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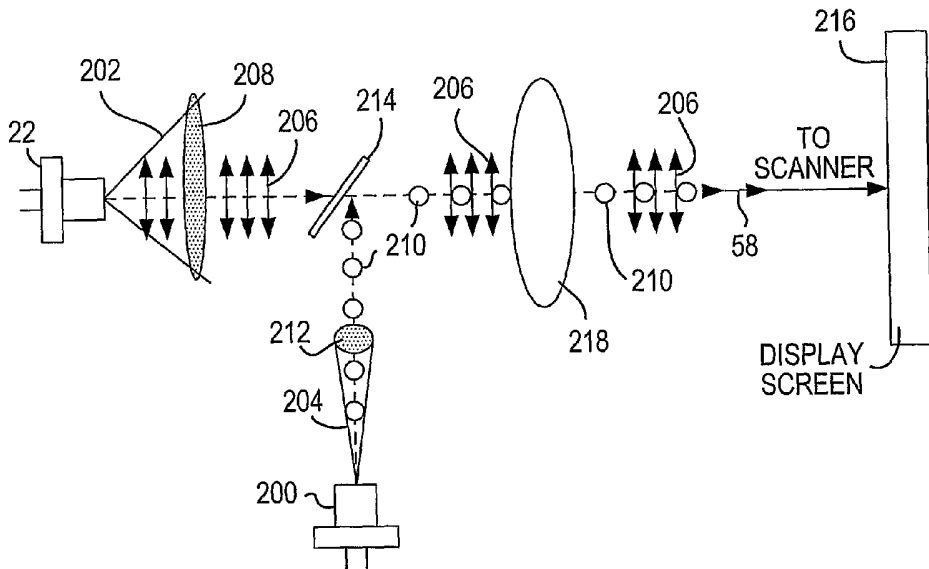
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- (71) Applicant (for all designated States except US): **SYMBOL TECHNOLOGIES, INC.** [US/US]; One Symbol Plaza - Mail Stop A6, Hightstown, NY 11742-1300 (US).
- (72) Inventors: **TAN, Chinh**; 14 Blue Top Road, Setauket, NY 11733 (US). **STERN, Miklos**; 329 Eastwood Road, Woodmere, NY 11598 (US).
- (74) Agent: **ISRAEL, Alan**; KIRSCHSTEIN OTTINGER ISRAEL & SCHIFFMILLER, P.C., 489 Fifth Avenue, New York, NY 10017 (US).

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(54) Title: ARRANGEMENT FOR AND METHOD OF IMPROVING IMAGE QUALITY, ESPECIALLY FOR IMAGE PROJECTION ARRANGEMENTS



(57) Abstract: A lightweight, compact image projection module, especially for mounting in a housing having a light-transmissive window, is operative for causing selected pixels in a raster pattern to be illuminated to produce an image of high resolution of VGA quality in color. The brightness of the illuminated pixels is enhanced by combining constituent laser beams of the same wavelength. The contrast of the illuminated pixels is improved by sweeping a composite beam across a polarized screen, and by making the polarizations of all the constituent laser beams of the composite beam the same.

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ARRANGEMENT FOR AND METHOD OF IMPROVING IMAGE QUALITY, ESPECIALLY FOR IMAGE PROJECTION ARRANGEMENTS

The present invention generally relates to projecting a two-dimensional image in color while maintaining low power consumption, high resolution, miniature compact size, quiet operation and minimal vibration and, more particularly, to improving the quality of the image.

It is generally known to project a two-dimensional image comprised of pixels on a screen based on a pair of scan mirrors which oscillate in mutually orthogonal directions to scan a laser beam from a laser over a raster pattern. The laser beam is incident as a beam spot on one of the mirrors, for example, a horizontal scan mirror, to sweep the beam spot along a horizontal scan line extending along a horizontal scan direction. The horizontal scan line is incident on the other of the mirrors, i.e., a vertical scan mirror, to sweep the scan line along the vertical direction, thereby creating the raster pattern. Turning the beam spot on by energizing the laser, as the beam spot is swept along each scan line, causes selected pixels in each scan line to be illuminated and rendered visible, while turning the beam spot off by deenergizing the laser causes the remaining pixels to be non-illuminated. The illuminated and non-illuminated pixels comprise the image being projected.

Although generally satisfactory for their intended purpose, the known image projection arrangements project the image with limited resolution, typically less than a fourth of video-graphics-array (VGA) quality of 640 x 480 pixels and, moreover, the quality of the image is somewhat degraded, especially when the image is rendered in color from red, blue and green laser beams emitted from individual red, blue and green lasers. The maximum brightness of each color in an illuminated pixel is limited by the maximum output power of the correspondingly colored laser. The contrast of each illuminated pixel is affected by ambient light levels. Polarized screens are sometimes employed to reduce the effect of strong ambient light, but this option has not been available to laser-based projection arrangements where the lasers emit laser beams of different polarizations.

Accordingly, it is a general object of this invention to provide an image projection arrangement that projects a sharp and clear, two-dimensional color image with improved image quality.

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Another object of this invention is to increase the brightness of the color image projected by such arrangements.

Yet another object of this invention is to reduce, if not eliminate, the effect of ambient light in the projected image.

An additional object is to provide a miniature, compact, lightweight, and portable color image projection arrangement useful in many instruments of different form factors.

In keeping with these objects and others which will become apparent hereinafter, one feature of this invention resides, briefly stated, in an image projection arrangement for projecting a two-dimensional, color image. The arrangement include a scanner for sweeping a main laser beam along mutually orthogonal scan directions to project a pattern of scan lines in space, each scan line having a number of pixels; and a controller operatively connected to the scanner, for causing selected pixels to be illuminated, and rendered visible, by the main beam to produce the color image.

In the preferred embodiment, the scanner includes a pair of oscillatable scan mirrors for sweeping the main beam along the generally mutually orthogonal directions at different scan rates and at different scan angles. At least one of the scan rates exceeds audible frequencies, for example, over 18 kHz, to reduce noise. At least one of the scan mirrors is driven by an inertial drive at a mechanical resonant frequency to minimize power consumption. The image resolution preferably exceeds one-fourth of VGA quality, but typically equals or exceeds VGA quality.

The arrangement is interchangeably mountable in housings of different form factors, including, but not limited to, a pen-shaped, gun-shaped or flashlight-shaped instrument, a personal digital assistant, a pendant, a watch, a computer, and, in short, any shape due to its compact and miniature size. The projected image can be used for advertising or signage purposes, or for a television or computer monitor screen, and, in short, for any purpose desiring something to be displayed.

In accordance with this invention, an optical assembly is provided for increasing the brightness of the illuminated pixels. The optical assembly is operative for generating a plurality of constituent laser beams having respective output powers and mutually orthogonal polarizations, and a polarization beam combiner for combining the constituent beams to form the main beam with an output power greater than each output power of the constituent beams. The

constituent laser beams are emitted from a corresponding plurality of lasers. The polarization of any one constituent laser beam can be changed by physically rotating a housing of the laser. Alternatively, a half-wave plate can be placed in the optical path of the constituent beam whose polarization is to be changed.

In the case of a color image, the aforementioned optical assembly is provided for each color laser, i.e., for red, blue and green lasers. The brightness of any one color constituent of an illuminated pixel is no longer limited by the maximum output power of a single color laser, but instead, is a function of how many additional lasers of that color are employed.

