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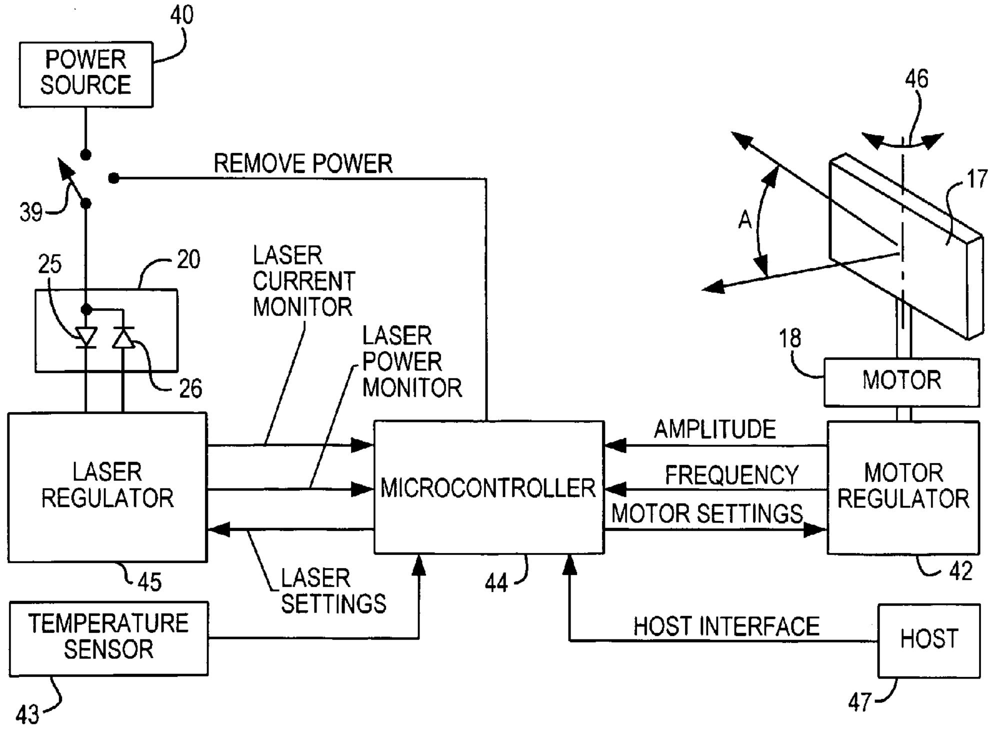
(54) Title: LASER POWER CONTROL ARRANGEMENTS IN ELECTRO-OPTICAL READERS



(57) Abstract: Laser power control arrangements interrupt power to a laser used in electro-optical readers upon detection of operating conditions not conforming to preestablished standards, and adjust power to the laser to enhance reader performance without violating prevalent safety standards.

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LASER POWER CONTROL ARRANGEMENTS IN ELECTRO-OPTICAL READERS

The present invention generally relates to electro-optical readers, such as laser scanners for reading indicia, such as bar code symbols and, more particularly, to laser power control arrangements for enhancing reader performance and safety.

Various electro-optical systems or readers have been developed for reading indicia such as bar code symbols appearing on a label or on a surface of an article. The bar code symbol itself is a coded pattern of graphic indicia comprised of a series of bars of various widths spaced apart from one another to bound spaces of various widths, the bars and spaces having different light reflecting characteristics. The readers function by electro-optically transforming the pattern of the graphic indicia into a time-varying electrical signal, which is digitized and decoded into data relating to the symbol being read.

Typically, a laser beam from a laser is directed along a light path toward a target that includes the bar code symbol on a target surface. A moving-beam scanner operates by repetitively sweeping the laser beam in a scan line or a series of scan lines across the symbol by means of motion of a scanning component, such as the laser itself or a scan mirror disposed in the path of the laser beam. Optics focus the laser beam into a beam spot on the target surface, and the motion of the scanning component sweeps the beam spot across the symbol to trace a scan line across the symbol. Motion of the scanning component is typically effected by an electrical drive motor.

The readers also include a sensor or photodetector which detects light along the scan line that is reflected or scattered from the symbol. The photodetector or sensor is positioned such that it has a field of view which ensures the capture of the reflected or scattered light, and converts the latter into an electrical analog signal.

In retroreflective light collection, a single optical component, e.g., a reciprocally oscillatory mirror, such as described in U.S. Patent No. 4,816,661 or U.S. Patent No. 4,409,470, both herein incorporated by reference, sweeps the beam across the target surface and directs the collected light to the sensor. In non-retroreflective light collection, the reflected laser light is not collected by the same optical component used for scanning. Instead, the sensor is independent of the scanning beam, and has a large field of view so that the reflected laser light traces across the sensor.

Electronic control circuitry and software decode the electrical analog signal from the sensor into a digital representation of the data represented by the symbol that has been scanned. For example, the analog electrical signal generated by the photodetector may be converted by a digitizer into a pulse width modulated digitized signal, with the widths corresponding to the physical widths of the bars and spaces. Alternatively, the analog electrical signal may be processed directly by a software decoder. See, for example, U.S. Patent No. 5,504,318.

