumination is attractive for applications that require high energy density since all energy from the source is directed to a single scan line.

FIG. **8** shows a scanner **800** in accordance with an embodiment of the invention that uses multiple light sources **810**A and **810**B rather than path selection optics and path switching as in scanners **100** and **300** of FIGS. **1**A, **1**B, and **1**C or a beam splitter as in scanner **400** of FIGS. **4**A and **4**B. Light sources **810**A and **810**B may be, for example, lasers, laser diodes, or other sources of electromagnetic radiation of suitable wavelength, intensity, and collimation. Light sources **81** OA and **810**B simultaneously direct separate input beams through respective pre-scan optics **830**A and **830**B to respective areas **846**A and **846**B. A scanning element **840**, which is a holographic disc in this embodiment, and areas **846**A and **846**B are positioned so that the same portions of two different facets of scanning element **840** are simultaneously in areas **846**A and **846**B. This causes symmetric deflections of scan beams **890**A and **890**B. The portions of scanning element **840** in areas **846**A and **846**B direct scan beams **890**A and **890**B into post-scan optics which include flat mirrors **852**A and **852**B, focusing elements such as curved mirrors **854**A and **854**B, and holographic elements **856**A and **856**B.

In FIG. **8**, the post-scan optics direct synchronized scan beams **890**A and **890**B to separate image planes so that scan beams **890**A and **890**B scan along the surfaces of drums **870**A and **870**B respectively. Systems having multiple image planes and drums are commonly employed, for example, in color laser printers. For color printing, beams corresponding to different colors must be synchronized for drums **870**A and **870**B to apply corresponding lines and pixels of different colors to the same locations on media being printed. Alternatively, both scan beams can be directed to the same image plane and conjoined to form a single extended scan line. Scanner **800** has the advantages of using a single scanning element **840**. In particular, variations in rotational speed of scanning element **840** have the same effects on scan lines on drums **870**A and **870**B. Use of separate light sources **810**A and **810**B may provide a more economical method of achieving a desired scan beam intensity than would using a single light source and beam splitting. According, separate light source can be employed in any of the above described embodiments employing multiple input beams.

Although the invention has been described with reference to particular embodiments, the description is only an example of the invention's application and should not be taken as a limitation. In particular, even though much of preceding discussion was aimed at holographic scanning elements having four facets, alternative embodiments of the invention include scanning elements including holographic discs and polygon mirrors having any number of facets. Additionally, due to the position and time synchronization provided by a single deflecting element, each of the embodiments described can be used in conjunction with the line correction techniques described to concatenate two or more scan lines to create longer extended scan lines. Various other adaptations and combinations of features embodiments disclosed are within the scope of the invention as defined by lowing claims.

I claim:

1. A scanner comprising:

a scanning element having an axis of rotation;

an illumination system comprising:

a light source that generates a source beam, and

path selection optics having a first operating mode and a second operating mode, wherein in the first operating mode, the path'selection optics direct the source beam along a first path to a first area, and the source beam forms a first input beam, and in the second operating mode, the path selection optics direct the source beam along a second path to a second area, and the source beam forms a second input beam,

wherein the first and second areas are separated from each other by an angle about the axis of rotation of the scanning element and situated so that portions of the scanning element move through the first and second areas during a scanning operation, wherein a first scan beam originates from deflection of the first input beam by portions of the scanning element in the first area, and a second scan beam originates from deflection of the second input beam by portions of the scanning element in the second area; and

post-scan optics that direct the first scan beam to illuminate a first scan line and direct the second scan beam to illuminate a second scan line.

2. The scanner of claim **1**, wherein the scanning element is a holographic disc.

3. The scanner of claim **1**, wherein the scanning element is a polygon mirror.

4. The scanner of claim **1**, wherein the illumination system alternates between directing the first input beam to the first area and directing the second input beam to the second area.

5. The scanner of claim 4, wherein:

the scanning element has a plurality of substantially identical facets; and

the first and second areas are situated so that a first portion of the scanning element in the first area when the scanning element has a first orientation is substantially identical to a second portion of the scanning element that is in the second area after rotating the scanning element from the first orientation by about one half an angular span of a facet.