In further accordance with this invention, the contrast of the illuminated pixels on a display screen is enhanced by reducing the effect of strong ambient light, such as sunlight, which tends to wash out the image. A polarized screen is typically employed to reduce such ambient light effects. However, a polarized screen cannot be used where the projected image is swept by a laser beam of mutually orthogonal polarizations.

Hence, to take advantage of the polarized screen, this invention proposes the use of at least one half-wave plate positioned in the optical path of at least one of the beams, for example, the green beam, to insure that the polarizations of the red, blue and green beams all match.

With the brightness increased, and with the contrast enhanced, the quality of the image is improved.

The novel features which are considered as characteristic of the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

FIG. 1 is a perspective view of a hand-held instrument projecting an image at a working distance therefrom;

FIG. 2 is an enlarged, overhead, perspective view of an image projection arrangement for installation in the instrument of FIG. 1;

FIG. 3 is a top plan view of the arrangement of FIG. 2;

FIG. 4 is a perspective front view of an inertial drive for use in the arrangement of FIG. 2;

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FIG. 5 is a perspective rear view of the inertial drive of FIG. 4;

FIG. 6 is a perspective view of a practical implementation of the arrangement of FIG. 2;

FIG. 7 is an electrical schematic block diagram depicting operation of the arrangement of FIG. 2;

FIG. 8 is a diagrammatic view of an optical assembly for improving brightness of a projected image in accordance with one embodiment of this invention;

FIG. 9 is a diagrammatic view of an optical assembly for improving brightness in accordance with another embodiment of this invention; and

FIG. 10 is a view analogous to FIG. 3, depicting an embodiment of this invention for enhancing image contrast.

Reference numeral 10 in FIG. 1 generally identifies a hand-held instrument, for example, a personal digital assistant, in which a lightweight, compact, image projection arrangement 20, as shown in FIG. 2, is mounted and operative for projecting a two-dimensional color image at a variable distance from the instrument. By way of example, an image 18 is situated within a working range of distances relative to the instrument 10.

As shown in FIG. 1, the image 18 extends over an optical horizontal scan angle A extending along the horizontal direction, and over an optical vertical scan angle B extending along the vertical direction, of the image. As described below, the image is comprised of illuminated and non-illuminated pixels on a raster pattern of scan lines swept by a scanner in the arrangement 20.

The parallelepiped shape of the instrument 10 represents just one form factor of a housing in which the arrangement 20 may be implemented. The instrument can be shaped as a pen, a cellular telephone, a clamshell or a wristwatch.

In the preferred embodiment, the arrangement 20 measures less than about 30 cubic centimeters in volume. This compact, miniature size allows the arrangement 20 to be mounted in housings of many diverse shapes, large or small, portable or stationary, including some having an on-board display 12, a keypad 14, and a window 16 through which the image is projected.

Referring to FIGS. 2 and 3, the arrangement 20 includes an edge-emitting, semiconductor red laser 22 which, when energized, emits a bright red laser beam at about 635-

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655 nanometers having an oval beam spot in cross-section. Lens 24 is a biaspheric convex lens having a positive focal length and is operative for collecting virtually all the energy in the red beam and for producing a diffraction-limited beam. Lens 26 is a concave lens having a negative focal length. Lenses 24, 26 are held by non-illustrated respective lens holders apart on a support (not illustrated in FIG. 2 for clarity) inside the instrument 10. The lenses 24, 26 shape the red beam profile over the working distance. The lenses 24, 26 are preferably rotationally symmetric.

Another edge-emitting, semiconductor blue laser 28 is mounted on the support and, when energized, emits a diffraction-limited blue laser beam at about 475-505 nanometers having an oval beam spot in cross-section. Another biaspheric convex lens 30 and a concave lens 32 are employed to shape the blue beam profile in a manner analogous to lenses 24, 26. The lenses 30, 32 are also preferably rotationally symmetric.

A green laser beam having a wavelength on the order of 530 nanometers is generated not by a semiconductor laser, but instead by a green module 34 having an infrared diode-pumped YAG crystal laser whose output beam at 1060 nanometers. A non-linear frequency doubling crystal is included in the infrared laser cavity between the two laser mirrors. Since the infrared laser power inside the cavity is much larger than the power coupled outside the cavity, the frequency doubler is more efficient generating the double frequency green light inside the cavity. The output mirror of the laser is reflective to the 1060 nm infrared radiation, and transmissive to the doubled 530 nm green laser beam. Since the correct operation of the solid-state laser and frequency doubler requires precise temperature control, a semiconductor device relying on the Peltier effect is used to control the temperature of the green laser module. The thermo-electric cooler can either heat or cool the device depending on the polarity of the applied current. A thermistor is part of the green laser module in order to monitor its temperature. The readout from the thermistor is fed to the controller, which adjusts the control current to the thermo-electric cooler accordingly.

As explained below, the lasers are pulsed in operation at frequencies on the order of 100 MHz. The red and blue semiconductor lasers 22, 28 can be pulsed at such high frequencies, but the currently available green solid-state lasers cannot. As a result, the green laser beam exiting the green module 34 is pulsed with an acousto-optical modulator 36 which creates an acoustic standing wave inside a crystal for diffracting the green beam. The modulator 36, however, produces a zero-order, non-diffracted beam 38 and a first-order, pulsed, diffracted beam

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40. The beam 40 has a generally circular beam spot in cross-section. The beams 38, 40 diverge from each other and, in order to separate them to eliminate the undesirable zero-order beam 38, the beams 38, 40 are routed along a long, folded path having a folding mirror 42. Alternatively, an electro-optic, modulator can be used either externally or internally to the green laser module to pulse the green laser beam. Other possible ways to modulate the green laser beam include electro-absorption modulation, or Mach-Zender interferometer.

The beams 38, 40 are routed through positive and negative lenses 44, 46. However, only the diffracted green beam 40 is allowed to impinge upon, and reflect from, the folding mirror 48. The non-diffracted beam 38 is absorbed by an absorber 50, preferably mounted on the mirror 48. The lenses 44, 46 preferably change the initial circular shape of the beam spot incident on the mirror 42 to an oval shape. After reflecting off the mirror 48, the diffracted green beam 40 has an oval beam spot in cross-section.

The arrangement includes a pair of dichroic filters 52, 54 arranged to make the green, blue and red beams as co-linear as possible before reaching a scanning assembly 60. Filter 52 allows the green beam 40 to pass therethrough, but the blue beam 56 from the blue laser 28 is reflected by the interference effect. Filter 54 allows the green and blue beams 40, 56 to pass therethrough, but the red beam 58 from the red laser 22 is reflected by the interference effect.

The nearly co-linear beams 40, 56, 58 are directed to, and reflected off, a stationary bounce mirror 62. The scanning assembly 60 includes a first scan mirror 64 oscillatable by an inertial drive 66 (shown in isolation in FIGS. 4-5) at a first scan rate to sweep the laser beams reflected off the bounce mirror 62 over the first horizontal scan angle A, and a second scan mirror 68 oscillatable by an electromagnetic drive 70 at a second scan rate to sweep the laser beams reflected off the first scan mirror 64 over the second vertical scan angle B. In a variant construction, the scan mirrors 64, 68 can be replaced by a single two-axis mirror.