The decoding process usually works by applying the digitized signal to a microprocessor running a software algorithm, which attempts to decode the signal. If a symbol is decoded successfully and completely, the decoding terminates, and an indicator of a successful read (such as a green light and/or audible beep) is provided to a user. Otherwise, the microprocessor receives the next scan, and performs another decoding into a binary representation of the data encoded in the symbol, and to the alphanumeric characters so represented. Once a successful read is obtained, the binary data is communicated to a host computer for further processing, for example, information retrieval from a look-up table.

Reading performance is a function of many factors, one of which is power output of the laser. Reading performance is enhanced when the laser power output is increased. Yet, stringent safety standards dictate the maximum power output of the laser. Also, reader malfunction must be reliably monitored.

Accordingly, it is a general object of this invention to control the power output of the laser to enhance system performance while meeting safety standards.

It is a general object of the present invention to deenergize the laser upon detection of a reader malfunction.

It is another object of the invention to increase the power output upon reading symbols over a wide field of view.

It is a further object of the present invention to deenergize the laser at clipping locations before reaching opposite ends of a scan line and increasing the power output between the clipping locations.

A still further object of the present invention is to repetitively deenergize and energize a laser to enhance system performance by serving as a visual indicator that a symbol has been successfully read

In keeping with the above objects and others which will become apparent hereinafter, one feature of the present invention resides, briefly stated, in laser power control arrangements in electro-optical readers for reading indicia, such as bar code symbols, by generating a laser beam having an output power upon energizing a laser, by monitoring various operating conditions of the reader, and by controlling the output power of the laser as a function of each monitored operating condition.

In one arrangement, the electrical current passing through the laser and/or the output power level of the laser is directly monitored and, if preestablished settings are not met, the laser is deenergized. In another arrangement, the laser includes a laser diode, and a monitor photodiode for monitoring the output power of the diode. If preestablished settings for the monitor photodiode are not met, the laser is deenergized. In yet another arrangement, the temperature of the reader is monitored, and the laser is deenergized if the monitored temperature is outside acceptable levels.

The reader may include a movable scan component, such as a scan mirror, driven by a drive at a prescribed amplitude and frequency over a scan angle so that a scan line is traced over the symbol. The laser is deenergized if the amplitude and/or frequency lies outside preestablished settings for these parameters. The laser output power is preferably increased when the scan angle is increased. The laser is deenergized at clipping locations before the opposite ends of the scan line are reached, and the laser output power is increased between the clipping locations.

Whenever the laser is deenergized, this signifies that a reader malfunction has occurred, or may be imminent, in which case, removal of the laser from its source of power discontinues the generation of the laser beam and serves as a safety measure. Whenever the laser power is increased, this boosts reader performance.

Still another arrangement for enhancing reader performance is to repetitively deenergize and energize the laser beam after a symbol has been successfully read. The flashing laser beam serves as a visual indicator on the symbol within the direct line of sight of an operator that the symbol was successfully read and is especially desirable in noisy environments, where the audible beep cannot be heard, and in those cases where the operator's attention is not to be diverted by having the operator look away from the symbol and to the visible indicator conventionally found on the reader.

FIG. 1 is a perspective view of an electro-optical reader in accordance with the prior art;

FIG. 2 is a circuit schematic depicting laser power control arrangements in accordance with the present invention especially useful in the reader of FIG. 1;

FIG. 3 is a diagrammatic view of additional laser power control arrangements in accordance with the present invention; and

FIGS. 4A-4E are diagrammatic views of details of still more components for additional laser power control arrangements in accordance with the present invention.

As used herein, the term "symbol" broadly encompasses not only symbol patterns composed of alternating bars and spaces of various widths as commonly referred to as bar code symbols, but also other one- or two-dimensional graphic patterns, as well as alphanumeric characters. In general, the term "symbol" may apply to any type of pattern or indicia which may be recognized or identified either by scanning a light beam and detecting reflected or scattered light as a representation of variations in light reflectivity at various points of the pattern or indicia. FIG. 1 shows an indicia 15 as one example of a "symbol" to be read.

FIG. 1 depicts a handheld laser scanner device 10 for reading symbols. The laser scanner device 10 includes a housing having a barrel portion 11 and a handle 12. Although the drawing depicts a handheld pistol-shaped housing, the invention may also be implemented in other types of housings such as a desk-top workstation or a stationary scanner. In the illustrated embodiment, the barrel portion 11 of the housing includes an exit port or window 13 through which an outgoing laser light beam 14 passes to impinge on, and scan across, the bar code symbol 15 located at some distance from the housing.

The laser beam 14 moves across the symbol 15 to create a scan pattern. Typically, the scanning pattern is one-dimensional or linear, as shown by line 16. This linear scanning movement of the laser beam 14 is generated by an oscillating scan mirror 17 driven by an oscillating motor 18. If desired, means may be provided to scan the beam 14 through a two-dimensional scanning pattern, to permit reading of two-dimensional optically encoded symbols. A manually-actuated trigger 19 or similar means permit an operator to initiate the scanning operation when the operator holds and aims the device 10 at the symbol 15.