6. The scanner of claim 5, wherein the scanning element is a holographic disc.

7. The scanner of claim 5, wherein the scanning element is a polygon mirror.

8. The scanner of claim 1, wherein the illumination system simultaneously directs the first input beam and the second input beam to the first and second areas, respectively.

9. The scanner of claim 1, wherein the first and second areas are situated relative to the scanning element so that when the post-scan optics direct the first scan beam to an end of the first scan line, the post-scan optics also direct the second scan beam to a start of the second scan line.

10. The scanner of claim 1, wherein the angle separating the first and second areas spans at least one facet of the scanning element.

11. The scanner of claim 1, wherein the angle separating the first and second areas spans an integer multiple of an angular size of a facet of the scanning element.

12. A scanner comprising:

a scanning element having an axis of rotation;

an illumination system comprising:

a light source that generates a source beam, and

path selection optics having a first operating mode and a second operating mode, wherein in the first operating mode, the path selection optics direct the source beam along a first path to a first area, and the source beam forms a first input beam, and in the second operating mode, the path selection optics direct the source beam along a second path to a second area, and the source beam forms a second input beam,

wherein the first and second areas are separated from each other by an angle about the axis of rotation of the scanning element and situated so that portions of the scanning element move through the first and second areas during a scanning operation, wherein a first scan beam originates from deflection of the first input beam by portions of the scanning element in the first area, and a second scan beam originates from deflection of the second input beam by portions of the scanning element in the second area;

post-can optics that direct the first scan beam to illuminate a first scan line and direct the second scan beam to illuminate a second scan line, wherein the post-scan optics form the first scan line and the second scan line, wherein the post-scan optics form the first scan line and the second scan line in an image plane; and

an alignment system that aligns the first scan line with the second scan line to form an extended scan line that extends along the length of the first and second scan lines.

13. The scanner of claim 12, wherein the post-scan optics comprise a mirror which is in an optical path from the scanning element to the image plane, the mirror comprising:

a first mirrored section positioned to reflect the first scan beam;

a second mirrored section positioned to reflect the second scan beam; and

a transparent section between the first and second mirrored sections.

14. The scanner of claim 13, wherein the alignment system further comprises a beam detector assembly mounted in the transparent section of the mirror.

15. The scanner of claim 12, wherein the alignment system comprises a beam detector assembly situated between the image plane and the scanning element and in a gap between a path of the first scan beam leading to an end of the first scan line and a path of the second scan beam leading to a start of the second scan line.

16. A method for illuminating scan lines, comprising:

generating a source beam by a light source;

directing a first input beam along a first path to a first area, the source beam forming the first input beam;

directing a second input beam along a second path to a second area separated from the first area by an angle about a rotation axis of a scanning element, the source beam forming the second input beam;

positioning the scanning element so that portions of the scanning element move through the first area and the second area during scanning, wherein portions of the scanning element in the first area deflect the first input beam to create a first scan beam, and portions of the scanning element in the second area deflect the second input beam to create a second scan beam; and

directing the first and second scan beams to post-scan optics that direct the first scan beam and the second scan beam to respectively form a first scan line and a second scan line.

17. The method of claim 16, further comprising:

generating the source beam; and

alternating between directing the source beam along a first path to perform the step of directing the first input beam to the first area and directing the source beam along a second path to perform the step of directing the second input beam to the second area.

18. The method of claim 16, wherein the steps of directing the first input beam to the first area and directing the second input beam to the second area are performed simultaneously.

19. The method of claim 16, wherein the scanning element is a holographic disc.

20. The method of claim 16, wherein the scanning element is a polygon mirror.

21. The scanner of claim 16, wherein the angle separating the first and second areas spans at least one facet of the scanning element.

22. The scanner of claim 16, wherein the angle separating the first and second areas spans an integer multiple of an angular size of a facet of the scanning element.