The inertial drive 66 is a high-speed, low electrical power-consuming component. Details of the inertial drive can be found in U.S. Patent Application Serial No. 10/387,878, filed March 13, 2003, assigned to the same assignee as the instant application, and incorporated herein by reference thereto. The use of the inertial drive reduces power consumption of the scanning assembly 60 to less than one watt and, in the case of projecting a color image, as described below, to less than ten watts.

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The drive 66 includes a movable frame 74 for supporting the scan mirror 64 by means of a hinge that includes a pair of co-linear hinge portions 76, 78 extending along a hinge axis and connected between opposite regions of the scan mirror 64 and opposite regions of the frame. The frame 74 need not surround the scan mirror 64, as shown.

The frame, hinge portions and scan mirror are fabricated of a one-piece, generally planar, silicon substrate which is approximately 150μ thick. The silicon is etched to form omega-shaped slots having upper parallel slot sections, lower parallel slot sections, and U-shaped central slot sections. The scan mirror 64 preferably has an oval shape and is free to move in the slot sections. In the preferred embodiment, the dimensions along the axes of the oval-shaped scan mirror measure $749\mu \times 1600\mu$. Each hinge portion measure 27μ in width and 1130μ in length. The frame has a rectangular shape measuring 3100μ in width and 4600μ in length.

The inertial drive is mounted on a generally planar, printed circuit board 80 and is operative for directly moving the frame and, by inertia, for indirectly oscillating the scan mirror 64 about the hinge axis. One embodiment of the inertial drive includes a pair of piezoelectric transducers 82, 84 extending perpendicularly of the board 80 and into contact with spaced apart portions of the frame 74 at either side of hinge portion 76. An adhesive may be used to insure a permanent contact between one end of each transducer and each frame portion. The opposite end of each transducer projects out of the rear of the board 80 and is electrically connected by wires 86, 88 to a periodic alternating voltage source (not shown).

In use, the periodic signal applies a periodic drive voltage to each transducer and causes the respective transducer to alternately extend and contract in length. When transducer 82 extends, transducer 84 contracts, and vice versa, thereby simultaneously pushing and pulling the spaced apart frame portions and causing the frame to twist about the hinge axis. The drive voltage has a frequency corresponding to the mechanical resonant frequency of the scan mirror. The scan mirror is moved from its initial rest position until it also oscillates about the hinge axis at the resonant frequency. In a preferred embodiment, the frame and the scan mirror are about 150μ thick, and the scan mirror has a high Q factor. A movement on the order of 1μ by each transducer can cause oscillation of the scan mirror at scan rates in excess of 20 kHz.

Another pair of piezoelectric transducers 90, 92 extends perpendicularly of the board 80 and into permanent contact with spaced apart portions of the frame 74 at either side of hinge portion 78. Transducers 90, 92 serve as feedback devices to monitor the oscillating

movement of the frame and to generate and conduct electrical feedback signals along wires 94, 96 to a feedback control circuit (not shown).

Alternately, instead of using piezo-electric elements for feedback, magnetic feedback can be used, where a magnet is mounted on the back of the high-speed mirror, and an external coil is used to pickup the changing magnetic field generated by the oscillating magnet.

Although light can reflect off an outer surface of the scan mirror, it is desirable to coat the surface of the mirror 64 with a specular coating made of gold, silver, aluminum, or specially designed highly reflective dielectric coating.

The electromagnetic drive 70 includes a permanent magnet jointly mounted on and behind the second scan mirror 68, and an electromagnetic coil 72 operative for generating a periodic magnetic field in response to receiving a periodic drive signal. The coil 72 is adjacent the magnet so that the periodic field magnetically interacts with the permanent field of the magnet and causes the magnet and, in turn, the second scan mirror 68 to oscillate.

The inertial drive 66 oscillates the scan mirror 64 at a high speed at a scan rate preferably greater than 5 kHz and, more particularly, on the order of 18 kHz or more. This high scan rate is at an inaudible frequency, thereby minimizing noise and vibration. The electromagnetic drive 70 oscillates the scan mirror 68 at a slower scan rate on the order of 40 Hz which is fast enough to allow the image to persist on a human eye retina without excessive flicker.

The faster mirror 64 sweeps a horizontal scan line, and the slower mirror 68 sweeps the horizontal scan line vertically, thereby creating a raster pattern which is a grid or sequence of roughly parallel scan lines from which the image is constructed. Each scan line has a number of pixels. The image resolution is preferably XGA quality of 1024 x 768 pixels. Over a limited working range we can display high-definition television standard, denoted 720p, 1270 x 720 pixels. In some applications, a one-half VGA quality of 320 x 480 pixels, or one-fourth VGA quality of 320 x 240 pixels, is sufficient. At minimum, a resolution of 160 x 160 pixels is desired.

The roles of the mirrors 64, 68 could be reversed so that mirror 68 is the faster, and mirror 64 is the slower. Mirror 64 can also be designed to sweep the vertical scan line, in which event, mirror 68 would sweep the horizontal scan line. Also, the inertial drive can be used

to drive the mirror 68. Indeed, either mirror can be driven by an electromechanical, electrical, mechanical, electrostatic, magnetic, or electromagnetic drive.

The slow-mirror is operated in a constant velocity sweep-mode during which time the image is displayed. During the mirror's return, the mirror is swept back into the initial position at its natural frequency, which is significantly higher. During the mirror's return trip, the lasers can be powered down in order to reduce the power consumption of the device.

FIG. 6 is a practical implementation of the arrangement 20 in the same perspective as that of FIG. 2. The aforementioned components are mounted on a support which includes a top cover 100 and a support plate 102. Holders 104, 106, 108, 110, 112 respectively hold folding mirrors 42, 48, filters 52, 54 and bounce mirror 62 in mutual alignment. Each holder has a plurality of positioning slots for receiving positioning posts stationarily mounted on the support. Thus, the mirrors and filters are correctly positioned. As shown, there are three posts, thereby permitting two angular adjustments and one lateral adjustment. Each holder can be glued in its final position.

The image is constructed by selective illumination of the pixels in one or more of the scan lines. As described below in greater detail with reference to FIG. 7, a controller 114 causes selected pixels in the raster pattern to be illuminated, and rendered visible, by the three laser beams. For example, red, blue and green power controllers 116, 118, 120 respectively conduct electrical currents to the red, blue and green lasers 22, 28, 34 to energize the latter to emit respective light beams at each selected pixel, and do not conduct electrical currents to the red, blue and green lasers to deenergize the latter to non-illuminate the other non-selected pixels. The resulting pattern of illuminated and non-illuminated pixels comprise the image, which can be any display of human- or machine-readable information or graphic.

Referring to FIG. 1, the raster pattern is shown in an enlarged view. Starting at an end point, the laser beams are swept by the inertial drive along the horizontal direction at the horizontal scan rate to an opposite end point to form a scan line. Thereupon, the laser beams are swept by the electromagnetic drive 70 along the vertical direction at the vertical scan rate to another end point to form a second scan line. The formation of successive scan lines proceeds in the same manner.