The scanner device 10 includes a laser source 20 mounted within the housing. The laser source 20 generates the laser beam 14. A photodetector 21 is positioned within the housing to collect at least a portion of the light reflected and scattered from the bar code symbol 15. The photodetector 21, as shown, faces toward the window 13 and has a static, wide field of view characteristic of the non-retro-reflective readers described above. Alternatively, in a retro-reflective reader, a convex portion of the scan mirror 17 may focus collected light on the photodetector 21, in which case the photodetector faces toward the scan mirror. As the beam 14 sweeps the symbol 15, the photodetector 21 detects the light reflected and scattered from the symbol 15 and creates an analog electrical signal proportional to the intensity of the collected light.

A digitizer (not shown) typically converts the analog signal into a pulse width modulated digital signal, with the pulse widths and/or spacings corresponding to the physical widths of the bars and spaces of the scanned symbol 15. A decoder (not shown), typically comprising a programmed microprocessor with associated RAM and ROM, decodes the pulse width modulated digital signal according to the specific symbology to derive a binary representation of the data encoded in the symbol, and the alphanumeric characters represented by the symbol.

The laser source 20 directs the laser beam through an optical assembly comprising a focusing lens 22 and an aperture stop 23, to modify and direct the laser beam onto the scan mirror 17. The mirror 17, mounted on a vertical shaft and oscillated by the motor drive 18 about a vertical axis, reflects the beam and directs it through the exit port 13 to the symbol 15.

To operate the scanner device 10, the operator depresses trigger 19 which activates the laser source 20 and the motor 18. The laser source 20 generates the laser beam which passes through the element 22 and aperture 23 combination. The element 22 and aperture 23 modify the beam to create an intense beam spot of a given size which extends continuously and does not vary substantially over a range 24 of working distances. The element and aperture combination directs the beam onto the rotary mirror 17, which directs the modified laser beam outwardly from the scanner housing 11 and toward the bar code symbol 15 in a sweeping pattern, i.e., along scan line 16. The bar code symbol 15, placed at any point within the working distance 24 and substantially normal to the laser beam 14, reflects and scatters a portion of the laser light. The photodetector 21, shown mounted in the scanner housing 11 in a non-retro-reflective position, detects the reflected and scattered light and converts the received light into an analog electrical signal. The photodetector could also be mounted in a retro-reflective position facing the scan mirror 17. The system circuitry then converts the analog signal to a pulse width modulated digital signal which a microprocessor-based decoder decodes according to the characteristics of the bar code symbology rules.

As shown in FIG. 2, the laser source 20 includes a laser diode 25 and a monitor photodiode 26 operative for monitoring the output power of the diode 25. The photodiode 26 is part of a feedback circuit operative for maintaining the laser output power constant. The feedback circuit includes a comparator 27 having a reference voltage applied to a positive input of the comparator through a voltage divider comprised of resistors 28, 29. The photodiode 26 is connected to a negative input of the comparator via a resistive network including resistors 30, 31. The output of the comparator 27 is conducted through a resistor 32 and capacitor 34 to a gate G of a field effect transistor (FET) 33. The drain output of the FET 33 is connected to the laser diode 25. The source output of the device 33 is connected to ground through a current sense resistor 35.

As described so far, the circuit of FIG. 2 is conventional in that the monitor photodiode 26 detects changes in output power of the laser beam emitted by laser diode 25 and sends a feedback signal to the comparator 27 for driving the FET 33 to allow more or less current to pass through the current sense resistor 35 and, in turn, through the laser diode 25. The greater this current, the greater the laser output power, and vice versa.

In accordance with one arrangement of this invention, a current sense comparator 36 has one input connected to the current sense resistor 35 to monitor the current flowing therethrough, and another input connected to a reference voltage that corresponds to the maximum current allowable through the resistor 35. The output of the comparator 36 is connected to an OR gate 37 which, in turn, is connected to a latch 38 and a switch 39, which is connected between a power supply 40 and the laser diode 25. If the comparator 36 senses that the current passing through the resistor 35 exceeds a maximum preestablished value, then an output control signal is conducted to the gate 37 and, in turn, to the latch 38 for opening the switch 39 to remove the power source 40 from energizing the laser diode 25.

In further accordance with FIG. 2, a window comparator 41 is connected to the resistor 32 and monitors the voltage being applied to the gate G of the FET 33. A maximum gate voltage and a minimum gate voltage are also applied to the window comparator 41. The comparator 41 is, in turn, connected to the OR gate 37. If the comparator 41 senses that the gate voltage being applied to the gate G is greater than the preestablished maximum gate voltage, or is less than the preestablished minimum gate voltage, then a signal is sent to the OR gate 37 to operate the latch 38 and open the switch 39, thereby deenergizing the laser diode. Thus, power is removed from the laser diode 25 in the event of malfunction or failure of the monitor photodiode 26, the FET 33, the comparator 27, the laser diode 25, or any circuit connection.

More specifically, the FIG. 2 circuit removes the power source 40 from the laser 20 after detecting an out-of-range condition in the error amplifier 27 that controls the output power of the laser. This circuit will remove power from the laser in the following conditions:

A failure of the device 33 in the output of the laser drive causes excess current to flow through the laser, thereby causing the laser output to exceed the factory set limit.

The monitor diode 26 connection is lost due to a device 33 failure or a circuit connection failure.

The laser fails and the laser drive current significantly increases as resistor 35 is used to sense a high current drive condition.

Advantageously, a timer could be added to the FIG. 2 circuit to remove power only when a malfunction persists for a predetermined time.