23. A method for illuminating scan lines, comprising:

generating a source beam by a light source;

directing a first input beam to a first area, the source beam forming the first input beam;

directing a second input beam to a second area separated from the first areas the source beam forming the second input beam;

positioning a scanning element so that portions of the scanning element move through the first area and the second area during scanning, wherein portions of the scanning element in the first area deflect the first input beam to create a first scan beam, and portions of the scanning element in the second area deflect the second input beam to create a second scan beam;

directing the first and second scan beams to post-scan optics that direct the first scan beam and the second scan beam to respectively form a first scan line and a second scan line; and

aligning the first and the second scan lines to form a third scan line that extends along lengths of the first and second scan lines.

24. The method of claim **23**, further comprising detecting respective positions of an end of the first scan line and a start of the second scan line using a detector assembly that is situated between the scanning element and a plane containing the first and second scan lines, the detector assembly being in a gap between a path of the first scan beam to the end of the first scan line and a path of the second scan beam to the start of the second scan line.

25. A method for scanning comprising:

generating a source beam by a light source;

generating an input beam, the source beam forming the input beam;

directing the input beam along a path to a first area of a scanning element while forming a first scan line; and

changing the path of the input beam to direct the input beam to a second area of the scanning element while forming a second scan line, the second area being separated from the first area by an angle about a rotation axis of the scanning element.

26. The method of claim **25**, wherein changing the path is performed during dead time when the first area of the scanning element would not direct the input beam into a desired scanning aperture.

27. The scanner of claim **25**, wherein the angle separating the first and second areas spans at least one facet of the scanning element.

28. The scanner of claim **25**, wherein the angle separating the first and second areas spans an integer multiple of an angular size of a facet of the scanning element.

29. A scanner comprising:

a scanning element;

an illumination system that directs a first input beam to a first area and a second input beam to a second area, the first and second areas being separated from each other and situated so that portions of the scanning element move through the first and second areas during a scanning operation, wherein a first scan beam originates from deflection of the first input beam by portions of the scanning element in the first area, and a second scan beam originates from deflection of the second input beam by portions of the scanning element in the second area;

post-scan optics that direct the first scan beam to illuminate a first scan line and direct the second scan beam to illuminate a second scan line, wherein the post-scan optics form the first scan line and the second scan line in an image plane, wherein the post-scan optics comprise a mirror which is in an optical path from the scanning element to the image plane, the mirror comprising:

a first mirrored section positioned to reflect the first scan beam,

a second mirrored section positioned to reflect the second scan beam, and

a transparent section between the first and second mirrored section; and

an alignment system that aligns the first scan line with the second scan line to form an extended scan line that extends along the length of the first and second scan lines, wherein the alignment system further comprises a beam detector assembly mounted in the transparent section of the mirror.

30. A scanning element;

an illumination system that directs a first input beam to a first area and a second input beam to a second area, the first and second areas being separated from each other and situated so that portions of the scanning element move through the first and second areas during a scanning operation, wherein a first scan beam originates from deflection of the first input beam by portions of the scanning element in the first area, and a second scan beam originates from deflection of the second input beam by portions of the scanning element in the second area;

post-scan optics that direct the first scan beam to illuminate a first scan line and direct the second scan beam to illuminate a second scan line, wherein the post-scan optics form the first scan line and the second scan line in an image plane; and

an alignment system that aligns the first scan line with the second scan line to form an extended scan line that extends along the length of the first and second scan lines, wherein the alignment system comprises a beam detector assembly situated between the image plane and the scanning element and in a gap between a path of the first scan beam leading to an end of the first scan line and a path of the second scan beam leading to a start of the second scan line.

31. A method for illuminating scan lines, comprising:

directing a first input beam to a first area;

directing a second input beam to a second area separated from the first area;

positioning a scanning element so that portions of the scanning element move through the first area and the second area during scanning, wherein portions of the scanning element in the first area deflect the first input beam to create a first scan beam, and portions of the scanning element in the second area deflect the second input beam to create a second scan beam;

directing the first and second scan beams to post-scan optics that direct the first scan beam and the second scan beam to respectively form a first scan line and a second scan line;

aligning the first and the second scan lines to form a third scan line that extends along lengths of the first and second scan lines; and

detecting respective positions of an end of the first scan line and a start of the second scan line using a detector assembly that is situated between the scanning element and a plane containing the first and second scan lines, the detector assembly being in a gap between a path of the first scan beam to the end of the first scan line and a pat of the second scan beam to the start of the second scan line.

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