The image is created in the raster pattern by energizing or pulsing the lasers on and off at selected times under control of the microprocessor 114 or control circuit by operation

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of the power controllers 116, 118, 120. The lasers produce visible light and are turned on only when a pixel in the desired image is desired to be seen. The color of each pixel is determined by one or more of the colors of the beams. Any color in the visible light spectrum can be formed by the selective superimposition of one or more of the red, blue, and green lasers. The raster pattern is a grid made of multiple pixels on each line, and of multiple lines. The image is a bit-map of selected pixels. Every letter or number, any graphical design or logo, and even machine-readable bar code symbols, can be formed as a bit-mapped image.

As shown in FIG. 7, an incoming video signal having vertical and horizontal synchronization data, as well as pixel and clock data, is sent to red, blue and green buffers 122, 124, 126 under control of the microprocessor 114. The storage of one full VGA frame requires many kilobytes, and it would be desirable to have enough memory in the buffers for two full frames to enable one frame to be written, while another frame is being processed and projected. The buffered data is sent to a formatter 128 under control of a speed profiler 130 and to red, blue and green look up tables (LUTs) 132, 134, 136 to correct inherent internal distortions caused by scanning, as well as geometrical distortions caused by the angle of the display of the projected image. The resulting red, blue and green digital signals are converted to red, blue and green analog signals by digital to analog converters (DACs) 138, 140, 142. The red and blue analog signals are fed to red and blue laser drivers (LDs) 144, 146 which are also connected to the red and blue power controllers 116, 118. The green analog signal is fed to an acousto-optical module (AOM) radio frequency (RF) driver 150 and, in turn, to the green laser 34 which is also connected to a green LD 148 and to the green power controller 120.

Feedback controls are also shown in FIG. 7, including red, blue and green photodiode amplifiers 152, 154, 156 connected to red, blue and green analog-to-digital (A/D) converters 158, 160, 162 and, in turn, to the microprocessor 114. Heat is monitored by a thermistor amplifier 164 connected to an A/D converter 166 and, in turn, to the microprocessor.

The scan mirrors 64, 68 are driven by drivers 168, 170 which are fed analog drive signals from DACs 172, 174 which are, in turn, connected to the microprocessor. Feedback amplifiers 176, 178 detect the position of the scan mirrors 64, 68, and are connected to feedback A/Ds 180, 182 and, in turn, to the microprocessor.

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A power management circuit 184 is operative to minimize power while allowing fast on-times, preferably by keeping the green laser on all the time, and by keeping the current of the red and blue lasers just below the lasing threshold.

A laser safety shut down circuit 186 is operative to shut the lasers off if either of the scan mirrors 64, 68 is detected as being out of position.

As previously noted, each illuminated pixel is illuminated by one or more of the red, blue and green laser beams. The brightness of each illuminated pixel is a function of the output powers of one or more of the red, blue and green lasers and, hence, the maximum brightness of any individual colored component of a respective illuminated pixel is limited by the maximum output power of the corresponding colored laser. For example, the maximum brightness of a red component of an illuminated pixel is limited by the maximum output power of the red laser 22.

In order to obtain a brighter colored component and, hence, a brighter image, one feature of this invention is to employ additional lasers for one or more of each color. As shown in FIG. 8 for the representative red laser 22, another red laser 200 is mounted on the support. Each red laser 22, 200 emits a linearly polarized, red constituent beam 202, 204. The linear polarization of each laser is fixed with respect to a housing of the respective laser. That is, turning the laser housing by 90° changes the polarization from vertical to horizontal, and vice versa.

As shown in FIG. 8 by the double-headed arrows 206, the polarization of the constituent beam 202 of the red laser 22 is parallel, i.e., vertically elongated along the longer beam spot dimension of the oval beam spot 208 of the red laser 22. As shown by the circles 210 in FIG. 8, the polarization of the constituent beam 204 of the red laser 200 is perpendicular, i.e., horizontally perpendicular to the parallel polarization indicated by the arrows 206. The cross-section of the oval beam spot along the horizontal direction is indicated by reference numeral 212.

A polarization beam combiner 214 is located in the paths of both orthogonally polarized constituent beams 202, 204. The combiner 214 transmits therethrough the beam 202 having a parallel polarization 206 parallel to the vertically polarized combiner, and reflects the beam 204 having a perpendicular polarization perpendicular to the vertically polarized combiner. Both constituent beams 202, 204 are combined by the combiner 214 to form the main beam 58

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and, in effect, the output power of the main beam 58 is greater than the output power of either laser 22 or laser 200 and is, in fact, doubled except for optical losses. Beam forming optics 218, which essentially constitutes the optical lenses 24, 26 (see FIG. 2), optically modifies and shapes the main beam 58. The main beam 58 is transmitted to the scanner, as described above, and then onto a display screen 216 onto which the image 18 is projected.

In order to achieve the mutually orthogonally polarized constituent beams 202, 204 incident on the combiner 214, one or the other of the red lasers 22, 200 is preferably physically rotated by 90° relative to the support. The FIG. 8 arrangement is also applicable to increasing the output power of the main blue beam 56 and of the main green beam 40. Essentially, for each color, an additional laser of the same color is added to the assembly and its output beam is combined with that of the initial colored laser.

FIG. 9 depicts an embodiment which is preferred over that of FIG. 8. As before, the constituent beams of the red lasers 22, 200 are combined in the combiner 214 to form the main red beam 58 for transmission to the scanner, and for projection onto the display screen 216. However, the following differences exist. First, rather than a single beam forming optical assembly 218 in the path of the main beam 58 (see FIG. 8), now a beam forming optical assembly 220 is provided in the path of each constituent red beam. The assembly 220 comprises the aforementioned lenses 24, 26, but is smaller in size than the optical assembly 218 of FIG. 8, primarily because each optical assembly 220 is physically closer to its laser.

Secondly, rather than rotating one or the other of the laser housings to change its polarization direction, in FIG. 9, both lasers are mounted and aligned on the support in the same way. That is, the constituent beam 204 of the red laser 200 has a polarization, as indicated by the double-headed arrows 222, which is parallel to the longer dimension of the oval beam spot 224, just like the arrows 206 are parallel to the longer dimension of the oval beam spot 208. The polarization of the constituent beam 204 is made orthogonal to that of constituent beam 202 by inserting a half-wave plate 226 in the path of the constituent beam 204 prior to reaching the combiner. The half-wave plate 226 is anisotropic, i.e., it has two axes of different indices of refraction. By orienting the half-wave plate with its axes at 45° to the incoming polarized constituent beam, the plate rotates the polarization by 90°.

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As before, the embodiment of FIG. 9 is equally applicable for the blue and the green lasers, again to increase the brightness of these differently colored constituents of the illuminated pixels.

The contrast of the image 18 on the display screen 216 is affected by ambient light. The stronger the ambient light, the lower in contrast the displayed image becomes. It is known to make polarized screens to reduce the effect of ambient light. However, in the embodiments of FIGS. 8-9, the main beam 48 that is scanned across the display screen 216 has mutually orthogonally polarized components and, hence, cannot take advantage of a polarized screen.

To take advantage of a polarized screen, it is desired that each of the red, blue and green beams has the same polarization when the composite main beam is scanned across the polarized screen. As shown in FIG. 10, which is analogous to FIG. 3, the red and blue lasers 22, 28 are semiconductor lasers and have the same polarized constituent beams 58, 56, as schematically illustrated by the double-headed arrows 228. The green laser 34, however, is a frequency-doubled, solid-state laser whose polarization direction, as schematically illustrated by the circles 230, is perpendicular to that of the red and blue constituent beams 58, 56.