As shown in the arrangement of FIG. 3, the laser source 20 is connected to the power source 40 by the switch 39 under control of a microcontroller 44, preferably the same component that decodes the symbol and controls overall reader operation. A temperature sensor 43 is connected to the microcontroller 44 for monitoring the ambient temperature of the reader, preferably in the vicinity of the laser source 20. If the monitored temperature exceeds a preset value, the microcontroller 44 opens the switch 39 to protect the laser source. A laser regulator 45 is connected to the laser source 20 and enables the microcontroller 44 to monitor the laser current and/or the laser output power and, if those values or other laser settings are outside preestablished values for these parameters, then the microcontroller 44 also opens the switch 39 to protect the laser source.

The aforementioned motor 18 for oscillating the scan mirror 17 in alternate circumferential directions denoted by the double-headed arrow 46 is under the control of a motor regulator 42 and the microcontroller 44. The microcontroller itself monitors the amplitude of scan angle A and the frequency of oscillation at which the mirror 17 is oscillated. If these values or other motor settings are outside preestablished values for these parameters, then the microcontroller 44 opens the switch 39. The microcontroller 44 can store the preestablished values, or it can communicate with a remote host 47 to retrieve the preestablished values, or updated values, or communicate to the host the presence of a fault condition, such as a laser or motor fault, or, at the request of the host, communicate operating parameters of the system such as motor frequency, temperature, and/or laser power, or the host can attempt to resolve such problems by initiating and controlling a system calibration episode to correct such faults, i.e., reduce laser power, or increase scan amplitude.

Other arrangements for removing power from the laser source 20 are depicted in FIGS. 4A-E. In each figure, the laser diode 25 emits the laser beam toward the focusing lens 22, and the monitor photodiode 26 is positioned behind a rear facet of the laser diode 25 to monitor the output power level.

In FIG. 4A, an auxiliary photodiode 48 is positioned behind a beam splitter 49 to monitor the outgoing laser beam. In FIG. 4B, a diffractive structure is located on the focusing lens 22 to direct a part of the outgoing beam to the auxiliary photodiode 48. In FIG. 4C, the auxiliary photodiode 48 itself is shaped as an annulus to serve as the aperture stop 23, and the walls bounding the aperture receive the outgoing beam for detection by the auxiliary photodiode. In FIG. 4D, an auxiliary photodiode is not used, but a light scattering surface 50 is provided inside the laser source to reflect a part of the outgoing beam back to the monitor photodiode 26. In FIG. 4E, again an auxiliary photodiode is not used, but an incident surface of the focusing lens 22 is used to backscatter a part of the outgoing beam back to the monitor photodiode.

In the arrangements of FIGS. 4A-E, the additional light detected by either the auxiliary photodiode 48, or the monitor photodiode 26, is monitored and converted by the microcontroller 44 to generate a control signal used to open the switch 39 when the monitored operating condition does not meet a preestablished value. This feature promotes safety in the use of a reader in which a laser beam is generated.

Rather than interrupt power to the laser, system performance is enhanced by increasing laser output power under certain conditions. For example, as noted above, a variable scan angle A is beneficial for readers in that a narrow scan angle (e.g., 35°) is desired for reading far-out symbols located at a distance (e.g., 20") from the reader, whereas a wide scan angle (e.g., 53°) is desired for reading close-in symbols located at a distance (e.g., 2") near the reader. Switching between different scan angles can be achieved by software commands, or by hardware, and can be configured in advance of reading indicia, or even during the reading of indicia.

In any event, this invention further proposes increasing the output power of the laser when the scan angle is wide. Safety standards permit increased laser power when the beam is spread. The microcontroller 44 detects the size of the scan angle via the motor regulator 42 and when it determines that the scan angle is wide, the microcontroller 44 commands the laser regulator 45, typically by adjusting the attenuation of a digital potentiometer, to enable more current to pass through the laser diode 25, thereby increasing the laser output power and, in turn, boosting reader performance while not exceeding prevailing safety standards.

Another example in which laser output power is increased occurs during each scan line. Safety standards determine the maximum laser output power when the beam is stationary and therefore most intense. This occurs at the extreme ends of each scan line. It will be recalled that a beam spot decelerates as it approaches in one direction towards each end of a scan line, stops at the extreme end of each scan line, and then accelerates in the opposite direction. It is at these ends when the beam spot is stationary that determine the maximum allowed laser output power.

This invention further proposes deenergizing the laser source during the approach toward each end and, in effect, electrically clipping the opposite end regions of each scan line. Now, the beam spot is not stationary at these clipping locations and, hence, the maximum laser output power can be increased between the clipping locations without violating safety standards.

The microcontroller 44 detects the length of the scan line via the motor regulator 42, determines the clipping locations, and commands the laser regulator 45 to increase the laser output power between the clipping locations. For example, it is conventional for the motor regulator to generate a start-of-scan (SOS) signal at each end of the scan line. The microcontroller 44 detects the length of the scan line by measuring the time between two successive SOS signals. The clipping locations can be set as a percentage, e.g., 95%, of the measured time. The increase in laser power can be achieved, as before, by adjusting a digital potentiometer.

To compensate for the shorter length of the clipped scan line, this invention also proposes the simultaneous increase in the scan angle A. System performance is enhanced by increased laser output power.