Hence, in accordance with another feature of this invention, a half-wave plate 232, analogous to plate 226, is inserted in the path of the constituent green beam, preferably the diffracted beam 40, to rotate the polarization as schematically illustrated by double-headed arrows 234, until it matches those of the red and blue beams 58, 56. With all three red, blue and green beams having the same polarization, the screen 216 can be polarized to thereby reduce the effect of ambient light.

It will be understood that each of the elements described above, or two or more together, also may find a useful application in other types of constructions differing from the types described above.

While the invention has been illustrated and described as embodied in an arrangement for and method of improving image quality, especially for image projection arrangements, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

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Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended claims.

WE CLAIM:

1. An image projection arrangement for projecting an image, comprising:
 - a) a scanner for sweeping a main laser beam along mutually orthogonal scan directions to project a pattern of scan lines each having a number of pixels;
 - b) a controller operatively connected to the scanner, for causing selected pixels to be illuminated, and rendered visible, to produce the image; and
 - c) an optical assembly for generating a plurality of constituent laser beams having respective output powers and mutually orthogonal polarizations, and a polarization beam combiner for combining the constituent laser beams to form the main laser beam with an output power greater than each output power of the constituent laser beams to increase brightness of the illuminated pixels.
2. The image projection arrangement of claim 1, and a support on which the optical assembly is mounted, the optical assembly including a pair of lasers for emitting a pair of the constituent laser beams with a same wavelength; and wherein the combiner is operative for transmitting therethrough one of the constituent laser beams along an optical path, and for reflecting therefrom the other of the constituent laser beams along the same optical path.
3. The image projection arrangement of claim 2, wherein at least one of the lasers is mounted on the support for rotation until the polarization of the constituent laser beam of said at least one laser is orthogonal to the polarization of the constituent laser beam of the other laser.
4. The image projection arrangement of claim 2, wherein the optical assembly includes a half-wave plate for changing the polarization of one of the constituent laser beams to be orthogonal to the polarization of the other of the constituent laser beams.
5. The image projection arrangement of claim 2, wherein the optical assembly includes beam forming optics for optically modifying the main laser beam.
6. The image projection arrangement of claim 2, wherein the optical assembly includes beam forming optics for optically modifying each of the constituent laser beams.
7. The image projection arrangement of claim 2, wherein the constituent laser beams of the pair of lasers has a red color; and wherein the optical assembly includes another pair of lasers for emitting another pair of constituent laser beams with a same wavelength and having

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a blue color, and another combiner for combining the blue constituent laser beams; and wherein the optical assembly includes still another pair of lasers for emitting still another pair of constituent laser beams with a same wavelength and having a green color, and still another combiner for combining the green constituent laser beams.

8. The image projection arrangement of claim 1, wherein the scanner includes a first oscillatable scan mirror for sweeping the main laser beam along one of the scan directions at a first scan rate and over a first scan angle, and a second oscillatable scan mirror for sweeping the main laser beam along a transverse scan direction substantially perpendicular to the one scan direction, and at a second scan rate different from the first scan rate, and at a second scan angle different from the first scan angle.

9. The image projection arrangement of claim 8, wherein at least one of the scan mirrors is oscillated at its mechanical resonant frequency to minimize power consumption.

10. The image projection arrangement of claim 2, wherein the controller includes means for energizing the lasers to illuminate the selected pixels, and for deenergizing the lasers to non-illuminate pixels other than the selected pixels.

11. The image projection arrangement of claim 7, wherein the optical assembly includes optical elements for aligning the pairs of red, blue and green constituent laser beams to form the main laser beam, the polarizations of the red, blue and green constituent laser beams in the main laser beam being the same; and a polarized screen across which the main laser beam is swept to enhance contrast of the illuminated pixels.

12. The image projection arrangement of claim 11, wherein one of the optical elements is a half-wave plate for changing the polarization of the pair of green constituent laser beams to match the polarizations of the pairs of red and blue constituent laser beams.

13. A method of projecting an image, comprising the steps of:

- a) sweeping a main laser beam along mutually orthogonal scan directions to project a pattern of scan lines, each having a number of pixels,
- b) causing selected pixels to be illuminated, and rendered visible, to produce the image;
- c) generating a plurality of constituent laser beams having respective output powers and mutually orthogonal polarizations; and

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d) combining the constituent laser beams to form the main laser beam with an output power greater than each output power of the constituent laser beams to increase brightness of the illuminated pixels.

14. The method of claim 13, wherein the generating step is performed by turning one of the constituent laser beams until its polarization is orthogonal to the polarization of the other of the constituent laser beams.

15. The method of claim 13, wherein the generating step is performed by positioning a half-wave plate in a path of one of the constituent laser beams to change the polarization thereof to be orthogonal to the polarization of the other of the constituent laser beams.

16. An image projection arrangement for projecting an image, comprising:

a) an optical assembly for generating a plurality of constituent laser beams having respective polarizations, and for combining the constituent laser beams into a composite main laser beam in which all the polarizations are the same;

b) a polarized screen;

c) a scanner for sweeping the main laser beam along mutually orthogonal scan directions to project a pattern of scan lines on the screen, each scan line having a number of pixels; and

d) a controller for causing selected pixels to be illuminated, and rendered visible, to produce the image on the screen to increase contrast of the illuminated pixels.

17. The method of claim 16, wherein the polarization of one of the constituent laser beams is orthogonal to the polarization of the other of the constituent laser beams, and wherein the optical assembly includes a half-wave plate for changing the polarization of the one constituent laser beam prior to being combined into the composite main laser beam.

18. The method of claim 17, wherein the one constituent laser beam has a green color, and wherein the other constituent laser beams have red and blue colors.