In still another proposal for increasing system performance, the laser source is rapidly and repetitively deenergized and energized to generate a flashing scan line after the symbol has been successfully read. As noted above, typically an audible beep is generated to audibly indicate a successful reading. However, the beep is not easily heard in a noisy environment. Also, a green indicator light on the housing 11 is also generated to visually indicate a successful reading. However, an operator must divert his or her gaze or line of sight away from the targeted symbol to confirm illumination by the green indicator light. The flashing scan line on the symbol after the reading has occurred maintains the operator's line of sight directly on the symbol.

The flashing scan line is generated by commands issued from the microcontroller 44 to the laser regulator 45 to rapidly and repetitively decrease and increase the laser current through the laser diode 25. By controlling the timing of the commands, the visual indicator need not be a flashing solid scan line, but could be a dotted or dashed scan line in which the laser current is changed during each scan line.

In some applications, more than one symbol is covered by a single scan line, and the operator, upon hearing or seeing an indicator, may not know which of the symbols was successfully decoded. One solution would be to generate the above-mentioned dotted scan line only over the symbol that was successfully decoded, thereby advising the operator which symbol was not decoded.

Although described in connection with moving-beam readers, the laser control arrangements of this invention can equally well be applied to imaging readers, laser projection displays and, in general, any system in which a light source is used for illumination of, and for aiming at, a target.

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

CLAIMS:

1. A laser power control arrangement in an electro-optical reader for reading indicia, comprising:

a) a laser for generating a laser beam having an output power;

b) a monitor for monitoring an operating condition of the reader; and

c) a controller for controlling the output power of the laser as a function of the operating condition monitored by the monitor.

2. The arrangement of claim 1, wherein the monitor is operative for monitoring the operating condition of the laser, and wherein the controller is operative for deenergizing the laser when the laser operating condition is not a preestablished setting.

3. The arrangement of claim 2, wherein the preestablished setting for the laser is one of a range of laser current levels and a range of laser power levels, and wherein the controller is operative for deenergizing the laser when the laser operating condition is outside one of the ranges.

4. The arrangement of claim 1,wherein the laser includes a laser diode and a monitor photodiode, and wherein the monitor is operative for monitoring the operating condition of the photodiode, and wherein the controller is operative for deenergizing the laser when the photodiode operating condition is not a preestablished setting.

5. The arrangement of claim 1, wherein the monitor is operative for monitoring the operating condition of a temperature of the reader, and wherein the controller is operative for deenergizing the laser when the temperature operating condition is not a preestablished setting.

6. The arrangement of claim 1, further comprising a movable scan component driven by a drive for scanning the laser beam across the indicia during reading, wherein the monitor is operative for monitoring the operating condition of the drive, and wherein the controller is operative for deenergizing the laser when the drive operating condition is not a preestablished setting.

7. The arrangement of claim 6, wherein the preestablished setting for the drive is one of a range of amplitudes and a range of frequencies at which the scan component is moved, and wherein the controller is operative for deenergizing the laser when the drive operating condition is outside one of the ranges.

8. The arrangement of claim 1, further comprising a movable scan component driven by a drive for scanning the laser beam across the indicia over a scan angle dependent on distance of the indicia relative to the reader, and wherein the controller is operative for adjusting the output power of the laser as a function of the scan angle.

9. The arrangement of claim 8, wherein the scan angle is larger for close-in indicia closer to the reader as compared to far-out indicia further from the reader., and wherein the controller is operative for increasing the output power of the laser for reading the close-in indicia with the larger scan angle.

10. The arrangement of claim 1, further comprising a movable scan component driven by a drive for scanning the laser beam across the indicia with a scan line, and wherein the controller is operative for deenergizing the laser at clipping locations before reaching opposite ends of the scan line and for increasing the output power of the laser between the clipping locations.

11. The arrangement of claim 1, further comprising a movable scan component driven by a drive for scanning the laser beam across the indicia with a scan line, and wherein the controller is operative for repetitively deenergizing and energizing the laser to flash the scan line on the indicia after the indicia has been read to serve as a visual indicator that the indicia has been successfully read.

12. A laser power control method in an electro-optical reader for reading indicia, comprising the steps of:

a) generating a laser beam having an output power with a laser;

b) monitoring an operating condition of the reader; and

c) controlling the output power of the laser as a function of the operating condition monitored by the monitor.

13. The method of claim 12, wherein the monitoring step is performed by monitoring the operating condition of the laser, and wherein the controlling step is performed by deenergizing the laser when the laser operating condition is not a preestablished setting.

14. The method of claim 12, wherein the monitoring step is performed by monitoring the operating condition of a temperature of the reader, and wherein the controlling step is performed by deenergizing the laser when the temperature operating condition is not a preestablished setting.

15. The method of claim 12, further comprising the step of scanning the laser beam across the indicia by a drive during reading, wherein the monitoring step is performed by monitoring the operating condition of the drive, and wherein the controlling step is performed by deenergizing the laser when the drive operating condition is not a preestablished setting.

16. The method of claim 12, further comprising the step of scanning the laser beam across the indicia over a scan angle dependent on distance of the indicia relative to the reader, and wherein the controlling step is performed by adjusting the output power of the laser as a function of the scan angle.