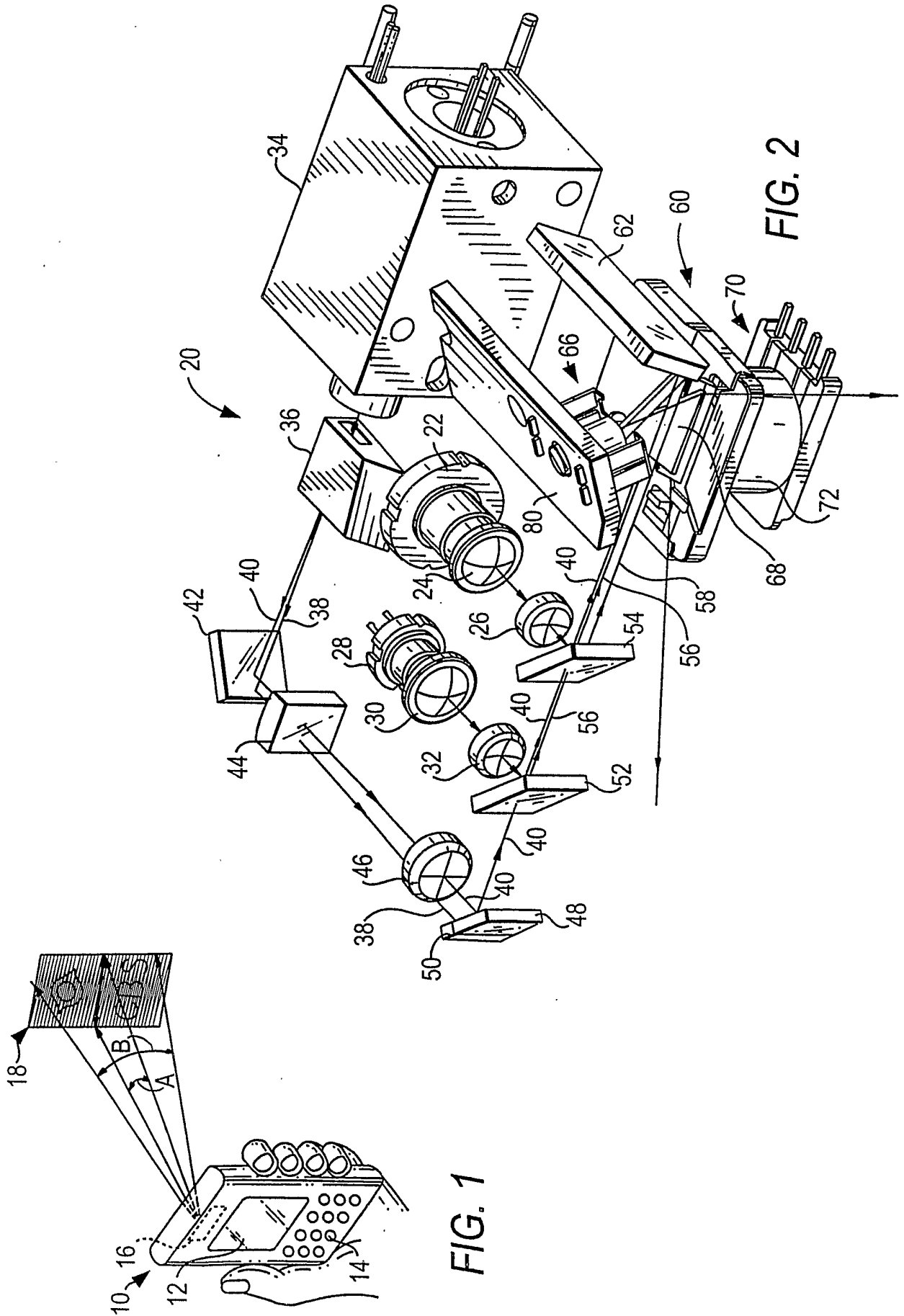
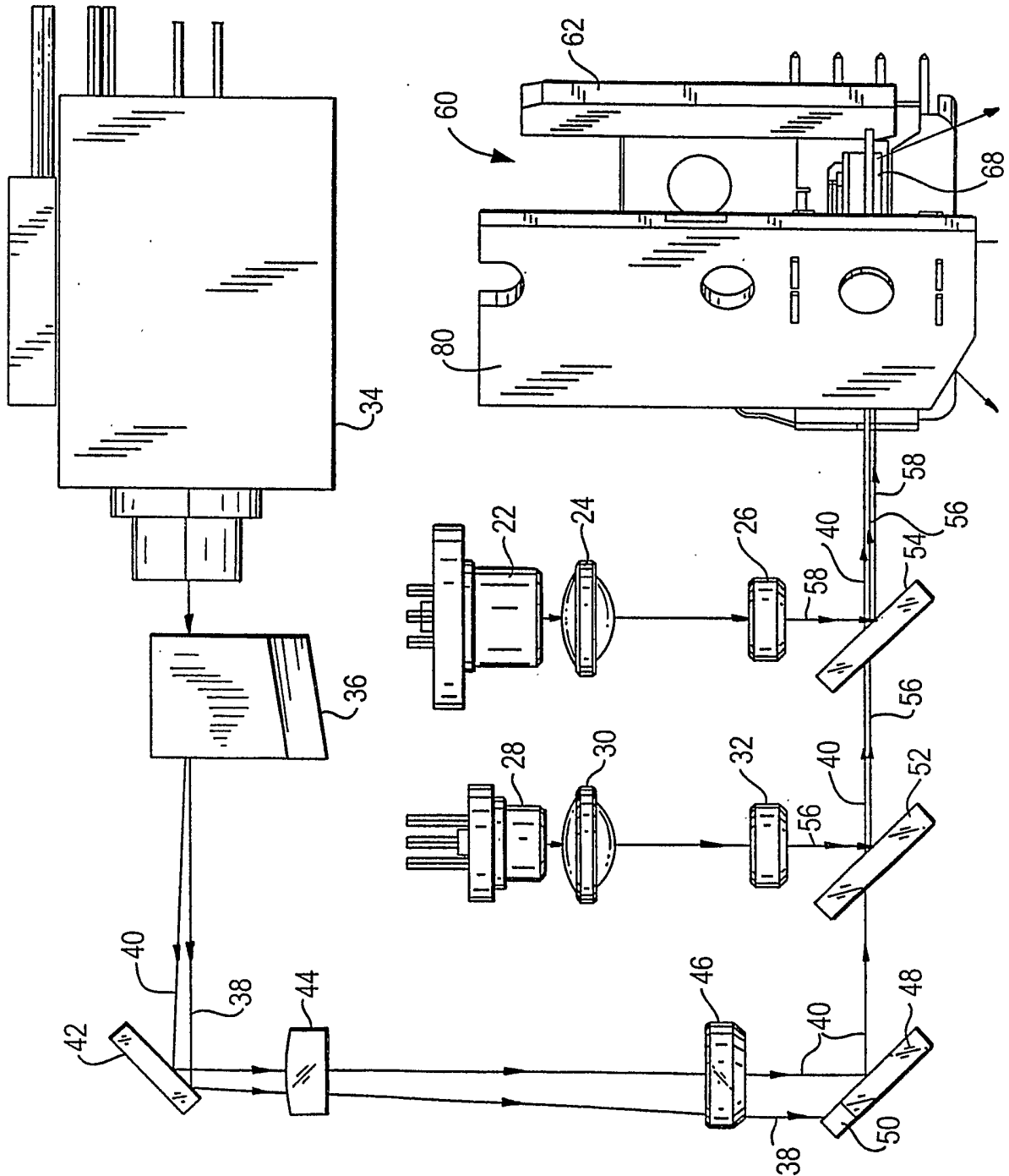