17. The method of claim 12, further comprising the step of scanning the laser beam across the indicia with a scan line, and wherein the controlling step is performed by deenergizing the laser at clipping locations before reaching opposite ends of the scan line and by increasing the output power of the laser between the clipping locations.

18. The method of claim 12, further comprising the step of scanning the laser beam across the indicia with a scan line, and wherein the controlling step is performed by repetitively deenergizing and energizing the laser to flash the scan line on the indicia after the indicia has been read to serve as a visual indicator that the indicia has been successfully read.

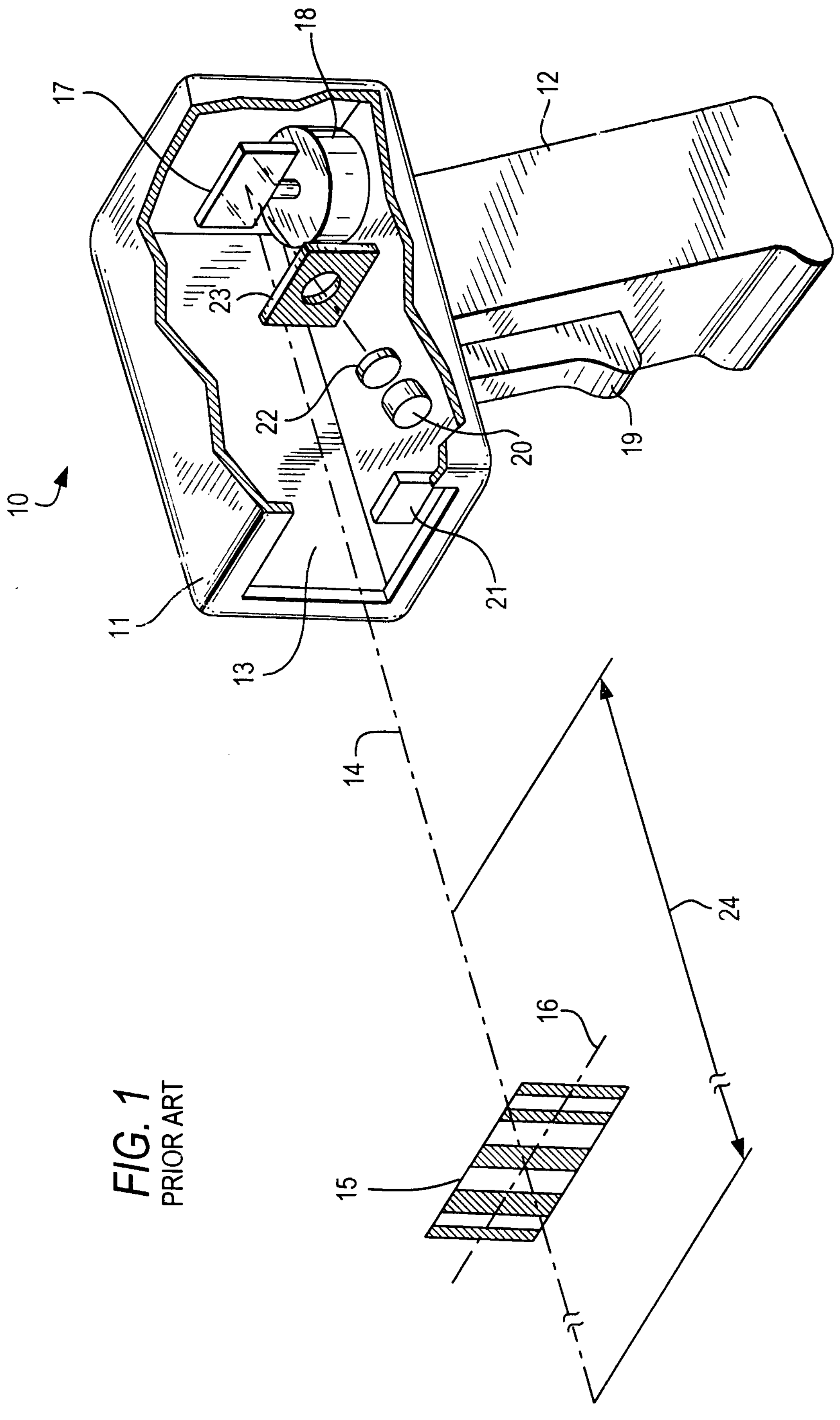
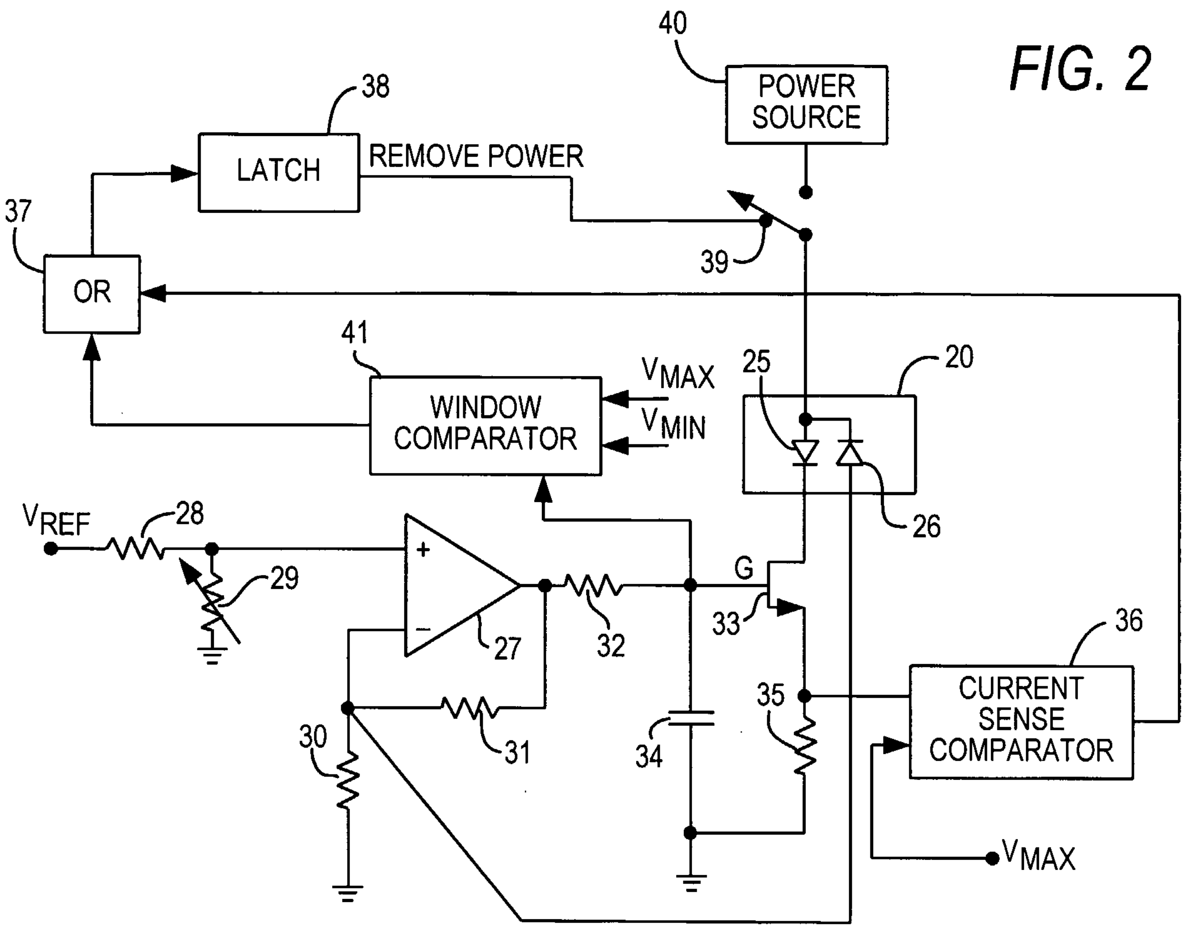