FIG. 2

FIG. 1

FIG. 3



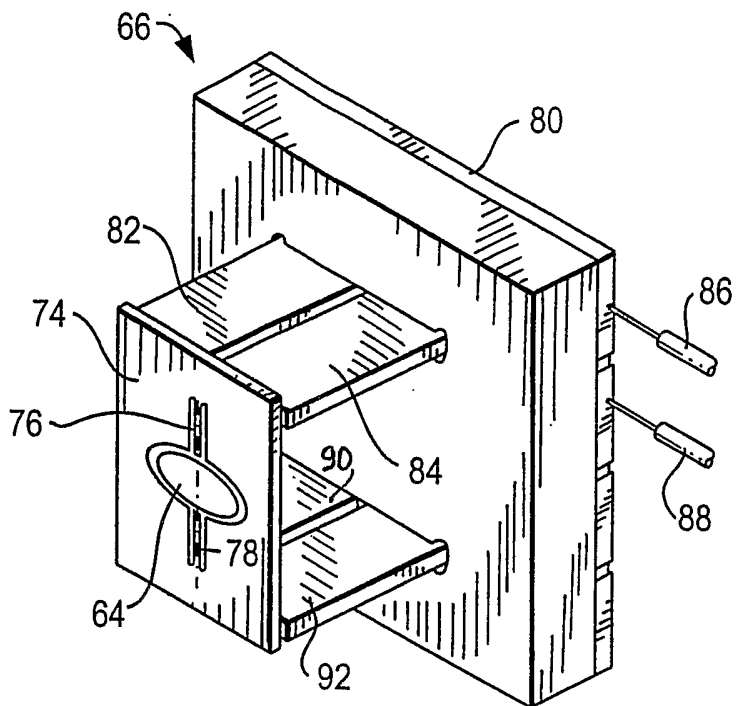


FIG. 4

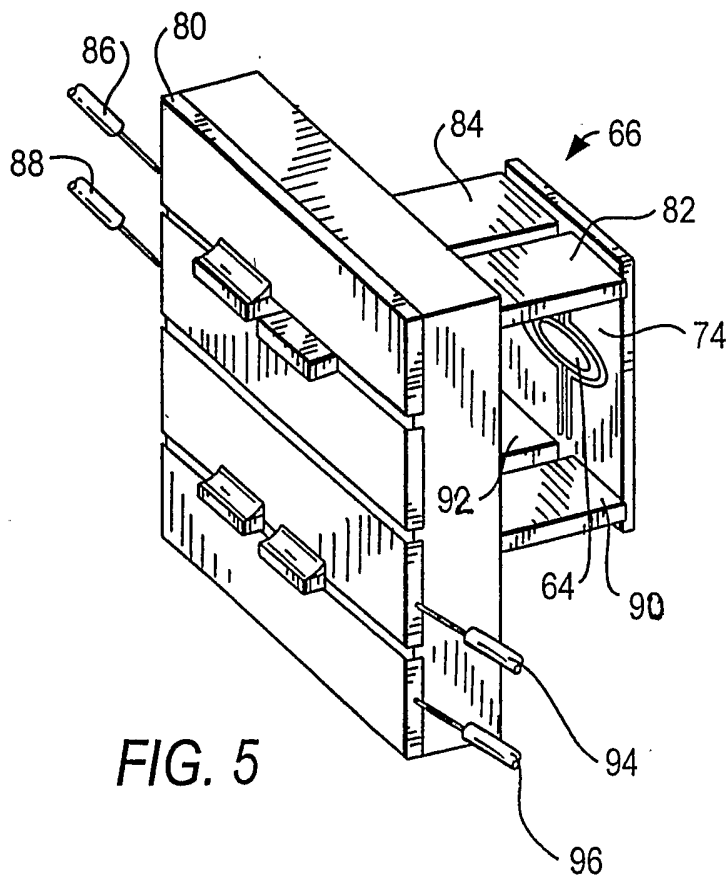


FIG. 5

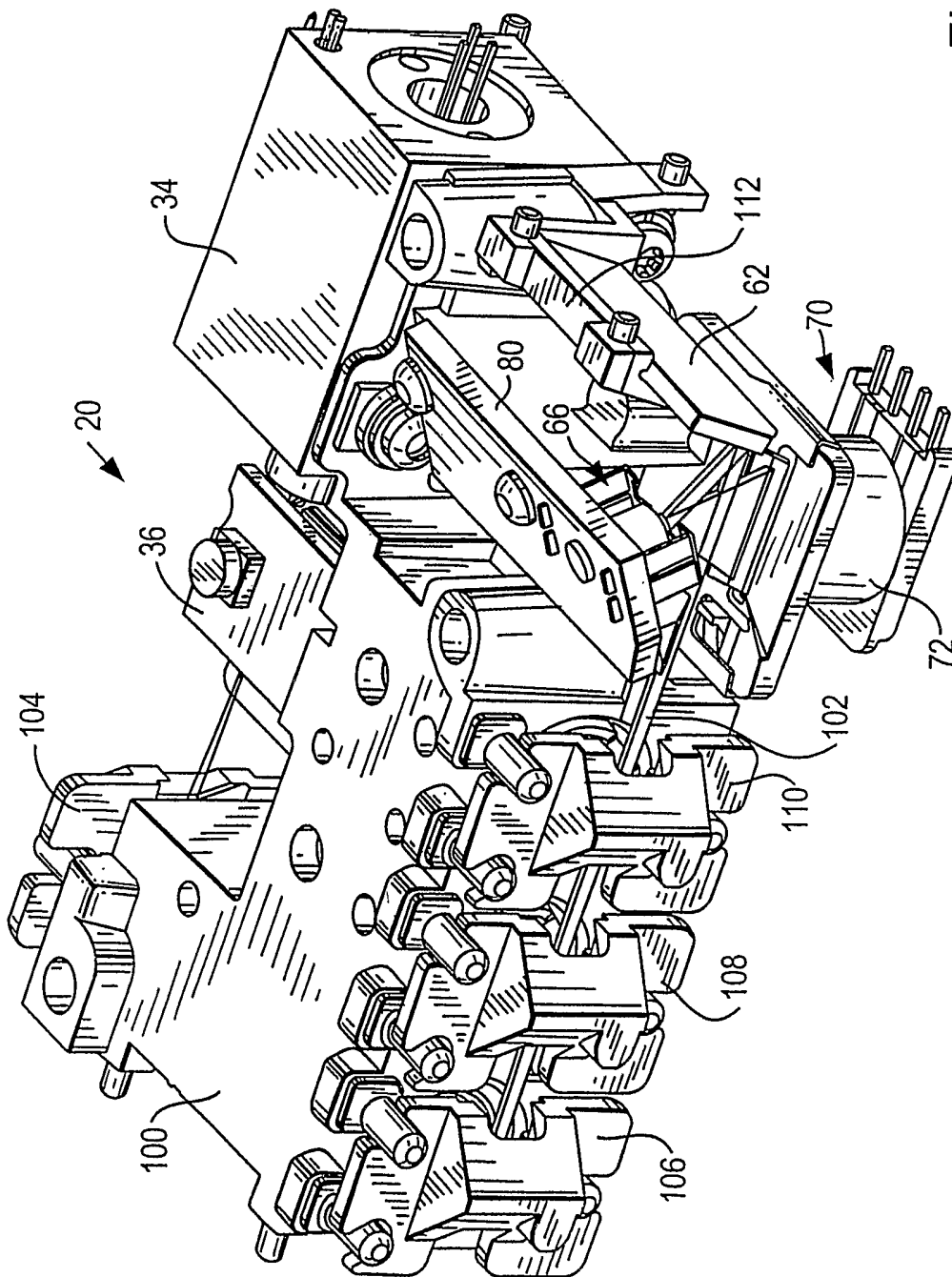
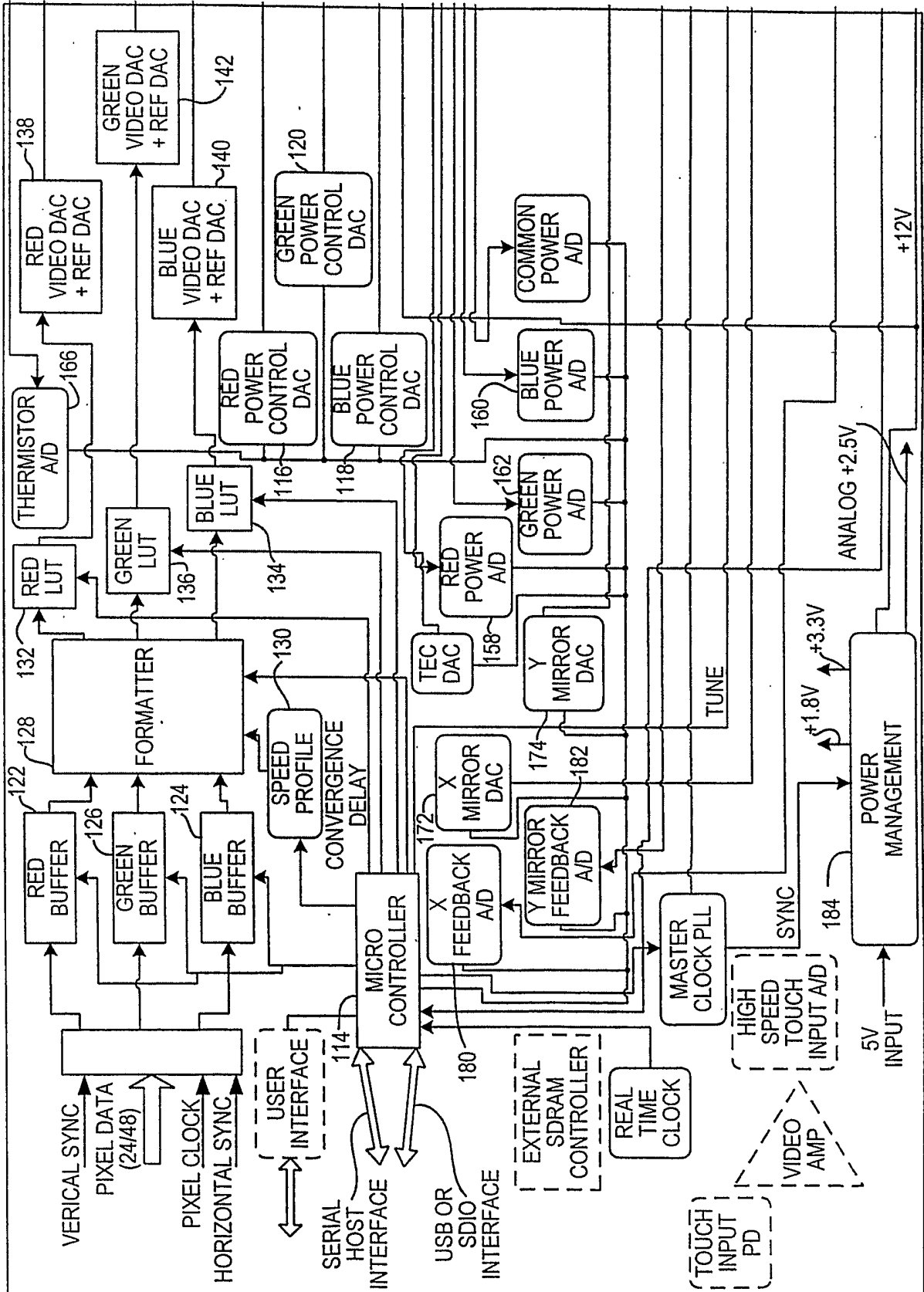