FIG. 1
PRIOR ART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REMOVE POWER
OR
WINDOW COMPARATOR
VMAX
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VREF
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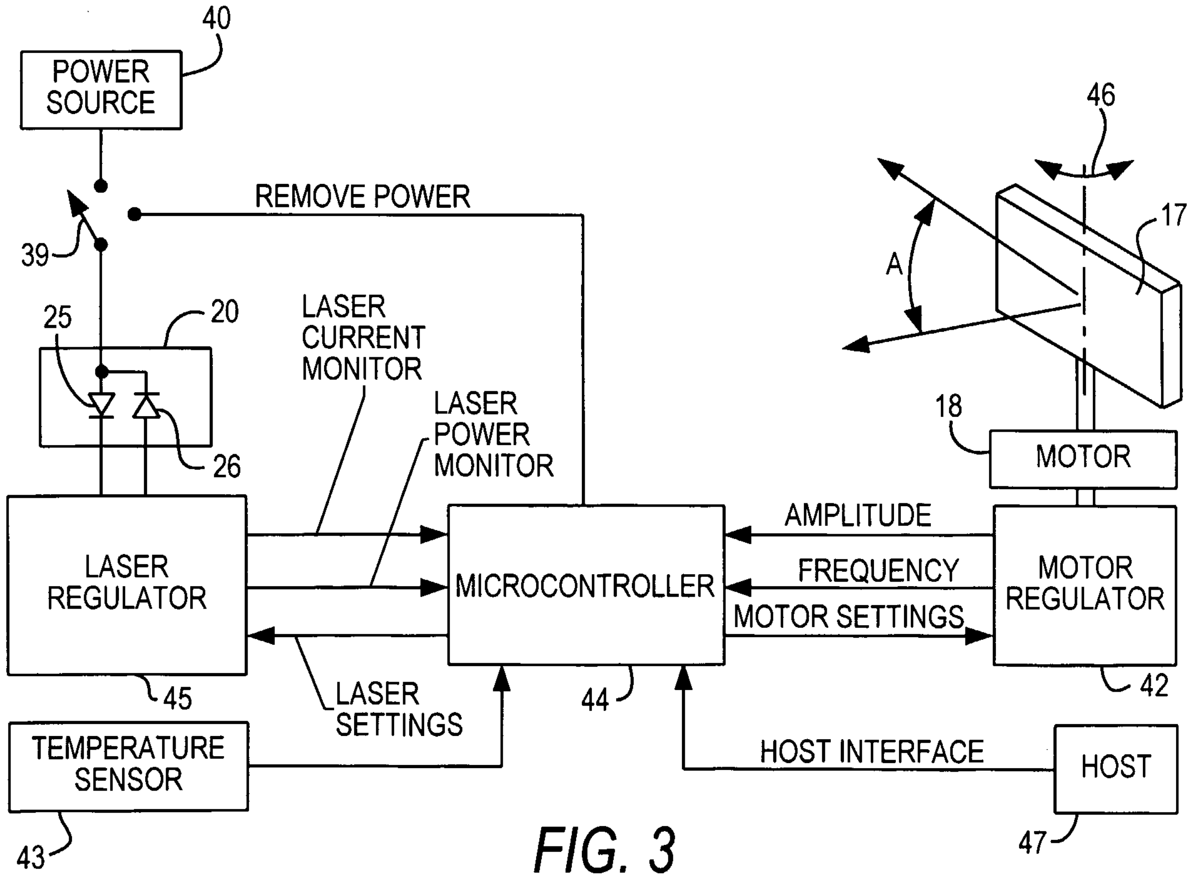
FIG. 2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MICROCONTROLLER
AMPLITUDE
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MOTOR REGULATOR
MOTOR
LASER SETTINGS
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FIG. 3

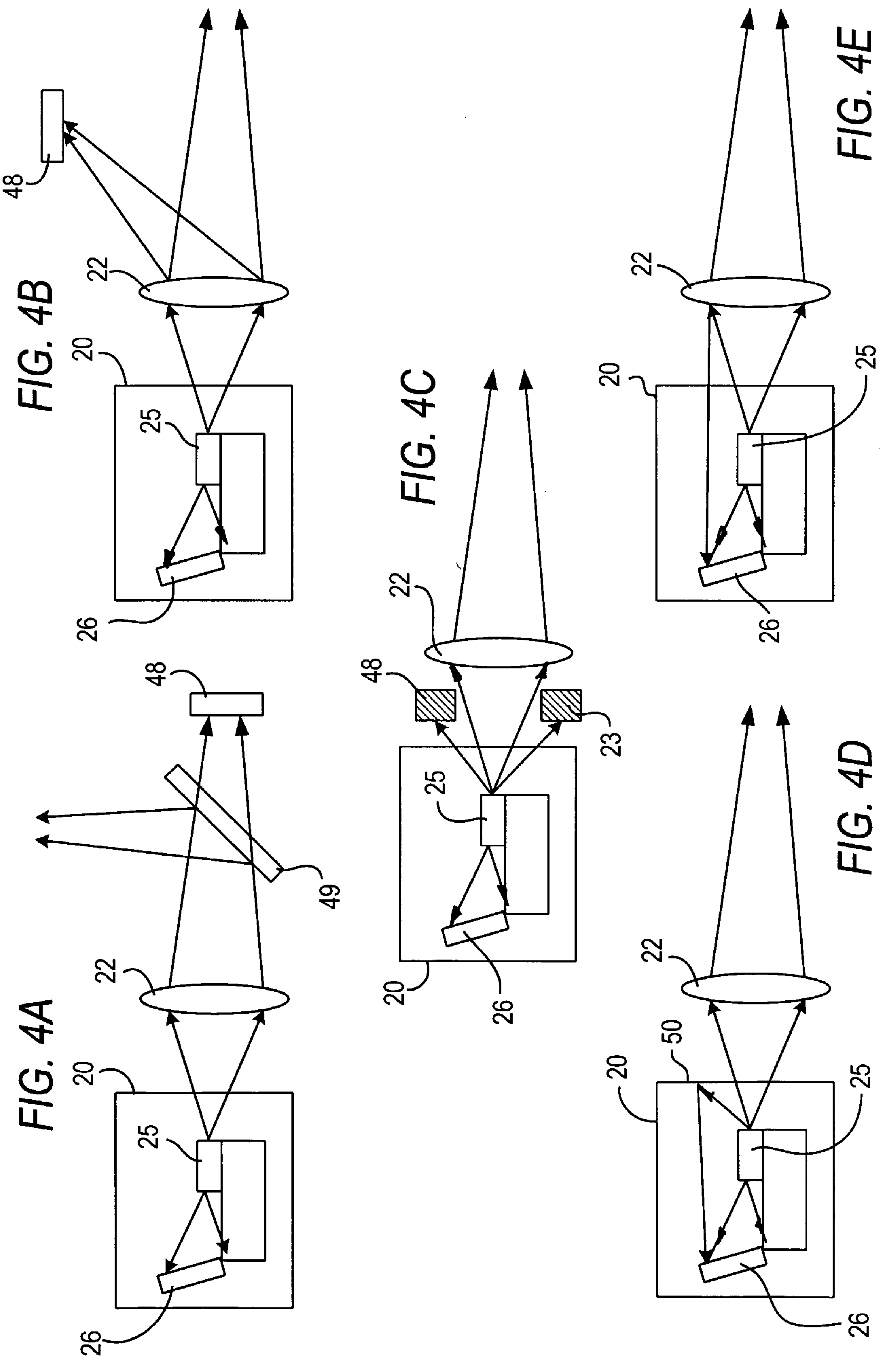

FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D

FIG. 4E