FIG. 6

FIG. 7



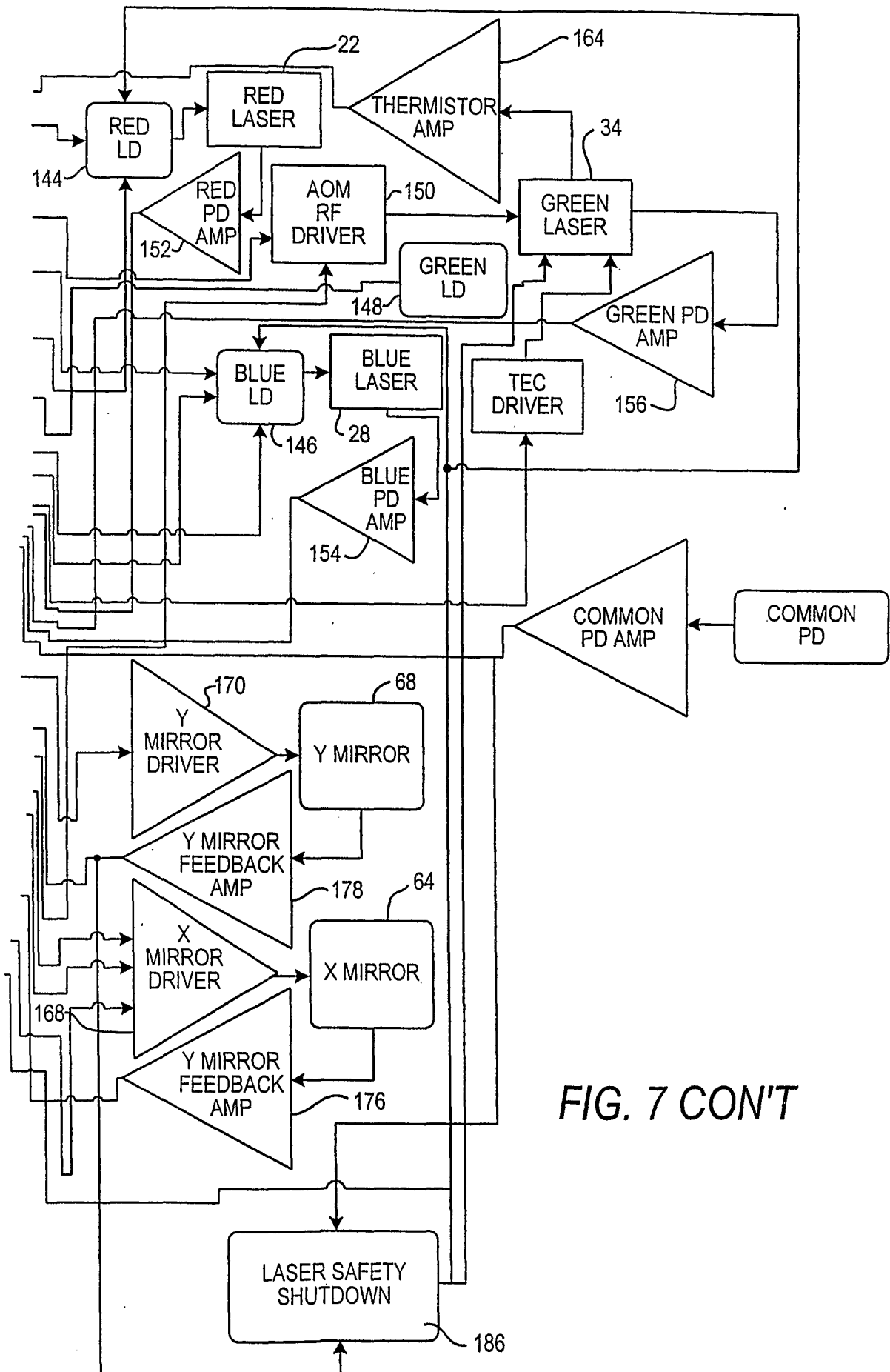


FIG. 7 CON'T

